SHRIMP-PRAWN FARMING IN BANGLADESH: IMPACTS ON LIVELIHOODS, FOOD AND NUTRITIONAL SECURITY

A thesis submitted for the degree of Doctor of Philosophy

By

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DECLARATION

I hereby declare that this thesis has been composed entirely by myself and has not been submitted for any other degree. Except where specifically acknowledged, the works described in this thesis is the result of my own investigations.

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ABSTRACT

The overarching aim of this research was to improve understanding of the synergies and trade-offs between economic and domestic food security benefits associated export-oriented shrimp and prawn aquaculture in a fragile developing country environmental context. The research scope covers the entire ‘seafood system’ incorporating production, distribution, trading and consumption in the south-west coastal region under greater Khulna District, Bangladesh. The primary research objective was to understand causal factors in variation of seafood nutritional quality and health outcomes, exploring correlations with seafood consumption across a range of agro-ecological, aquatic farming systems and socio-economic conditions. The study also focused on differences in intra-household allocation with a special focus on adolescent girls, being amongst the most vulnerable members of society. These objectives necessitated a highly inter-disciplinary approach to understand complex interactions between biophysical aspects (e.g. where and which species are most effective in supplying essential nutrients) and the social norms of food allocation.

Fieldwork was conducted in Satkhira, Khulna, and Bagerhat Districts of Khulna Province over 17 months during 2012 to 2015. Four villages across a peak-annual surface water salinity gradient; high saline (>10 ppt), medium saline (>5<10 ppt), low saline (<5 ppt) and freshwater (<0.5 ppt) were selected for case-studies. The thesis begins with a literature review of the evolution of shrimp and prawn farming in Bangladesh and the wider region and identification of knowledge gaps.

Research resolved from district to community to household level. Key informant (KI) interviews were used to establish well-being criteria (based on a range of 5 social and economic assets) at community level. In each community a census of households (n=1082 households) were derived from the same interviews and KIs asked to ranked households on the established well-being criteria. Results were validated through a short interview of all the identified households (HH). This sample-frame provided the based for two concurrent survey efforts.

Stratified-random selection of 160 HH on two well-being categories (better-off and worse-off) for ‘farm level’ analysis using a semi-structured questionnaire. Key topics included inputs/outputs characteristics, economic benefits and the fate of farmed products were evaluated.

Another 240 households with single adolescent girls were selected from the same frame, again with randomized-stratified sampling based on well-being categories for ‘intra-household’ analysis. This resulted in selection of 60 HH per community consisting of 30 ‘better-off’ and 30 worse-off households (further analysis was conducted on a range of secondary sampling outcomes based on livelihood options, intra-household food distribution and aquatic farming assets). A 24-hour food recall method, food frequency questionnaire, food photography and measuring cup sets were used to estimate individual members’ food consumption at the household level. Anthropometric

measures (stunting, wasting, BMI, MUAC) and biomarkers (omega-3 index in RBC and LC n-3 PUFA/LC PUFA in whole blood cell) were used to assess food security outcomes of adolescent girls (n=200 subject).

In an entirely separate effort, samples of shrimp/prawn and fish polyculture species (57 species and 9 by-products, 1 live feed; n=672) were collected from the major agro-ecologies (four saline gradients; HS, MS, LS and FW) and culture systems (extensive, semi-intensive, intensive, organic and pocket *gher*). At least 3 sites from each saline gradient (3×4=12 sites) were selected for sampling and pooled samples to represent all the culture system in the region. The major macro and micronutrients of the collected species were analysed and these datasets were used to know the nutritional distribution among the family members in household level study.

Two aggregate indices of wealth (or well-being) and aquaculture were developed based on a range of quantitative (ordinal and interval) measures. Principle Component Analysis (PCA) was used to understand how aquaculture influences on wealth gain. Wealth index of the same social well-being did not differ among the agro-ecologies. However, the aquaculture index was varied in agro-ecologies. Most of the households (60-80%) were involved directly in aquaculture however, a majority portion of the households was worse-off (48-64%). Both HS and LS area had more livelihood options due to their proximity to mangrove forest Sundarbans and city amenities, respectively compared to MS and FW area. Ownership of the land did not influence any involvement in aquaculture and yields but he willingness and risk-absorbing capacity of the farmers were the main factor to get involve in aqauculture.

In aquatic farming system the importance of export-oriented shellfish yield gradually decreased from HS to FW area (55-20% by volume). The intentional stocking of finfish and PLs were common across the saline areas however the wild caught juveniles and hatchery originated fingerlings were usual in higher and lower saline areas, respectively. The low priced tilapia took the place of wild recruited mangrove fishes in MS area. Diseases, especially the devastating white spot virus (WSSV), frequency were higher in higher saline areas. The indicators like wild recruitment, salinity, water productivity and water management also a vital factor to gain yield. The integration of aquatic and terrestrial crops (rice and dyke crop) in the lower saline areas provide higher yield compared to higher saline areas. However, the net economic returns were largely determined by the aquatic products. The income of *ghers* in FW and MS area was sensitive to the lower prices of freshwater finfish and tilapia.

The protein content in shellfish was higher than the other finfish, however, lower in other essential nutrients. Species living in the higher saline areas contained higher total n-3 PUFA (in weight) and LC n-3 PUFA/LC-PUFA compared to the same species living in lower saline areas. Small Indigenous Species (SIS) and Self-Recruiting Species (SRS) were proven to provide higher micronutrients and total n-3 PUFA than larger fish. Seafood that destined for the international markets contained less n-3 PUFA and micronutrients in comparison to the domestically consumed fish.

Customary intra-household food distribution disparity (mainly fish) still exists at household levels where females, especially adolescent girls, were deprived. Fish consumption (>77 g /capita/day) and fish originated protein supply (>25% of total protein intake) was higher than the other part of Bangladesh. The protein consumption of adolescents was 2-3 times higher than the Recommended Nutritional Intake (RNI). However, the energy intake was lower than the required level. High protein, low energy consumption was not reflected in body mass. Micronutrients (zinc) consumption was above the RNI level. However, iron and calcium consumption was less than the RNI. The n-3 PUFA in RBC of adolescent girls accurately reflected their access to, and availability of, oily fish. In the omega-3 index (n-3 PUFA in red blood cell) both HS and MS areas, adolescent females were in the intermediate stage (4-8%), and rest of the two areas were in the undesirable stage (<4%). The n-3 LC-PUFA was around 20-30% of total LC-PUFA content in whole blood and gradually decreased from higher saline to lower saline areas.

The thesis concludes that the *gher* based aquatic animal farming in S-W Bangladesh is a dynamic system operated by both rich and poor. The salinity level and the presence of mangrove forest make the farming system dynamic. The holistic scenario suggested aquaculture in *ghers* is a family driven small scale polyculture where varieties of aquatic foods are produced both for global and local value chain. Higher amounts of valued products (both in terms of nutrition and price), less disease susceptibility, more alternative livelihood options both in HS and LS were found in better position than the other two sites, however the nutritional content of fish and its manifestation in adolescents strongly mirrors agro-ecologies irrespective of social position of households.

The thesis provides an important, grounded importance of the system and the linkage of the community people for livelihoods, food production and food security. The dynamic systems were understood and effective messages formulated for the policy makers. In doing so, the thesis contributes to an understanding of how small-scale polyculture equally benefited local food security and macroeconomic growth of a developing country.

DEDICATION

This dissertation is dedicated to my mentor Prof. Dave Little, dear friends, and family members who have left an imprint on my life throughout this journey. To my parents, thank you for teaching me the importance of getting an education. To my wife Kohinoor Afroz (Rini) and son Safayet Tahsin (Taqi), for your love and support.

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Regards

Mamun

Stirling, UK

LIST OF ACRONYMS

AIDS	Acquired Immune Deficiency Syndrome
AA	Amino Acids
ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
BFFEA	Bangladesh Frozen Food Exporters Association
BMRC	Bangladesh Medical Research Council
BDT	Bangladeshi Taka
BCR	Benefit-Cost Ratio
BO	Better-off
BMI	Body Mass Index
BHT	Butylated Hydroxytoluene
CVD	Cardiovascular Disease
CCI&E	Chief Controller of Imports and Exports
CST	Closed System Technology
CEP	Coastal Embankment Project
CLO	Cod Liver Oil
CHD	Coronary Heart Disease/ Cardiac Heart Disease
DFID	Department for International Development
ds/m	Deci-Siemens Per Meter;
DoF	Department of Fisheries
DO	Dissolved Oxygen
DHA	Docosahexaenoic Acids [(22:6(n-3)]
DPA	Docosapentaenoic Acid [22:5(n-3)]
EPA	Eicosapentaenoic Acids [20:5(n-3)]
EUS	Epizootic Ulcerative Syndrome
EC	European Commission
EU	European Union
FAME	Fatty Acid Methyl Esters
FAO	Food and Agricultural Organization
FBS	Food Balance Sheets
FCR	Food Conversion Ratio
FIQC	Food Inspection and Quality Control
SFVC	Food Value Chain
FW	Freshwater
GC	Gas Chromatography
GLC	Gas-liquid Chromatography
GIFT	Genetically Improved Farmed Tilapia
GPS	Global Positioning System
GVC	Global Value Chains
GDP	Gross Domestic Production
Ha	Hectare
HS	High Saline
HSE	High Saline Extensive
HSSI	High Saline Semi-intensive
HYV	High Yield Varieties
HUFA	Highly Unsaturated Fatty Acids
HPLC	High-Performance Liquid Chromatograph
HBS	Household Budget Survey
HIV	Human Immunodeficiency Virus
ICP-MS	Inductive Coupled Plasma-Mass Spectrometry
ICP-AES	Inductively Coupled Plasma–Atomic Emission Spectrometry
IFI's	International Finance Institutes
IU	International Unit
ICZ	Inter-saline Convergence Zone

IHFA	Intra-Household Food Allocation
KIs	Key Informants
Laos PDR	Lao People's Democratic Republic
LM	Linear Model
LF	Local Facilitator
LC-PUFA	Long-Chain Polyunsaturated Fatty Acids
LMIC's	Low Medium-Income Countries
LS	Low Saline
LSSI	Low Saline Semi-Intensive
MTA	Materials Transfer Agreement
MS	Medium Saline
MSE	Medium Saline Extensive
MSSI	Medium Saline Semi-Intensive
MUAC	Mid-Upper Arm Circumference
MTT	Modified Traditional Technology
MUFA	Monounsaturated Fatty Acids
NSTU	Noakhali Science and Technology University
NGO	Non-governmental Organization
NAS	Nutritional Analytical Service
OSP	Organic Shrimp Project
PPM	Part Per Million
PRA	Participatory Rural Appraisal
PPT	Parts Per Thousands
PCR	Polymerase Chain Reaction
PUFA	Polyunsaturated Fatty Acids
PL	Post-Larvae
PCA	Principle Component Analysis
RNI	Recommended Nutritional Intake
RBC	Red Blood Cell
SFA	Saturated Fatty Acids
SABINCO	Saudi-Bangladesh Industrial and Agricultural Investment Company Ltd
SRS	Self-Recruiting Species
SIS	Small Indigenous Species
SEP	Socioeconomic Position
SRDI	Soil Resource Development Institute
SE	Southeast
S-W	South-west
SD	Standard Deviation
SARG	Sustainable Aquaculture Research Group
SLR	Sustainable Livelihood Framework
SEAT	Sustaining Ethical Aquaculture Trade
SIPPO	Swiss Import Promotion Programme
SPF	Specific Pathogen Free
OECD	The Organisation for Economic Co-Operation and Development
TLC	Thin-Layer Chromatography
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphate
TSP	Triple Super Phosphate
UoS	University of Stirling
VLDL-TAG	Very Low-Density Lipoprotein-Triglycerol
WSSV	White Spot Syndrome Virus
WFC	Worldfish Centre
WO	Worse-off

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1 CHAPTER 1: A REVIEW ON SHRIMP-PRAWN FARMING IN BANGLADESH: LIVELIHOODS, ENVIRONMENTAL SUSTAINABILITY, TRADE, FOOD AND NUTRITIONAL SECURITY

1.1 INTRODUCTION

Aquaculture is one of the fastest growing food production sectors in Bangladesh; with growth primarily linked to the decline of capture fisheries (Belton & Thilsted, 2014). Bangladesh was ranked globally 4th largest aquaculture producer in volume by 2014 (FAO, 2014b). A homestead, pond based semi-subsistence system has been transformed to an entrepreneur, pond based commercial system over the last decade to meet the deficit in market demand for fish (Belton & Azad, 2012). Feed based aquaculture and shrimp-prawn export earnings have brought major changes in the aquaculture industry of Bangladesh. Bangladesh is the 7th most populous country in the world with a population of 149.77 million in 2011 (BBS, 2016) virtually elbowing each other in a small piece of land. About 75% of people live in rural areas where high levels of functional-landlessness and livelihood dependence on small-holder agriculture still coexist (Khan, 2008). Fisheries contribute approximately 5% to GDP and 2.5% to total export earnings (DoF, 2015). Moreover, fish is a core part of most Bangladeshi peoples' diets and provide 60% of animal protein (DoF, 2015). The main two export fishery 'cash-crop' commodities are black tiger shrimp (*Penaeus monodon*) and giant freshwater prawn (*Macrobrachium rosenbergii*) locally known as *bagda* and *golda*, respectively (FRSS, 2014). Most production is undertaken by small-holders in poldarised estuarine floodplain areas of South-west Khulna Division. Extensive shrimp polyculture systems predominate in higher salinity conditions close to mangrove areas whereas prawn and shrimp/prawn systems predominate in transition areas and areas of year-round freshwater availability further inland. Despite livelihood benefits to smallholders along a fragmented value chain, shrimp farming here has also attracted enormous controversy regarding perceived negative socio-economic, environmental and food security impacts (e.g. Swapan & Gavin, 2011). However, there is a clear knowledge deficit around the generalisability of such claims, many of the anti-shrimp narratives being based on worst case scenarios. Most shrimp and prawn production is practised as extensive or semi-intensive polyculture with other stocked or naturally recruiting aquatic species; this underwater biodiversity and its contribution to local food supply is an area around which such knowledge gaps are especially acute.

This chapter presents historical perspectives on aquaculture development, livelihood impacts, key drivers of developments, and the environmental and food security issues of shrimp and prawn farming in Bangladesh. Key issues underpinning the sustainable development of fish production systems (fish used hereafter to refer to finfish and shellfish or interchangeably) and future research needs to be identified.

1.2 HISTORICAL PERSPECTIVE OF AQUATIC ANIMAL FARMING IN S-W BANGLADESH

The dynamic history of sustainable fish and crustaceans farming dates back in Asia at least 3000 years ago (Stickney, 1979) however, shrimp and prawn farming in Bangladesh is a recent development. The historical trend of aquaculture in Bangladesh derives from a small-scale, low-intensity freshwater pond based polyculture system (Ali et al., 2013). The agrarian economy of the country mostly driven by the small-holder farmers (Turner & Ali, 1996). The shrimp and prawn farming run by small-holders in the low-lying agricultural land is known as the *gher* or *bheri* culture in Bangladesh (Milstein et al., 2005). Shrimp farms are situated in coastal margins, often on the shore of estuaries lined or previously lined with mangrove forests which have access to saline water (Bolanos, 2012). About 80% of the shrimp farming area has been developed in Greater Khulna District, close to the world’s largest mangrove forest the "Sundarbans" in S-W Bangladesh (Alam, 2014).

Over the last two centuries, a vast area of the Sundarbans mangrove (in both part India and Bangladesh) was converted into paddy field and only more recently into shrimp farms (Gopal & Chauhan, 2006). In the 1960’s the limited supply and rising price of rice in the international market led the government of Bangladesh to support adoption of ‘Green Revolution’ High Yielding Varieties (HYV) of rice in the coastal belt (Foxon, 2005). To manage salinity in these low-lying tidal areas the government built embankments to enclose land within a series of ‘*polders*’ as part of the Coastal Embankment Project (CEP). However, in the intervening years, silt deposits in drainage canals and rivers between the polders has contributed to saline water logging within many *polder* systems. Some farmers started shrimp farming in the region as a consequence of this trend whilst in other cases, unilateral conversion of rice lands to shrimp *ghers* left other farmers little option other than to convert themselves.

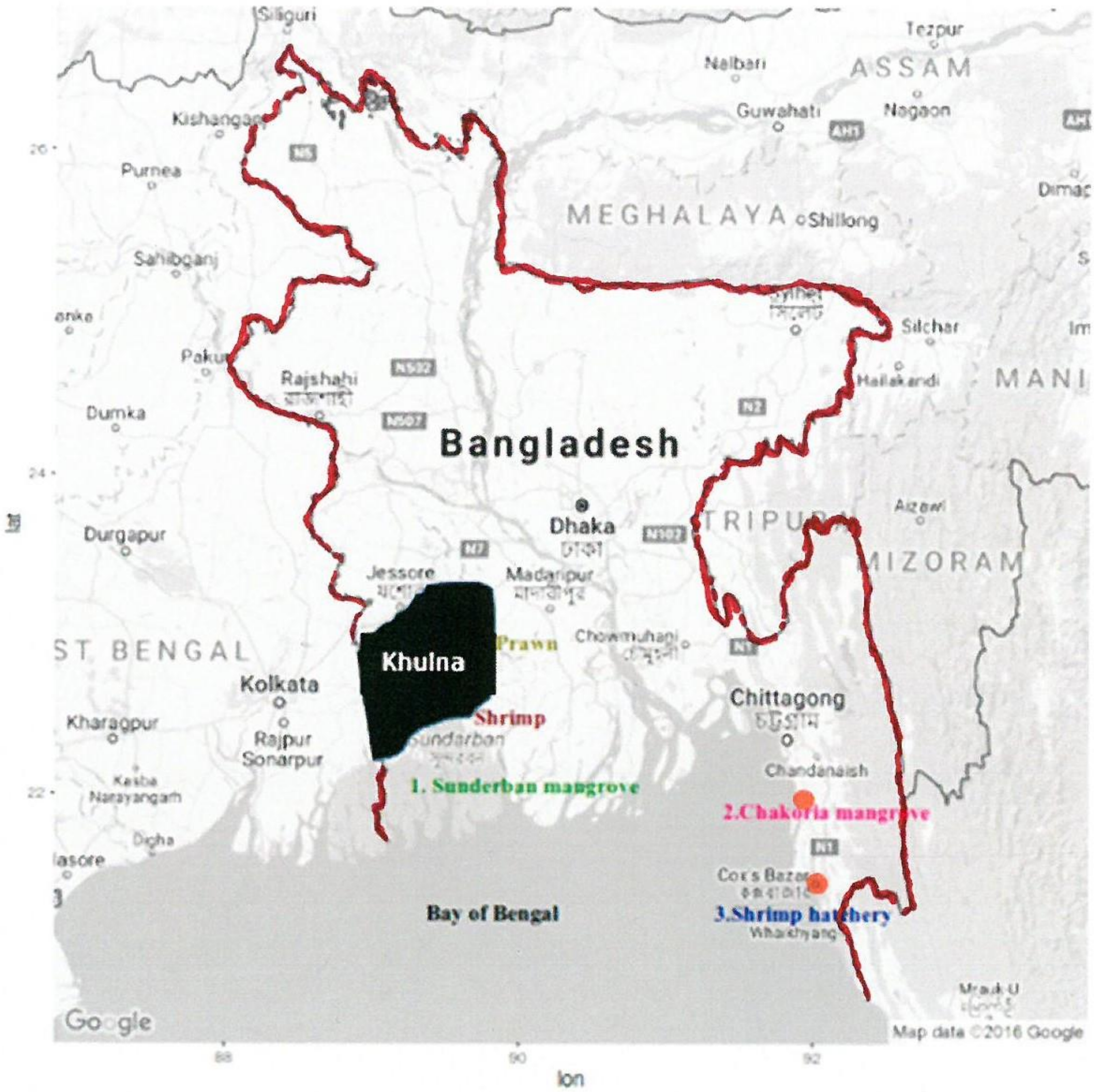


Figure 1.1 Main shrimp and prawn farming area (Khulna), mangrove forests (1&2) and location of shrimp hatcheries (3) are shown on the map in coastal Bangladesh

Since the 1980s International Finance Institutes (IFI's such as World Bank) started to support shrimp farming expansion in developing countries to minimise overexploitation of wild resources and boost economic growth. Mainly tropical countries responded and formulated pro-shrimp farming policies (Rivera-Ferre, 2009). The Bangladesh government responded by establishing the Food Inspection and Quality Control (FIQC) laboratory in 1973, primarily to ensure the quality of frozen export foods (Kabir, 2014). External investment such as that channelled through SABINCO (Saudi-Bangladesh Industrial and Agricultural Investment Company Ltd) was also aimed to support the development of semi-intensive shrimp farms in Khulna and Cox's Bazar region in 1987 from its more traditional extensive base. The ministry of the industry also provided credit and input supplies to boost up the industry

(Debnath et al., 2015). However, despite such initiatives, the industry remained dominated by small-holder ventures as it expanded in the area (Ali et al., 2013) now extending to nearly 275274 ha (DoF, 2013).

Shrimp and prawn farming development from 1970 to 2000 was divided into four phases by Ahmed (2013a). The first decade was the 'Green Revolution' period with rapid agriculture development nationally whilst shrimp and prawn farming was restricted to the S-W region, Bangladesh. The second decade was a 'Fake Blue Revolution' where shrimp farms expanded in an unplanned way with unintended social costs. The third decade was the 'Blue Revolution' expansion of aquaculture in extensive system. The fourth decade was 'Blue-Green Revolution' widespread expansion of shrimp-rice, shrimp-prawn, and shrimp-prawn-rice integration.

1.3 SHRIMP-BASED AQUATIC ANIMAL PRODUCTION

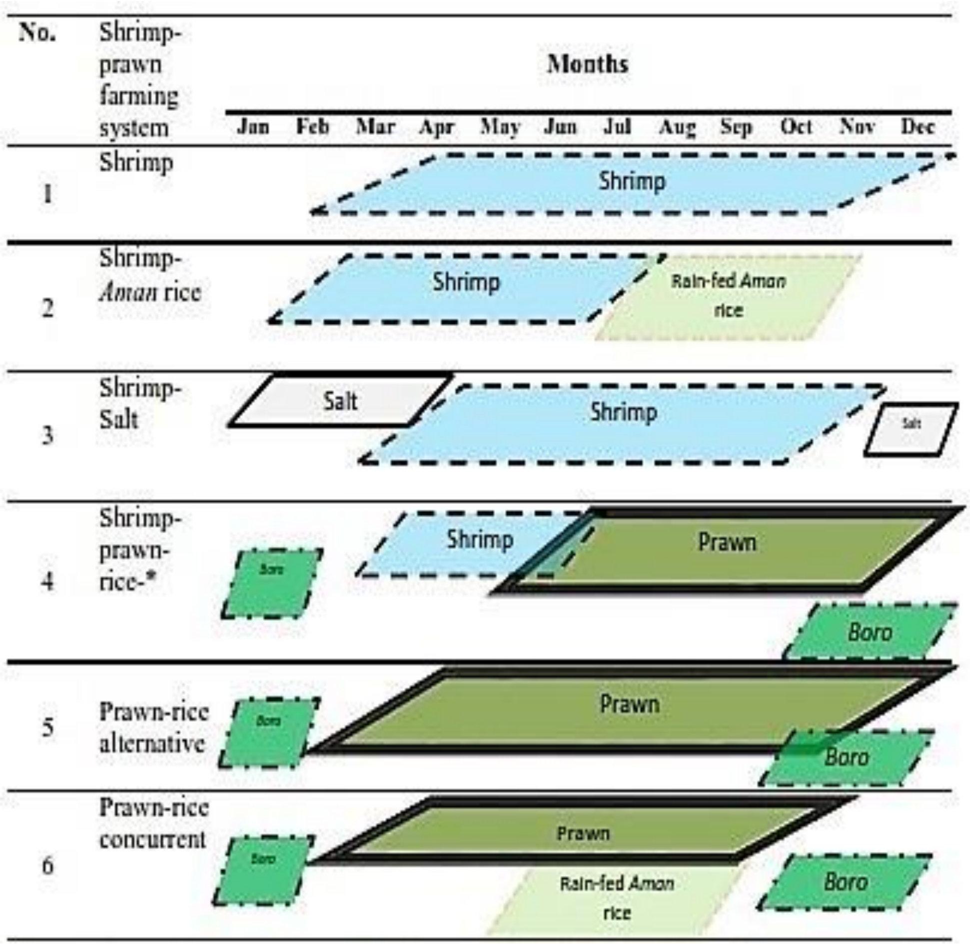
Traditionally shrimp are raised together with finfish in a polyculture that complemented the seasonal social and ecological rhythm of rural life in Bangladesh (Pokrant, 2014)**.** Shrimp farmers typically fill their *ghers* with tidal water which naturally carries shrimp PLs (Post-Larvae) and other aquatic animals fry and then farmers are trapped them. However, dependency on wild recruitment is decreasing, as farmers increasingly stock wild captured and hatchery originated PL and fry (Azad et al., 2009). Much production remains extensive still relying on natural productivity for food and growth of aquatic animals with limited application of fertilisers and feeds; farm-made or formulated.

Based on integration strategy, shrimp farming system can be divided into three distinct groups in coastal Bangladesh (1) shrimp alternate rice (2) shrimp alternate salt (practised along the south-east coast) (3) shrimp (Azad et al., 2009; Muir, 2003), (Table 1.1). All of these systems also yield other shrimp, finfish and mud crabs. Shrimp is grown during the dry season (November-February) and rice in the monsoon season (June-October) following the flushing of water and soil salinity. In the S-E shrimp is produced during the monsoon season and salt during the dry season. The third system; shrimp culture alone is practised in areas where water salinity remains comparatively high for 6-9 months annually, and rice farming is not possible (Ahmed, 2013a).

1.4 PRAWN-BASED AQUATIC ANIMAL PRODUCTION

Over 80% of prawn, *ghers* are located in low-lying rice fields, and the rest in excavated ponds (Ahmed et al., 2008). A range of freshwater fish species including Indian major carps is commonly cultured with prawns (Ahmed, 2013a). Prawn farming in low-lying rice field is classified as (1) integrated: the concurrent culture of prawn and rice (2) alternate: the rotational culture of prawn and rice (Table 1.1). The first is more commonly practised than the latter type (Ahmed & Garnett, 2011). In the integrated system prawn, PLs are stocked in May and harvested in November-December (Ahmed, 2013a). Transplanted '*aman'* rice is cultivated during the monsoon (June-October) in the same field (Ahmed, 2013a). In alternate rice-prawn farming systems, prawn are cultured in rice fields during the monsoon season. This farming is practised in deep flooded lowlands (Ahmed & Garnett, 2011). Due to high water level in the field farmer avoid the *aman* rice cultivation in monsoon season (Ahmed, 2013a). Farmers cultivate summer rice (*boro*) in the dry season (November-February). Farmers are not able to produce prawn with *boro* rice due to unavailability of prawn PLs at that time (Ahmed, 2013a).

Table 1.1 Shrimp and prawn farming systems in coastal Bangladesh [redrawn from (Alam, 2014)]



Note: Dyke crop is common from the 4th row and gradually increase with progression of rows. *Aman* is transplanted rice mainly cultivate during summer season known as summer rice; *Boro* rice is mainly cultivated during winter season known as winter rice. The pocket farm is the mostly like row 4; Organic farms are in row1&2.

Location: Row 1& 3 is in Cox's Bazar region, rest including 1 in south-west region

1.5 INTEGRATED AQUATIC ANIMALS AND TERRESTRIAL FOOD PRODUCTION

Integrated aquaculture has potential to support food production and broader sustainability (Marques et al., 2016). It also provides a broad range of socio-economic and environmental benefits (Ahmed et al., 2014). Due to the different salinity tolerance level of shrimp and prawn, the mixed culture was rare in the coastal areas of Bangladesh (Ahmed, 2013a). Progressive farmers become gradually involved in integrated farming in the region (Wahab et al., 2012). Howson (2014), found farmers adapting to a wide range of integration strategies in the lower saline areas of S-W coastal area (Table 1.1). Some innovative farmers used artificial salt in freshwater areas to cultivate shrimp with prawn (Bhowmik, 2016). Shrimp and prawn farming aquaculture and fisheries are assessed within this continuum in the next section.

1.6 FISHERIES AQUACULTURE CONTINUUM

Aquaculture is taking the lead to mitigating the future challenges of feeding 9 billion people by 2050 (FAO, 2012b). Aquaculture progressively incorporates both the natural and human components of fishing (Anderson, 2002). This incorporation can be seen as an intensification continuum (Figure 1.2); at one end human controlled intensive system and on the other part nature dependent fisheries (Anderson, 2002).

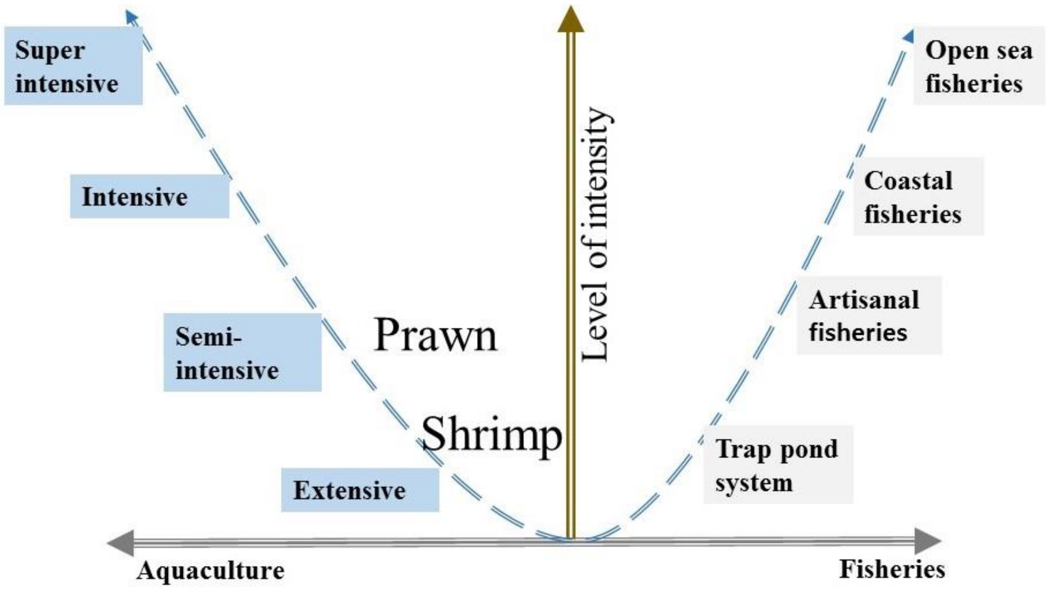


Figure 1.2 Aquaculture-Fisheries continuum showing major shrimp-prawn farming pattern in Bangladesh (Redrawn from (Guttman, 1996))

In Bangladesh shrimp and prawn farming remains one of the most extensive systems of indigenous shrimp farming in the world (Tenison-Collins, 2016). The intensity of shrimp and prawn farming are described in the next section.

1.7 Asian seafood farming and Bangladesh

Aquatic farming aims to provide appropriate conditions for ensuring optimal survival, and interventions to reduce levels of competitors and predators from the system (extensive), enhance food supply (semi-intensive) and ensuring all required nutritional demand (intensive) (Naylor et al., 2000).

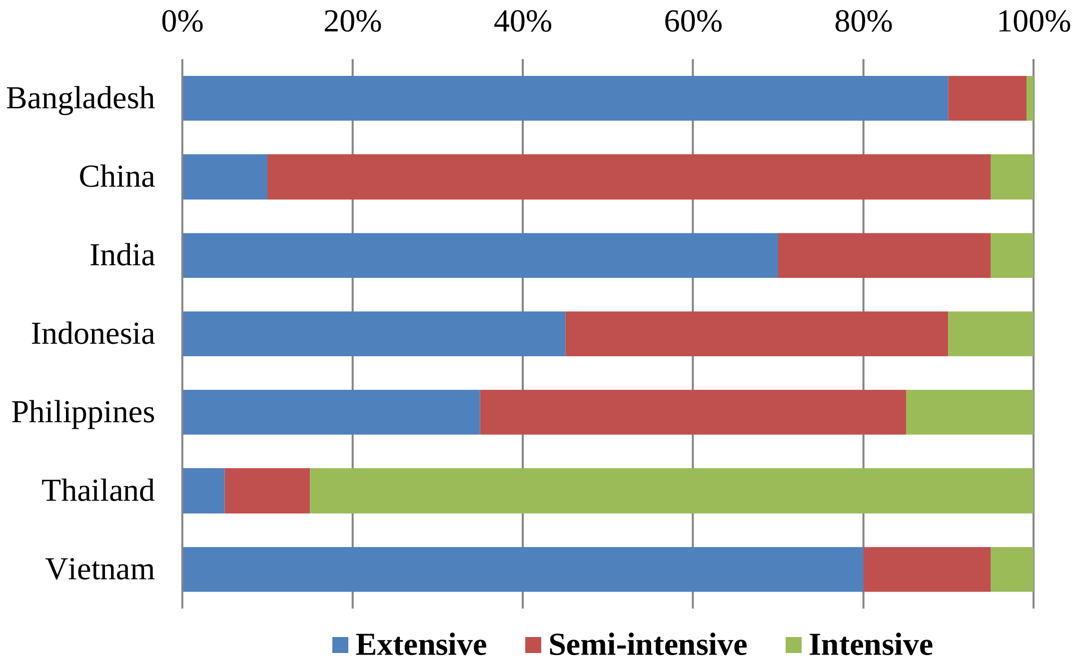


Figure 1.3 Shrimp culture system in Asian countries [Derived from Shang et al. (1998) and Vogl and Paul (2011)]

In 2010, the global bulk of shrimp production by weight was derived from the two major species the white leg shrimp (*L. vannamei*) 72% and black tiger shrimp (*P. monodon*) 21% (Tacon et al., 2013). Bangladesh remains one of the last Asian shrimp producing countries to exclusively culture indigenous species of shrimp and prawn, with most other Asian shrimp producers (Figure 1.3) having intensified production through the introduction of white leg shrimp (Tenison-collins, 2016). The majority of shrimp production takes place in small scale extensive *ghers* while the majority of prawn is produced in semi-intensive *ghers* either on its own or with shrimp (Jahan et al., 2015; Murray et al., 2013). However, the intensification of prawn is still low; only about 20% of farmers practice semi-intensive culture (Ahmed, 2013a). In recent years there have been several development initiatives to help farmers maintain access to export market through quality assurance measures including certification (with or without a guaranteed premium). The Swiss Import Promotion Programme (SIPPO) began a pilot project, the Organic Shrimp Project (OSP), in S-W Bangladesh to demonstrate and develop how are chain of custody for extensive small-holder systems free of artificial feed, fertiliser, and chemicals (Pokrant, 2014). The recent evidence suggested improved environmental and economic value as well as better chain of custody of the end product in organic farming (Paul & Vogl, 2012). Other innovations include so-called MTT (Modified Traditional Technology) have been piloted by the WorldFish Centre (WFC) Bangladesh to intensify shrimp production whilst reduce the risk of disease outbreak (Karim et al., 2014). This involves use of screened PL, in-field PL nursing before stocking in the grow-out systems, which remain low input (Hoque, 2013). Nevertheless, small-scale traditional systems continue to dominate.

1.8 GLOBAL AQUACULTURE PRODUCTION AND BANGLADESH

Globally, shrimp by value constituted the largest single product and comprised about 15% of total traded fishery commodities in 2010 (FAO, 2012b). The global export quantity assumes to increase as the fish production is expected to increase from 154 million tonne in 2011 to 180 million tonne in 2030. Expansion of aquaculture is supposed to be the key factor for the increment. However the fall of capture fisheries in some developing countries may bring negative consequence son food and nutrition security (Golden et al., 2016). Both shrimp and tilapia will be major drivers of aquaculture trade, and Southeast Asia has been identified as a key growth area (Kobayashi et al., 2015). Currently, Asia constitutes 86% of the seafood farming area in the globe (FAO, 2014b). Bangladesh produces over 3.4 million tonne fish with a reported 1.73 million tonne derived from aquaculture in 2012 (FAO, 2014b). Bangladesh ranks 5th in global aquaculture (Table 1.2) production by 2012 (FAO, 2014b). Aquaculture production now exceeds yields from unmanaged fisheries. Both shrimp and prawn comprises 7% in volume of total fish production (FRSS, 2014).

Table 1.2 Global production of farmed species from inland and Mariculture in 2012 (FAO, 2014b)

Country	Finfish		Crustaceans	% in Global fish production
	Inland aquaculture	Mariculture		
China	23341134	1028399	3592588	61.7
India	3812420	84164	299926	6.3
Vietnam	2091200	51000	513100	4.6
Indonesia	2097407	582077	387698	4.6
Bangladesh	**1525672**	**63220**	**137174**	**2.6**
Norway	85	1319033	0	2.0
Thailand	380986	19994	623660	1.9
Chile	59527	758587	0	1.6
Egypt	1016629	0	1109	1.5
Myanmar	822589	1868	58981	1.3

Total shrimp and prawn production was 223788 tonne in 2014 of which about 50000 tonne was exported (value 529.25 million US$) to international markets (Figure 1.5) (DoF, 2015). The average production volume is 250-300 kg shrimp and 500-600 kg prawn/ha/year with additional finfish (DoF, 2013).

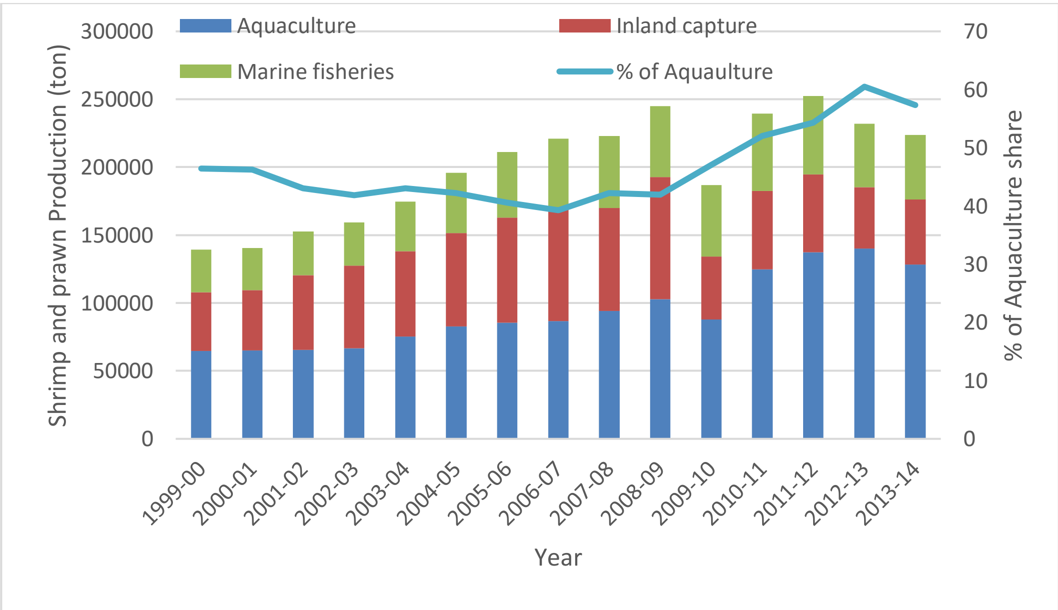


Figure 1.4 The trend of production of shrimp and prawn from different water bodies and contribution of aquaculture to total production in Bangladesh (FRSS, 2014).

Developing countries have increased the export volume of fish by many folds during the last decade, while developed countries remain as the main importers (Ottinger et al., 2016). The main importers of Bangladeshi shrimp and prawn are EU (57%), USA (31%), India (9%), and Japan (3%) (Hensler, 2012). The contribution of the fisheries sector to national GDP is 2.01% (DoF, 2015) (Figure 1.5). The rapid growth of shrimp and prawn farming is positively correlated with the national economic growth (Ahmed et al., 2010; Ito, 2002).

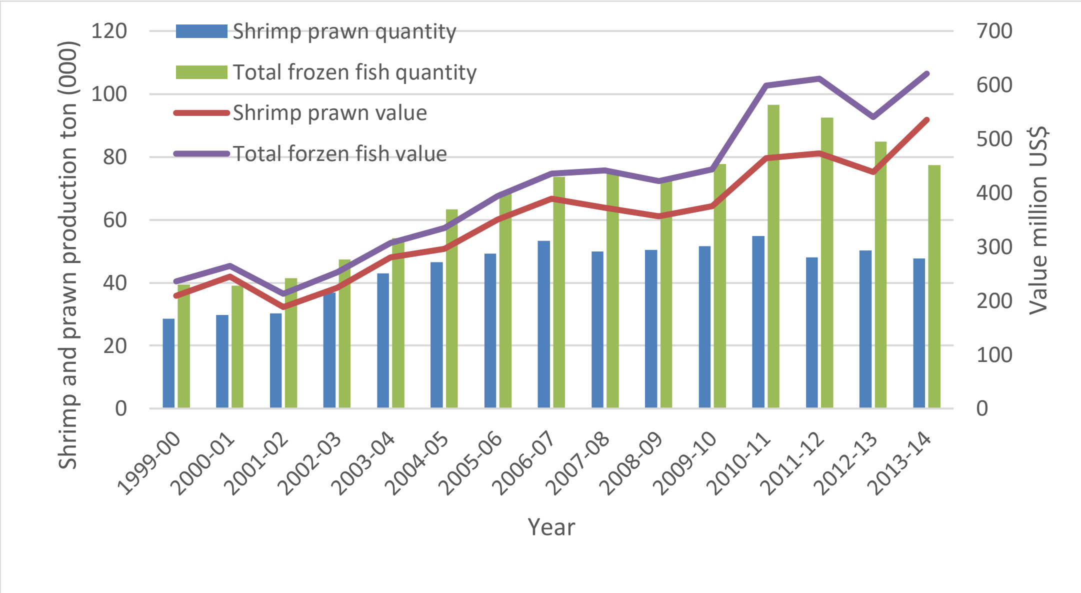


Figure 1.5 Trend of shrimp and prawn production, export volume, and value in relation to total frozen foods from Bangladesh (2000-2014), (FRSS, 2014)

The total shrimp and prawn production volume and the export volume indicated that a significant portion of the shrimp prawn yield remained in Bangladesh as by-products and whole products (Table 1.3).

Table 1.3 Trend of shrimp and prawn export (in tonne) and market distribution in Bangladesh in (1990-2010); data in parenthesis is percent in volume to total head-on shrimp and prawn production

Year	Enter into global value chain		Remain in domestic market head on weight	Total head-on
	Export	processed by-products*		
1990-91	17684 (22%)	14469 (18%)	48231(60%)	80384
1995-96	25225 (22%)	20639 (18%)	70791(60%)	116655
2000-2001	29713 (21%)	24311 (17%)	86326(62%)	140350
2005-2006	49317 (23%)	40350 (19%)	121343(58%)	211010
2010-2011	54891 (23%)	44911 (19%)	139658(58%)	239460

*Processed by-products are about 45% of total weight head-on shrimp and prawn selected for export (modified from Ahmed, 2013a).

About 40% of total shrimp and prawn production in relation to the total volume enter into the global value chain. In the global value chain about 55% by volume entered international markets and the rest (45%) remained as processed by-products in Bangladesh (Table 1.3). The volume of by-product varied on species and product types (head-on, shell-on). In some cases, the by-product of fish and shellfish can be varied 40-70% weight of the total product (Heu et al., 2003; Newton, 2014; Olsen et al., 2014; Sachindra et al., 2005).

1.9 GLOBAL VALUE CHAIN OF SHRIMP AND PRAWN

Aquaculture has a profound impact on broader society (Welch, 2015). The shrimp and prawn value chain links the life cycle of shrimp and prawn from brood collection to consumer plate (Galappaththi, 2013). Developing countries are major actors in global fishery commodity supply chains which supply half of all fishery products by value and >60% by quantity (World Bank, 2011). More than 37% total fish production of developing nations is thought to enter global markets (Welch, 2015). Global Value Chains (GVC) connects producers to consumers, but major shortcomings are the power asymmetry (Lim & Neo, 2014). Both suppliers and buyers are the most powerful actors and can regulate the prices of commodities to the detriment of producers and other GVC actors with little power (Armitage, 2002). Control over value chains in the major Asian shrimp producing countries can be defined as unipolar, bipolar or multipolar (Jespersen et al., 2014). In Bangladesh, the shrimp supply network is buyer-driven i.e. unipolar (Jespersen et al., 2014), and buyer decision is vital. For example in 1997 Bangladeshi products were banned in EU market on safety grounds, and the sector suffered a lot financially (Cato & Santos, 1998). However, the Chinese shrimp sector coped well with a similar ban in 2004 by absorbing the product through domestic markets (Zhang et al., 2015).

The quality standards of Bangladeshi shrimp and prawn have been questioned on several occasions (Alam & Pokrant, 2009). The shrimp industry in Bangladesh is facing challenges on poor post-harvest management (Rahman & Hossain, 2009). There is a growing concern due to the presence of banned antibiotic nitrofurans, which is believed to be linked to contaminated fish feeds (Islam et al., 2009). Nitrofurans are a group of antibiotics believed to be carcinogenic (Ahmed, 2013). Part of the remedy action, the government of Bangladesh executed a self-imposed ban on exporting prawn in 2009. After eight months of the ban, Bangladesh resumed prawn exports clean of nitrofurans (Ahmed, 2013a). In the same time since the suspicion of feed adulteration, the government of Bangladesh has taken remedy measures and approved a Fish and Animal Feed Act 2012 and Fish and Animal Feed Regulation 2011 (Ahmed, 2013a). Adoption of traceability for more than 200000 farms is quite challenging, but some efforts like *gher* registration, institutional monitoring, paper-based traceability, e-traceability, third party certification schemes have been attempted, although impacts on quality loss during the chain of custody have not been demonstrated. Although Bangladesh has been struggling to maintain a proper chain of custody in post-harvest management, the shrimp and prawn markets have growing strongly both in volume and value over the decades. Trade liberalisation and the hard cash earnings from international markets have had both positive and adverse consequences in developing countries economy and food security.

1.10 TRADE LIBERALISATIONS IMPACT ON DEVELOPING COUNTRIES ECONOMY

Trade is termed as an engine of growth for the developing countries that have vast fishery resources (FAO, 2006). Export contributes to earning hard cash (Bostock et al., 2004) which, it has been postulated supports the import of low-cost food to mitigate domestic food demand (FAO, 2006). Trade liberalisation and market value in the international market opened up opportunities for resource-poor developing countries. It has been the prime impetus for economic growth, poverty reduction, employment, revenue earning, specialisation on products, efficient uses of resources (Cline, 2004). Many international organisations have focused on pro-fish trade. The OECD (the Organisation for Economic Co-operation and Development) for instance claimed: "trade and investment liberalisation has proven to be powerful stimuli to economic growth and a key factor in integrating an expanding number of developing countries in the world economy" (OECD, 2008). This foreign exchange flow was described as a 'life-raft' for the many developing countries to buoy up their poor economic conditions. However, on many occasions, the free access to food and earning hard cash by the developing countries are questioned for the real improvements of the poorer portion of the society.

1.11 SEAFOOD EXPORTS AND IMPACTS ON POVERTY

The actual effect of macroeconomic development on poverty reduction is still debated (Edward, 2006). Some commentators claimed that high demand for shrimp in international markets decreased fish availability both in nature and local markets in Southeast Asia (Van Mulekom et al., 2006). Farmers were encouraged to produce export-oriented high priced products rather than the locally consumed items, which eventually led to shrinkage of local food availability (Ghosh, 2005). Reduced fish supply and high price may cause serious consequences regarding both economics and nutrition of low-income people compared to middle and high-income people (Kent, 1997). A mechanism called "trickle down" proposed by Aghion and Bolton (1997), was used to understand the linkage between hard cash earning and poverty alleviation. Limited evidence was obtained for this, and the greater part of this hard cash appears to be absorbed somewhere between the rich-country consumer and developing country producer (Kurien, 2005). Export of seafood also shrank local jobs and adversely effects on the domestic fishing industries (Janssen & Goldsworthy, 1996).

Some NGO's on behalf of small-holders are the vocal critics of open access market (Bardhan, 2006) and have developed the concept of "food sovereignty" which treats trade as a means to an end, rather than an end itself (UUNN, 2004). The food sovereignty actors hold ambiguous stance to distribute the peasant products in local channel rather than export. However, in Ecuador indigenous peasant preferred to export their products to the global market as it is fair and stable compared to the local markets (Soper, 2016). Chile, one of the largest fish exporters of the world, the region dense with export-oriented salmon farming experienced the lowest average per capita income of the people (Kurien, 2005). However, Montero et al. (2006) reported the expansion of salmon industries in Chile sharply decreased poverty level, increased the participation of young entrepreneurs from the rural community. In Lake Victoria in Kenya; growing fishery industry caused a threat to employment and food security of the people (Kurien, 2005). This is not all about trading but some also identified the change of attitude and values of fishers that they like to sell fish to obtain money to buy other goods rather than eat that fish, i.e., fish is seen as goods and not as food (Abila, 2003). Recently Asche et al. (2015) analysed volumes, value, and quality of traded seafood and found that imports and exports between developed and developing countries were well balanced by volume but there was an inequality of quality; developing countries tended to supply high nutrient seafood to developed countries and purchased lower quality in exchange. The real impact of shrimp and prawn farming on people's livelihoods got mixed experiences in Bangladesh and are discussed next section.

1.12 IMPACTS ON LIVELIHOODS

Real improvements in the livelihoods of local poor people are not always correlated with the expansion of aquaculture (Bergquist, 2008). In major shrimp producing countries, including Bangladesh poverty, food insecurity, landlessness and human rights abuse have been associated with the rise of a shrimp industry (EJF, 2003). The S-W coastal Bangladesh is considered as the one of the poorest area of the country along with the higher malnutrition and food insecurity (HKI, 2011). In contrast to that Hossain et al. (2016) reported shrimp and prawn farming has been increasing both aquatic and inland food production in the S-W Bangladesh. Therefore, the proportion of total population below the poverty line has reduced by 17%. However, drinking water, terrestrial food production and land stability have been reduced (Hossain et al., 2016). Shrimp and prawn farming have created a huge array of jobs that paddy farming could not generate in Bangladesh (Islam, 2008b). The labour demand is particularly becomes high during *gher* construction (Ito, 2002). Social displacement also reported in Bangladesh where farmers were forced to migrate to the nearby cities to sell labour (Alauddin & Hamid, 1998) and family members remain in the village (Barraclough & Finger-Stich, 1996). In the south-east coastal area the rapid intensification of shrimp farming reduced the socio-economic status of the marginal people, shrinkage job options (Hossain & Lin, 2001).

In contrast, shrimp and prawn farming improves the livelihood of everyone in society (Gurung et al., 2016). Shrimp farming is seen as positive for the developing countries livelihoods (World Bank, 2013). Globally, aquaculture has often been considered as a vital contribution to poverty alleviation, a source of employment and means to generate income opportunities for hundreds of thousands of people (FAO, 2006). Aquaculture provides employment for 23.4 million people and Asia accounts for 92% of the global total (Valderrama et al., 2010). According to FAO (2014b), aquaculture produces four additional jobs, created at a secondary level which leads to a figure for total employment of around 170 million globally (Welch, 2015). In Bangladesh 1.5 million people are directly or indirectly involved in the shrimp and prawn sector (Wahab et al., 2012). In Bangladesh, shrimp farming has increased employment opportunities, wage rates, purchasing power, food security, women empowerment, sanitation and drinking water facilities, poverty alleviation (Lewis et al., 2003). In Mozambique, shrimp farmers are in a better livelihood position compared to those who not involved in shrimp farming (Blythe et al., 2015).

The participation of the landless and marginal people both in production link and the marketing link in shrimp and prawn sector are widely acknowledged (Ahmed, 2013a). The marketplace in rural landscapes is a vital institution not only for product flow, however, created livelihood options for many rural poor people. There is flexibility to entry and exit to fish marketing jobs which enabled the poorer to diversify their livelihood options which also helped to cope with the seasonal variability of opportunities and stable income (Faruque, 2007). The participation of landless and marginal farmers in rice-prawn farming is one of the main reasons for its rapid expansion in the region (Barmon et al., 2005). After successful prawn-rice farming, it was evident that some marginal and landless people became the owner of a small piece of land. It indicated the progress of socio-economic conditions through integrated culture systems (Barmon et al., 2005). The marketing channels of shrimp and prawn potentially provide livelihood opportunities to thousands of people (Pokrant & Reeves, 2003). Male labourers are mainly engaged in transporting, handling, cleaning, sorting, grading and icing activities at market level. While a significant number of women are involved in cleaning, beheading, processing shrimp and prawn in the processing plant and urban depot (Islam, 2008a). Women's participation in shrimp and prawn farming value chains is an indicator of women empowerment both at family and social level (Islam, 2008a). Such empowerment has been shown to reduce domestic violence and social inequality in Guyana (UNDP, 2010).

Involvement in aquaculture activities enhanced the well-being status of the poor (Belton et al., 2014). Overall coastal shrimp and prawn farming have a positive impact on social and economic sustainability (Ahmed & Garnett, 2011). However, for better economic growth poor farmers required access to improved technology and credit (Gurung et al., 2016). Some commentators believed that agrarian sovereignty could bring the greater equality in agrarian class relations. The main benefit of agrarian sovereignty is to provide the self-determination power of agricultural production to the landless and marginal people (Paprocki & Cons, 2014). The contribution of aquaculture to poverty reduction is context-specific. If the target of aquaculture development is to reduce poverty than labour intensive technology should implement and the use of yield increasing properties should minimise (Stevenson & Irz, 2009). Despite livelihood improvements still, there is some issue on social harmony across the shrimp and prawn farming areas.

1.13 RESOURCE USE CONFLICTS

Shrimp typically records the highest profitability among the commonly farmed and traded seafood (Rivera-Ferre, 2009) but has also resulted in resource use conflicts over the privatisation and degradation of common property (Sebastiani et al., 1994). Shrimp farming has been linked to shrinkage of multi-use of land and water, and lower diversification of resources (Pradhan & Flaherty, 2007). In India, the marginal poor of coastal areas has been highly affected by land acquisition for shrimp aquaculture (Nayak & Berkes, 2011). Resource use conflicts among different users like shrimp, forest, ship-breaking yards, ports, and industry exist in Bangladesh coast (Islam, 2006). Fatema and Miah (2011), worked in the Dacope sub-District, Khulna and found a mixed opinion on either rice or shrimp farming options. For environmental resilience the majority opined for rice despite the higher profit from shrimp. Paul and Røskaft

(2013), reported that landless and marginal people are vocal against shrimp farming as it is linked to unemployment, through loss of traditional agriculture. Bangladeshi NGO *Nijera Kori* is steering the marginal people's movement against shrimp farming and declared some area for instance *Polder* 22 as shrimp free zones (EJF, 2003). The tragic death of *Karunamoi Sardar,* one of the marginal women, died in such a protest on 7 November 1990 remained as the distressing event of such social mobilisation. Conflict over the land redistribution is also a cause of social unrest. In Bangladesh, government-owned land (*Khash* land) is to be distributed or leased to the landless people by the land reform act 1989. However, the majority of them are grabbed by the politically influential elite, bureaucrat, bankers and business people (Deb, 1998). Knowler et al. (2009) observed less conflict in Indian Sundarbans areas due to extensive culture pattern. Degradation of natural resources is one of the main reason behind squeezing the livelihood options of coastal communities (Miah et al., 2010). Participation of poorer in such social movement is also believed to the limited access of poorer in shrimp farming.

1.14 DISPARITY ON ACCESS TO SHRIMP AND PRAWN FARMING

Some commentators noted shrimp farming is linked to high investment, and that access to shrimp farming is not equal to all (EJF, 2003; Van Hue & Scott, 2008). Shrimp farming has been implicated in introducing entrepreneurs from outside the community to the detriment of access for local community people (Dewalt et al., 1996; Neiland et al., 2001; Shiva, 1995; Stonich & Bailey, 2000) and leading to broken social cohesion in Bangladesh and India (Murthy, 1997). Barraclough and Finger-Stich (1996), observed that about 75% shrimp farmers in the Satkhira District of Bangladesh were found to be outsiders and that their involvement created social conflicts (Neiland et al., 2001). Less participation of local people was anticipated due to lease fees being beyond the reach of local people (Hossain et al., 2013). In the last decade, the demand for aquaculture products has increased many folds and many formal and informal institutes have lent money and provided support to expand participation in aquaculture by poorer groups (Jahan et al., 2015). Therefore, the participation and benefits of local and poorer households in aquaculture remains contested (Faruque et al., 2016). Alam (2014), for example, reported an inverse relationship of outsider participation to that stated by Barraclough and Finger-Stich (1996) in aquaculture at greater Khulna region.

In Bangladesh for shrimp and prawn farming, farmers benefit without any requirement for land and oxen as described by Guimarães (1989), for agriculture. Rural farmers with the capacity to conduct key activities like embankment construction, water exchange, guarding and harvesting can be involved in shrimp farming. Willingness and capacity to be involved in aquaculture are vital (Krause et al., 2015). Rich households in Bangladesh tend to lease out land to the poorer which creates opportunities for the latter (Gurung et al., 2016). A poorer farmer can lease land for shrimp farming in a fixed rental scheme. This is like the sub-Saharan Africa where the property title is unaffected (Brasselle et al., 2002). Nevertheless, whether the poorer are engaged in the agricultural or non-agricultural link for their livelihoods, they entered into the development process. Indeed, engage in works not the ownership of land is crucial for the livelihood in the new world (Toufique & Turton, 2003). Commercialisation of agricultural activities has been found to undermine the participation of women and other disadvantaged groups and this is now considered for aquaculture.

1.15 CULTURE, ETHNICITY GENDER IN SHRIMP AND PRAWN FARMING

Transformation of rice farming to commercial aquaculture decreased the control and access of women over the agricultural product in Bangladesh (Gurung et al., 2016) but the contrary has been observed in Bangladesh. Commercialization, fish processing, and small-scale aquaculture offer important livelihood opportunities for women in developing countries (FAO, 2014b). The increasing commercial attitude in Bangladesh aquaculture involved more women in aquaculture activities. Generally, women are involved in fish feed preparation, feeding and growing vegetables (Faruque, 2007). In poorer households, women are also involved in hard physical work like pond construction to avoid hired labour cost. This involvement of women increased their workload but appeared to lead to greater empowerment in household decisions (Faruque, 2007). Globalisation also favoured the unskilled and uneducated women mostly to involve in export-oriented processing factories (Borraz & Lopez-cordova, 2007). In Nigeria and Vietnam, females are more evident in the grow-out farm, processing plant and marketing (Veliu et al., 2009). In Bangladesh, female in coastal rivers are involved wild PL collection. About 60% of total workers (20000 in number) in Bangladesh shrimp processing industries are female (USAID, 2006). Their job is mainly de-heading, peeling and cleaning raw product in processing plants, activities with relatively low prestige, power, and benefits (Laven & Verhart, 2011) compared to male counterparts (Islam, 2008a). Women are also involved in snail breaking where snail meat is used as prawn feed (Ahmed, 2013b). The dependency on wild PL collection is decreasing day by day as the natural resources have been overexploited.

1.16 IMPACT ON CAPTURE OF COASTAL RESOURCES

Both aquaculture and fisheries impact on one another in dynamic and often unexpected ways (Welch, 2015). Fisheries resources like wild PL of shrimp and prawn are preferred to stock by the farmer who eventually encourages local poor men and women to collect them from adjacent rivers and tributaries (Ahmed et al., 2010). During PL collection non-target species are caught incidentally which has been linked to biodiversity degradation (Naylor et al., 2000). In Bangladesh about 100000 fishers are involved in fry collection, catching approximately 2000 million PLs/year (Islam & Wahab, 2005). The PL number from wild sources has been decreasing dramatically, and in 2013-14 it was estimated 900 million (DoF, 2014). Due to poor handling and transportation about 40% die before stocking in the *gher* (Brown, 1997). For every 1 kg of shrimp (*P. monodon)* larvae caught, around 10 kg of by-catch are sacrificed (Hoq et al., 2001). This over-exploitation has been related to significantly reduced catches of wild shrimp (Paez-Osuna et al., 2003) from where the broods are collected. For shrimp hatchery operations, brood stock is collected from the deep sea through trawling (Primavera, 2006). For prawn hatchery, more than 80% of hatcheries relied on wild broodstock (Ahmed et al., 2008a). In this regard to save the wild brood and other aquatic resources, Department of Fisheries (DoF) imposed a ban on wild PLs collection in late 2000 (DoF, 2002). Alternative livelihood options for the PL catcher could help to implement the embargo by DoF (Ahmed et al., 2010). Moreover, the continuous and timely supply of quality PL from hatcheries could minimise the damage to natural resources.

1.17 ESTABLISHMENT OF HATCHERIES

Bangladesh shrimp and prawn farming system have been expanded by area (Figure 1.6), and the demand for PLs has been increasing day by day. In 2000-2001 the hatchery originated shrimp and prawn PL was around 3000 million in number and wild source PL for both species were about 75% of hatchery source. In 2012 the hatchery originated PL increased in number for more than decade at least 3 times and the wild stock declined to half which was represented 10% of hatchery originated PLs. This is because, a growing demand for seafood has led to intensified shrimp production in many places and enhanced the requirement for seed, both locally and globally (Nietes-Satapornvanit, 2014). Demand for quality seed (less heterogeneity in size), in sufficient quantities, and more stress-resistant has increased with the advancement of shrimp farming (De Silva & Davy, 2010).

Table 1.4 Shrimp and prawn hatchery and production volume in Bangladesh (FRSS, 2014)

Species	Prawn		Shrimp	
Source	No. of hatchery	PLs production (million)	No. of hatchery	PLs production (million)
Govt. hatchery	5	1	0	0
Private hatchery	16	32.1	60	9239.2
Total	21	33.1	60	9239.2

In response to the demand, a good number of shrimp and prawn hatcheries have been developed in Bangladesh in early 1990's. The shrimp hatcheries are confined in the SE coastal Cox's Bazar region of Bangladesh (Figure 1.1), and prawn hatcheries are sporadically distributed across the country. Disease and relatively low profit are the main barriers of shrimp hatcheries. Transport cost (carried in the southeastern region via air cargo, microbus, and truck), production cost and disease occurrence narrow the margins of profit (Debnath et al., 2015). Disease control and genetic improvement remain the main challenges in shrimp hatcheries. Specific Pathogen Free (SPF) brood stock might offer a partial solution to disease problem, however, both the hatcheries and grow-out are unlike to absorb this, due to poor technical capacity (Debnath et al., 2015). The increasing shrimp and prawn farming system also required more inputs (feed and fertilisers) to gain sustainable development.

1.18 FEED AND FERTILISERS USED IN SHRIMP AND PRAWN FARM

Globally, shrimp and freshwater crustaceans are one of the major fastest growing species group, and the annual growth rate is about 12.8% and 11.8%, respectively (Tacon & Metian, 2015). The estimated global requirement of aqua feed will increase from 39.6 in 2012 to 65.4 million tonne in 2020. Moreover, the annual inclusion rate will be at least 4 million tonne (Tacon & Metian, 2015). As mentioned earlier sections the shrimp and prawn farming in Bangladesh is largely managed by small-holders and the system is fairly extensive, and inputs and outputs minimal. In shrimp and prawn farming systems most of the farmers are utilised feed ingredients rather than pelleted feed (Tasnoova et al., 2015). There is an inverse relationship exist on feed and fertiliser use in shrimp and prawn farming (Boyd & Massaut, 1999). Barmon et al. (2006) also noted in Bangladesh prawn farmers use less fertilisers and more feed while shrimp farmers are vice-versa. Fertilisers have a wide-spread use in shrimp ponds to increase the growth of natural productivity (Boyd & Massaut, 1999). Among organic fertiliser chicken and cow manure are used in the South-east Asian shrimp and prawn farming system (Primavera, 1993). In Bangladesh, two major fertiliser organic (cow dung) and inorganic (Urea, TSP) are used in *gher* based aquaculture system (Ahmed et al., 2007). Therefore, fertiliser is the major contributor of total nitrogen and total phosphorus in *gher* system (Islam et al., 2004). The less feed prawn-rice integration in Bangladesh is technically possible is due to low stocking density (Boock et al., 2016). The prawn feed based research got more space in literature (Ahmed, 2013b; Hossain & Paul, 2007; Jahan et al., 2015) compared to shrimp-based study indicated the importance of feed prawn farming than shrimp.

In Bangladesh, the pelleted feed is mainly used in the intensive shrimp farm which is few, and the rest of system used agricultural ingredients. The agricultural ingredients are widely used as feed for the shrimp and prawn farming in Bangladesh (Henriksson et al., 2015). For prawn culture snail meat is commonly used along with the mixture of locally available ingredients; rice bran, mustard oil cake, wheat bran (Ahmed, 2013b). Intensive prawn farmers usually used pelleted feed, and the medium and poorer farmers have used ingredients and snail meat (Ahmed, 2013b). The low input system is also linked to lower carbon emission. Agricultural activities strongly impact the global carbon (C) cycle (Adhikari et al., 2014). Regarding global warming and eutrophication, the shrimp and prawn *gher* of Bangladesh were in better position than other major Asian producers (Henriksson et al., 2015). However, the location of shrimp and prawn farm in Bangladesh is highly susceptible to climate change effect which is now considered.

MAJOR CHALLENGES TO THE SEAFOOD SECTOR

1.19 CLIMATE CHANGE AND OTHER NATURAL EVENTS

Climatic change has significantly increased the adverse natural events like sea level rise (SLR), cyclones, floods, water logging and salinity intrusion in Bangladesh (Ahmed et al., 2013a). As a result of global warming and glacier melting in the Himalayas would rise the sea level and inundated a coastal area of Bangladesh. The susceptibility of inundation is high as because 70% area of Bangladesh is <5 meters high from the sea level (Dasgupta et al., 2014). About 1 m rise in sea level would entirely lose the Sundarbans mangrove forest and also affect the vast majority of shrimp and prawn farming area in S-W Bangladesh (World Bank, 2000). It is estimated that a one-metre in the rise of sea level will result in a reduction 7% of national Gross Domestic Production (GDP) (Rashid, 2005).

The coastal area of Bangladesh is also very vulnerable to devastating storms and cyclones. Most of the tropical cyclones originated in the Indian Ocean track through the Bay of Bengal and mostly hit Bangladesh coast (Ali, 1996). Along with smashed crops, cyclones has killed millions of peoples in Bangladesh on many occasions (World Bank, 2000). One of the recent devastating cyclones so-called *Sidr* in November 2007 affected 9 million people in Bangladesh coast (MOEF, 2010). Another cyclone in May 2009 named *Aila* affected the shrimp and prawn *ghers* in S-W Bangladesh (Dasgupta et al., 2014). The frequent incidences of cyclones in the region like so-called *Nargis* in 2008, *Bijli* in 2009, *Giri* in 2010, *Mahasen* in 2013, *Roanu* in 2016 brought huge damage, vulnerability in coastal life.

Flooding is another natural calamity which affected at least one-fifth area of the country annually (Ahmed, 2013a). Shrimp and prawn *gher* are often damaged due to sudden or prolonged flooding (Ahmed & Garnett, 2011). The main causes of flooding in the S-W coastal region are river overflow, rainfall, tidal charges and sedimentation in river beds (Banerjee 2010; Gregory et al., 2010). Moreover, in most cases, farmers are unable to raise their characteristic low and narrow pond dykes before flood events. This is why most of the farmers fail to prevent the escape of aquatic animal during flooding (Ahmed, 2013a). Along with the Cyclones, daily tidal charge causes salinity intrusions in the region (Ahmed et al., 2013a).

1.20 SALINITY INTRUSION

The coastal embankments (*polder*) were built during the 1960's to avoid tidal saline water. However, hydrodynamic events (siltation from upstream and tidal overflow) brought environmental changes and formed saline water logged area (Foxon, 2005). These changes also brought the land use changes from rice to shrimp linked to the water salinity regimes in the region (Hossain et al., 2016). Shrimp farming is considered as one of the few economic adaptations to the saline water. The saline water intrusion area and the shrimp farming are geographically co-located (Johnson et al., 2016). The saline tidal water through numerous estuarine rivers and tributaries intruded up to 160 km inland, which causes increase saline levels both in water and soil (Haque, 2006). Inundation of land by saline water over longer periods alters soil chemistry and can undermine soil fertility (Islam et al., 2004). In the S-W coastal Bangladesh, about 70% of cultivated land (1.02 million hectares) are affected to various degrees by salinization (Haider & Hossain, 2013). In this area salinization not only reduces water for agriculture but also for drinking, domestic needs and irrigation (Deb, 1998). Salinization of groundwater also occurs in the south-west coastal region (Turner & Ali (1996). In a community appraisal, it was revealed that the drinking water scarcity is linked to the water salinity rather than arsenic and drought hazards (Abedin et al., 2014). Increased salinization has been related to increased gastrointestinal infections of human, reduced crop diversity, poultry, and fodders (Ali, 2006).

Salinity levels in this area of Bangladesh vary both seasonally (high during the dry season and low during winter) and by location (Bhuiyan & Dutta, 2012). The onset of monsoon rains and the freshwater flow from the Ganges river system reduces water salinity significantly from May onwards. During the dry season, the drastic fall in the river Gange's water level and the water withdrawal at the *Farakka* (India) point significantly reduced the freshwater flow (Gain & Giupponi, 2014; Mirza, 1998). The predominantly eastward movement of Gange's Rivers contributed significantly to reduce salinity levels from the south-west corner to northeast corner of S-W region (Rahaman et al., 2015). The salinity is seasonal, the timing of salinity level (both natural and deliberate flush out during the wet season) helped the rice/shrimp production in higher saline areas (Belton et al., 2014; Kabir et al., 2015a; Nuruzzaman, 2006). The distributional differences of aquatic animals across the S-W coastal *gher* indicated water salinity differences across the region (Carbonara, 2012; Murray et al., 2013).The mangrove has an important role in the aquatic animal diversity and shrimp farm development process.

1.21 MANGROVE DESTRUCTION

Mangrove forests occur along coastlines throughout the tropics and support many ecosystems and environmental services including fisheries production (Godoy & Lacerda, 2015). The S-W coastal region is famous for the existence of unique mangrove ecosystem, the Sundarbans. The Sundarbans mangrove in Bangladesh is stretching in the southern part of three districts of greater Khulna within an area of 0.57 million ha, has more than one-third of its area (0.17 million ha) occupied by rivers, canals, channels and other watercourses (Lewis, 2011). Mangrove has a positive impact on the availability of fish (Blaber, 2007). The Sundarbans mangroves support 250 species of fishes (Gopal & Chauhan, 2006). Over the last two centuries, a vast area of Sundarbans mangrove (in both part India and Bangladesh) converted into paddy field and most recently into shrimp farms. Nevertheless, in the last three decades, a significant part of remaining Sundarbans have been protected by declaring sanctuaries and biosphere reservoir, world heritage sites (Gopal & Chauhan, 2006). However, Swapan and Gavin, (2011) claimed that about 90% of shrimp *ghers* in the S-W coastal area had been converted from mangrove and agricultural land. In contrast, Sohel and Ullah (2012) and Hossain et al. (2013) has stated that due to the construction of shrimp pond the exact amount of mangrove loss are not documented. The coastal area in Bangladesh is highly complex and diverse. Brammer (2014), subdivided the coast into four physiographic regions and the south-east is different from the south-west coast. In the south-east coastal area of Bangladesh Chakaria mangrove forest with an area of 18200 ha converted to shrimp pond (Akhtaruzzaman, 2000). Commercial shrimp farming in the south-east coastal region was responsible for the destruction of the Chakaria mangrove forest (Ishtiaque & Chhetri, 2016), and it was one of the devastating examples of fake blue revolution decade of shrimp and prawn farming in Bangladesh. Hamilton (2013), assessed the mangrove losses from 1970 to post 2004 in eight countries including Bangladesh concluded that about 28% mangroves were lost due aquaculture combined in these countries. In Bangladesh case, mangrove loss due aquaculture was much lower (19%) than the average loss of these eight countries. Expansion of shrimp farming is believed to cause serious damage to mangrove ecosystem (Ahmed et al., 2008). Shrimp farms located close to mangrove affect mangrove indirectly through changes in hydrology increased sedimentation, and water contamination (Walters et al., 2008).

Human interference illicit felling of trees encroachment (Saenger, 2002) urbanisation, industrialisation (Uddin et al., 2014) are major causes of mangrove deforestation in Bangladesh. About 10 million people directly or indirectly rely on mangroves (Islam & Wahab, 2005). Some also warned the future of the Sundarbans will depend on the upstream freshwater flow along with the conservation of its biological resources (Gopal & Chauhan, 2006). Despite the wide variety of negative consequences, climatic change is expected to lead to expanded mangrove (Godoy & Lacerda, 2015). In this regard, Uddin and his colleagues found evidence for mangrove expansion in Bangladesh (Uddin et al., 2014). There have been greater increases of land under land accretion observed in the Meghna floodplain area (Islam et al., 2014). Rather than towards mangrove, shrimp and prawn farming has been expanded inland.

1.22 IMPACT ON LOW-GRADE ARABLE LAND AND RICE FIELD

The conversion of different agro-ecological settings including rice fields to shrimp farms spurred controversy in many shrimp producing areas (Primavera, 1997). In the Philippines, cane fields were transformed into shrimp pond by wealthy sugar families in conjunction with large corporation (Hall, 2004). In central Thailand intensive shrimp farming provided ten times more return than rice and farmers convert their fields into shrimp farm (Belton & Little, 2008). In the inner Gulf of Thailand urban elites, local fishers, and rice farmers cleaned mangrove forest with state support (Hall, 2004). In Bangladesh, the climate change along with anthropogenic pressure brought many remarkable changes in land use pattern in the coastal area.

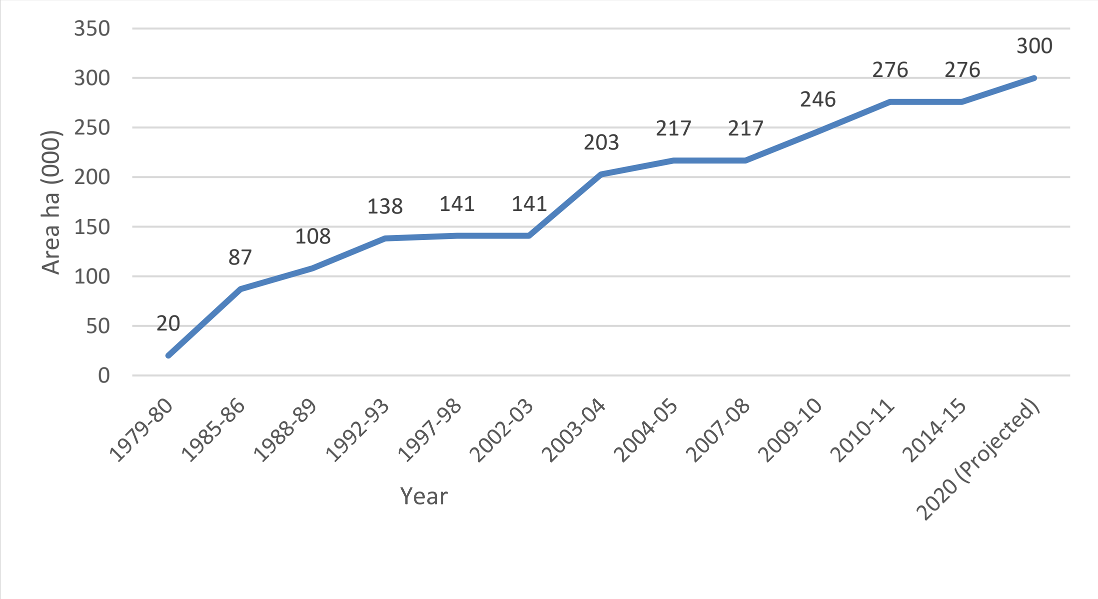


Figure 1.6 Cumulative quantity of land area occupied by shrimp and prawn farm in Bangladesh (DoF, 2015)

Land use in coastal environment is diverse and has become competitive. In 1950 the land had been mainly used for paddy culture, however, salinity and tidal flooding lowered the productivity which polderisation was implemented to reverse. Farmers in the region have a history of traditional shrimp farming and rice farmers took the advantage for shrimp farming (Islam, 2006). The land used pattern in S-W coastal area has been largely guided by the level of salinity (Kabir et al., 2015b). Shrimp farming increased land use change at a rate of 2.05% per annum in the Ganges delta (Islam et al,. 2014). The majority of the shrimp *gher* area gained from converted single cropland (Islam et al., 2014). The mainly low productivity and unstable production of rice influenced the dynamic change of land use pattern (Islam et al., 2014). *Ghers* in the lower saline areas were modified through constructing a trough or trench inside the earthen enclosure to retain water in this deeper part over a portion of the field (Kabir et al., 2015b). The shrimp and prawn farming area in Bangladesh was 20000 ha in early 1980's and the next five years expanded more than 300% (BFFEA, 2015). Now the total area is estimated at about 275274 ha, and the vision of Bangladesh Frozen Food Exporters Association (BFFEA) is for it to expand to 300000 ha (Figure 1.6) by 2020 to fulfil the target of tripling the current shrimp export volume. The horizontal expansion of shrimp and prawn farming in Bangladesh have been a continuous process, however, due to the devastating disease occurrence, the production volume has increased only marginally.

1.23 IMPACTS OF DISEASE OUTBREAK

Since 1994, diseases mainly viral pathogens, globally caused losses worth $US 3 billion each year in the shrimp industry (Lightner, 2003) and remain the major concern of sustainable development and profitability (Walker & Mohan, 2009). Crop loss due to disease occurrence in Thailand leads the impacts on the smallholder's food security and the job security of the workers in large farms, the feed industry and in processing plants (Bondad-Reantaso et al., 2012). EMS (Early Mortality Syndrome) in shrimp is a recent terrifying disease (Tran et al., 2013) documented in South-east Asian countries causing mass mortalities in shrimp.

The major disease threat to shrimp farming in Bangladesh has been White Spot Syndrome Virus (WSSV), an epidemic-causing, transmittable viral disease (Stentiford et al., 2012). Apart from WSSV diseases red colour, soft shell, tail rot and black gill are diseases that have occurred and caused losses in shrimp farms in Bangladesh (Alam et al., 2007). In 1996 in Bangladesh WSSV caused about 44.4% production loss (Hossain et al., 2013). Karim et al. (2014) noted that more than 50% *gher* in higher saline areas are affected by WSSV. This argument is widely supported by Hossain et al. (2015) where they obtained 80% cultured shrimp in high saline and 40-50% in low saline areas are infected by WSSV confirmed by PCR (Polymerase Chain Reaction) test. Import of exotic shrimp PL without quarantine brought viral disease to Bangladesh (Deb, 1998). However, the exact amount of loss is not well documented due to this disease outbreak. Most of the farmers do not have adequate knowledge about specific diseases and aquatic animal mortality (Ali et al., 2016) and typically all mortalities are assumed to be white spot viral disease. However, local knowledge may be better developed in some places as one study found farmers were able to notify the symptoms of white spot diseases by observing spot on the carapace, aggregation of shrimp and sluggish movements (Ali et al., 2016).

In prawn and finfishes in S-W Bangladesh some less dangerous diseases like antenna and rostrum broken syndrome in prawn and EUS (Epizootic Ulcerative Syndrome) in finfishes have been reported (Ali et al., 2016). Some believe that larger *ghers* tend to more susceptible to disease (Karim et al., 2012). Sharing polluted water from adjacent farms often spreads water-borne diseases (Paez-Osuna, 2001). Some also believed that the fluctuation of water quality parameters viz. water temperature, pH, dissolved oxygen level makes shrimp susceptible to stress, leading to disease (Paez-Osuna et al., 2003). The water depth of shrimp *gher* is less than the accepted level (<60 cm) which exacerbates temperature fluctuations and sharp salinity drop events which made the animals more susceptible to disease (Ahmed et al., 2014).

Farmers attempted to mitigate disease losses using chemicals without proper diagnosis (Ali et al., 2016). Uncontrolled use of antibiotics, chemicals for disease treatment may be taken up by and accumulate in the co-habitat fish species after resolving in water, thus affecting the seafood safety (Biao & Kaijin, 2007). Because indiscriminate use of antibiotic enhances the bacterial resistance of aquatic animal which in turns can lowering the effectiveness of cultured animal immune system (Primavera, 2006). Rico et al. (2013) noted that about 26 were antibiotic ingredients out of 60 commonly used ingredients in four Asian shrimp producing countries including Bangladesh. However, the use of antibiotic in Bangladesh was lower compared to other countries because of the extensive farming pattern. Use of antibiotics and chemicals developed antibiotic resistance among non-targeted species and having a wide range of public health concern (Akinbowale et al., 2006). The antibiotic resistance bacteria already spotted both in shrimp and prawn in coastal Bangladesh (Neela et al., 2012). However, compared to crop farmers fish farmers utilised less chemicals both in volume and frequencies (Rahman, 2003).

Rather than chemical use to mitigate the mortality of shrimp due to disease, farmers tend to frequently stock shrimp PLs (Ali et al., 2016). Proper dyke, removal of sludge from the *gher* and use of screened PL (PCR; Polymerase Chain Reaction tested) can minimise disease occurrence (Karim et al., 2012). Though, the S-W Bangladesh is highly susceptible to climate change which might exacerbate infectious diseases in aquaculture systems and preventive measure should be taken to ensure food security and gain economic return (Leung & Sharma, 2000). The environmental impact due to shrimp and prawn farming are reflected in the next section.

1.24 POLLUTION

In intensive shrimp production systems, excess utilisation of feed, fertilisers and chemicals enrich the waters with nutrients and pollutants (Sohel & Ullah, 2012); levels of suspended solids are often high (Hall 2004; Páez-Osuna, 2001). Direct discharge of shrimp pond water easily pollutes the surrounding soil and water quality (Deb, 1998). It also causes eutrophication and alters the structure of the benthic community observed in a study in Honduras (Dewalt et al., 1996). However, in Bangladesh, the eutrophication was not noticed. Moreover, the biological oxygen demand for five days (BOD_5) both in *gher* and outside canal of *gher* were above the recommended level (5 ppm) (Chowdhury et al., 2011). In the surface sediment of Sundarbans in Satkhira and Khulna region were found less. Total Organic Carbon (TOC) and Total Nitrogen (TN) indicated lesser human intervention (Hossain & Bhuiyan, 2015). It is claimed that *ghers* discharge polluted water, produce a huge amount of sludge containing particulate matter, unused feed, fertilisers and chemicals (Azad et al., 2009). In prawn farms, India, the nutrient load in effluent, provide important application to cropland production as organic manure and the water as liquid fertiliser (Adhikari et al., 2014). Despite the trend of intensification, the majority of the aquatic animal production originated from the extensive and semi-intensive systems (Hall et al., 2011). Such systems have lower environmental impacts, using less chemicals, indeed Wahab et al. (2003) found extensive shrimp farming in Bangladesh acts as a nutrient sink rather than source of pollution as shown for other shrimp farming systems (Primavera, 2006).

Shrimp and prawn farming globally has responded to these challenges by moving to develop best management practices and moving under the governance of private standards which are considered in the next section.

1.25 DOES CERTIFICATION ACKNOWLEDGE THE KEY CHALLENGES?

Product certification and eco-labelling are the means to support fisheries management and sustainable development (Wessells, 2001). The awareness of ethical and environmental issues is increasing among the consumers. The consumers are demanding more information about the environmental performance and how ethically produced the products they purchased (Murray et al., 2013). Food-related risks within the sector have stimulated a change in attitudes and procedures regarding food safety issues, and from regulation by the traditional provider, the state, to more politically legitimate public-private organisations. This move has been interpreted as being at the behest of a connection of importers and customers of the global north (Bernstein & Cashore, 2007). There is a variation between standards but a common goal is an aim to reduce risk related to shrimp farming. Commodity supply through certification schemes should theoretically reduce transaction costs and enhance market access and competitiveness (Jaffee & Henson, 2005). Some empirical achievements can result from certification based on private standards including premium price (Goedhuys & Sleuwaegen, 2013), improved market access, and enhanced quality, efficiency, and export revenues, workers training, etc. (Blunch & Castro, 2005). Certification was also found to provide eco-friendly management systems to small-holders crop producers in Cameron (Alemagi et al., 2006), Ghana (Ofori & Hinson, 2007) and Kenya (Dolan & Opondo, 2005).

There is a diverse opinion on the role of standards in improving species labelling and environmental issues (Bush et al., 2015). The financial benefit from certification is not well documented (Fikru, 2014), but widely seen as the pressure from global northern markets (Carlsen et al., 2012). Some commentators did not find any evidence of positive effects (Iraldo et al., 2009), but rather claimed that it deprived small-holders (Hatanaka et al., 2005), and favoured large-scale farms (Jaffe et al., 2011). It also prevented many actors from participation in the global value chain process (Schuster & Maertens, 2013) and transformed the quality control cost from retailers to suppliers (Belton et al., 2011). Some have given priority to the community-based approach (Vandergeest, 2007) and to consider the adaptability (both technical and financial) of small-holders within emerging certification schemes (Belton et al., 2011). Recent, third-party certification system for organic shrimp farming in Bangladesh experienced little turnover on volume (Murray et al., 2013). The low volume of production of shrimp is only utilising the 15-20% capacity of processing plants, and exporters emphasised to intensify the shrimp production rather than support certification of shrimp produced in existing systems (Kabir, 2014).

1.26 GROWING DEMAND-TRENDS TOWARDS INTENSIFICATION

IFI's (International Finance Institutes) have favoured intensification of culture to reduce price and promote consumption. This attitude has contributed to the transformation of traditional culture into the high input (feed, seed, chemicals) dependent systems which are part of global trade and consumption, in which product flows from developing to developed countries (Skladany & Harris, 1995). Besides financial support many national governments have formulated export-oriented policies which have favoured large corporations to invest in shrimp production. Intensive systems might be able to support poverty alleviation through increased production, enhanced employment, and lower prices of fish in local markets (Brummett, 2011). For intensive farming, the rapid responses obtained from the S-E coastal area of Bangladesh. Commercial shrimp farming lost Chakaria mangrove in the region (Ishtiaque & Chhetri, 2016). Available natural resources, exotic PL supply, and rich entrepreneurs stimulated the rapid transformation in the S-E coastal area compared to the S-W region of Bangladesh (Akhtaruzzaman, 2000). However, a devastating disease which believed to came through exotic PL shut-down many of shrimp farms (Deb, 1998). Though 20000 ha coastal land is suitable for semi-intensive farming (USAID, 2006), a very negligible proportion of the area is utilised. Though intensive culture system can provide 50 times higher production than traditional culture, researchers suggested that Bangladesh should to go for the improved traditional system (USAID, 2006). According to NACA, on efficiency level Bangladesh is sixth out of 10 countries regarding operating extensive shrimp farming (NACA/FAO, 2001). One of the reasons are most of the farmers are smallholders and cannot absorb the shock of crop loss due to disease uncertainty. Moreover, the modern technology adoption ratio is very low among the shrimp and prawn farmers (Bala & Hossain, 2010).

1.27 WHY MONOCULTURE LOST GROUND?

Intensive systems require sophisticated techniques and well trained, labour; in 2012 only 10% of global shrimp was estimated to be supplied from this sector (Bolanos, 2012). Intensifying any agricultural food production system may come at the cost of increased risk of fatal diseases and environmental degradation (Bhattacharya & Ninan, 2011; Sinh, 2009). In an intensive system having higher loadings of feed and stocking densities degrade water quality which further creates stress and spread diseases in shrimp (Paez-Osuna et al., 2003). The long-term impact of monocultures has often been adverse for farmers, leading to overcapitalization, pollution, debt after price declines, low margins, and poor ecological sustainability (Flaherty et al., 1999). A semi-intensive system producing 4 tonnes shrimp/year/ha, requires the productive and assimilated capacity of 38-139 ha of natural ecosystem (Islam & Wahab, 2005). Despite the support from the government, business and international aid agencies for shrimp monoculture (Pokrant, 2014) a majority of farmers manage their operations based on low-intensity shrimp and/or prawn polyculture in the region.

1.28 BENEFIT OF POLYCULTURE

Crop diversification has been a means of reducing risk and increasing food security (Kanji & Barrientos, 2002). Suggestions have been made for the small-holders to grow another crop along with shrimp to be profitable. Shrimp culture integrated into rice production has often been promoted and has developed independently in several locations in India (ICAR, 2007). Disease outbreaks in polyculture systems are seen as positive in shrimp farms in the Philippines as shrimp mortality provide space other co-habited species to grow. This approach reduced the economic loss due to disease occurrences (Tendencia et al., 2011). Nevertheless, the overall poor management in polyculture will not be profitable (Alam et al., 2007). The benefit of polyculture of shrimp and prawn systems are well documented and economically viable for the farmers (FRSS, 2014; Islam & Wahab, 2005). The wild aquatic animal diversity especially mangrove fish diversity play an important role to maintain diversity both in open waters and *ghers* in the region (Islam & Haque, 2004). Natural biodiversity is a major source of wild food such as crustaceans and insects along with fish in the rice based aquatic agricultural system (Halwart et al., 2006). To overcome the environmental impact of aquaculture in coastal zones, Primavera (2006), suggested polyculture and integration of rice-fish culture were key adaptations. To enhance grain production government of Bangladesh has initiated a massive program of *boro* cultivation in the S-W Bangladesh. However, Bell et al. (2015), argued that expansion of rice alone will not be profitable while brackish shrimp can provide an equitable and sustainable livelihood. This indicated the ecological benefit of existing polyculture pattern. As the prawn are less susceptible to disease, some also argued for intensification. However, Kutty (2005), suggested the failure of shrimp in India in 1990's through poorly designed intensification should be considered.

Seafood is pivotal for ensuring food security of marginal people in the fish-dependent societies. It also provides essential elements for desirable nutritional outcomes for all segments of society. The link between seafood and the public health development are discussed in the following section.

1.29 FISH CONSUMPTION PATTERN

“Agricultural biodiversity is the first link in the food chain, developed and safeguarded by indigenous people throughout the world, and it makes an essential contribution to feeding the world”- (Nakhauka, 2009)

Two decades ago the majority of fish consumed originated as wild stocks. Due to overexploitation of fisheries resources, the wild fish consumption has been decreased significantly. The fish consumption diversity has also reduced (Belton et al., 2014). Rapid aquaculture development enhances the fish consumption especially of larger, individually sized of fish. This transformation of diets based on small to large fish may have negative consequences on diet quality (Belton & Thilsted, 2014). The fish consumption diversity in Bangladesh however, remains high with, as many as 75 species revealed in a study in Kishoregonj District Bangladesh (Thilsted, 2013). In rural Bangladesh, fish is the third most commonly consumed food item after rice and vegetable (Powell et al., 2015). Fish was more frequently consumed than green vegetables, lentils and egg by children revealed in a study in Bangladesh (HKI, 2002). The fish consumption trends in different case studies indicate a gradual growth along with the food production. In 1970 the rice production for 75 million populations was not sufficient. However, the production has increased three-fold and Bangladesh is now sufficient in food production (Thilsted, 2013). The fish consumption pattern per capita per day was 28 g in 1962-64, 23 g in 1981-82 (Thompson et al., 2002), 38 g in 2000, 40 g in 2005 (BBS, 2007), 82 g during peak season (October) in Kishoregonj in 1997-98, (Roos, 2001). Some commentators warned that increased productivity based on only a few species would not assure the nutritional and health targets are met and suggested to make aquaculture more aligned with a nutrition-sensitive policy (Thilsted et al., 2016).

1.30 VARIATION OF NUTRITIONAL QUALITIES IN DIFFERENT SYSTEMS

Fish provide high-value protein, an excellent combination of essential micronutrients, vitamins and long-chain n-3 PUFA (Poly Unsaturated Fatty Acids) (Karapanagiotidis et al., 2006). Fatty acids are important biomarkers to distinguish and characterise species in a given ecosystem (Budge et al., 2002), and can be used to compare the of the nutritional value of wild and farmed fish (Nettleton & Exler, 1992). The source of fish may impact the type and location of fat in its tissues. Wild fish and fish farmed extensively contained a higher percentage of n-3 PUFA (Nettleton & Exler, 1992), whereas fish that has been farmed intensively can have high levels of intraperitoneal fat (Nakagawa et al., 1991). Flesh fat quality can be manipulated by the management of feeding farmed fish. For example, n-3, n-6 ratios can be improved by dietary change in the month preceding harvest feeding a diet containing a high amount of n-3 fatty acids enhanced fat composition to be equivalent with that in wild product (Stone et al., 2011). Water salinity of the fish being cultured influences the amount of fat and n-3 fatty acids in fish (Love, 1988). In nutritional content both farmer managed aquaculture system and wild are often no longer distinct (Amilhat et al., 2009). Farmed fish in Bangladesh contained lower levels of some micronutrients compared to the nonfarm species revealed in recent research (Bogard et al., 2016).

1.31 FOOD AND NUTRITIONAL SECURITY

The importance of fish farming in securing food security has been emphasised since the 1960s (Woodham, 1966). The term ‘food security’, was defined by FAO (1996) as ‘a condition when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life.'

The information revolutions and trend to increased globalisation have created opportunities and challenges in improving the food security of low-income people (Pinstrup-Andersen, 1999). Access to food by all is an important element to ensure the food security (Borton & Shoham, 1991). Sen (1981), also emphasised on food entitlements rather than self-sufficiency. Developing countries have increasingly recognised the role of balanced nutrition, including critical vitamins and minerals in the diet rather than just food production and consumption in achieving food security (Ahmed et al., 1999).

1.32 NEXUS BETWEEN FISH-BASED NUTRITION AND PUBLIC HEALTH

For the outstanding nutritional quality, fish deserves a central position in food and nutritional strategies (Figure 1.7). The level of fish-based animal protein in human diets varies from 30% in Asia to 20% in Africa and 10% both in Latin America and the Caribbean. A portion of 150 g of fish provides about 50-60% of the daily protein requirements of an adult (For example, Bangladesh) (FAO, 2012b). Apart from their taste, fish and fishery products provide high value protein, an excellent combination of essential micronutrients, vitamins (D, A and B), minerals (Ca, iodine, zinc, iron and selenium), long-chain n-3 PUFA (Karapanagiotidis et al., 2006), less well-known nutrients such as taurine and choline (FAO, 2014b), and are with some exceptions, low in saturated fats, carbohydrate and cholesterol (Sriket et al., 2007). Fish and shrimp is rich in protein like milk, eggs, and meat and contain a complete amino acid profile (USDA, 2012).

The consumption of Polyunsaturated Fatty Acids (PUFA) has an inverse relationship with the occurrence of fatal and nonfatal CHD (Coronary Heart Disease) (Harris et al., 2009). PUFA also have anti-cholesterolemic, anti-lipidemic, anti-inflammatory, antiplatelet and anti-arrhythmic mechanisms (Bragagnolo & Rodriguez-Amaya, 2001). PUFAs are also believed to have positive impacts on infant growth and cognitive development (Koletzko & Cetin, 2007) and also enhance physiological process

(Simopoulos, 1999). They have also been found to protect people against certain cancers as well as several neurological disorders, including Alzheimer's disease and have an important function in the brain and retina. Its fundamental role in neural development affords it a unique role in the nutritional biochemistry of *Homo sapiens* (Crawford et al., 1999). DHA is also vital in maintaining mental health as brain disorders are dramatically increased globally. Mental health treatment costs now exceed the combined treatment cost of CHD and cancer in the world (FAO, 2014b). The digestive and absorptive properties of n-3 fatty acids in food are superior to supplements as have been demonstrated in comparisons of intake of smoked salmon against Cod Liver Oil (CLO) (Elvevoll et al., 2006). Fish consumption influences the levels of amino acids and DHA in the breast milk of lactating women, for instance, DHA concentration in breast milk of women living in the coastal areas of China are higher than in other parts of the country (Ruan et al., 1995). A fish-based nutritional strategy has been found useful for people living with HIV/AIDS (WHO, 2003; FANTA, 2007), for example, infections and chronic wounds were found to heal better in Zambia after adding small freshwater fish, *kapenta* (*Limnothriss amiodon*), to the diets of people living with HIV/AIDS (Kaunda et al., 2008). The n-6 fatty acids are important for the female reproductive cycle and n-6 to reduce the risk of arteriosclerosis (Bhavan et al., 2010).

However, the combined effort of these is well established, and EPA and DHA are majorly derived from fish or fish oil. The same enzymes are required for both n-3 and n-6 LC-PUFA desaturation, elongation and each class of PUFA has a different effect on human health, an appropriate ratio is important (Strobel et al., 2012). In fact, an imbalanced proportion of n-3/n-6 in human diets has been related to the occurrence of chronic diseases (Simopoulos, 2002). Some previous studies suggest that the proportion of n-6/n-3 of approximately 1:1 (Simopoulos, 2008) and between 1:1 and 5:1 (Simopoulos, 2002) is beneficial for health. Increased fish consumption, especially based on marine species, can provide a higher amount of n-3 LC-PUFA and the dietician's advice to consume fish twice a week and preferably one meal with oily marine fish (Molendi-Coste & Legry, 2011). The recommended levels of total EPA and DHA are between 200 mg/d and 500 mg/d, respectively (EFSA, 2009; Mozaffarian & Wu, 2012). Micronutrients deficiencies are a vital issue for Low-Income Countries (LIC's) public health.

Some nutrient dense fish contain higher levels of vitamin A and calcium that are, respectively, 10 to 20 times higher than in other commonly cultured fish (Prein & Ahmed, 2012). Both vitamins A and C can be stored in the liver for 3-4 months and consumed vitamin-rich fish in a specific season are still effective to meet the nutritional demand for a longer time (Haard, 1992). Some small fish can meet 45% of the daily iron requirement of a woman in Cambodia (Karim et al., 2011), and the addition of small dried fish to children's' meals supported significant increases in iron, zinc, and calcium intakes in Malawi (Gibson & Hotz, 2001).

1.33 MAJOR PUBLIC HEALTH ISSUES

Micronutrient deficiencies are a real public health challenge for developing countries (Kawarazuka, 2010). An estimated hundred million people, particularly women and children, are suffering from micronutrient deficiencies (UNICEF, 2011). The hidden consequences of micronutrient deficiency included impaired immune activity, cognitive development, child growth, reproductive performance and work capacity (Underwood, 2000). More than 250 million children are at risk of vitamin A deficiency, 200 million people have goitre with 10% of them suffering related learning deficiency as a result of iodine deficiency. More than one-third of the global population are iron deficient, and 0.8 million child die each year due to zinc deficiency (FAO, 2014b).

Every year 7.6 million children die before they reach the age of 5 years, mostly related to preventable or treatable illnesses and almost all in developing countries (UNICEF, 2011). Malnutrition is an underlying cause of more than 35% of these deaths (Black et al., 2008). The direct cost of malnutrition is estimated at US$20-30 billion/year, and annual GDP loss is 2-3% in developing countries. Adults who are malnourished can earn 20% less than those who are not (Grantham-McGregor et al., 2007), and recent evidence showed that nutritional interventions can enhance 46% earnings of adults (Hoddinott et al., 2008). About 27% of all children are stunted, a level which can be cut by 20% at 12 months if children in the developing world received adequate nutrient rich solid foods with breastfeeding (Grantham-McGregor et al., 2007).

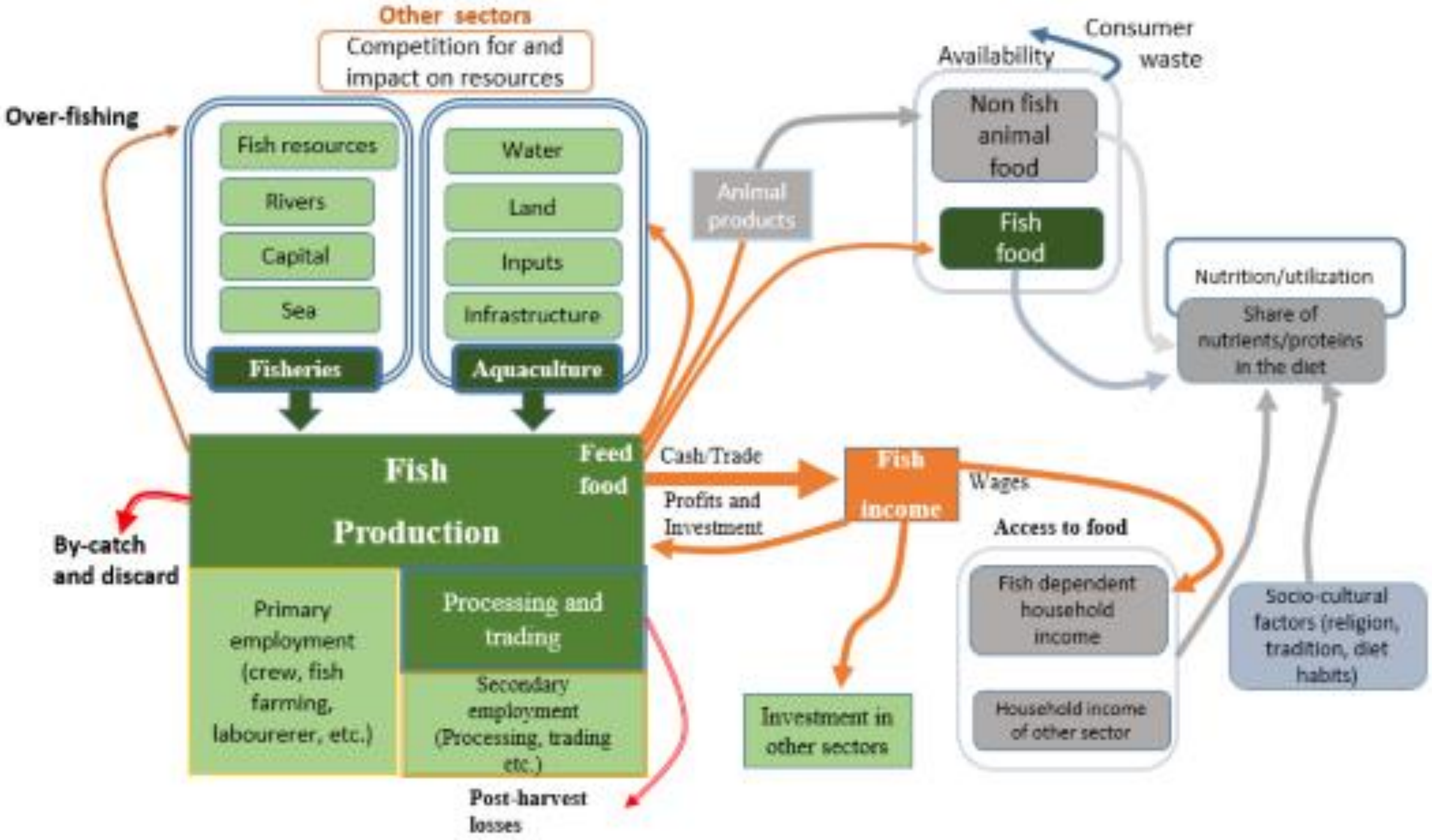


Figure 1.7 Conceptual representation of the different pathways between fish and food security and nutrition [Redrawn from HLPE (2014)]

Poor diets and frequent infections caused stunting (low-height-for-age) and occurred before age 2, and the effects are largely irreversible. This causes delayed motor development, impaired cognitive function, and poor school performance. About 10% (60 million) of total children are wasted (low weight-for-height) (de Onis et al., 2011). Worldwide more than 100 million children are underweight (UNICEF, 2011), a status implicated in nearly 20% of all child deaths (Black et al., 1984). It was assumed that this figure would worsen following the consequences of the food crisis and economic recessions (UNSCN, 2010). In contrast, many people around the world suffer from obesity and diet-related complexity. Consumption of high-fat foods and processed products, inappropriate dietary and lifestyle choices is the main cause of this problem (FAO, 2012a).

About two-thirds of the undernourished originate in seven countries (Bangladesh, China, the Democratic Republic of the Congo, Ethiopia, India, Indonesia, and Pakistan) (FAO, 2012a). Child malnutrition problem is typically strongly correlated with the living standards of the household. Malnutrition, food insecurity, low birth weight, and stunting are higher in shrimp farming S-W coastal area compare to other administrative division (Dhaka, Chittagong, and Rajshahi) of Bangladesh (Anwar, 2003). The first-born female child is 75% more likely to be severely malnourished compared to a male child. Although there is a lack of a clear pattern of data, it indicates that mothers aged 14-18 years and 35-50 years are at somewhat greater risk of malnutrition than those born to mothers aged 19-34 years (Deolalikar, 2005). In Bangladesh, female children experience higher mortality, especially after the neonatal period (Hill et al., 1996) and disparity in intra-family food distribution and health care, were thought to be a possible cause (Henry et al., 1993).

1.34 ADOLESCENT GIRLS: THE MOST VULNERABLE GROUP AND CRITICAL 1000 DAYS

Adolescence (10-19 years) is a very vulnerable period, and one-fifth of the world population is currently within that age range (IFPRI, 2000). Adolescence is the stage of life when both males and females undergo the last intense phase of their growth to attain full adult height, concomitant with profound changes in body structure and physiology. As a result, nutrient demand is high to support these developmental changes and particularly crucial for the women in developing countries. Accessible and affordable fish may be particularly important for children and women specifically during reproductive stage (Kawarazuka, 2010). According to Aiga et al. (2009), a lower prevalence of malnutrition was observed among children in fish-farming households than those in non-fish farming households in all malnutrition indicators (stunting; low height for age, underweight and wasting; low weight for height). The nutritional status of the infant ultimately depends on the interactions of first 1000 days when the mother fully and/partially supplies nourishment. In Bangladesh, 11-56% of adolescent girls suffer from subclinical vitamin A deficiency and 30-40% are anaemic. It may be related to the fact that 34% get married before the age of 18 years and 33% have their first pregnancy between the ages 15-19 years. They are at increased risk of developing anaemia during pregnancy, compromising their health as well as that of their offspring (Hyder et al., 2007). About 15-25% of the adult height and 45% of the skeletal developments occur during adolescent stage. However, in the case of undernourished populations, the tempo of growth during adolescence is slower (Eveleth, 1990). Malnutrition causes poor bone growth resulting in contracted pelvis and difficult labour, greater risk of increased maternal and infant mortality (Ahmed et al., 1998). During adolescence, the protein might be especially important along with other nutrients. However, in developing countries, the iron requirement is even higher due to insufficient intake and infections such as malaria, schistosomiasis and hookworm and the effects of inflammation on iron absorption. Vitamin A is also identified as necessary for growth, development, and sexual maturation with the positive association being reported between plasma retinol and indices of sexual maturation. Micronutrient calcium requirement increases for skeletal development to be greater during adolescence rather than either childhood or young adulthood (Ahmed et al., 1998). Millions of mothers in developing countries struggle to give their children a healthy start in life. Many children are born undernourished because their mothers are undernourished; as much as half of child stunting occur in utero (UNSCN, 2010).

In most developing countries the nutritional status of women and girls is linked to limited access to food, lack of women empowerment at the household level. Traditions and customs may limit women's consumption of nutrient-rich foods, heavy physical labour may demand more energy, and the nutritional demands of frequent pregnancies and breastfeeding be exacerbated by frequent infections and limited access to healthcare. However, pregnancy and infancy are vital periods, and good nutrition is required for child’s brain development, future cognitive, motor and social skills and school success and productivity. Children with restricted brain development in early life are at risk for later neurological problems, poor school achievement, early school dropout, low-skilled employment and poor care of their children, thus, accelerate to the intergenerational transmission of poverty (Prado & Dewey, 2014). There is currently a lot of focus on animal source foods, including fish, in the first 1000 days of life.

1.35 CONCLUSION

In this chapter, we have framed the research gaps and guided some ways for sustainable shrimp and prawn farming to obtain both economic and nutritional benefits. The commercially profitable venture quite often are socially and environmentally unprofitable (Dasgupta, 2002). The export-oriented primary products (fish and agricultural products) can promote social, economical and ecologically sustainable development. Sen's theory emphasises food exchange (import/export) at the national level to mitigate the demand at household levels, which is considered as 'food security through trade' (Béné et al., 2010). One development initiative in Bangladesh concluded " there is no technical reason why raising shrimp should not be as sustainable or in some cases more sustainable than agriculture, fisheries, or another kind of development" (Consortium Program, 2002). The degree of environmental and socio-economic impacts ultimately depends on the institutional arrangement, the degree of intensification and the level of local knowledge participants (Rivera-Ferre, 2009).

Indigenous and traditional knowledge is vital to achieving a social, ecological and economically sustainable development (IAASTD, 2008). An equilibrium level in between the local environment and business management must achieve for sustainable development (Bolanos, 2012). The media and civil society groups have important watchdog functions in the sustainable development, but sometimes over-sensationalize problems encountered in aquaculture and create obstacles in the process (Little, 2010). Shrimp aquaculture resilience is linked to how the aquaculture-livelihoods-wetlands connection is constructed (Adger, 2000). A key constraint remains our limited understanding of aquaculture compared to other life sciences including the fisheries branch.

Earlier, seafood production relied on fishing, and most of the intellectual effort was expended on fisheries regulation (Daw & Gray, 2005), overfishing (Worm et al., 2009), and fishing efficiency (Dunn et al., 2011). The shifting of seafood supply dominance from fisheries to aquaculture brought many cross-cutting issues of social and environmental aspects, but aquaculture discipline was studied less (Welch, 2015). Some suggested that special plans and policies to promote international trade of fish and fish related commodities are required (Winters et al., 2004). For example in Bangladesh, many other cases studies ignore the wider agro-ecological diversity of these systems and the contribution of co-products to local food security. This polarisation of views, often exacerbated by vested interests and rarely informed by quality field research, has resulted in a policy vacuum. So, holistic research is needed in developing countries like Bangladesh to determine the nutrient content of fish in different culture systems and to trace the distributional pathway from farm to fork and assess the role of fish nutrients to diminish the double burden of malnutrition micro-nutrient deficiency and obesity. National level fish consumption growth may not reflect the equal distribution in between worse-off and better-off segment of the society. Intra-household fish distribution pattern in most of the developing countries is heterogeneous, and the women, infant, and adolescent girls are in the vulnerable group. Particular attention is needed to provide towards adolescent girls as most of them in developing countries become a mother at this stage. An in-depth study of household levels allocation and manifestation of nutritional outcomes both in anthropometrically and biochemically (omega-3 biomarker) in whole blood will allow understanding the preparedness of these vulnerable group for the critical 1000 days.

1.36 RESEARCH OBJECTIVES

Our in-depth investigations will allow understanding of the core phenomenon of food security and related sets of actions and reactions (ecological settings, social well-being, food production and allocation, health outcomes of adolescent girls) at household and individual level. These studies should reveal a range of invisible/hidden hunger scenarios even among the better-off segments of the community which are found to vary with the specific agro-ecological context, itself highly correlated with the availability of saline and freshwater. Recent narratives about shrimp production in Bangladesh have been almost wholly negative; claims have been made in terms of poor impacts on the environment and community that range from polemic to those that simply lack scientific rigour. As a result, there has been little research support for effective policy development and civil society actors have lacked leverage on politicians who have resorted to "business as usual." In addition to a more reliable evidence base that has highlighted the fragility and heterogeneity of shrimp and prawn systems that this recent research now provides, improved horizontal and vertical communication between service providers is urgently required. Inter-disciplinary approaches that integrate water management, broader agroecology, and public health knowledge and assemble key external and local evidence are required. There is a clear need for sharing of perspectives and more joined up actions.

1.37 RESEARCH QUESTIONS

This thesis is designed to assess how export-oriented aquatic farming systems impact on local food security at the household and intrahousehold level in communities across a gradient of salinity in S-W Bangladesh where shrimp and prawn farming are well established. By employing a multidisciplinary framework, the thesis asks the contribution of seafood farming on domestic food security and hard cash earnings. There are six specific research questions within the thesis. Each is now presented below.

First, to understand the agro-ecological settings the thesis classifies the area into geographical zones by soil-water salinity level (Chapter 2).

Secondly to understand livelihood profiles of the producer their linkages to the export-oriented shrimp-prawn farming in the south-west coastal area of Bangladesh the thesis aims to understand the social profiles, demographic structure, and stratification of household well-being. In this aspect the main research question was:

What is the impact of aquatic animal farming on the livelihood aspects of different social group in different saline agro-ecologies in S-W Bangladesh? (Chapter 3)

Third, the thesis classifies the shrimp and prawn farming into categories by inputs across the saline agro-ecologies. To understand the farming system the following question was asked:

What is the level of inputs and outputs of shrimp and prawn farms and how does yield vary among the systems and saline agro-ecological areas? (Chapter 4)

Fourth, the nutritional content of aquatic products varied in the culture systems and saline regimes. So, samples of aquatic products were collected and analysed important nutritional profiles to answering the following question:

Which culture system and saline agro-ecologies resulted in the optimal harvest of essential nutrients (LC n-3 PUFA, micronutrients), at species level? (Chapter 5)

Fifth, living in a fish producing area does not necessarily mean community peoples are having access to it. Adequate food supply at household level does not necessarily ensure equal access for all members, especially the more vulnerable groups *i.e.* female, adolescent girls and children.

The study further investigates this by assessing nutritional vulnerability at the household level in terms of food allocation and the impacts of household socio-economic status (Chapter 6)

Sixth, the nutritional outcomes for adolescent girls and their relationship to overall dietary intake of aquatic animal and other food types requires better understanding through assessment of their health status using specific indicators (wasting, stunting, MUAC, omega-3 in whole blood) to allow the research question:

What are the causal factors and health outcomes of adolescent girl's malnutrition at different social groups and saline agro-ecologies? (Chapter 6)

Finally synthesise the major link domain of livelihood, aquaculture, household food allocation and adolescent girl's health impact and formulate an effective strategy for sustainable development (Chapter 7).

2 CHAPTER 2: MATERIALS AND METHODS

2.1 INTRODUCTION

This chapter describes the detailed research process and overall methodology used to explore the livelihood options of household, aquatic food production systems, nutritional profiles of farm products and contribution to local food and nutrition security in different saline agro-ecologies of the south-west (S-W) Bangladesh. It is divided into three main sections. In the first section, development of a conceptual framework, design of research framework, identification of strategies, and research boundaries were set. Secondly, the water salinity context of the region is widely scoped to understand the hydrodynamics and seasonal fluctuations. The sites of the current piece of research work were selected on salinity gradients in the S-W coastal Bangladesh area. Thirdly, methods for the livelihood study, comparing aquatic food production systems across saline agro-ecologies, aquatic animal sampling, nutrition content analysis of aquatic animals, intra-household food allocation, nutritional outcomes, and LC n-3 PUFA content testing in whole blood of adolescent girls are described. However, specific methods of the respective research questions if not mentioned here are illustrated in individual chapter.

2.2 FRAMEWORKS OF THE STUDY

2.2.1 CONCEPTUAL FRAMEWORK

The aim of this piece of research was to explore the impact of aquatic food production on local food security broadly on the ecological and economic sustainability of seafood production. This will provide background research to support the development of an ongoing policy framework for food security, aquatic food production, public health issues and community development in the S-W coastal area of Bangladesh. The conceptual framework (HLPE, 2014) drawn in figure 1.7 in the previous chapter were used to explore the impact of aquatic food production on food and nutrition security. By using this framework the livelihood options of the community people, their engagement level in aquatic food production system, utilisation of aquatic foods, social norms on food allocation at household levels, nutritional contents of the aquatic animals and health outcomes of vulnerable population the adolescent girls were assessed at different stages of the study (Table 2.4). In case of community-level study both the PRA (Participatory Rural Appraisal) tools and structured questionnaires were used in this study. For food allocation and nutritional outcomes study 24 hours food recall and food frequency method and direct measurements were executed. For the nutritional study and blood sample, analysis standard laboratory techniques were used for the specific sample. The causes of health outcomes differences were linked to the social norms, social stratification, differences of agro-ecological settings and the differences of nutrient content at species level. The individual-level health outcomes linkage to the agro-ecologies and aquaculture practices are manifested through this framework. The methods and steps (Table 2.4) are mentioned in the following sections.

2.2.2 MULTI-DISCIPLINARY RESEARCH FRAMEWORK

Multi-disciplinary research is about generating new concepts and methods (Rosenfield, 1992). Many have successfully institutionalised multi-disciplinary approaches for academic programmes and practice (DeWalt, 1985). Bringing a research question from more than one discipline is not new. William Petty, a nonmedical researcher in the 1600's, worked on the systematic analysis of the complex interactions between health demographic, social and economic conditions. This was the initiation of traditional holistic approach to public health and well-being (White, 1991). Agriculture advancement has been rapid in the last half century however research has faced obstacles concerning environment, public health, animal welfare and in generally upgrading and sustainability (Alrøe & Kristensen, 2001). A clear concept can provide success of multi-disciplinary works. Bruce et al. (2004) reviewed the multi-disciplinary integration of the 5th European Union (EU) framework program and found few funded research programs which were able to cross individual discipline boundaries especially in natural and social sciences. Therefore, Yossa (2014), suggested aquaculture researchers should make bridges and collaborate far more with other disciplines and to sincerely accept the new concept that can assist to create innovative and more productive research.

In this piece of research, a multi-disciplinary approach was maintained throughout the study. The Sustainable Aquaculture Research Group (SARG) of the Institute of Aquaculture, University of Stirling, UK, has played the central coordinating role. The Nutritional Analytical Service (NAS) at the Institute of Aquaculture was also a major part of this program and entirely helped to formulate a research design, collection, shipment, and nutrient analysis of aquatic animals and adolescent girl's blood samples. Standardisation of a questionnaire for household food consumption and training of the female enumerators were executed with the support of experts from the relevant field. Nutritional experts from the Institute of Nutrition and Food Science (INFS), University of

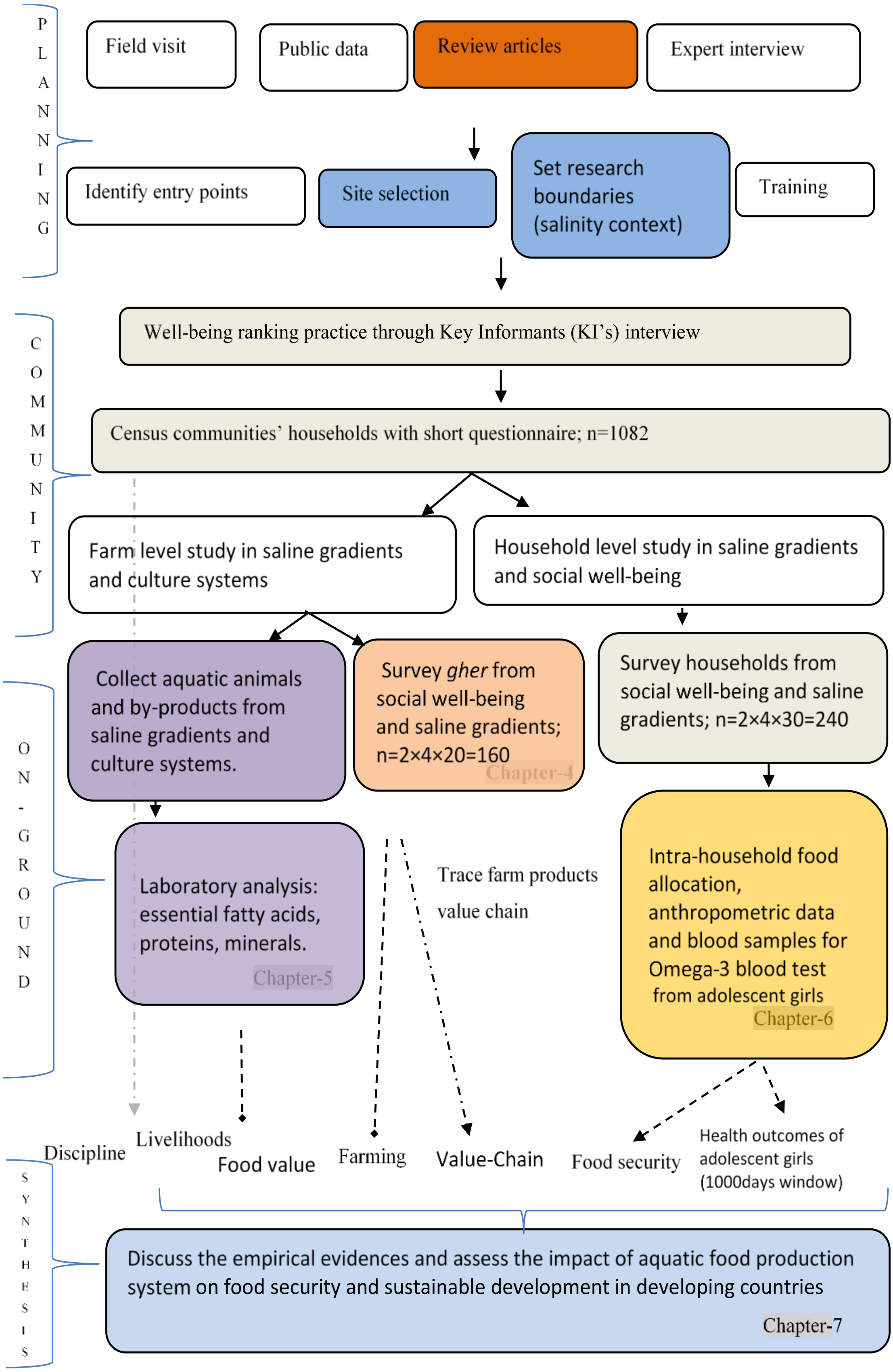


Figure 2.1 Research design for assessing the impact of aquatic farming system on food security of household members in the S-W coastal Bangladesh (Different colour in the box indicated different chapter of this thesis)

Dhaka, WorldFish Centre, Jessore Science and Technology University, Noakhali Science and Technology University (NSTU), and Khulna University, Bangladesh provided their insights throughout the work.

2.2.3 ANALYTICAL FRAMEWORK

To understand the human-environment interactions within the wider and deeper contexts the view of ‘Progressive contextualisation' was developed by Vayda (1983). This concept emphasised on not making a prior assumption about the system when endeavouring to develop a holistic view. However, this piece of research was based on the contextual idea about the aquatic farming system in the south-west coastal Bangladesh from the previous robust data from the EC FP7 funded Sustaining Ethical Aquaculture Trade (SEAT) project (Murray et al., 2013).

Most of the research methodology followed the conical approach either ‘zooming in’ or ‘zooming out’ on an issue, which means starting or departing with a particular issue, respectively. Van Mele (2006), used zooming in and zooming out approach to scaling up sustainable agricultural technology in Bangladesh and Benin and acknowledge it as a unique method. In this piece of research, an ‘hourglass approach’ was used (Figure 2.2) that is the hybridization of the traditional methods ‘zooming in’ and ‘zooming out.' This same approach was used in aquaculture research in Laos PDR and Bangladesh (Bush, 2004; Haque, 2007). The core questions of this thesis linked global perceptions and the local ‘certainties.' The analysis starts at the macro spatial level and gradually ‘zooms in’ to meso and micro scales of empirical research, and then zooming out to macro scale at which stage policy can then be articulated.

Empirical research is then presented throughout the dissertation step by step. Social profiles and livelihoods of the community people were the studies at mesoscale which included community leaders, stakeholders, and service providers. Studies on the aquatic farming systems, input-output, eventual distribution, intra-household food allocation among the household members, adolescent girls health outcomes were micro-level in-depth studies. This study gradually narrows down from community to farm and households, and then to the individual level and then zooms out for policy formulation in the wider scope. Finally, all the empirical research based evidence from multi-disciplinary approaches were brought into account to compare the orthodoxies and ground realities.

	Macro-level study	Meso-level	Meso-level	Micro-level	Macro-level
Area	Global issue			Household HH members Adolescent girl	International
	National context	Districts		Farm Aquatic animal	Regional/national
	Local setting		Community	Aquatic food value	Local
Chapter	1	2	3	4,5 & 6	7
Research questions	Identify research gap	Research boundary, salinity context	Well-being ranking, households profile, livelihood options	Aquatic food production system; Food value; Food security at HH level; Nutritional outcomes of adolescent girls; 1000days window.	Policy formulation challenge and opportunities

Analytical framework

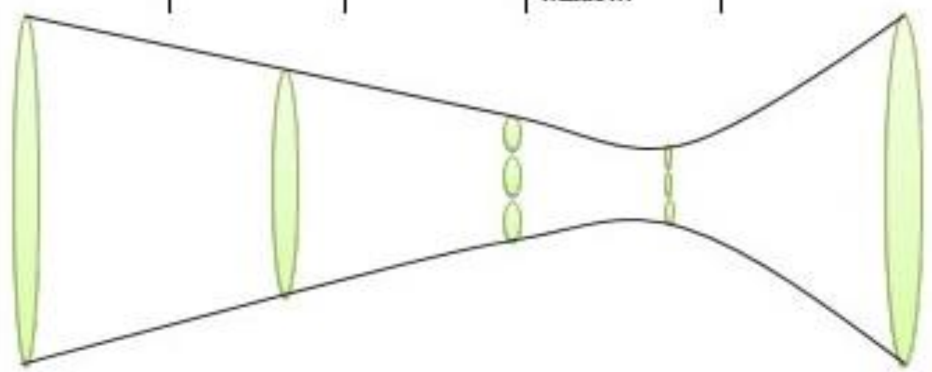


Figure 2.2 Relative progression of thesis and analytical framework (Adopted from Bush 2004)

2.3 SITE SELECTION AND SALINITY CONTEXT

Salinity intrusion has been one of the major challenges linked to aquatic farming systems in the S-W Bangladesh necessitating an in-depth understanding of prevailing salinity regimes in the area before addressing the aquatic farming and its implications on food security and livelihoods. Before bringing the salinity settings the overall agro-ecological settings of Bangladesh, people’s general livelihoods and subsistence options are described briefly. This wider context will help to understand the local background and will also be useful to formulate holistic guidelines for sustainable development.

2.3.1 BANGLADESH: THE LAND OF DIVERSITY

Bangladesh is a riparian state at the end point of the second largest river system in the world- the Ganges-Brahmaputra-Meghna basin (Figure 2.4) (Adnan, 2013). The Sundarbans mangrove stretches into the southern part of three districts within an area of 0.57 million ha, has more than one-third of its area (0.17 million ha) occupied by rivers, canals, channels and other watercourses. This highly productive deltaic ecosystem has been providing higher agricultural productivity and attracting people for thousands of years (Lewis, 2011).

Bangladesh is the 7^{th} most populous country in the world with a population of 149.77 million in 2011 (BBS, 2016) virtually elbowing each other in a small piece of land. About 75% of people living in rural areas experience and live within village level society which is a central part of their daily lives and livelihoods. About one-fourth GDP of the country derived from agriculture. The agricultural sector is mainly divided into four sub-groups like agricultural & horticulture, animal husbandry, forestry and fisheries (Rashid, 2005).

The location of Bangladesh at the junction of a unique delta provides a rich heritage of biodiversity of both animal and plant species. The main two export fishery commodities are black tiger shrimp (*Penaeus monodon*) and giant freshwater prawn (*Macrobrachium rosenbergii*) locally known as *bagda* and *golda*, respectively, predominantly cultured in the south-west coastal region of Bangladesh (FRSS, 2014).

2.3.2 SOUTH-WEST COASTAL AREA OF BANGLADESH

The coastal belt of Bangladesh is 32% of the total area of the country which comprises of 47201 km^2 (Islam & Haque, 2004). About 2500 km^2 is classed as a tidal area which is favourable for aquaculture (Deb, 1998). The low-lying floodplain agricultural lands in this area are dedicated to aquatic farming with or without integration of rice and dyke crop production. The integration of fish, rice, and dyke crops are dependent on the degree of water salinity. The Bangladeshi floodplains while being regionally diverse are locally complex (Brammer, 2004).

2.4 SALINITY CONTEXT IN THE SOUTH-WEST BANGLADESH

Before starting aquatic farming in the S-W coastal Bangladesh area (Figure 2.4) was almost exclusively used for rice cultivation (Foxon, 2005). Improper water management of this area created a saline water logged area. The south-west coastal area became the victim of the green revolution and farmers started aquatic farming (shrimp) in the region (Foxon, 2005).

Empirical evidence illustrates the relationship of accelerating sedimentation and increased salinity in the region due to the reduced discharge of freshwater in the Gorai river, one of the major distributaries of freshwater to the south-west coastal region of Bangladesh (Figure 2.5) (Mirza, 1998). During the dry season, the drastic fall in the river Gange's water level and the water withdrawal at the *Farakka* (India) point significantly reduced the freshwater flow (Gain & Giupponi, 2014). The saline tidal water through numerous estuarine rivers and tributaries intruded up to 160 km inland, which caused increased saline levels both in water and soil (Haque, 2006). These hydrological changes in the region brought changes in land use patterns and salinity gradients which varied seasonally across the agro-ecological areas.

2.4.1 SCALE OF SALINITY VARIATION IN THE REGION

The salinity of tidal floodplains areas varied significantly depending on the elevated level of land from the saline water source and proximity to the salt water rivers and tributaries. To understand the complex salinity regime in the region, we brought the empirical evidence from groundwater, soil, river water salinity data and biological indicators. Brammer (2004), categorised the upstream part of south-west Bangladesh as non-saline, the middle part as saline, and in between middle area and mangrove forest (Sundarbans) as saline acid sulphate soil (Brammer, 2014).

The Soil Resource Development Institute (SRDI) in Bangladesh monitors and maintains soil salinity and river water salinity data across the country. Soil salinity data in SRDI is robust compared to water salinity. Both soil and water salinity data have a correlation to each other (NSW, 2016). The soil salinity data (Deci-Siemens Per Meter; ds/m) can be transformed to water salinity units (ppt; Parts Per Thousands) multiplying by the conversion factor 0.640 (1ds/m=0.64 ppt) (NSW, 2016). The salinity data throughout this thesis are presented as a ppt unit. SRDI classified the region by soil salinity into five zones. The classification indicated that in the S-W coastal area about 20-30% of its area is under 5 ppt, 25-30% under 10 ppt and 5-15% above 10 ppt of water salinity and the salinity level is gradually decreasing to inland ward movement (SRDI, 2012). Water salinity during dry season varied from >10 ppt, 5-10 ppt and <5 ppt from sea line distance of >180, 100-180 and 100 km, respectively in the region (Bhuiyan & Dutta, 2012).

Salinity level variation in the major river systems in the region was observed by Rahaman et al. (2015). The major river systems in the area are (1) *Kholpetua-Arpangashia* (S1), (2) *Rupsha-Passur* (S2) and (3) *Baleswar-Bhola* (S3) (Figure 2.5). The salinity level in the S1 river system ranged from 8-24 ppt in a year. While the salinity in the S2 and S3 river system ranged from 4-10 ppt (Rahaman et al., 2015). The predominantly eastward movement of these rivers contributed significantly to reduce salinity levels. The S2 and S3 systems uptake more freshwater and had lower salinity than the S1 system indicated the salinity decreases from south-west to northeast corner in the region (Figure 2.5).

2.4.2 SEASONAL VARIATION OF WATER SALINITY

Apart from the location, the water salinity in the S-W coastal Bangladesh differed seasonally. In the dry season (October~March) the water salinity is varying below 5 ppt to above 10 ppt, while during wet season (June~October) salinity below 5 ppt existed close to the sea line (Bhuiyan & Dutta, 2012). Water salinity on seasonal basis were divided into three distinct zones in S-W coastal Bangladesh viz. (1) high saline (water salinity >5 ppt at least for six months), (2) medium saline (<5 ppt at least for six months) and (3) low saline (<5 ppt at least fro three months) (Mahmood et al., 1994).

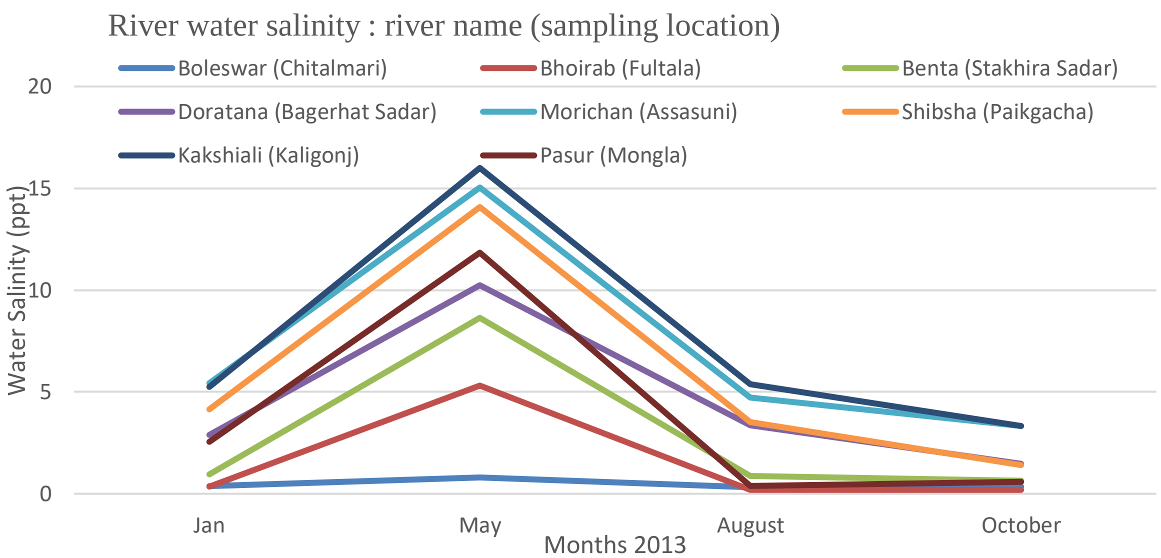


Figure 2.3 Seasonal variation of water salinity of major rivers in the south-west coastal region, Bangladesh [Redrawn from (SRDI, 2016)]

The water salinity levels in the major rivers of the S-W coastal area are presented in the previous section (Figure 2.5). The monthly salinity data of the same rivers show significant seasonal differences across the region. Salinity irrespective of location rises from January onwards to May and then from the onset of the monsoon rains (June-July onward) it declines (Figure 2.3).

Some village level case studies also provide fluctuations in the regional water salinities both in *ghers* and rivers at Shaymnagar; Satkhira was more than 10 ppt during the dry season and less than 5 ppt during monsoon (Grant et al., 2015). Soil salinity in the village of Dumuria, near Khulna (low saline area), was around 5 ppt in the dry season and reduced to half the value during the monsoon (Mondal et al., 2006). Ali also observed similar seasonal fluctuations of water salinity close to Satkhira town nearest to the Betravati river, where shrimp-prawn-rice are integrated (Ali, 2006b). Moreover, the alternate and/or concurrent rice (*aman* rice in rainy season) cultivation with aquatic animal in higher saline areas confirmed the seasonal and local variation of salinity in the region (Belton et al., 2014; Nuruzzaman, 2006).

2.4.3 GROUNDWATER SALINITY VARIATION

Groundwater is vital for domestic, irrigation and industrial use. The ground water salinity both in the shallow and deep aquifer was investigated across the S-W coastal area of Bangladesh. The area in proximity to the sea had higher water salinities both in shallow and deep aquifers compared to the more inland areas. In the shallow aquifer, the majority of the area's water salinity falls into the group 1-2 ppt. It is only in Paikgacha one of the coastline areas where 40% area's water salinity was above 2 ppt (Table 2.1) (Hasan et al., 2014).

Table 2.1 Groundwater salinity level variation within and among the communities of south-west coastal area of Bangladesh [Data redrawn from (Hasan et al., 2014)]

% of area covered								
	Shallow aquifer (35-120m)				Deep aquifer (150-340m)			
Water salinity (ppt) Area	<0.6	0.6-1	1-2	>2	<0.6	0.6-1	1-2	>2
Paikgacha	20	4	35	41	0	4	26	70
Batiaghata	1	5	89	5	68	8	18	6
Tala	71	2	27	0	36	32	7	25
Dumuria	12	21	57	10	75	5	3	17

2.4.4 BIOLOGICAL INDICATORS FOR WATER SALINITY

Apart from using abiotic indicators, biological indicators like aquatic species salinity tolerance and distribution pattern also indicative of salinity variation. The salinity tolerance of aquatic species differed from species to species. There is a common trend observed from the recent studies in the region by Carbonara (2012) and Murray et al., (2013). On that basis, the following table was prepared, and the aquatic farming system in S-W Bangladesh divided into four categories (Table 2.2).

Table 2.2 Biological indicators (aquatic and terrestrial) for water salinity tolerance utilised to separate aquatic farming systems in S-W coastal Bangladesh

	Water salinity level in ppt			
Indicator	High (>10)	Medium (5-10)	Low (<5)	FW (<0.5)
Species/crop (name)	Degree of intensity			
Mud crab (*Scylla serrata*)	√√√	√√	√	×
Bagda (*P. monodon*)	√√√	√√	√	×
Golda (*M. rosenbergii*)	×	×	√	√√√
Indian major carps	×	×	√	√√√
Vetki (*L. calcarifer*)	√√√	√√	√	×
Horina (*M. monoceros*)	√√√	√√	√	×
Caine magur (*Plotosus canius*)	√√√	√√	×	×
Koi (*Anabas testudineus*)	×	×	√	√√√
Rice	√	√	√√√	√√√
Dyke vegetables	×	×	√√	√√√

Degree of availability: √√√=High; √√=Moderate, √=Low, ×=Nil or rare [These are the general pattern of availability based on the studies by Carbonara, (2012) and Murray et al. (2013)]

2.4.5 CLASSIFICATION OF THE REGION BY SALINITY

Considering all above the aquatic farming system in south-west coastal Bangladesh can be divided into four major agro-ecological areas: (1) high saline area (HS); most of the time of the year water salinity is >10 ppt (2) medium saline area (MS), salinity ranging between 5-10 ppt (3) low saline area (LS) typically the salinity remains <5 ppt and (4) freshwater area (FW); salinity <0.5 ppt (Figure 2.6). This classification is based on the dry season water salinity of adjacent rivers and canals. However, some exceptions like *gher* with low saline exist in higher saline areas (pocket *gher*) as the salinity context depends on characteristics and proximity of the *gher* to the river/tributaries, the elevated level of *gher*, etc.

2.5 AQUATIC FARMING SYSTEM IN S-W BANGLADESH

Referring to the aquatic farming systems in S-W Bangladesh review in Chapter 1 the *gher* based systems are divided into three broad classes: (1) extensive (use no feed and fertiliser used mainly during pond preparation) (2) semi-intensive (use feed and fertiliser) (3) intensive (use feed, fertiliser, and aeration). Apart from these two, other distinct systems were considered in this study (1) organic (maintained set of rules in management aspect (Paul & Vogl, 2012) the extensive type with special care on post-harvest management) (2) pocket *gher* (extensive/semi-intensive in nature, separated only by its location i.e., lower saline *gher* located in higher saline areas).

2.6 SITE SELECTIONS

Before detailed field research begun, a series of meetings were held with different stakeholders and desk-based review work given an idea about the area and the stakeholders with their working boundaries. Four communities from the four saline agro-ecologies were selected by purposively based on the previous cluster analysis of SEAT (Sustaining Ethical Aquaculture Trade) project data in the region. SEAT worked in 36 communities in the region over four years (2008-2012). Only Hindu communities were selected for the survey. Though the national level Hindu communities are representing below 10%, however, the proportion in the study areas were quiet high for instance in Shymnagar (high saline areas), Ashashuni (medium saline areas), Dumuria (low saline areas) and Chitlamari (freshwater area) sub-district it was 22.36%, 28.27%, 41.18% and 35.23% respectively (Banglapedia, 2015, BBS 2001). To minimise the variable number and to compare the food consumption pattern across the saline areas only Hindu region were studied. This was because the food consumption varies by religion and ethnic tradition (Roman & Russell, 2009) in South-east Asian countries. The four purposively selected aquatic farming communities are mentioned in the following Table 2.3. Which also illustrate in Figure (2.7).

Table 2.3 Site selections for research work

Area	Acronyms	Salinity level	Village	Sub-district	District	Area
High saline	HS	>10 ppt	Arapangasia	Shaymnagar	Satkhira	High saline
Medium saline	MS	5-10 ppt	Jaduardanga	Ashashuni	Satkhira	Medium saline
Low saline	LS	<5->0.5 ppt	Shuvna	Dumuria	Khulna	Low saline
Freshwater	FW	<0.5 ppt	Chor-Borobaria	Chitalmari	Bagerhat	Freshwater

Figure 2.4 Map of Bangladesh showing the aquatic farming areas in S-W coastal area [map source: ggmap; R (R Core Team, 2016)]

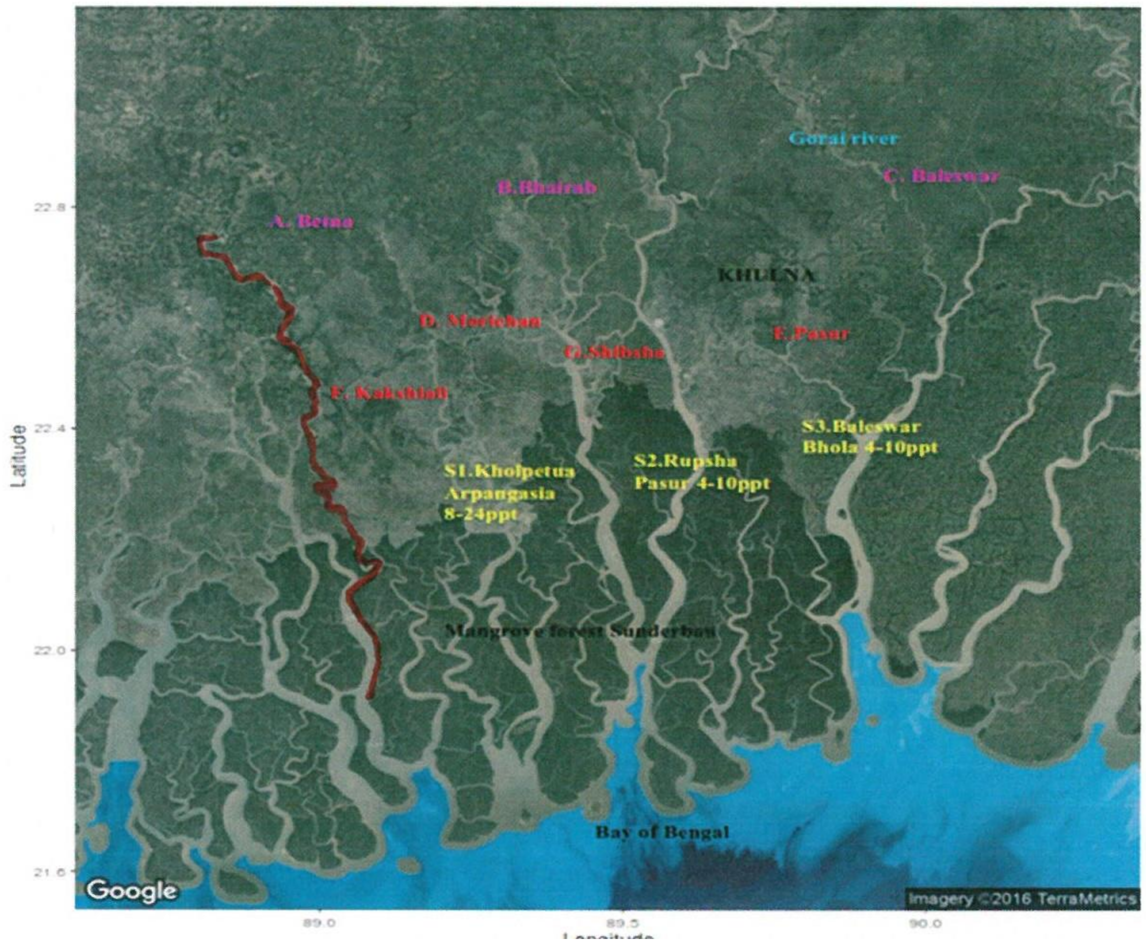


Figure 2.5 Map showing water salinity range in major rivers and rivers systems in S-W coastal aquatic farming areas in Bangladesh [data derived from (Rahaman et al., 2015; SRDI, 2016). From higher latitudes, the Gorai river is the main distributor of freshwater in the region. Rivers A-C, D-G are ranged from 0.2-5 ppt and 0.3-16 ppt. River system S1 salinity ranged 8-24 ppt and S2 & S3 4-10 ppt [map source: ggmap; R (R Core Team, 2016)]

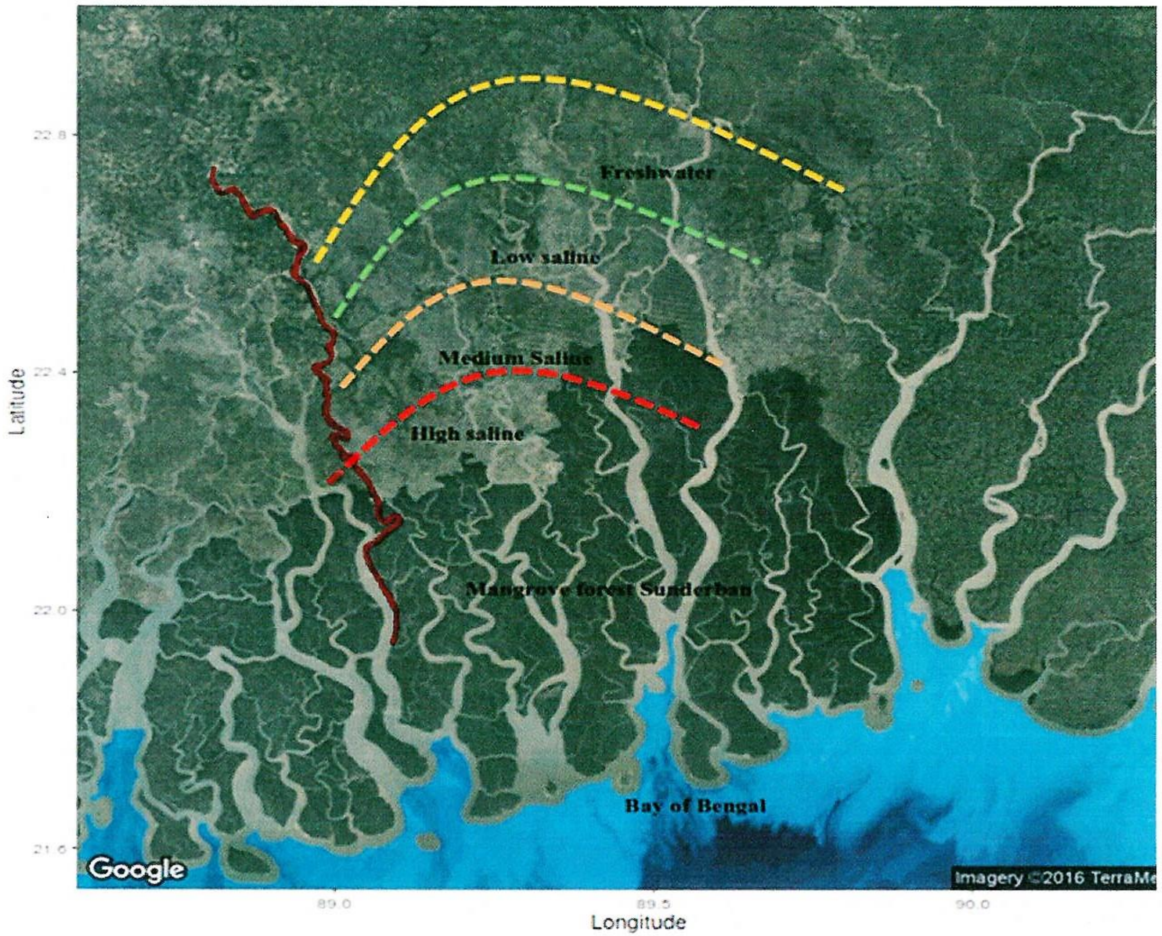


Figure 2.6 Classifying aquatic farming areas in S-W Bangladesh on the basis of water salinity [The dotted line from lower altitude to higher altitude denotes the salinity boundary of each category. High saline is for >10 ppt, medium for 5-10 ppt, low saline <5 ppt and freshwater area <0.5 ppt. [map source: ggmap; R (R Core Team, 2016)]

Figure 2.7 Survey areas/community across the saline gradients of aquatic farming areas in S-W Bangladesh [Each point denotes a community in high saline (>10 ppt), medium saline (5-10 ppt), low saline (<5 ppt) and freshwater (<0.5 ppt)). Two areas in lower latitudes are higher saline areas dedicated mainly for shrimp and the remaining two in higher latitudes are lower saline areas integrated with shrimp-prawn-rice-dyke vegetables farming systems. [map source: ggmap; R (R Core Team, 2016)]

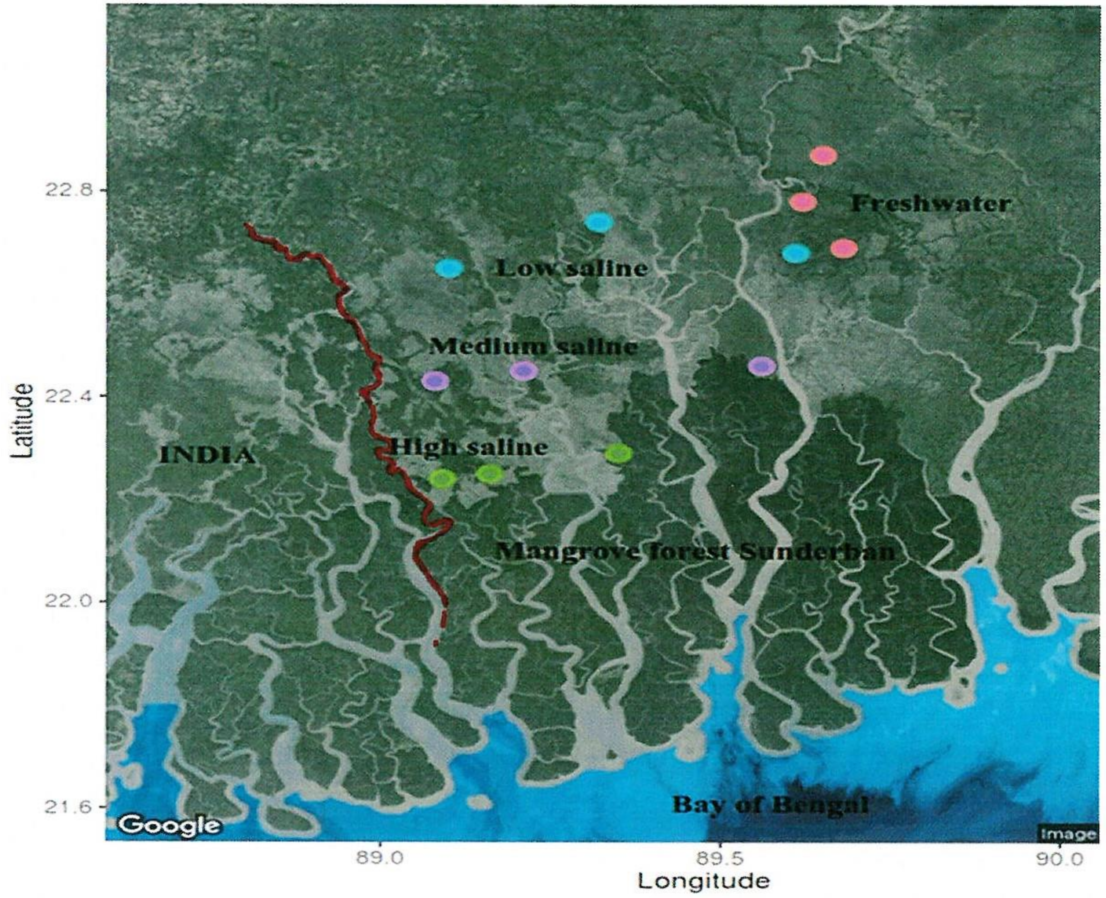


Figure 2.8 Aquatic samples for nutritional study collection areas across the saline gradients of the aquatic farming systems in S-W Bangladesh [Three sites from each saline area were selected for sampling and then pooled as major saline gradients (High, Medium, Low and Freshwater). Samples for Pocket and organic *ghers* were collected from higher saline areas [map source: ggmap; R (R Core Team, 2016)].

Plate 2.1 Female research assistants with the nutrition experts at a demo survey at Jhilerdanga village, Dumuria, Khulna

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2.7 FIELD STAFF TRAINING

To execute socio-economic related work male enumerators (n=3) were selected from Noakhali Science and Technology University. The female enumerators (n=10) for the household level survey were selected from Khulna University affiliated college Khulna Collegiate School. They were postgraduate students from fisheries and nutrition backgrounds. Both classroom-based and in field training (Pretty, 1995) were carried out. Experts from the relevant disciplines were invited to provide hands-on training. Researchers and the demonstrators were actively present at field level to monitor and support the field enumerators. An initial pilot survey and then model data were collected from the adjacent village (Jhilerdanga, Dumuria) of Khulna city and presented in the interactive reflection session (Plate 2.1). Emphasis was also given to appropriate attitudes, behaviour (Pretty, 1995) local customs and researcher self-awareness (Morales, 2007). Support and the knowledge about the local context and customs were obtained from WorldFish Centre (WFC) and local NGO's staff.

2.8 LIVELIHOOD STUDY

2.8.1 TOOLS FOR COMMUNITY RESEARCH

The participation of people in research is not recent, and both social group rich and poor can be a part of it (Biggs & Farrington, 1991). The researcher often chooses only one method among qualitative and qualitative. According to Chambers (2001), a combination of both techniques is most popular and helps to more comprehensively understand livelihoods of the communities and individuals studied. Both are considered as complementary to each other, with qualitative methods providing a wider view of the issues and contributing to narrow down for in-depth quantitative study. The qualitative methods while being challenging are quite informative and effective in identifying the key factors and processes underlying poverty. However, large-scale quantitative analysis can at times fail to determine the impacts as well (Howe & McKay, 2005). The Globalism Research Centre suggested that integration of both qualitative and qualitative methods should be set within as an applied framework of community mapping (James et al., 2012).

2.8.2 PARTICIPATORY RESEARCH APPROACH

The engagement of community members and mutual understanding with the researchers makes the research successful. Participatory Rural Appraisal (PRA), is considered as a more collaborative and also collegiate research practice (Chambers, 1994). The aforementioned PRA tools are popular in developing countries research and throughout the development process. Chambers (1994), considered it as the set of methods which allowed local people to share their experiences to plan and act. Some commentators described it as an interactive learning platform about rural life which was governed by the people (WCED, 1987), convenient for field level study on farming systems, agroecosystem analysis and as a starting point for understanding the local situation (Shaner et al., 1982). To maintain the central tendency and omit dramatic events, a combination of PRA and questionnaire survey found effective in research (Kleih et al., 2003). Both the PRA tools and structured questionnaires were used in this study.

2.8.3 PARTICIPATORY MAPPING

In research and development activities participatory mapping is another popular, widely used PRA tools method which can be used in diverse ways and for the purpose (Chambers, 2008). The community people enjoyed the mapping practice, and it allows building rapport with the researcher which ultimately helping to explore in depth information in greater extent. Use of participatory mapping was found to be satisfactory in Bangladesh for aquaculture research (Faruk-ul-islam, 2007). In the current piece of work, the development workers who worked with the community in the long-term helped to find out the key informants, and geographical boundaries of the community. The communities' people in this study enjoyed the mapping practice and developed the village resource map.

Table 2.4 Activity flows chart followed during community appraisal and throughout the research

Stage	Stage name	Activity	Outcomes
1	First visit	Introduction	Contact local NGO workers and visit the village
		Village transect walk	Familiar with the village geography
		Visit elite people	Rapport building and seeking support for smooth research
2	Key informants (KIs) sessions	Village mapping	Significant natural and physical resources at community level
		Well-being practice	Understand social well-being stratification at community level
3	Community discussions	Feedback and discussion	Validation and clarification unclear information derived from KI's interview
4	Community census	One-off questionnaire	Major demographic and ecological information from 1082 households (HH) census across the four communities
		Sorting households	Select households for in-depth survey
5	Household selection for detail survey	Analyses KIs and census data	Combine rich and medium categories into better-off and poor and ultra-poor into worse-off social well-being group. Selected at least 30 households from each social well-being of four communities (30×2×4=240 HH)
6	In-depth Household Survey	24-hours recall and food frequency questionnaire	Detailed livelihoods and food consumption pattern at household and individual level were studied with structured questionnaire survey. Anthropometric data of adolescent girls and their whole blood collected to assess the n-3 PUFA content in blood level across the saline gradients and social well-being group.
7	*Gher* survey and aquatic animal collection	In-depth *gher* survey and sample collection	Detailed *gher* level information obtained from the two social well-being group of each community. At least 20 farmers from each social group of each community were randomly selected (20×2×4=160 *gher*). Representative samples of each aquaculture system from each saline gradient with three replicate places were collected from the *gher* for nutritional analysis.
8	Laboratory work		Collected aquatic animal and adolescent blood samples were analysed at the NAS in UoS.

2.8.4 WELL-BEING PRACTICE

Household level well-being ranking is widely accepted and replaced the traditional wealth ranking interview survey in many developments and research program (Scoones, 1998). Well-being indicators included social, education, health, culture and wealth (Stirrat, 2003). This technique is suitable for rapid identification of the lowest income group, stratification of social levels and households status in a given community (Chambers, 1994). It is also a useful tool where community people can exercise the social stratification in a realistic way (Pretty, 1995). In the recent aquaculture impact studies in Bangladesh, well-being ranking was widely used (Haque, 2007; Karim, 2006).

In this study well-being exercise brings the livelihood context of the community people using well-being status based on key informant's (KI's) interviews and focus group discussions. The primary objective was to understand the stratified community people by their capital and household resources. A collaborative approach was undertaken among the researcher, facilitators, enumerators and key informants. The KI's selection was executed with the help of local facilitators of WorldFish Center (WFC), OSP (Organic Shrimp Project) and local NGO's. At least three key informants from each site were selected similarly to Morales (2007). Local leaders, *matbbor* (head of the community), school teacher and most knowledgeable person were selected as the KI's. The KI's of course remained in the area for most of the time (Mukherjee, 1997).

In the first meeting with the KI's the scope and goal of the research work was described clearly by the researcher and sought the neutral and unanimous information for quality work. A list of the households was developed first with the active participation of the key informants and most recent voter list (comprising of people over 18 years old living in the particular locality). This helped to ensure the inclusion of all the members of the community. The well-being ranking was then executed according to other researchers in aquaculture (Haque, 2007; Morales, 2007). Details of the key informants are presented in Table 2.5.

Table 2.5 Key informant's attributes during the well-being ranking exercise

Salinity	Village	Sub-district, District	Average age ± SD	Occupation
HS	Arpangasia	Shaymnagar, Satkhira	51.67±21.22	School teachers, ex-member
MS	Jaduardanga	Ashashuni, Satkhira	41.4±11.15	Ex-member, progressive farmers
LS	Shuvna	Dumuria, Khulna	45±7.56	*Matabbor*, progressive farmers
FW	Chor-Borobaria	Chitalmari, Bagerhat	54.67±10.50	*Morol*, Member*, progressive farmer

*Members are the elected representatives of Ward the lowest tier of administrative hierarchy in Bangladesh

The KI's got the freedom to group individual households (Keough, 2014). Finally, each of the households obtained three scores from the respective KI's and then average scores were calculated and grouped into four different categories with natural breaks of score *viz*. rich, medium, poor and ultra-poor. This type of well-being studies was practised in Bangladesh and proved useful in field research (Haque, 2007; Lewis, 1997).

2.8.5 Criteria generated by the Key Informants for grouping

The criteria for the well-being exercise were determined by the key informants and then the researchers only explained the research objective and the process that would follow. Mainly land ownership, access to the aquatic farming system (*gher)*, house type, occupation, education level were the main criteria to address social well-being grouping addressed by KI's. The ethical certificate was obtained from the national authority accordingly.

2.8.6 Community discussions

The data generated from the KI's regarding social well-being were discussed at the community level to overcome the differences on well-being allocation by the KIs. This discussion allowed validating and triangulation of the results generated from the key informants (Smucker et al., 2004). In the current research work theses discussion were took at the central place of the communities. These were found as a helpful tool to validate and discuss the KI's outcomes also described by Morales (2007), and Smucker et al. (2004). The key personnel took part in the discussion are presented in Table 2.6.

Table 2.6 Participants in the community discussions in S-W coastal area of Bangladesh

Saline areas	No. of people involved in the open discussion	Major occupation	Facilitator
HS	11	Member, son of ex-chairman, school teacher, progressive farmer	OSP field assistants
MS	15	Present and ex-member, school teacher, progressive farmer, student	Local NGO
LS	12	*Matobbor*, school teacher, village doctor, student, progressive farmer	WFC field supervisors
FW	9	Elected member. *Morol*, progressive farmers, student	Local NGO

2.8.7 COMMUNITY CENSUS

From the KI's session and community's discussion, a full list of the 1082 households across the saline agro-ecologies (communities) was obtained with social well-being allocation (rich, medium, poor and ultra-poor). To get the consistency of allocation by the key informants and the wealth index, a set of data were collected from the communities' census through a semi-structured one-off questionnaire. This questionnaire dealt with indicators used by the KIs including family size, gender ratio, adolescent girls and boy's number and their age, education level, etc. In the ecological part the farm area, ownership, main species cultivated and, dyke crops, etc. were also collected (refer to the questionnaire in Appendix 1 (2.1)).

In social research, it is a common phenomenon to use questionnaires, and it is found to be a useful tool for collecting socio-economic quantitative and qualitative data. It provides authentic data on livelihoods strategies and outcomes (Ellis, 1998). However, large-scale questionnaire surveys can under some circumstances be not cost effective and error free (Gill, 1993). For one-off studies, they remain one of the most authentic and widely accepted methods used in rural research (Guijt, 1992). The key information under major categories of sustainable livelihood frameworks (DFID, 1999) presented in Table 2.7.

Table 2.7 Checklist of information collected through one-off questionnaire survey in south-west coastal Bangladesh

Category	Information
Human capital	Number of adolescent boys and girls, age, household members number, the education level of household head
Natural capital	Land area, household area, *gher* number, and area, major species dyke cropping and rice cultivation
Physical capital	Household type hired labour
Social capital	Ownership of aquatic farm

2.9 HOUSEHOLD SELECTION FOR IN-DEPTH SURVEY

The consistency of outcomes of the community census and KI's sessions regarding social well-being allocation were tested in next chapter (Chapter 3). For the in-depth survey, the rich and medium categories were combined into better-off and poor and ultra-poor into worse-off social well-being group. These type of lined up of social class into major cluster also practised by Karim (2006), in aquaculture research in Bangladesh. Households from each social well-being group were selected purposely, and the criteria were selected households having at least one unmarried adolescent girl (10-19 years old) (refer to Table 2.4; stage number 5). On this ground, at least 30 households from each social well-being of four communities (30×2×4=240 HH) were selected (Table 2.8). Socio-economic data obtained from the community census (n=1082) and in-depth household survey (n=240) were utilised to develop the livelihood aspects of the communities people in Chapter 3. Intra-household food allocations, nutritional outcomes of the adolescent girls are derived from the in-depth survey and develop the food allocation and food security of household people in Chapter 6.

Table 2.8 Research design for in-depth survey at household levels in aquatic farming areas in S-W Bangladesh

	Sample size			
Activity	High	Medium	Low	Freshwater
Households census	273	206	298	305
In-depth household survey (better-off: worse-off::50:50)	60	60	60	60
Whole blood samples from adolescent girls (better-off: worse-off::50:50)	50	50	50	50

2.10 COMPARATIVE STUDY ON AQUATIC FARMING SYSTEM

In the community census and KI's session, a complete list of the households along with the member list and their occupation were obtained. From the list, at least 20 farmers from each social well-being of four communities (20×2×4=160 farmers) were randomly selected. A semi-structured questionnaire (Appendix 2 (2.2)) was prepared, and data were collected in a face to face interview and mostly took place in their farm area. Precautions including pre-testing/piloting of the questionnaire, training of the enumerators, modifying questionnaire, local interpretation terminologies were taken to avoid any shortcomings in the research design. Global Positioning System (GPS) tracker devices, a refractometer to measure water salinity and record book were carried out during the survey.

2.11 NUTRITIONAL PROFILES OF AQUATIC ANIMALS IN AQUATIC FARMING SYSTEM

Measuring scales, weight scales, ice box, ice, Global Positioning System (GPS) tracker devices, refractometer for water salinity measurement, marker pen, and record book were used in the field during the aquatic farming system survey. The collected samples were transferred to UoS (University of Stirling) and nutritional profiles were analysed in the Nutritional Analytical Service (NAS). All reagents used for chemical and biochemical analysis in this study were HPLC (High-Performance Liquid Chromatograph) grade. The reagents and materials used consisted of potassium hydrogen carbonate (KHCO3), sodium hydrogen carbonate (NaHCO3), iodine, Butylated Hydroxytoluene (BHT), 17:0 free fatty acid standard; each was obtained from Sigma (Poole, UK.). Chloroform, methanol, toluene, iso-hexane, diethyl ether, ethyl acetate, ethanol, acetonitrile, acetone, propan-2-ol, methyl acetate, potassium chloride, sulphuric acid and glacial acetic acid were obtained from Fisher Scientific

UK, (Loughborough, England). Precoated silica gel 60 Thin-Layer Chromatography (TLC) (20×20×0.25 cm) plates, without a fluorescent indicator, were obtained from Merck (Darmstadt, Germany). All compressed gases: oxygen-free nitrogen, hydrogen, oxygen and helium were obtained from the British Oxygen Company (Glasgow, UK).

2.11.1 SAMPLING PROCEDURE

To cover the entire *gher* based aquatic farming system in the S-W coastal Bangladesh, two more sites in previously selected saline areas were added (Figure 2.8). Therefore, in the four saline gradients, total 12 sites were chosen for aquatic animal (finfish, shellfish, mud crab) collections. For high saline areas Shymnagar, Koyra and Dacope, for medium saline area Kaligonj, Paikgacha, and Mongla, for low saline areas, Satkhira Sadar, Dumuria, and Bangerhat sadar, for freshwater area Terokhada, Fakirhat, Chitalmari subdistricts were the main sampling stations in greater Khulna district (Figure 2.8). There are three major production intensity levels used to characterise aquaculture globally- extensive, semi-intensive and intensive; systems in the research area were predominantly extensive and semi-intensive. The details about the existing aquatic farming systems in the region are described in Chapter 1. In addition to these culture system both organic *gher* (extensive system with an advanced chain of custody during post-harvest) and pocket *gher i.e.* low saline *gher* in higher saline areas were also considered. Farming systems, both pocket *gher* and organic *gher*, were selected due to their unique attributes in management. The unique nature might have an influence on the nutritional features and therefore selected for sampling. Aquatic food samples from the three replicates sites of each saline area were pooled, however, samples from different culture systems and saline areas were kept separate. The aquatic animal sample was collected twice in 2013 (T1) and 2014 (T2). Both occurred during the peak harvest seasons in December.

Table 2.9 Sampling sites for aquatic animal collections from different culture systems and saline gradients in the S-W Bangladesh [√=sample collected; -=sample not collected/nil]

Salinity	Culture system				
	Extensive	Semi-intensive	Intensive	Organic	Pocket
High	√	√	√	√	√
Medium	√	√	√	√	-
Low	√	√	√	√	-
Freshwater	-	√	-	-	-

Aquatic animal samples from the intensive systems were only *bagda* (*Penaeus monodon*). In organic system, *bagda* and other co-products are produced similarly to the extensive system, and only *bagda* and *horina* shrimp (*Metapenaeus monoceros*) were collected from these systems for nutrient analysis. In the rest of the systems, all the available species were considered to collect and analysis. In addition to these wild species *illish* (*Tenualosa ilisha*) and *illish* by-product (*illish* eggs) were taken for the study. The aim of covering all the available species is to report the nutritional content of all the existing species from all available culture system and saline agro-ecologies. These data were used to transform the food consumption into nutrition consumption at the household level study in Chapter 6 to address the nutritional security and health outcomes household members.

During the sample collection, the individual length and weight of the fishes was recorded and considered in terms of the size ready for consumption. From on ground study and secondary datasets the available species were categorised into large and Small Indigenous Species (SIS). Species attained the maximum size less than 25 cm is considered as SIS (Roos et al., 2007b). For small indigenous species the pooled size for each species was 1 kg in volume and for large fish, it was 2 kg in volume. Samples were cleaned by the local household women to get raw; edible parts according to local practice. The inclusion of head, viscera, bones as edible part depending on the species. Water salinity data of the respective farms were recorded using the refractometer. The fresh fish were kept in insulated ice buckets. A unique code number was used for each specimen and location and culture systems. The code numbers were written on the top of each transparent polyethene bag and then recorded in a notebook. These samples were then immediately transported and placed in o the Cold storage (-20°C) facility of shrimp processing plant in Khulna.

2.11.2 Aquatic animal samples shipments

For shipment of the samples the health certificate (from DoF), a temporary export certificate from Office of Chief Controller of Imports and Exports (CCI&E) were collected accordingly. Dried ice was kept within the insulated samples box, and the ratio was maintained 3:1 (dry ice: fish) in weight. Then the samples were shipped to the UoS, UK. It took less than 24 hours to arrive at the UoS, and the samples temperature within the box were measured. In all occasions about 40% dry ice was found to remain intact indicating that the samples remained frozen during the transportation (Karapanagiotidis et al., 2010). For nutritional profile study of the specimens were then homogenised and the sub-samples were kept in a small vial for a specific nutritional analysis.

2.12 Nutritional Analysis of aquatic animals and by-products

The gross chemical compositions of the fish and by-products were determined by the proximate analysis based on official methods of the Association of Official Analytical Chemists (AOAC, 2000). All samples were determined directly from the wet samples where selenium and energy content were determined from the dry sample. The samples were finally ground and blended homogeneously before analysis.

2.12.1 Moisture content (drying oven)

The moisture of samples was determined by placing 1 g of wet samples in a drying oven at 110°C for overnight (AOAC, 2000).

2.12.2 Crude Protein content

The crude protein content was determined from the nitrogen content of each aquatic animal samples which assumes that protein contains 16% nitrogen, using automated Kjeldahl analysis (Tecator Kjeltec TM 2300 analyser, Foss, Warrington, UK) according to the standard method (AOAC, 2000) and the manufacture’s protocol.

2.12.3 Crude Lipid content

Total lipid for fatty acids analyses was extracted from the fish flesh and by-products by homogenisation in chloroform-methanol according to a standard protocol (Folch et al., 1957). The total lipid was re-dissolved in chloroform: methanol (2:1 v/v) + containing 0.01% (w/v) BHT to a concentration of 10 mg/ml and stored under nitrogen at -20°C for further analysis.

2.12.4 Ash content

The inorganic matter or total ash content of samples was determined by placing a 1 g wet sample into a muffle furnace at 600°C for 16 h (AOAC, 2000).

2.12.5 Determination of fatty acid compositions

Fatty Acid Methyl Esters (FAME) were obtained from total lipid subjected to acid catalysed transesterification according to a standard method and quantified by gas chromatography (Christie, 2003). The procedure for fatty acids analysis was carried out according to the protocols developed/followed by the Nutritional Analytical Service (NAS), Institute of Aquaculture, University of Stirling, UK (Pratoomyot, 2010).

2.12.6 Energy content

The gross energy content of fish and by-products samples were determined by bomb calorimeter (Parr© 6200; Foss, Warrington, UK) where the dried samples were completely combusted in an oxygen filled container and the heat released measured and energy content calculated according to manufacturer's protocol (Pratoomyot, 2010).

2.12.7 Micronutrients

The micronutrients were determined in acid digestion ICP-MS (Inductive Coupled Plasma-Mass Spectrometry) (Erkan & Özden, 2007; Wheal et al., 2016). Regarding selenium determination, ICP-MS without acid digestion was used (Silva et al., 2011). Wet samples were used for all of the micronutrients tests, however, for selenium dried (ash) samples were used and then data converted to wet weight basis (Baeverfjord et al., 2007).

2.13 HOUSEHOLD SURVEY FOR FOOD CONSUMPTION AND HEALTH OUTCOMES STUDY

2.13.1 HOUSEHOLD SURVEY

Blood sample pad (supplied from NAS, UoS), MUAC tape, height scale (cm), weight scale (for female body weight), measuring cup sets, weight scale (food), food photography (Appendix-4 (2.4)) album (developed in the training session) were carried out by the researchers during the survey.

A person or persons related or unrelated, living together and taking food from the same kitchen considered a household. Consent in writing was obtained from the participants and in some occasion from the legal guardian (Appendix 3 (2.3)). Ethical clearance certificate (Appendix 2.6) and Materials Transfer Agreement (MTA) (Appendix 7 (2.7)) were obtained from the proper authority of Bangladesh Medical Research Council (BMRC). Food photography was prepared on the cooked major food items to adjust the food weight and portion size (Foster et al., 2006; Nelson et al., 1996). The measuring cup sets were also adjusted with the actual food weights that were also used during the survey. So these were the combination of taking the direct weight of food, utilised the standardise measuring cup sets, and food photography album used whenever necessary, depending on food type, availability of particular food item during the survey that eaten in last 24 hours. Utilisation of the combination of these three tools was found helpful to extract the actual amount eaten at household level by the individuals. Firstly family level cooking consumption was measured and then individually asked for their consumption. In the case of children, their parents were given the answer.

2.13.2 DIETARY ASSESSMENT:

A 24-hour food recall method and food frequency questionnaire (Appendix 5 (2.5)) were developed and validated accordingly. The livelihoods of households, individual diet and nutrition consumption, were sampled on two occasions. All the food items were grouped into ten major food groups based on standard approaches (Handa & Mlay, 2006; INFS, 2013). The major food groups are cereals (boiled rice, puffed rice), vegetables (plants, vegetables, leafy vegetables), pulses (pulses and legumes), fish (seafood, finfish and shellfish), meat (chicken and meat products), milk (milk and milk products), beverage (tea, coffee), eggs, fruits and others (ice-cream, chocolate). To measure food frequency of the main food items consumed over 14 days at household level were recorded in the developed questionnaire (Appendix 5 (2.5). The relationship among the household members was drawn in relation to the household head. Thus housewife or homemaker was titled as a wife, girls as a daughter, and boys as a son. Although the dietary data of all members of the household were collected only these four members over the age of 10 were selected for in-depth dietary analysis.

2.13.3 Anthropometric outcomes of adolescent girls

Measurement method like the summation of diet and nutrient intake in association with health outcomes rather than coherent behavioural pattern study are more reproducible and accurate (Tucker, 2010). Anthropometric data (height in cm and weight in kg) were collected by using measuring scale and weight scale. Mid-upper Arm Circumference (MUAC) tape was used to determine the MUAC (in mm) according to Sultana et al. (2015).

2.13.4 Blood samples analysis of adolescent girls

Out of 240 surveyed households, 200 households (HH) were randomly selected for collecting blood samples from adolescent girls (10-19 years old). At least 15% HH was kept on a reserve list for blood samples. Whole blood was collected using blood lance (Accu-Chek, Safe-T-Pro Plus, Roche Diagnostics GmbH, Mannheim, Germany). The drop of blood was obtained by punching the fingertip with an automatic lancing device equipped with a lancet and blood drops were absorbed on Whatman 903 cards that were adding by butylated hydroxytoluene (BHT; 50 mg/100 ml in ethanol) to cover each collection spot thoroughly. The cards were air dried for 1h and put with silica in the individual Zip-lock foil bags with a tight closure. The samples were then kept in the freezer -18^{0}c and then shipped to the University of the Stirling (UoS) within two weeks. The fatty acids properties in stored (-80^{0}c) samples remained unchanged up to four years (Hodson et al., 2002).

After arrival in UoS, the dried whole blood samples were detached from the collection pad using forceps and placed into a screw-cap vial. FAME (Fatty Acids Methyl Esters) were separated and quantified by GLC (Gas-Liquid Chromatography) (ThermoFisher Trace, Hemel Hempstead, Herts, UK) using a 60 m 0.32 mm 0.25 mm film thickness capillary column (ZB-Wax; Phenomenex, Macclesfield, Cheshire, UK). The precession of the whole blood fatty acids analysis was conducted by measuring duplicate samples. The whole process was done according to the procedure followed by Bell et al. (2011) and Marangoni et al. (2004).

2.14 REFERENCE VALUE

Reference values for Body Mass Index (BMI), Mid-Upper Arm Circumference (MUAC), total PUFA (omega-3 and 6) in blood content, micronutrients, protein, and energy were obtained from standard sources; (NIH, 2016; WebMd, 2016). The consumed amount of food item by species and, in some cases, type-wise (tea, ice-cream) were recorded and converted to nutrient content using secondary values (Islam et al., 2010; INFS, 2013). The nutritional data of all food items except fish obtained from secondary sources (Islam et al., 2010; INFS, 2013). The fish nutritional profiles are generated from this piece of work are presented in Chapter 5.

Table 2.10 Reference values for nutritional study value in parenthesis were considerd for the study

Nutrients	Reference value	Reference
BMI	The lower and upper SD boundaries limits -6 to +6	WHO (2011)
MUAC	The lower and upper SD boundaries limits (-6 to +6)	WHO (2011)
Protein	0.83 g/kg body weight	NIH, 2016; WebMd, 2016
Energy	2300 kcal/day	NIH, 2016; WebMd, 2016
LC n-3 PUFA	250-500 (500) mg/day	NIH, 2016; WebMd, 2016
Ca	1300 (1100) mg/day	NIH, 2016; WebMd, 2016; FAO, 2001
Fe	22-62 (9.5) mg/day depended on bioavailability	NIH, 2016; WebMd, 2016; FAO, 2001
Zn	4.6-15.5 (11) mg/day depended on bioavailability	NIH, 2016; WebMd, 2016; FAO, 2001
Se	26-50 (55) µg/day	NIH, 2016; WebMd, 2016; FAO, 2001

2.15 General statistical methods

To understand the differences of variables (*gher* area, *gher* inputs & outputs, etc) among households of different social positions across the agro-ecologies boxplot was prepared. An ANOVA by using a lm model (Linear Model) was run to understand the role of the *gher* area in local context. The middle horizontal line that divided the box into two are the median, the upper and lower "hinges" correspond the 3rd and 1st quartile. The upper and lower whisker represents the maximum, and minimum scores outside the middle, the separately plotted points in the chart is the outlier represents an individual sample. The different letter above the each whisker indicated significant differences (P<0.05) among the variables (saline areas and social well-being). The aquaculture and asset-based wealth indices were prepared from aquaculture and household wealth related data obtained in the survey by using PCA (Principle Component Analysis). These two indices were also tested by ANCOVA with unrelated variables to test the influences of the variables on indices. The disparity of variables (landholding, income) among the households in four different saline areas were tested by using Gini coefficient. All the analysed data, graphical presentation of data have been customised from the statistical package program R (R Core Team, 2016).

3 CHAPTER 3: DOES AQUATIC ANIMAL FARMING IMPROVE WELL-BEING IN THE SOUTH-WEST DELTA, BANGLADESH?

3.1 INTRODUCTION

Agriculture is considered as one of the main engines of rural development in developing countries (Rigg, 2006). Rice-based agricultural systems have been changing through the exploitation of new ecological, economic and technical development including crop diversification, vegetable production, improved farming mechanisms, and integrated rice-fish culture (Toufique & Turton, 2003). Aquatic animals are the fastest-growing food globally and becoming the largest source of animal protein for human consumption (Ottinger et al., 2016). Both the conventional ponds and nonconventional rice fields have been using for aquatic animal production in Bangladesh (Jahan et al., 2015). Small-holder agrarian economy dominates Bangladesh. Small-holders on an average maintained the agricultural production at the pace of demands (Turner & Ali, 1996). Since the 1970's the changes in the local agro-ecologies, international support, local market needs and global market demand have shaped the shrimp and prawn based aquaculture in the south-west coastal Bangladesh. The development of shrimp and prawn based on the export-oriented production of two crustaceans black tiger shrimp and giant freshwater prawn (Faruque et al., 2016). Aquaculture in low-lying rice fields is a major pillar in rural areas of some developing countries (Martin et al., 2013). This aquatic animal production system in the low-lying agricultural land is locally called *gher* or *bheri* (Milstein et al., 2005). Aquatic farming by the small-holder in south-west coastal Bangladesh is an important livelihood option for rural people. Above 80% of households are directly involved in aquaculture value chain in S-W Bangladesh (Faruque et al., 2016).

In rural settings, farming systems determine the livelihoods options which eventually set up the well-being of individual and household level (Adato & Meinzen-Dick, 2002). A livelihood is the combination of activities and belongings that generate the means of household survival (Martin & Lorenzen, 2016) and deal with the coping tactics of individual or household level during the vulnerable condition (Ellis, 2000). DFID define livelihood as “the capabilities, assets, and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base”- (DFID, 1999).

Livelihood assets are of natural, physical, human, financial and social capital. The access and the level of activities on these capitals determine the livelihood standard of an individual or household (Ellis, 2000). Sustainable Livelihood Framework (SLR) is used to understand the impact of assets and diverse occupations on the social well-being position (DFID, 1999).

A wide variety of variables can be measured to determine the well-being of households and individuals. The variables selected are dependent on the aim and context of the study. The extent of urbanisation (rural, urban and peri-urban), for examples, determine which variables are expected to have a major impact on well-being. The socio-economic position (SEP) in the community have an impact on the measure of people’s well-being (Camfield & Guillen-Royo, 2010). There are also some general views like a silo full of rice and a stomach full of boiled rice is considered as the household and individual well-being, respectively in Bangladesh (White, 2010).

Directly measurable aspects of household well-being from studies in Bangladesh include the variables income, ability to intake three meals in a day, working capacity of male household head, holding cultivable land, owning cattle and oxen, house type, and capacity to educate children (Mahbub & Roy, 1997; Mahmuda, 2003; Nabi et al., 1999). Among all, both economic solvency and consumption expenditure are routinely used in long-term poverty and well-being studies (Filmer & Pritchett, 2001). Income is problematic to measure because it is not always possible to assign the monetary value of goods in a practical way (Martin & Lorenzen, 2016).

Farmer’s landholding and ownership of land are important variables of social well-being in rural Bangladesh (Gurung et al., 2016). Ownership includes all aspects of the property rights i.e. the right to use the good, to earn money from the good, transfer the good, transform the good (Krause et al., 2015). Ownership of the property has a significant role for socio-economic development in developing countries (Ruddle & Davis, 2013). It has been estimated globally 100 million households which cover 500 million individuals do not have ownership right or ownership-like access to agricultural land (Carter, 2000). Rich households tend to lease out the land, and the poorer households operate the agricultural activity. The concept of sharecropping has emerged in the developing countries where poorer utilise the agricultural land of rich households. Sharecropping systems in Turkey involves the provision of land and equal share of inputs (Unal, 2002). In Bangladesh, landlords provide only the land, and the tenants bear all relevant costs to operate the farm. The yield from the sharecropping farm is divided into equal share between the landlord and the tenants (Guimarães, 1989). Many mono-cropped agricultural lands have been converted to shrimp and prawn farms in south-west Bangladesh since the 1980s. The transformation occurred mainly due to the low and unstable agriculture productivity and higher market demand for shrimp and prawn (Islam et al., 2014). With the emergence of shrimp and prawn farming (also integrated and alternated with rice), the rental agreement between tenants and landlord changed from sharecropping to fixed rental system (Barmon et al., 2005; Guimarães, 1989). The fixed rental system of shrimp and prawn *gher* is locally called *hari* (leased-in). The land owner provides written/verbal consent to the tenants similar to cases in Africa where the informal local order given guarantees many villagers basic rights (Brasselle et al., 2002).

Ponds have been viewed as social assets and symbol of social status in some part of Africa (Harrison et al., 1994). Social interactions among the member of the community are established through exchanged experiences of pond-based aquaculture (Haque et al., 2010). This improved social capital helped to manage village ponds by farmers group in Asia (Murray, 2004). However, the coastal shrimp pond establishment in northern Vietnam reduced social cohesion (Adger, 2000). Pond raised fish can mitigate various shocks and improve the resilience of households to unforeseen events (Little et al., 2007). Pond raised fish can be considered as the liquid assets that can be sold even in smaller fraction if needed. The role of fish in this regard is similar to small livestock within small-holder household (Little & Edwards, 2003). Aquaculture activities and the output of the systems are an important part of sustainable livelihood capitals. Fish is the vital source of essential nutrients is considered as natural capital (Ruxton, 2007)

Along with land area and its ownership, other assets are considered to build an asset-based wealth index in well-being studies. In the livelihood framework of DFID, assets denote resources owned or accessed by the household’s members (DFID, 1999). Howe et al. (2008)

suggested the use of a maximum number of variables to get a clear pattern of household livelihood. Where livelihoods are heavily linked to aquacultural activity, we need to evaluate its contribution separately from a simple wealth index. In rural settings, farming systems are important to determine household livelihoods (Adato & Meinzen-Dick, 2002). Moreover, export-oriented agricultural activities tend to receive attention due their impacts on local livelihoods; for example shrimp and prawn farming in the south-west coastal Bangladesh are generate both positive and negative perceptions regarding their impact on livelihood development, food security and sustainability (Ahmed, 2013a; Ahmed & Garnett, 2011; Hossain et al., 2013).

The majority of people in Bangladesh are among the poorest in the world (Ahmed et al., 1991). Such poor people are highly susceptible to the risk of natural disaster. To identify such poverty and provide mechanisms to combat natural disaster, the inequality at individual and household levels needs to calculated. The Gini coefficient is used as a measure of the inequality income or wealth. The Gini value lies between 0 and 1, with 0 meaning perfect equality and one representing absolute inequality. Therefore the lower the Gini value among the households are more homogenous distribution of wealth and income (Brouwer et al., 2007).

In developing countries, most aquaculture research lack social scientific knowledge and wider participation of stakeholders (Belton et al., 2011a; Belton & Bush 2014). The question remaining unanswered in literature is whether aquatic animal farming improves social well-being. The options for poorer households in aquaculture activities and pre-requisites to access on it are essential to understand to formulate effective strategies. In this chapter to answer the above questions, an index of household involvement in aquaculture ('aquaculture index') along with a separate index of household wealth (wealth index) were developed. The influences of both indices are examined carefully to understand the links between aquaculture and well-being.

3.2 OBJECTIVES OF THIS CHAPTER

It is important to understand whether the social position is more important than a person's skills and access to physical resources and to weigh up the different effects on well-being. This piece of work investigated how social position, agro-ecological landscapes, and involvement in aquaculture provide benefits to households' livelihoods and well-being. This work also investigated the livelihood options of people. The social, economic and ecological dimensions of households were assessed case by case in multiple contexts. It shows how the households from different social positions are involved in aquatic animal farming and how it affects their socio-economic position. The effect of salinity level on farming systems, economic benefits and ecological resilience is also discussed.

3.3 MATERIALS AND METHODS

Four communities from the aquatic animal farming area of south-west coastal Bangladesh were selected (Figure 2.7, Table 2.3)**.** For some analyses, to simplify the salinity gradient, high and medium saline areas were grouped as higher saline whereas low saline and freshwater were grouped as lower saline area. Both a community census questionnaire (n=1082 households) and key informants (KIs) session were used to allocate households into four social well-being groups: rich, medium, poor and ultra-poor. The selection process, criteria and well-being ranking practice by the KI's were presented in Section 2.7 of Chapter 2. The rich and medium households were grouped as better-off and poor and ultra-poor as worse-off for some analyses. The in-depth household survey covered households with at least one adolescent girl (10-19 years old). At least 60 households from each community with an equal number from each social well-being (30 from better-off and 30 from worse-off) were sampled in the in-depth survey. The details of the research design are presented in Section 2.8 of Chapter 2.

Socio-economic and aquaculture variables were derived regarding community census and household survey. These data were used to build asset-based wealth index and aquaculture index. Both the indices were tested to look at the relationship between these two and other associated factors such as location on the salinity gradient and ownership of the *gher*.

3.4 INDICES

The data from census and in-depth survey were then analysed using Principal Component Analysis (PCA) to develop two indices; a wealth and an aquaculture index. Each variable were given a specific score. Both indices were developed using PCA to transform the set of relevant correlated variables into a set of "components" (Martin & Lorenzen, 2016). Factor weights against each variable were obtained from a PCA test. The first principle component captured the largest amount of information common to all variables as the linear index which was then used as the index (Córdova, 2008). The variables with the highest factor loading indicated the higher influence of the particular variable on the development of specific index.

3.4.1 WEALTH INDEX

The asset-based wealth index is considered as an appropriate metric to assess the socio-economic status of people in the community (Howe et al., 2008). Variables from our data were chosen to be similar to other studies by Filmer and Pritchett (2001) and Vyas and Kumaranayake (2006). The selection of a wide range of variables related to the wealth helped to avoid the problems associated with clumping/clustering and truncation (McKenzie, 2005). To build the wealth index, a wide variety of variables with specific score were used (Table 3.1). The interpretation of the value of each variable, as well as the livelihood assets categories of sustainable livelihood framework (DFID, 1999), are mentioned in the separate columns.

Table 3.1 Variables used to develop the asset-based wealth index (Values assigned to each variable are given accordance to the level of economic value)

SLR capitals	Variable	Element with score	Explanation of scoring
Natural capital	Total land area	total land area in ha	the sum of *gher* area and household area
Natural capital	Household area	household area in ha	including the backyard and front yard space/garden.
Physical capital	House type	building, semi-building=3 tin-shed=2 tin-bamboo and tin-mud=1	stratified on the basis of utility and economic value
Physical capital	Toilet	offset pit=3 direct pit=2 open=1	stratified on the basis of utility and economic value
Physical capital	Stove	commercial (*bondhu chula*)=3 improved=2 traditional=1	stratified on the basis of utility and economic value
Natural and Physical capital	Source of drinking water	tubewell=4 filter=3 rainwater=2 pond=1	stratified on the basis of utility and economic value

Table 3.1 Variables used to develop the asset-based wealth index (Cont'd)

SLR capitals	Variable	Element with score	Explanation of scoring
Physical capital	Profession	government job along with agri-aqua activities =10 NGO and medium salaried job= 9 integrated agriculture and aquaculture=8 aquaculture and other works=7 only aquaculture=6 only agriculture=5 small shop and lower paid job=4 dependent on natural resources=3 labour and rickshaw puller =2 unemployed =1	stratified on the basis of paid salary
Human capital	Education	postgraduate or graduate =4 higher secondary and secondary=3 primary=2 illiterate=1	at least one member on specific education group given the score for the household. No matter about the other member's education level.
Human capital	Income	net income per month at household levels	subtracting the total expenditure from total earning and transform to log base
Human capital	Ratio of dependency		number of earners divided by the number of household members.

In the variables, the leased-in area was also included in the total area however the leased-out area was excluded as it remained in the custody of others under some agreements. For the categorical variables, it was ranked by its utility and score given against each variable.

Households members were engaged in a variety of professions, and different methods were considered to measure the activity diversity (Cinner et al., 2010). These categories were given scores regarding paid salary/income on a 1 to 10 scale basis (Table 3.1). These categories were also used elsewhere in the literature (e.g. Martin & Lorenzen, 2016).

The wealth index among the social well-being in four agro-ecologies was tested by using ANOVA and the results are described in the wealth index sub-section under result section. The wealth index in social well-being group would follow the allocated trend given by KI's and community census. However, the wealth index variation across the saline gradient informed the vulnerable location despite involvement in aquaculture. No variation between the areas would indicate the homogenous social structure despite salinity variations in locations.

3.4.2 AQUACULTURE INDEX

The impacts of aquaculture activities on livelihood have been explained elsewhere in the literature (Little et al., 2007). The increasing commercial orientation of aquatic products enhanced livelihood opportunities of the community people (Faruque, 2007; Karim, 2006). In aquaculture index fish farm (*gher*/pond) is physical capital, fish species is natural capital, knowledge of aquaculture and utility of pond water is social capital and income from aquaculture which also increases purchasing power is financial capital (Little et al., 2007).

The aquaculture based index was prepared from aquaculture related data with specific score obtained in the survey by using PCA on variables relating to natural and social capital of aquaculture. The variables used to develop the index are presented in Table 3.2. The value/unit for each variable as well as the livelihood asset categories of sustainable livelihood framework by DFID is mentioned in the separate column (DFID, 1999) (Table 3.2).

The aquaculture index across the saline gradients and social well-being were tested. An ANOVA was run and the results are mentioned in the aquaculture index subsection in result section. Variation in the aquaculture index between the social well-being groups would indicate that aquaculture technology was impacted by the socioeconomic level of the adopting household, and no difference would indicate equal access, and opportunities exist for all class of households. The variation of aquaculture index among the locations would indicate the intensity of aquatic activities or level of dependency of households on aquatic activities. The higher value of aquaculture index would also indicate that the households had minimum alternative options or kept most of the households in aquaculture as it is profitable.

Table 3.2 Variables used to develop aquaculture index fit into the sustainable livelihood (SRL) framework in aquatic farming system in S-W Bangladesh

SLR capitals	Variables	Element with score	Explanation of scoring
Natural capital	*Gher* area	*gher* area in ha	area dedicated for aquatic farming
Natural capital	% of *gher*	% of *gher* area to total area	*gher* area divided by total area and then multiply by 100
Natural capital	Number of *gher*	none=1 single=2 more than one=3	stratified on number of *gher*, no matter the area,
Physical capital	Permanent labour	hired=2 none=1	depends on labour engagement
Natural capital	Dyke and rice crop	yes=2 none=1	stratified on the basis of utility and economic value
Natural capital	Species combination	Prawn and shrimp=4 shrimp=3 prawn=2 finfish=1	shrimp is short cycled and economic return is higher than other crop
Financial capital	% of aquaculture income to total income	Log income (BDT per month at the household level)	aquaculture income divided by total income multiply by 100

Although a wide range of varieties of aquatic animal were produced, black tiger shrimp and giant freshwater prawn were considered as major indicator species to evaluate the systems as these items provided highest economic return compared to other aquatic species. The ownership of *gher* and the year of experience in aquaculture were considered as associated variables. These variables were utilised to test the interaction of aquaculture and wealth index.

3.5 ANALYSIS OF INDICES

The first component of each of the PCAs for wealth and aquaculture were used as the index values for each household. The interactions between the wealth and aquaculture index were tested to understand their contribution to livelihoods. In order to do this, the diversity of livelihood profiles, access to aquaculture and ownership categories of *gher* were also assessed. Data analysis and graphical presentation used the statistical package programme R (R Core Team, 2016).

3.5.1 Consistency tests of social well-being allocation

Tests were executed to estimate whether the key informants in each location allocated households into different social well-being in a consistent way. The consistency of social well-being grouping derived from the KI's sessions and community census. In both occasions, households were allocated four social well-being groups: rich, medium, poor and ultra-poor. The mean average residual for each KI and the mean standard deviation residual were calculated separately for each saline area to see the level of deviation among the KI's regarding assigning the socio-economic position. To get the consistency of segregation by the key informants with the wealth index, the wealth index was tested against the key informants' classification using ANOVA with KI wealth class as explanatory and wealth index as a response. A consistent result among the KI's in each location indicated the KI's selection, and the process was done accurately. In the second phase the consistency between KI's and census result will prove the view of the KI's, and on ground truth was corresponding to each other method.

3.5.2 Relationship between aquaculture and wealth index

To find if the households involved in aquaculture are wealthier than the households not involved an ANCOVA (which separated the regressions lines for salinity) was drawn between wealth and aquaculture index. Both aquaculture and wealth index, were considered separately by salinity area and with the interaction between salinity areas. Correlations between the indices would indicate that involvement of aquaculture was linked with wealth.

3.5.3 Relationship between duration of aquaculture experiences and aquaculture index

To test whether long-term involvement in aquaculture increases the aquaculture index an ANCOVA (which separated the regressions lines for salinity) was done. The aquaculture index was kept as a response to the interaction between experience (years) and salinity area (to account for underlying differences). In this case study, we did not follow the longitudinal data at household levels, therefore considered the current aquaculture data as the representative of past. Correlation between duration and index indicated the existence of a relationship. A strong positive correlation indicated experience required gaining success in aquaculture and the culture technique was critical for farmers take the time to adopt the mechanisms (as people gain experience, they increase their involvement). A weak relationship will denote accessible techniques that were not a barrier to successful new entry i.e. farmers could become heavily involved with little experience.

3.5.4 Relationship between duration of aquaculture experience and wealth index

To test whether long-term involvement in aquaculture increased asset-based wealth index an ANCOVA (which separated the regressions lines for salinity) was done. The wealth index was kept as a response to the interaction between experience (years) and salinity area (to account for underlying differences). In this case study, we did not follow the longitudinal data at household levels, therefore we considered the current assets data as the representative of past. Correlation between duration and index indicated the existence of a relationship. Aquaculture might be profitable, then it might influence wealth index or might be a limitation for the other options (due to water salinity) keep engaged households in aquaculture.

3.5.5 *Gher* area distribution

To understand the distribution of *gher* area among households of different social positions across the saline gradient a boxplot was prepared. An ANOVA by using a lm model (Linear Model) was run to understand the role of the *gher* area in local context. Variation between the social positions in a particular location is expected as the *gher* area was used by the KIs to allocate the positions. The variation of *gher* area across the saline gradients in the same social group would indicate the variation of local context. This result would also help to understand how *gher* size influences on the socio-economic position across the locations.

3.5.6 Variation between leasing and owning *gher*

The relationship between either owning *gher* land or access to *ghers* through lease mechanisms and aquaculture and wealth index was evaluated. To understand the impact of ownership both the wealth and aquaculture index were tested by ANCOVA and separated by ownership categories which was not considered for index development. A significant difference between two regression lines: one for owned category and another for the leased-in category will indicate that either owning or leased in was superior regarding gaining success in aquaculture and being wealthy. An insignificant result will demonstrate that no matter of ownership category to get aquaculture productivity and gain wealth.

3.5.7 MEASURING INEQUALITY OF LAND HOLDING AND INCOME BY GINI COEFFICIENT

The Gini value ranged from 0~1, and the lower value is always expected for social equality and sustainable development. The landholding and income disparity among the households in four different saline areas were tested by using Gini coefficient. A Gini Value 0 indicated the homogenous distribution of resources and income. On the other hand Gini value 1 is indicated a single household occupies all the resources and income.

3.6 RESULTS

3.6.1 VILLAGE CHARACTERISTICS

The village characteristics were derived from the PRA (Participatory Rural Appraisal) which was exercised across the four communities. The village characteristics of the specific area provide an overview of the village resources and livelihood options. The agri-aquaculture system and the livelihood options are varied across the locations. The key characteristics of each community are mentioned in Table 3.3.

Table 3.3 Village characteristics (from PRA) of aquatic farming system in the south-west coastal area of Bangladesh

Salinity level	Village	Sub-district (District)	Farming system	Livelihood system	System response
High (>10 ppt)	Arpangasia	Shaymnagar (Satkhira)	Shrimp dominated some freshwater pockets access to rain-fed rice	Near mangrove forest	Worse-off depends on natural resources resulted in few ultra-poor households and rest heavily involved in aquatic animal farming
Medium (5-10 ppt)	Jaduardanga	Ashashuni (Satkhira)	Shrimp dominated	Far distance from the district headquarter,	Heavily dependent on aquatic animal farming, less alternative livelihood options
Low (<5 ppt)	Shuvna	Dumuria (Khulna)	Shrimp-prawn, rice and dyke crop	Close to the district town	Dependent on fish-rice-crop production and alternative livelihood options in nearer town
Freshwater (<0.5 ppt)	Chor-Borobaria	Chitalmari (Bagerhat)	Prawn-finfish, rice and dyke crop	Far distance from the district head quarter	Mostly dependent on fish-rice-crop production, less alternative livelihood options

3.6.2 SOCIOECONOMIC STATUS

Across the four communities key informants (KI's) had chosen indicators unanimously. The scoring from KI's for each household was found to be consistent. The residual is the difference between a single key informant and the average of three key informants. Although, there were differences between KI's (means) the variation within KI's was bigger (bigger standard deviation than mean of residual) than the difference between the KIs scoring was not mattered in practice (Appendix 8 Supplementary Table 3.1).

Results showed that overall, the majority of households in aquaculture communities were poor. Around 40% fall in the poor category, 15% in ultra-poor category; and the remaining 30% and 10% fall in the medium and rich category, respectively (Table 3.4). The proportion of ultra-poor group was higher in FW and the MS area compared to the other two areas.

Table 3.4 Allocation of households into different social well-being across the saline gradients of aquatic farming areas in S-W Bangladesh (Percent of the household are in parenthesis; data derived from KI's sessions and community census)

	Number of households (% of household)				
Salinity	Rich	Medium	Poor	Ultra-poor	Total
High	22 (8.06)	91 (33.33)	137 (50.18)	23 (8.42)	273
Medium	25 (12.14)	47 (22.82)	86 (41.75)	48 (23.3)	206
Low	39 (13.09)	114 (38.26)	119 (39.93)	26 (8.72)	298
Freshwater	41 (13.44)	70 (22.95)	122 (40)	72 (23.61)	305
Total					1082

The indicators and attributes for each category in the study areas are summarised in Table 3.5.

Table 3.5 Attributes of the main well-being indicators assigned by the key informants and adjusted through household census in the aquatic farming areas of S-W Bangladesh

Social well-being	Theme	Specific attributes	General attributes
Rich	Land	Owned large area of land (>1ha)	The rich were the local leaders, owner of big shops, fish depot, and *gher*. The rich hired permanent and seasonal labours more frequently than the other social groups. Higher educated segment of the community and had limited barrier to entry in a higher paid job.
	House type	Building, semi-building, tin-shade	
	Occupation	Community leader, service holder	
	Education	Secondary level to post-graduate	
	Aquatic farming	Farming in own land & leased-out	
Medium	Land	Own medium area of land (>0.42ha)	Households involved in farming, business, and medium paid service.
	House type	Semi-building, tin-shade, bamboo-tin	
	Occupation	Trader, school teacher, farmer	
	Education	Secondary up to post-graduate	
	Aquatic farming	Farming in own land	
Poor	Land	Own small area of land (>0.08ha)	The poor had a small piece of land for farming. Involved in small business within the village market including working in the fish depot and lower paid job.
	House type	Tin-shade, bamboo-tin, mud, straw-shade	
	Occupation	Farmer, shopkeeper	
	Education	Primary to secondary school level	
	Aquatic farming	Own land as well as leased-in	
Ultra-poor	Land	Own tiny area of land (>0.01 ha)	Possess only a small piece of land. They worked on the shrimp and prawn *gher*, rice land and in some extent sold their labour in the nearest district town. Some poorer were dependent on the nearest mangrove forest for natural resources (fish fry, mud crab, honey) collection.
	House type	Tin-shade, bamboo-tin, mud, straw-shade	
	Occupation	Selling labour, rickshaw/van puller, work in shop	
	Education	Mostly illiterate to primary level	
	Aquatic farming	Tiny owned and leased in.	

The distinctions between the four social groups were observed (Appendix 9 (SupplementaryTable 3.2)) however some indicators between the two close groups were shared. The attributes of both the medium and poor were overlapping with rich and poor, respectively to some extent.

3.6.3 PCA OUTCOMES FOR WEALTH INDEX

The factor weight for PC1 for each variable in the wealth index PCA is presented in Table 3.6.

Table 3.6 Factor weight for each variable of the first principle component of wealth index surveyed at household levels in aquatic farming areas of S-W Bangladesh

Rank	Wealth variables	Factor loading
1	Profession	0.88
2	House type	0.26
3	Total land holding area	0.21
4	Educational level of households	0.21
5	Source of drinking water	0.17
6	Net income (log base)	0.17
7	Stove type	0.09
8	Latrine type	0.04
9	Household area	0.002
10	Ratio of dependency for income	-0.0006

The first principle component explained 36% of the variance, similar to the findings of others in general socio-economic positions of households (Vyas & Kumaranayake, 2006). Profession had the highest factor weighting followed by house type, education level, and total land holding (Table 3.6). Net incomes also had an influence on wealth index at the household level. Households have a tendency to enhance their net income to cope with vulnerability. Only the ratio of dependency at household level was given a negative value (-0.006) indicating that a low number of dependents in relation to the main breadwinner was not correlated to greater wealth. A negative value in PCA is common, and it indicates the small negative value having a little influence on the determination of socio-economic position in the society. In the current study, a higher number of employed or self-employed household members was not always correlated with higher household income. It depends on the rank of the job and the salary paid for it. Poorer households with less educational and technical capacity tended to have low paid job, and inherently higher numbers of family members took part in the same job. However, in better-off households, a single person in a high paid job can give more economic return compared to worse-off. Therefore, the negative value of the ratio of dependency is not unlikely. Toufique and Turton (2003), noted that proper education and knowledge in the relevant issue could give success otherwise poor people cannot achieve progress. Both the education level and land holding area at household levels had a similar impact on the wealth index. Better-off household owned more land area and had higher educational levels than the worse-off segment of the community. Land holding and education level at household are positively correlated (Gerstter et al., 2011). Drinking water scarcity in higher saline areas was prominent (Abedin et al., 2014). The toilet facilities of the worse-off households were much poorer than those of the better-off. This is not surprising as about 60% of Bangladesh's population do not have suitable toilet facilities (Gregory et al., 2010). In most cases, better-off households were found to maintain quality sanitation, stove and drinking water facilities compared to worse-off.

The wealth index in the rich category was significantly ($P<0.05$) higher than the medium, the medium was higher than poor and ultra-poor. Only poor and ultra-poor were not significantly ($P>0.05$) different. In the case of comparing wealth index among the four saline gradients no significant differences were obtained ($P>0.05$) i.e. rich in the HS area were statistically similar to rich in FW area.

3.6.4 PCA FOR AQUACULTURE INDEX

Another PCA was executed to develop an aquaculture index for the household level. This PCA result helped to identify the comparable importance of aquaculture supporting household livelihood (Table 3.7). The first principle component explained 79% of the variance. The proportion of aquaculture income compared to total income having highest control on determining aquaculture index followed by the percent of *gher* area to total area. The underwater species combination had an influence on aquaculture index with a minimal impact from other factors including *gher* area, the number of *gher* and permanent labour. The dyke cropping was given negative value (-0.0015) indicating a very poor influence on the aquaculture scores. The higher saline area is dominated by shrimp farming along with other brackish water shrimp and finfish. The lower saline area is dominated by the concurrent culture of shrimp and prawn along with finfish, dyke crop, and rice.

Table 3.7 Factor weight for each variable of the first principle component of aquaculture index surveyed at household levels in aquatic farming areas of S-W Bangladesh

Rank	Aquaculture variables	Factor loading
1	% of aquaculture income to total income	0.80
2	% of *gher* area to total area	0.59
3	Aquatic species combination	0.018
4	Number of *ghers* operated	0.006
5	*Gher* area	0.005
6	Hired labour (permanent)	0.0002
7	Dyke and rice cropping	-0.0015

Unit, scoring, and details of each variable are described in Section 3.2.2 of this chapter

The aquaculture index among the social well-being group was not significantly ($P>0.05$) different across different salinities. It indicated that the access to aquaculture activities was not a barrier to the poorer segment of the community. Therefore, the poorer also can gain equally from participation in aquaculture as social position was not a barrier to entry. The aquaculture index among the saline locations were significantly ($P<0.05$) different (Figure 3.1). The higher aquaculture index in the MS area indicated that majority of the livelihood options were highly linked to the aquaculture activity followed by the HS, LS, and FW. This result indicated that lower saline areas were characterised by greater diversity of economic activities. The lower aquaculture index in the HS area than the MS area in the current study was due to the dedication of an elevated portion of the villages for rice cultivation in HS area. Moreover, the proximity to the Sundarbans mangrove forest opened up livelihood options based on the natural resource base for the poorer *i.e.* hunting ,fishing and collecting from the forest.

3.6.5 Relationship of aquaculture index to wealth index

The correlations in between two different indices were tested and the coefficient of correlation (R^2) was poorly correlated. The coefficient of correlation line among the agro-ecological settings are not significantly (P>0.05) differ to each other (Appendix 10 Table (Supplementary) 3.3).

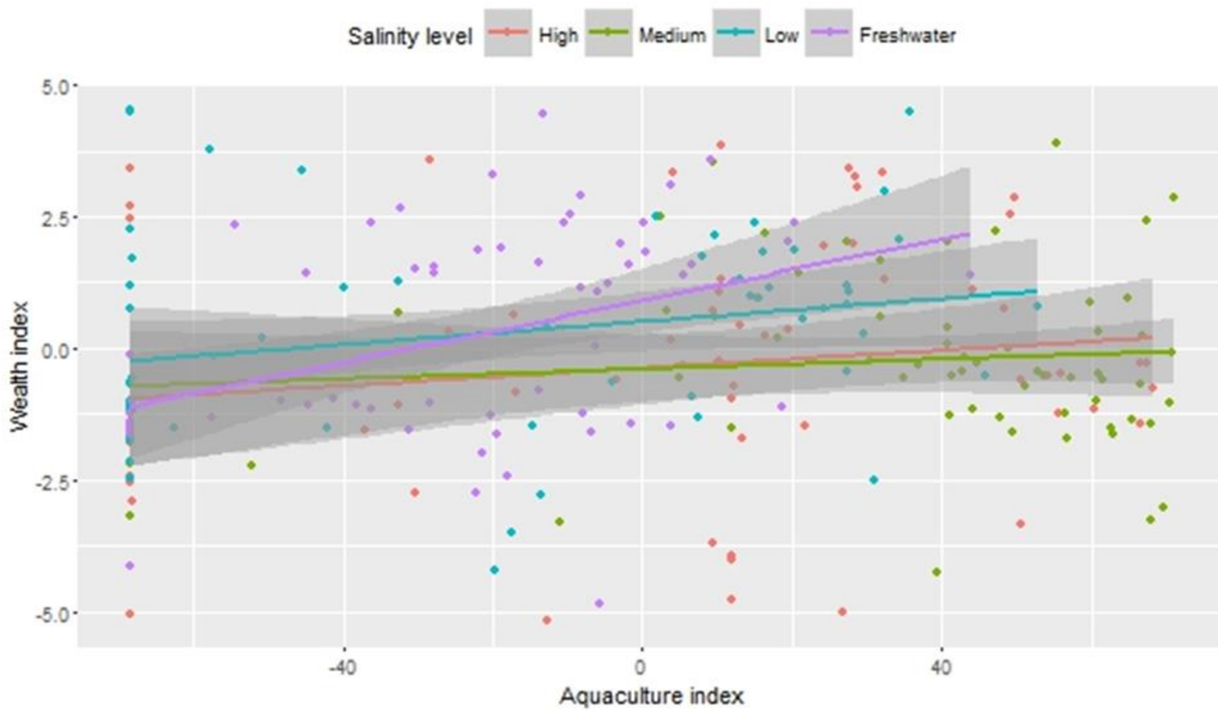


Figure 3.1 Relationship between aquaculture index and wealth index for each of the four saline areas in the aquatic farming system in south-west Bangladesh [Each data point represents a single household]

There are two competing (but non-exclusive) hypotheses for the positive correlation between the aquaculture index and the wealth index. Either it means that increasing involvement in aquaculture increases wealth, or that a lack of wealth is a barrier to involvement in aquaculture. In either case, the weak statistical relationship suggests that at a household level this is not a strong effect.

3.6.6 IMPACT OF AQUACULTURE INVOLVEMENT ON AQUACULTURE INDEX

To know the impact of long-time participation in aquaculture on the success of aquaculture venture a linear regression between aquaculture experiences years and the aquaculture index was run across the saline gradients (Figure 3.2). The coefficient of correlation in aquaculture index and aquaculture experience are strongly (R^2=0.47) correlated. The coefficient of correlation line among the agro-ecological settings were also significantly (P<0.05) differ to each other (Appendix 11 Table (Supplementary) 3.4). This model means that increased experience enhances the participation in aquaculture, implying that people can enter aquaculture with minimal capacity and tend to increase their involvement over time. This would suggest low barriers to entry and the opportunity to become involved with a minimum commitment to diversify livelihood options. Households could enter the industry at both high and low commitment levels, maintain this level and progress slowly.

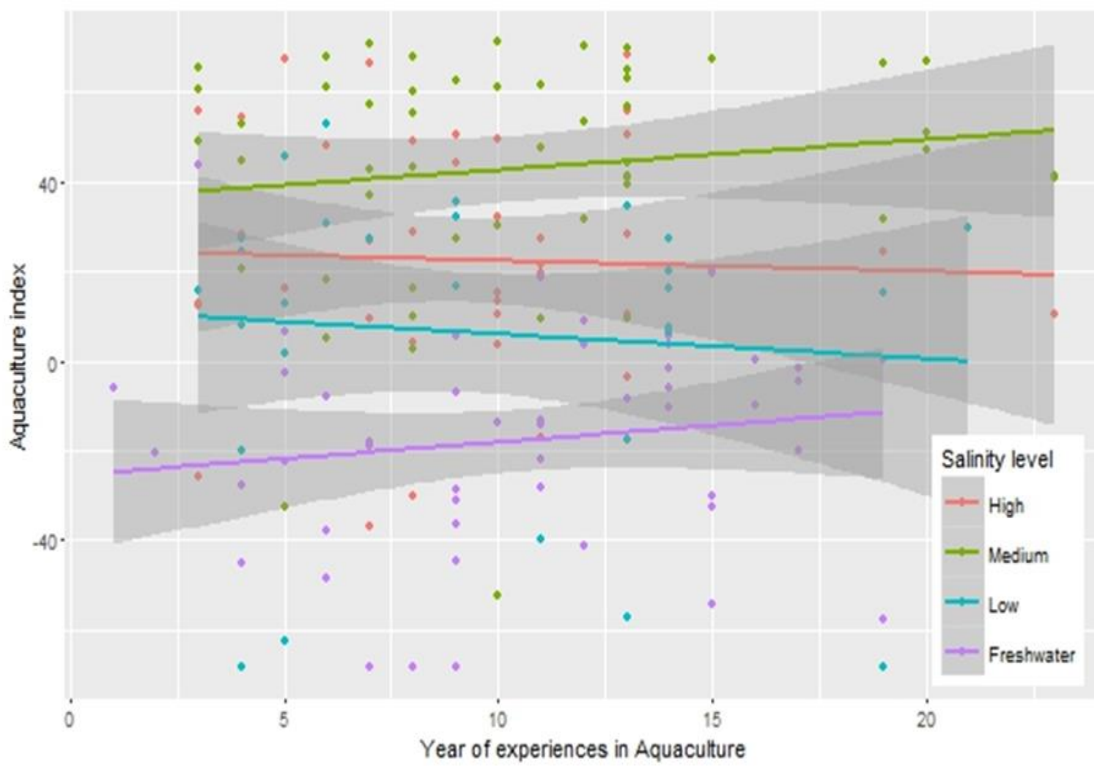


Figure 3.2 Correlation between involvement in aquaculture experience and aquaculture index for each of the four saline zones of aquatic farming system in south-west Bangladesh [Each data point is a single household]

3.6.7 IMPACT OF AQUACULTURE EXPERIENCES ON SOCIAL WELL-BEING POSITION

To see whether longer time involvement in aquaculture leads to greater asset-based wealth index a linear regression test were run between wealth index and years of experience in aquaculture across the saline gradients (Figure 3.3). The coefficient of correlation in wealth index and aquaculture experience were poorly (R^2=0.0006) correlated. The coefficient of correlation line among the agro-ecological settings were also not significantly (P>0.05) differ to each other (Appendix 12 Table (Supplementary) 3.5). These results indicate that the longer households are involved, the wealthier they are now. This weak positive correlation can be interpreted as that past involvement in aquaculture had enriched the household or that in the past it was only possible for the better-off households to enter into aquaculture i.e. that opportunities for participation in aquaculture by the poor have increasingly become more significant.

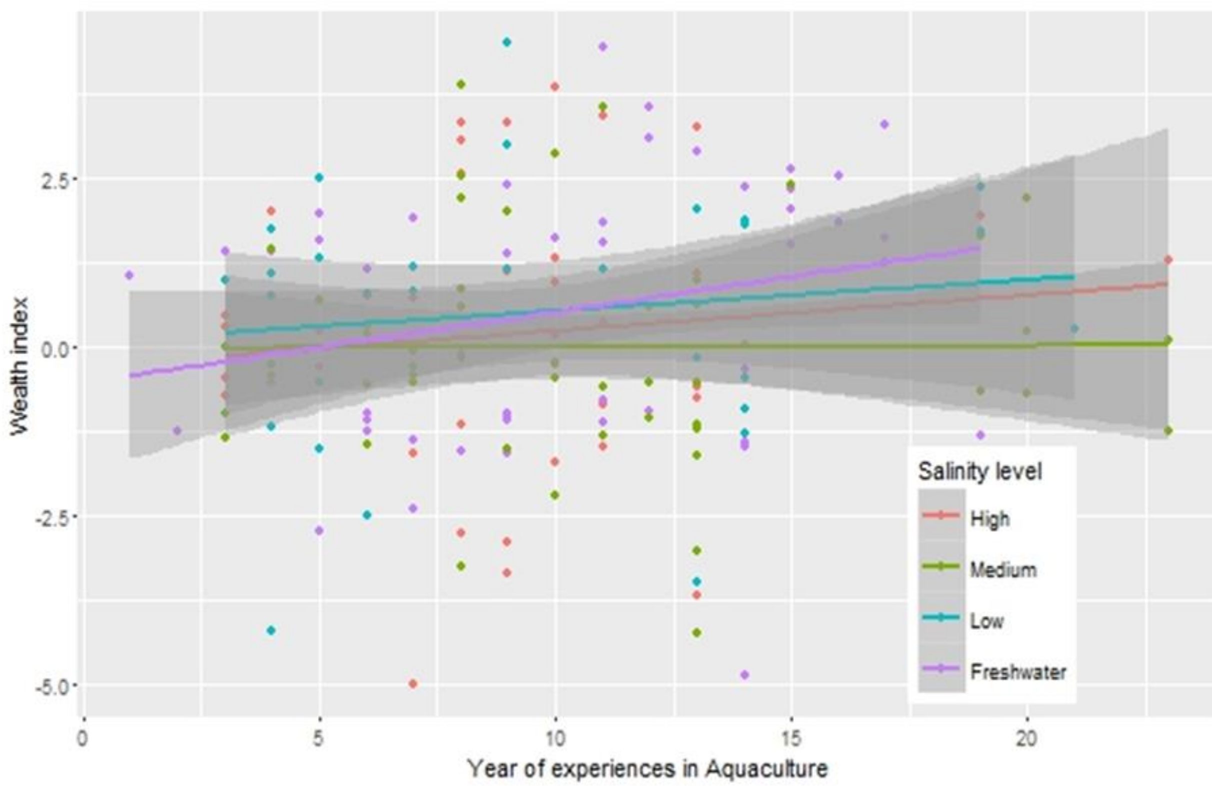


Figure 3.3 Relationship between involvement in aquaculture and wealth index for each of the four salinity areas in the aquatic farming system in south-west Bangladesh [Each data point represented a single household]

3.6.8 COMPARATIVE TOTAL *GHER* AREA ACROSS SALINE REGIME

Gher area is assigned as the area utilised for aquatic animal farming in the low-lying agricultural land. Better-off households were characterised by larger holdings followed by medium, poor and ultra-poor along the four saline agro-ecologies (Figure 3.4). Dyke structure in the higher saline areas were poorly constructed and in lower saline areas it was larger and elevated and appropriate for cropping. Among the four saline zones, total *gher* area was higher in the HS followed by MS, LS, and FW area. The proximity to mangrove, longer distance from the district town, and lower land prices pushed people to attain higher area of *gher* in HS zone compared to other agro-ecologies.

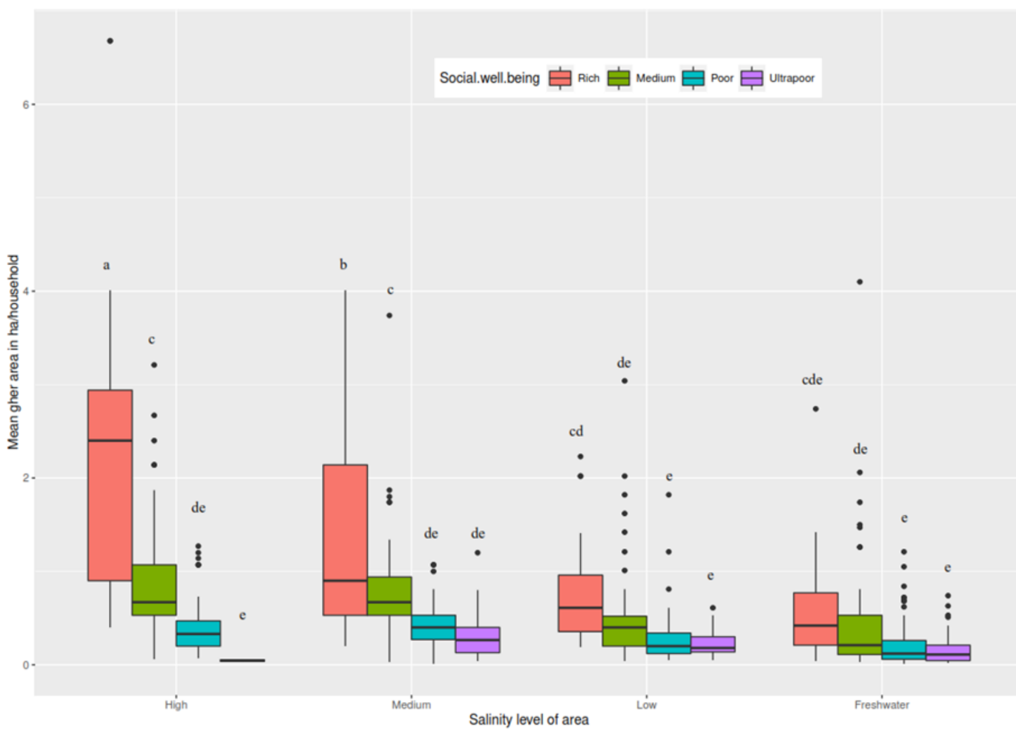


Figure 3.4 Distribution of *gher* area (ha) among the different social well-being group across the saline gradients in the aquatic farming system in south-west Bangladesh (n=1082) [The middle horizontal line that divided the box into two are the median, the upper and lower "hinges" correspond the 3rd and 1st quartile. The upper and lower whisker represents the maximum and minimum scores outside the middle, the separately plotted points in the chart is the outlier represents an individual sample. Different superscript letters above the whisker indicated significant difference (P<0.05) of *gher* area by ANOVA test]

3.6.9 ACCESS TO AQUATIC FARMING SYSTEM

At least 60% households along the saline gradient had access (owned/leased-in) to an aquatic farming system. The highest number was obtained in the MS area (above 80%) followed by FW (above 75%) and almost identical levels were observed (about 60%) in both HS and LS areas (Table 3.8). Surprisingly, a lower number of households were found to be involved in the HS area. This was probably due to the specific topography of the community; a portion of the HS village was dedicated to rainfed rice cultivation being elevated above the high tide level of nearby rivers and tributaries. Access to *ghers* among the different social well-being groups varied significantly. Most of the rich and medium households had access to a *gher*. It does not necessarily mean that being poor prevents access to *gher*.

Table 3.8 Access to *gher* in percent (n=1082) from different social well-being across the saline gradients of aquatic farming system in the south-west Bangladesh

Socio-economic position	Salinity level (no. of HH)			
	HS (273)	MS (206)	LS (298)	FW (305)
Rich	100% (22)	96% (25)	87.2% (39)	90% (41)
Medium	85.7% (91)	100% (47)	69.7% (114)	91.4% (70)
Poor	46% (137)	81.4% (86)	56.3% (119)	77% (122)
Ultra-poor	8.7% (23)	66.7% (48)	38.5% (26)	54.2% (72)

The impacts of owning or leasing *gher* land on level of both aquaculture and wealth index was assessed. The ownership of the *gher* were categorised into four categories owned, leased-in, mixed (owned and leased in/leased-out), and leased out. Among the four variables the subset data on purely (not mixed) owned and purely leased-in households were selected. In these two variables, owned (129 households) and leased-in (15 households) were considered for the test (Figure 3.5). There was no significant ($P>0.05$) differences between gaining wealth and aquaculture score both in own and leased-in farmers (Figure 3.5) (Appendix 13 Supplementary Table 3.6). In the present study multi-ownership by an individual household were higher in the freshwater area compared to other agro-ecological areas. Multi *gher* access was more common in the FW area (30% households) followed by MS (18%), LS (15%) and HS (12%).

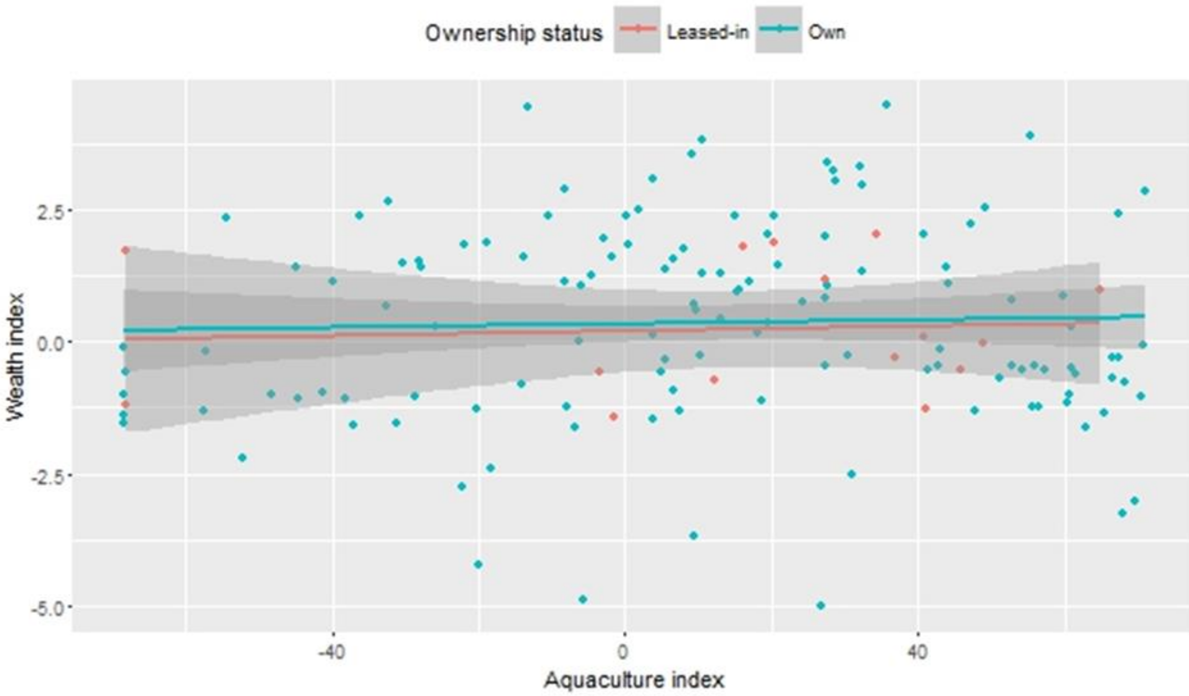


Figure 3.5 Correlation between wealth index and aquaculture index (x-axis) in between own and leased-in farmers in aquatic farming system in south-west Bangladesh [Each data point is a single household]

3.6.10 INEQUALITY OF LAND AND INCOME DISTRIBUTION

The total land area custody by individual household differed significantly ($P<0.05$) across the agro-ecologies. Total land holdings inequalities were relatively higher in both FW and HS compared to MS and LS area (Table 3.9). The overall Gini value for land holding was above 0.45. The overall income Gini value ranged from 0.26~0.29 (Table 3.9) across agroecology. Abdullah et al. (2016) also obtained similar findings (0.27) in a village next to the Sundarbans of Khulna District. Only 11% of the households owned more than 50% *gher* area across the four different saline gradients.

Table 3.9 Gini-coefficients of land holding area at different saline gradients of aquatic farming systems in south-west Bangladesh

Salinity level	Total land holding	Income
High	0.54	0.28
Medium	0.45	0.26
Low	0.45	0.29
Freshwater (FW)	0.54	0.27

Household income is defined as the return on family labour, plus those assets owned after the current cost of production was excluded from the gross value of production. In the present study the major costs incurred were for input purchase, labour hire, education, medical, clothes and *gher* leases. Agricultural income was divided into two categories aquaculture and agricultural (livestock, rice and dyke crop). Service, trading, labour and natural resource exploitation were also a vital source of household income.

3.6.11 LIVELIHOOD OPTIONS

The livelihood options of the household members were obtained from community census and in-depth household survey (Section 3.2.2). In the occupational set, a wide variety of professions (Table 3.10) from high ranked government officer to natural resource dependent collectors and harvesters were obtained in the region. There was a strong trend to be involved in aquaculture across the saline gradients. In general, worse-off households were most proactive. Although the opportunities for work for the poorer are unstable and often highly seasonal. Better-off households inherited land and business assets and were properly educated allowing them to gain better positions and controlling power over others in the community. Involvements in aquaculture activities were found as a stable option though the shrimp yield fluctuates. The high saline area close to the mangrove forest Sundarbans provided few extra options for poorer household income. Livelihood options like *Mowali* (honey collector), *Bawali* (tree leaves collector), fish and mud crab catcher are common in this area among the poorer. In most the cases services for these activities such as fish catching boat, net and licenses were managed by the richer people who extracted a proportion of the value from the poor dependent on such activities. In the LS area, ultra-poor household's had the option to sell their labour, often as rickshaw pullers in nearby Khulna city. In MS and FW area poor people struggled most to find alternative livelihood options as they are far from both natural resources and city amenities. The infrastructural development and communication facilities affect the livelihood of the people living in MS and FW area.

Table 3.10 Options for the practical activities in the aquatic farming system in south-west Bangladesh

Natural resource-dependent	Non-natural resource dependent
Collection (forest, aquatic resources)	High-rank job (teacher, officer)
Fishing	Trade and business
Fry catching (shrimp PL, crablings)	Aquaculture labour, small business
Aquaculture (extensive)	Small shop, lower level jobs
Agriculture (rainfall, freshwater)	Rickshaw/van puller
Dyke cropping (rainfall, freshwater)	Skilled labour (carpenters, painter, sculpture)

3.7 DISCUSSION

The results presented in this chapter confirmed that participation of worse-off household’s in aquatic animal production was substantial. Diversified livelihood options were also highly linked to aquaculture activity. The contribution of both shrimp and prawn farming equally impacted on gaining asset-based wealth index. The aquaculture intensity was linked to water salinity. The higher the water salinity, the higher the dependency on aquaculture activities. The ownership status of the land did not influence either wealth or aquaculture index. The access of the poorer to farming systems is dependent on the risk-absorbing capacity and willpower. Though the land holding was given the highest factor loading in PCA analysis, other factors like infrastructure, access to natural resources and participation in aquaculture value chain were influenced by livelihood choices. The main influential variables that stimulated livelihoods are discussed in more detail in the following sections.

3.7.1 LAND HOLDING DISPARITY

Land holding area was considered as an important indicator of social position and household livelihood. The farmer's landholding is the most important indicator of social well-being in rural Bangladesh (Gurung et al., 2016). The land holding area decreased from higher saline to lower saline areas. This is due to the proximity of higher saline areas to the mangrove forest and far from the district town amenities. According to local observers, both land and land rental price were lower in the higher saline areas but dependent on the rural infrastructure. The susceptibility to natural calamity like Cyclone, salinity intrusions, and poor infrastructure limit the population pressure in the high saline area. The land use pattern in S-W coastal area of Bangladesh can be largely related to the level of salinity. Almost similar trend of land distribution across the saline zones was also observed by Ahmed (2013a). The land holding pattern among different social well-being groups was similar to other parts of Bangladesh where poorer households owned smaller portions of land than the better-off households (Toufique & Turton, 2003). In the current study the social position was allocated through the census, and PRA exercise and higher land holding was one of the main criteria of social well-being.

The functional landless in the current study is close to the national figure of the country (60%) (Magnani et al., 2015). In the Bangladesh context the functionally landless means households owning at least 50 decimal (0.2 ha) of land (Hossain et al., 2007). This is due to half of the community land being occupied by only 10% households of the community (Magnani et al., 2015). The squeezing of land ownership towards the richer households has continued as in 1980’s it was 15% households who occupied more than half of the community land (van Roosmalen & Guimares, 1982). The general tendency of land holding by the better-off was common elsewhere in Bangladesh where a substantial amount of land was owned by the larger landowners (Guimarães, 1989). The higher Gini value on the land holding in the current study was also indicative of land distribution disparity. However, the Gini value was within the range of agrarian land inequality (0.37-0.92) determined by Carter (2000). The income disparity was also shown to be of lesser disparity compared to the land holding. The income Gini value is close to the range proposed by Deininger and Olinto (2000) in 62 countries (Carter, 2000). The minimum disparity on income (Table 3.9) indicated that land holding is discrete to household income.

3.7.2 IS LAND HOLDING VITAL FOR LIVELIHOODS?

The direct involvement in aquaculture in the current piece of work was above 70% of community households. Belton and his colleagues also obtained similar proportion in the same study area (Belton et al., 2014). The involvement of better-off is higher than the worse-off households. However, the number was significant especially in MS and FW areas where alternative livelihood options were limited. The involvement of poorer people in aquaculture was not as common two decades ago. The landless were excluded from renting land for agriculture and aquaculture activities in the region. The poorer households had to have land, draft animals and agricultural tools to get access to land (Guimarães, 1989). Formal land property rights were required for access to credit in many developing countries (De Soto, 2000). In Thailand, farmers with the land titles are more likely to obtain credit compared to non-occupied land owner (Feder et al., 1988). In East Laguna, Brazil, agricultural initiatives and investment benefited the poor with access to land. Therefore, development interventionists are increasingly focused on redistribution of rural resources. The concept of agrarian sovereignty was the basis for re-distribution for *Khas* land to the poorer households in Bangladesh. This concept aims to bring greater equality in agrarian class relation and provide the self-determination power of agricultural production to landless and marginalised people (Paprocki & Cons, 2014). However, some commentators warned that equal land distribution would not be feasible if nonfarming activities provide higher turnover than farming (Breman & Wiradi, 2002 p.232). Some observers believed the actual solution of rural poverty alleviation is not in the agricultural production, especially as day by day livelihoods and poverty have become increasingly detached from land and even from farming (Rigg, 2006). This idea was backed by Griffin et al. (2002). They argued that land/resource redistribution is not the key solution for rural poverty for two distinct reasons. Firstly, land titles are not the main key to progress, and secondly, redistribution only may provide land title to the landless which mean itself be unproductive and unsustainable. Some scholars opposed De Soto's suppositions of formal property rights and it is evident in many places (Galiani & Schargrodsky, 2010).

Some commentators noted that in general shrimp farming is linked to high investment, and access to shrimp farming is not equal to all (EJF, 2003; Van Hue & Scott, 2008). On some occasions, for the community people, the costs of leases can be beyond their limit (Latorre, 2014). The current study demonstrated that in contemporary Bangladesh, shrimp and prawn farming does not require, as a pre-requisite, land title and agricultural instruments as described by Guimarães, (1989). In the agricultural sector as a whole in Bangladesh, sharecropping has increased many folds, to an estimated 40% of total farmers (Thomas et al., 2013). In contrast, for shrimp and prawn farming, the sharecropping system has transformed to fixed cash rents (lease) dominated arrangements, and this study found this trend was comparatively higher in more saline areas than lower saline areas.

Rural people involved in activities like embankment construction, water exchange, guarding and harvesting can benefit from shrimp farming. A reliance on manual labour persists and there is little requirement for sophisticated technical knowledge for most aquaculture activities. The willingness and capacity to become involved in aquaculture is vital (Krause et al., 2015). This is like the sub-Saharan Africa case where property titling does not influence investment (Brasselle et al., 2002). In this piece of work four types of ownership, categories were obtained own, leased-in, leased-out and mixed (own and leased-in/out). Alauddin and Hamid (1998), obtained a similar pattern in the same area. In this piece of work the participation in shrimp and prawn farming from outside the community were absent. This result supports the findings of Alam (2014), who found about 80% shrimp and prawn farmers in greater Khulna region were from inside the community. However, financial capacity and mobilisation of capital are crucial to getting sustainable development (Thulstrup, 2015). Investment for *gher* development and farming is required to acquire higher profits and mostly better-off farmers can afford this (Islam et al., 2015). Apart from non-formal credit sources; friend and family, many formal credit providers exist to provide a substantial amount of money for aquaculture including shrimp and prawn farming (Jahan et al., 2015). A non-formal credit (locally called *dadon*) system exists in S-W Bangladesh where wholesalers (shrimp and prawn traders) lend money to farmers in advance based on verbal agreement. In this case, the money lender does not charge interest but product sales are tied through the lender (Guimarães, 1989).

Landholding is not always a perfect indicator of food and nutrition security (Rammohan & Pritchard, 2014). In Bangladesh, economic and infrastructure development increasingly transform the rural landscapes and livelihood options. Many have limited options to land and increasingly engage in the non-agricultural sector. Most of the poor utilise their labour- a strong pair of hands is crucial for their livelihood options. Indeed, a pair of hands, not land, is crucial for livelihoods in the new world (Toufique & Turton, 2003).

3.7.3 OPTIONS FOR THE POOR

The south-west coastal area of Bangladesh is considered as the one of the poorest regions of the country with higher malnutrition and food insecurity (HKI, 2011). Most of the farmers were found to cultivate their land. Better-off households tend to rent their land mostly to the poorer households. The richer households produce sufficient food and farm income securing food security and livelihood throughout the year (Gurung et al., 2016). This is due to the better-off having a higher land area that is not easy to manage by the family members as most of their children are engaged in education rather than working. Gerstter et al. (2011) obtained a significant positive correlation between holding land and level of education at household.

The poorer households' ratio of dependency (Table 3.1) is higher indicated that more family members are in the work force. Sometimes the better-off are engaged in other professions and had minimum time to invest in aquaculture allowing them to rent out their land. Disease occurrence and distance of the *gher* from the household were also reasons to rent out land. The leasing system was more prominent in the higher saline areas than the lower saline. This study also indicated that shrimp based systems opened up more options for the marginal people to rent land for aquaculture. In this study, none of the farmers were found to be from outside the community. The participation of the outsiders have faded over time; Barraclough & Finger-Stich (1996) noted two-thirds of total farmers in Satkhira in the 1990s were 'outsiders'(a person/persons unconnected to the community and enter for farming) and Alam (2014) obtained reverse scenario in 2014 in greater Khulna region. It is widely stated that shrimp farming brought the entrepreneurs from outside the community and denied the access of local community people (Delwalt et al., 1996; Neiland et al., 2001; Shiva, 1995; Stonich & Bailey, 2000,). Such involvement of outsiders broke social cohesion in shrimp growing areas of Bangladesh, India (Murthy, 1997). These conflicts might be linked to the relatively intensive culture system introduced by outsiders and the early stage of shrimp and prawn farming in Bangladesh. In a study in India which is close to the Bangladesh, Sundarbans area revealed that extensive shrimp farming brought less social conflict (Knowler et al., 2009). Moreover, in the surveyed area most of the aquaculture was low input and output system, where outsider's involvement would not be feasible. Nevertheless, it is not an easy task for the outsiders to buy land as the locals have cultural and historical ties to their land.

It is noted that export-oriented shrimp and prawn farming reduced traditional livelihood options, reduced food security and create unemployment (Hossain et al., 2013). In the current study the direct participation of worse-off households in aquatic animal farming is substantially high (Table 3.8). However, the other livelihood options created in the region are mostly linked to aquaculture activities (Table 3.10). Some of the farmers combined agricultural and non-agricultural activities to sustain their livelihoods. A similar type of combination by most households was observed in aquaculture community in Laos PDR (e.g. Martin & Lorenzen, 2016). It is seen as the sensible strategy adopted by the pro-active and better-off households (Cinner et al., 2010). Better-off households considered non-agricultural activity (like a job if they have) as the primary occupation and aquaculture as supplementary. Non-agricultural activities reduced vulnerability to poverty and provided a form of insurance to households against the risk of farming and a dependency on natural resources (Rigg, 2006). In contrast, the worse-off considered aquaculture as their main earning source and selling their labour in other work as lower category job (Table 3.2). From the wide range of livelihood options created by the shrimp and prawn farming sector, rural households including small, marginal and even landless poor have benefited (Ahmed et al., 2010). These varieties of options including marketing of seeds (PL and fry), feed, shrimp, prawn, reduced the migration of coastal poor (Ahmed, 2013a). Poorer households are mostly involved in the value chain of shrimp prawn farming (Ahmed & Garnett, 2011). The marketing channels of shrimp and prawn potentially provide livelihood opportunities to thousands of people (Pokrant & Reeves, 2003). Male labourers are mainly engaged in transporting, handling, cleaning, sorting, grading and icing activities at market level. While a significant number of women are involved in cleaning, beheading, processing shrimp and prawn in the processing plant and urban depot (Islam, 2008). Womens' participation in the shrimp and prawn farming value chain is an indicator of women empowerment both at family and social level (Islam, 2008), leading to reduction of domestic violence and establishment of social equity as was revealed in a study in Guyana (UNDP, 2010). After successful expansion of prawn-rice farming, it was evident that some marginal and landless became the owner of a small piece of land. In the S-W area of Bangladesh population, poverty has reduced by 17% (Hossain et al., 2016). Both examples indicated the progress of socio-economic conditions through adoption of integrated culture systems (Barmon et al., 2005) along with other influences like remittances and rural infrastructural development. The participation of landless and marginal farmers in rice-prawn farming is one of the main reasons for its rapid expansion in the region (Barmon et al., 2005).

Johnson et al. (2016) noted that shrimp farming is not suitable to adopt in poor and marginalised area. Nevertheless, aquaculture improves the livelihood of everyone in society. Poor farmers require access to improved technology and credit (Gurung et al., 2016). Overall coastal shrimp and prawn farming have positive impacts on social and economic sustainability (Ahmed & Garnett, 2011). The participation of the ultra-poor segment in aquaculture in the high saline area was low compared to other areas (Table 3.9). This is due to the presence of mangrove forest Sundarbans which opened up opportunities to extract natural resource and mostly linked to the aquaculture activities like shrimp PL and mangrove fish fry and crablings collection (Table 3.10). Poor households have a high dependence on mangrove forest resources (Abdullah et al., 2016).

The infrastructural facilities and proximity to the big city Khulna also opened up options for the poorer in the LS area through the sale of their labour. Poorer in the LS were also sold labour, pulled *rickshaw* and engaged in non-agricultural city based activities. The more intensive aquaculture and integration agriculture system created more option for the poorer to involve in the value chain. For example, lower saline areas aquaculture is intensive and recruited more labour than higher saline areas (Belton et al., 2014). These findings indicated that the agro-ecological settings, farming pattern, rural infrastructure and the proximity to the natural resources have influences on livelihood options. The ultra-poor households in the MS and FW area are more vulnerable and had lower alternatives. In the MS area, disease occurrence in shrimp is the major threat to gain aquaculture return. Higher salinity also hinders integration of the system with rice and dyke crop. In the FW area, the system required higher investment which is sometimes beyond the capacity of the poorer household.

Nevertheless, the involvement in aquaculture activities enhanced the well-being status of the poorer (Belton et al., 2014). Small-holders can get more yields per unit area compared to the better-off. This happens due to the high level of commitment of small-holder to production (Boselie et al., 2003). The contribution of aquaculture to poverty alleviation is context-specific. If the target of aquaculture development is to reduce poverty then labour, intensive technology should implement. The use of yield increasing inputs in aquaculture should minimise for sustainable livelihoods (Stevenson & Irz, 2009).

3.8 CONCLUSION

The findings of this chapter have shown that the livelihoods of the majority of households in shrimp/prawn producing communities in S-W Bangladesh are linked to the aquatic farming system irrespective of social well-being group. The livelihood options across the saline gradients differed, but were widely linked to aquaculture value chain. The land ownership is not the only important variable to gain success. Higher educational level, higher paid job, inherited land ownership and long experience in aquaculture put the better-off in the upper tier of the socio-economic position in the community. The options for the poorer to be involved in farming were common across the saline gradients. This would suggest low barriers to entry and the opportunity to become involved with a minimal commitment to diversify livelihood options. Therefore, social well-being group is not an obstacle to getting an entry to the aquaculture activities. The overall mixed scenarios call for creating multiple options for the poor, accelerating education programme and enhancing technological advancements. In details, aquatic animal production system and household level food and nutritional study in the next chapters will allow the understanding of the actual role of aquatic animal production systems on people's standard of living.

4 CHAPTER 4: COMPARATIVE STUDY OF AQUATIC FARMING SYSTEMS ACROSS DIFFERENT AGRO-ECOLOGICAL LANDSCAPES IN SOUTH-WEST BANGLADESH

4.1 INTRODUCTION

Aquaculture has been recognised as an important opportunity to enhance household nutritional security in many developing countries. In Bangladesh fisheries and aquaculture contribute 3.3 million tonnes of fish production and provide an estimated 60% of animal protein (DoF, 2014). Aquatic farming systems based on exported-oriented shrimp (*Penaeus monodon*) and prawn (*Macrobrachium rosenbergii*) have emerged as one of the vital aquaculture technologies to supply food and support local livelihoods (Jahan et al., 2015). High growth rates and lucrative profits attract both national and international organisations to invest in shrimp sectors around the world. Due to its high value shrimp and prawn are locally known as 'white gold' in Bangladesh (Islam, 2008). About 80% of the shrimp and prawn farming is confined to the south-west (S-W) coastal Bangladesh, on the northern edge of the mangrove forest, the Sundarbans. The estimated aquatic animal (of which, the main value crop is shrimp and prawn), farming area, is 275232 ha, which covers nearly 35% area of total inland water body of Bangladesh. Aquatic animals in these areas are farmed in low-input/output systems relying on a mix of natural and supplementary feeds and fertilisers, and are based on wild and hatchery produced juveniles. These low input-output farming systems provide average aquatic animal yields of around 0.7 tonne/ha/year (DoF, 2015). The yield covers a broad range of naturally recruited and stocked aquatic species, both from the freshwater and brackish water environments, alongside the primary tiger shrimp and freshwater prawn species. Mangroves support fishery products in three distinct ways (1) organic detritus originating from mangroves provides food for the juvenile shrimp and fish in off-shore areas (2) numerous freshwater rivers and canals are passing through mangroves also carry terrestrial run-off which supports off-shore fisheries. (3) the mangrove itself serves as a nursery ground for juvenile fish and shrimp (Islam & Haque, 2004). The rich biodiversity of fish in the Sundarbans supports around 400 fish species in contrast to a total of 260 freshwater and 342 marine species in Bangladesh (Islam & Haque, 2004). High feed availability, low predation and the complex structure of mangroves result in high productivity (Robertson & Blaber, 1992). Organic materials and nutrients from mangroves are exported to the adjacent open water channels or directly to the inland aquaculture systems enhancing primary productivity (Islam & Haque 2004). Wild larvae and juveniles of shellfish and finfish are believed to constitute the main contribution of mangroves to coastal aquaculture. Wild seed, are introduced to the farm system, either directly through tidal flush or as juveniles caught by fishermen/women before stocking in the *gher* (Islam & Wahab, 2005). Mangroves not only provide nutrients and seed but also help to maintain water quality (such as DO, pH) balance and bind nitrates, which prevents pollutants such as that observed in the silvofishery system in Indonesia (Purwiyanto & Agustriani, 2014). In traditional *gher* farming in India, it was revealed that a huge number of shrimp PLs (Post larvae) and juvenile fish are recruited through tidal water, supported by artificial stocking (Biswas et al., 2012). In Bangladesh, mangrove fish maintain the diversity of *gher* aquaculture (Islam & Haque, 2004). In rice based aquatic farming systems, crustaceans and fish play the vital role of providing wild foods (Halwart et al., 2006). Along with the indigenous species, some alien species like tilapias are increasingly playing a role in Bangladesh. Tilapia culture has expanded rapidly in a wide range of farming environments from extensive to intensive, in both fresh and brackish water, in Bangladesh (Hussain et al., 2013). The incorporation of tilapia in polyculture systems in Bangladesh has remained underdeveloped compared to other Asian countries (Little & Bunting, 2005). Tilapia has emerged in the *gher* system, in the higher saline area of S-W coastal Bangladesh, along with other indigenous species. Tilapia has a long history of farming in Bangladesh (Alam et al., 2012). The Mozambique tilapia (*O. mosambicus*) and Nile tilapia (*O. niloticus*) are commonly available. However, the Nile strain is superior in growth and widely accepted for farming. Due to the higher demand for excellent growth, GIFT (Genetically Improved Farmed Tilapia) have dominated since the 2000s (Hussain et al., 2013). Farming tilapia with the other indigenous species may lead to competition for space and other inputs when resources are limited (Ahmad et al., 2010). Tilapia dominant polyculture provides higher yields when receiving a higher amount of fertilisation (Hossain et al., 2003). Semi-intensive aquaculture systems have mostly used agricultural ingredients like mustard oil cake and rice bran as supplementary feeds. Whereas, intensive systems rely on formulated, pelleted feed (Jahan et al., 2015). Despite the potential of rice-fish farming in 2-3 million ha area in Bangladesh, very little is known about the social, economic and policy dimensions of this system. Concurrent rice-fish, alternative rice-fish and collective management systems in Bangladesh can provide sustainable yields and economic returns (Dey et al., 2013). The benefit of polyculture of shrimp and prawn systems are well documented and economically viable for the farmers (FRSS, 2014; Islam & Wahab, 2005). To overcome the environmental impact of aquaculture in coastal zones, Primavera (2006), argued strongly for polyculture and integration of rice-fish culture, along with other measures.

Aquaculture farmers in Bangladesh rely on both formal and informal sources of credit. Banks, NGOs, relatives, neighbours and businessmen are the main sources of credit. The interest rate varied from 10-48% per year. In *gher* based aquaculture system wholesalers provided loans to the farmers and the repayment is both in kind and in cash (Jahan et al., 2015). Disease occurrences, poor water management, and post-harvest management have remained major challenges, along with the lack of quality seed and feed, in shrimp and prawn farming systems (DoF, 2013).

Moreover, the yield of aquaculture systems differs according to location, supply, and market demand. The understanding of the role of integrated dyke crop and aquaculture on the livelihood of the better-off and worse-off segments of the community is lacking in Bangladesh (Karim et al., 2011).

In this Chapter, *gher* systems are characterised and defined based on the level of inputs (seed, feed, and fertiliser) and outputs (aquatic animal, dyke vegetables, and rice) through the salinity gradients. The total yield of export items; locally traded fish, vegetables and rice, are compared regarding yield and level of intensification, in relation to agro-ecological settings. Farming practice and outcomes, related to farming by households of different social well-being groups (better-off, worse-off) were assessed. The objective of this Chapter was to quantify the input and outputs of shrimp and prawn farming across the saline gradients, and social well-being groups and its impact on their livelihoods. The specific research questions are described below.

a) How does farming intensity, species combination and management vary across the salinity gradient, and among farmers of different social well-being groups?
b) What is the importance of exported cash crops compared to those contributing to local food supplies?

4.2 MATERIALS AND METHODS

The salinity regime across the aquatic farming system in the S-W coastal Bangladesh are varied and divided into high (HS), medium (MS), low saline (LS) and freshwater (FW) area. The four communities were purposefully selected from these four saline zones, according to specific site characteristics (Figure 2.7) and the salinity regime described in Section 2.4 Chapter 2. In some cases, both high and medium saline clustered as higher saline and low saline and freshwater as lower saline area. For this study, 160 farming household from the four saline gradients (40 at each site to give equal numbers from each social well-being group) were randomly sampled. On the basis of fish type (shellfish or finfish) and their habitat (mangrove or freshwater) aquatic animals were classified into four major groups: (1) shellfish, (2) mangrove fish (3) freshwater fish and (4) tilapia. Tilapia is a freshwater self-recruiting species (SRS), however, kept separate to understand its role in the *gher* based aquaculture in S-W Bangladesh. The research design is shown in Table 4.1.

Table 4.1 Research design on aquatic animal production system in S-W Bangladesh

Item	Salinity level			
	High (HS)	Medium (MS)	Low (LS)	FW
Total household	268	206	305	299
No. of *gher* surveyed				
Better-off	20	20	20	20
Worse-off	20	20	20	20
Major aquatic animals	Shrimp-fish	Shrimp-fish	Shrimp-prawn-fish	Prawn-fish
Major fish type	Shellfish, mangrove fish, and Tilapia	Shellfish, mangrove fish, and Tilapia	Shellfish, mangrove fish, and FW fish	Shellfish and FW fish
Terrestrial crops	-	-	Rice-Vegetable	Rice-Vegetable

Fertilisers utilised in *gher* were converted to nitrogen and phosphorus content from a standard source (CTAHR, 2016). During the calculation of *gher* input and output zero figure were ignored as the results wre presented per unit area with the frequencies. All the analysed data, graphical presentation of data have been customised from the statistical package program R (R Core Team, 2016).

4.3 RESULTS

4.3.1 INDIVIDUAL *GHER* SIZE

The individual *gher* size declined gradually from higher saline to lower saline areas (Figure 4.1). *Gher* size (mean±SD) in the HS area (0.59±0.3ha) was significantly (P<0.05) higher than LS and FW area, however, not significantly different to the MS area. MS *gher* area (0.53±0.3ha) was significantly (P<0.05) higher than FW, however, not significantly different to the LS area. *Gher* size both in LS (0.40±0.2ha) and FW (0.31±0.2ha) area was found same (P>0.05). In between the two social well-being groups, better-off (0.56±0.3ha) was significantly (P<0.05) greater than the worse-off (0.37±0.2ha) households. The *gher* size among the worse-off households across the saline gradients is not significantly (P>0.05) different. However, the better-off households *gher* size strongly decreased from higher to lower saline areas (Figure 4.1).

4.3.2 *GHER* PREPARATION

Gher in the higher saline areas (HS and MS) are dedicated mostly to aquatic animal production, whereas in the lower saline areas (LS and FW area) aquatic animals tend to be integrated with rice and dyke vegetables. In all four sites, final harvesting of the aquatic animals took place after drainage in December. After harvesting, farmers started to prepare *gher,* through drying, dyke management, fertilisation, and the introduction of tidal water. Stocking of shrimp PLs begins in January-February onwards. Wild mangrove finfish are naturally recruited into the *gher* through tidal flushing and also stocked as wild caught fingerlings by the farmers. During the onset of monsoon rain (July), some farmers also stocked low-saline-tolerant fish like tilapia and a tiny amount of freshwater species, depending on the *gher* water salinity (Figure 4.2). In the lower saline areas, integration of aquatic animal with rice-dyke-vegetables are practised concurrently and alternately. The well-structured dyke and deeper canal, to the periphery of the plot, provided unique structure for integration of aquatic and terrestrial agricultural components. It has been found that the farmers are running year-round fish, dyke vegetables and rice cultivation in the region. In the LS farmers produce both shrimp and prawn concurrently, with the integration of other aquatic animals, rice, and dyke crops.

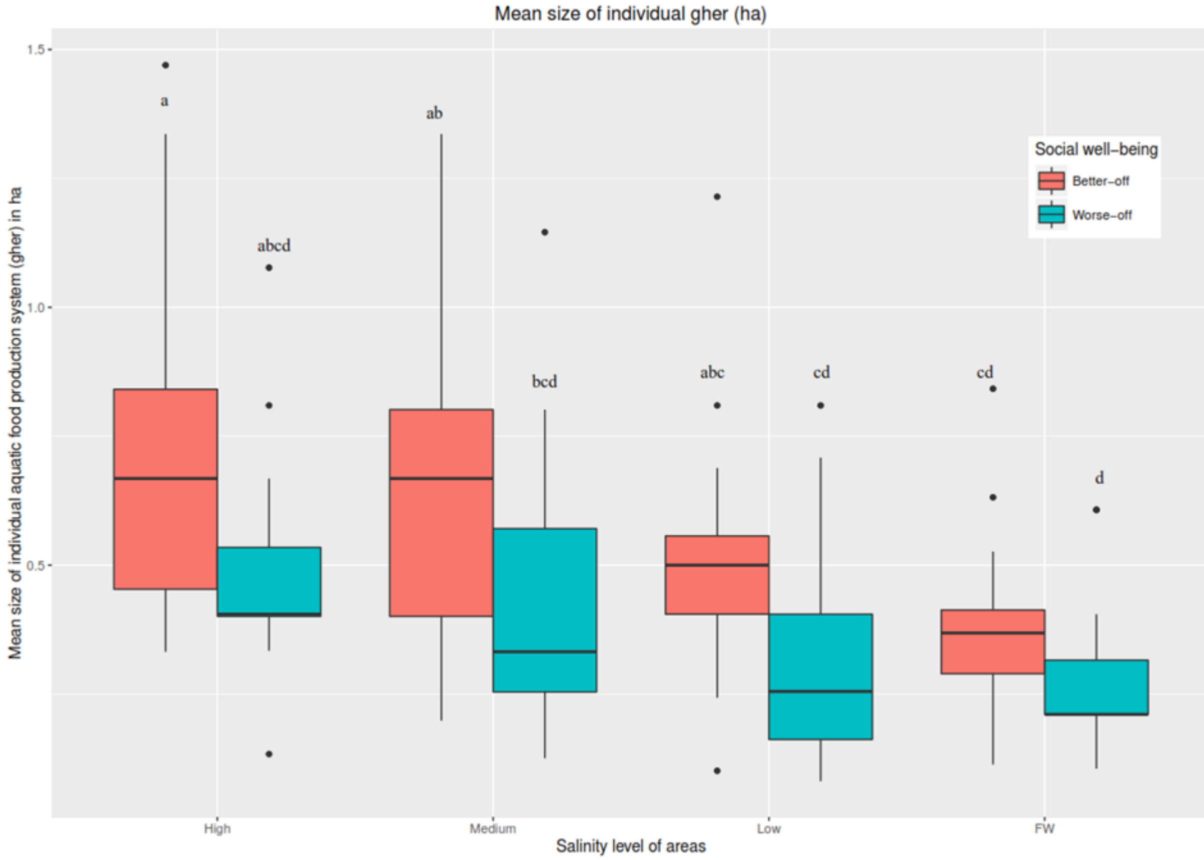


Figure 4.1 Individual *gher* size (ha) across the saline gradients and social well-being in the aquatic farming areas in S-W Bangladesh [Different letter above the each whisker indicated significant differences among the saline areas and social well-being (P<0.05)]

Shrimp is cultured in the earlier phase of the year (February-May) when water salinity remains higher. In the later part, prawn is added along with mangrove and freshwater fish species. In the lower saline areas, as the culture season is short (5-6 months), farmers used the overwintered freshwater fish fingerlings (average weight 25-30 g) to get the average size fish for consumption within the peak culture season (July-December).

4.3.3 STOCKING OF AQUATIC ANIMALS

The stocking density (in number) in the aquatic animal production area gradually decreased from higher saline to lower saline areas. However, the biomass was different as the individual shrimp PL weight was much lower than the carps in lower saline areas. In the HS area, the stocking density (mean number±SD) (in '000') was 87.6±29.9/ha/year, significantly (*P*<0.05) more than three other sites demonstrating the very high numbers of small shrimps PLs stocked. In the MS area, the stocking densities 61.6±26.2/ha/year were significantly (*P*<0.05) higher than LS and FW area. LS area's (36.1±25.7) stocking density were significantly (*P*<0.05) greater than the FW area (16.6±8.5) (Figure 4.2). Regarding social well-being, there were no significant (*P*>0.05) differences in stocking density between the better-off (50.2±34.3) and worse-off (48.4±36.5) across the saline gradients.

Among the four major aquatic animal groups, the shellfish group stocking number ranged from 70-90% of total stocking number of all aquatic animal PLs and fingerlings. The shellfish stocking constitutes above 85, 90, 80 and 70% in HS, MS, LS and FW area, respectively. Among the 7-8 major shellfish species only *bagda*, *golda*, and *horina* were stocked, and the rest, along with these three, were believed to be introduced through tidal water exchange. Regarding core mangrove species, about 10% is comprised of the total number stocked in the HS area followed by 6% in MS, 5% in LS and negligible numbers in the FW area. It was always expected by the farmers that tidal flushing brings mangrove fish juveniles and shrimp PLs into the *gher*. However, overexploitation of natural resources resulted in a decline in wild recruitment through the tidal exchange. In this regard, farmers used to introduce wild caught juveniles of mangrove fish species like *parsey* (*Liza subviridis*), *khorshula* (*Rhinomugil corsula*), *vetki* (*Lates calcarifer*).

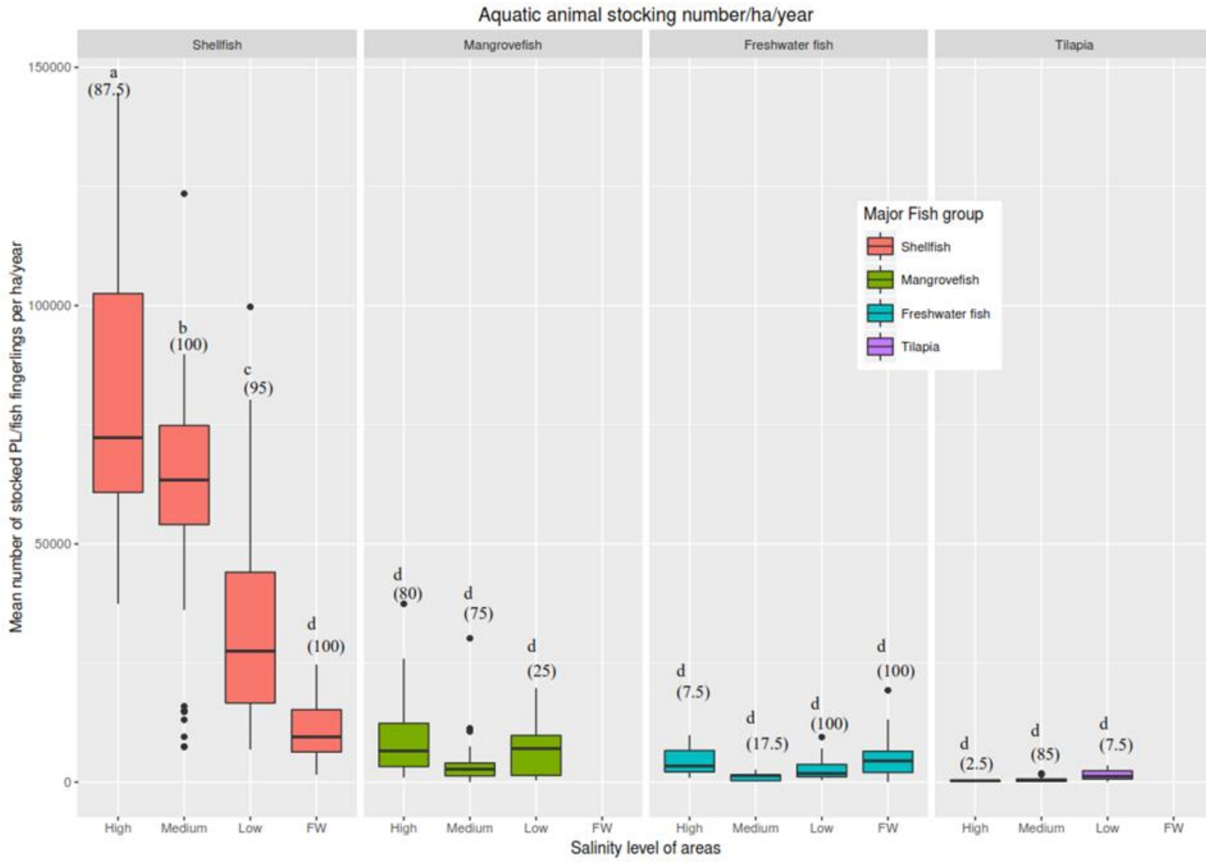


Figure 4.2 Mean stocking of PL and fingerlings number/ha/year across the saline gradients of different aquatic animal groups in S-W Bangladesh [Different letter above the each box indicated significant differences ($P<0.05$) across saline areas; number above the each box within the parenthesis is the % of *gher* stocked with specific aquatic animals]

Freshwater species comprised 5% of the total stocked number of aquatic animals in both LS and HS areas, 1% in MS area and 30% in the FW area. Tilapia is a core harvested product in higher saline areas. However, they made up less than 1% of the total stocked number. Farmers have been found to rely both on natural and hatchery originated seeds. All farmers stocked hatchery-derived seed and about 70% stocked some juveniles from the wild. The dependency on wild sources dominated for *golda* in lower saline areas and mangrove species in higher saline areas. In the HS area about 15% farmers have been found to stock tilapia juveniles, transferred from others *ghers*, either free of cost or at a minimum price. In MS area farmers tended to purposefully stocked tilapia juveniles in their *ghers* (Figure 4.2).

Shellfish stocking frequency was higher than the other groups of aquatic animal, which were stocked on average 4.5 times/year in the same *gher* across the saline areas. Farms (*ghers*) located in MS area were stocked (mean±SD/year) significantly ($P<0.05$) more frequently (9.5±1.9) than in HS (4.98 ±1.18), LS (2.11±0.7) and FW (1.22±0.35) areas. There was no significant ($P>0.05$) difference between better-off and worse-off farmers regarding stocking frequency across the region.

The shellfish were available in all the *ghers* across the saline gradients. Mangrove fish were mostly found in higher saline areas and freshwater fish in the lower saline areas (Figure 4.2). The stocking frequency and the utilisation of fertilisers had a positive relationship which is described in the next section.

4.3.4 FERTILISER AND CHEMICALS

A range of fertilisers and other chemical inputs were used in *ghers* to enhance primary productivity. A good number of inputs like cow dung, urea, Triple Superphosphate (TSP), Di-ammonium Phosphate (DAP), and weed-compost were found in use, that were categorised into organic, inorganic, lime and chemicals (Table 4.2). Total fertiliser inputs including organic, inorganic and lime utilizations gradually decreased from higher to the lower saline area (Table 4.2). Only chemical utilisation was higher in the lower saline areas compared to higher saline areas. No significant ($P>0.05$) variation was observed between better-off and worse-off households regarding fertiliser and chemical use. Among the entire group, organic inputs were found to be utilised more than inorganic, lime, and chemicals (in dry weight). Among the four major items, lime was used by more than 94% farmers followed by inorganic fertilisers (70%), organic fertilisers (35%) and chemicals (15%). Chemicals or health promoters were used by 75% farmers in the lower saline areas. Cow dung is the major organic fertiliser type and urea, triple superphosphate (TSP), di-ammonium phosphate (DAP) are the major inorganic fertilisers. The total organic and inorganic fertiliser use were transformed to total nitrogen (TN) and total phosphate (TP) and presented in Figure 4.3 & 4.4. The TN and TP from fertilisers used in LS and MS were significantly higher than HS and FW areas.

Table 4.2 Major fertilisers (organic [cowdung] and inorganic [urea, TSP]) utilisation amount tonne/ha/year in the aquatic animal production system in the S-W Coastal Bangladesh [Data in the parenthesis indicated the % of *gher* utilised the specific fertiliser, chemicals, total nitrogen, and Phosphate; different superscript letters in each row indicates significant difference (P<0.05); n= number of *gher* surveyed]

Inputs	HS (n=40)	MS (n=40)	LS (n=40)	FW (n=40)
Lime ($CaCO_3$)	0.097±0.01 (100)	0.124±0.07 (100)	0.0716±0.07 (85)	0.062±0.06 (97.5)
Weed-compost	0.029±0.0^{b} (2.5)	-	0.631±0.85^{b} (5)	3.38±3.82^{a} (35)
Chemicals	-	0.005±0.005 (16.6)	0.066±0.05 (20)	0.001±0.01 (35)
Total fertiliser and chemicals used*	0.59±0.6^{a}	0.42±0.28^{ab}	0.28±0.22^{b}	0.07±0.06^{c}

*Except weed compost

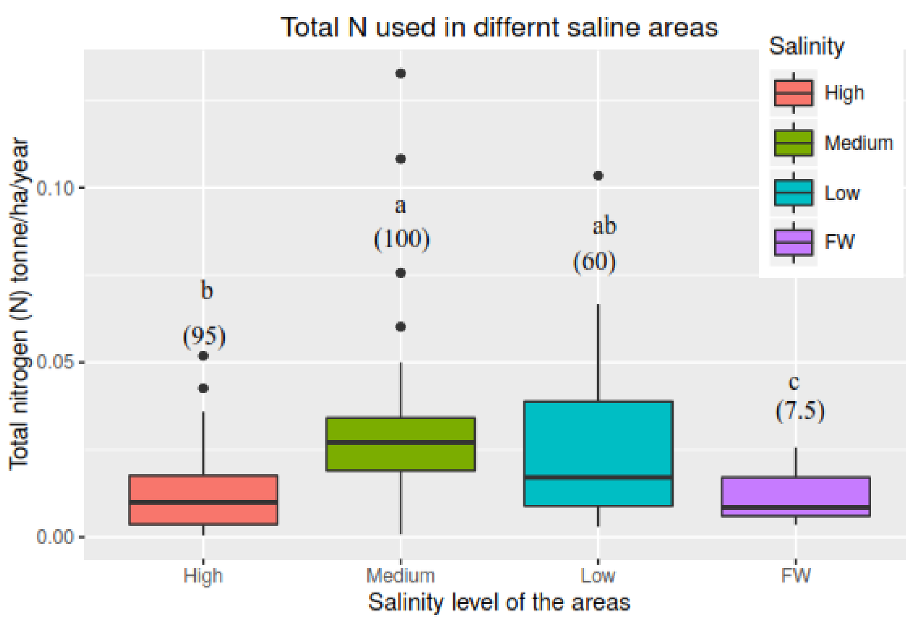


Figure 4.3 Total nitrogen tonne/ha/year derived from fertilisers that utilised in the aquatic animal production system (*gher*) across the saline gradients of S-W Bangladesh [Different letter above each whisker indicates significant difference (P<0.05); a number above the each whisker within the parenthesis is the % of *gher*, which utilised total nitrogen (TN) from fertilisation]

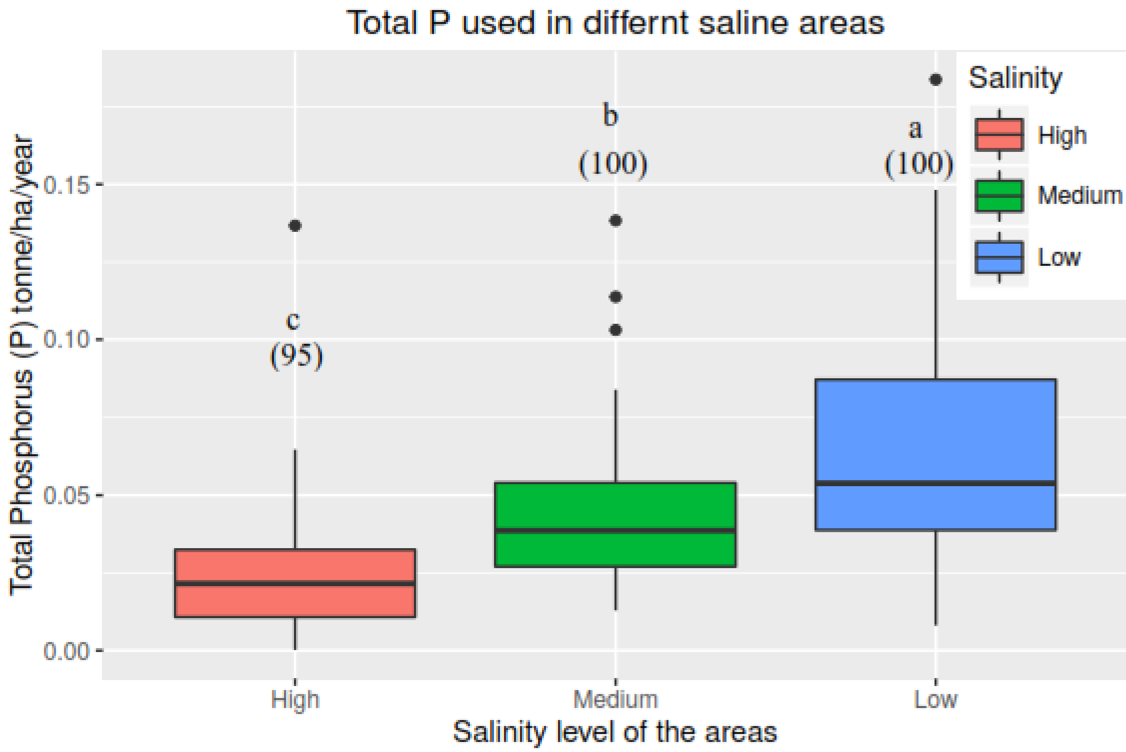


Figure 4.4 Total phosphorus tonne/ha/year derived from fertilisers that utilised in the aquatic animal production system (*gher*) across the saline gradients of S-W Bangladesh [Different letter above each whisker indicates significant difference (P<0.05); a number above the each whisker within the parenthesis is the % of *gher*, which utilised total phosphorus (TP) from fertilisation]

4.4 FEED USED IN AQUATIC ANIMAL FARMING

The feed and feed ingredients utilisation in the aquatic farming system was inversely correlated to the total fertilisers used in the system. Almost all the farmers in both the FW and LS areas used feed ingredients. On a dry matter basis, farmers in the FW area used significantly (P<0.05) more feed (mean±SD) (1.33±0.58 tonne/ha/year) than the three other sites. The LS area (0.75±0.69 tonne/ha/year) is significantly (P<0.05) higher than the MS and HS area; the latter two sites were not significantly different (P>0.05). About half of the surveyed farmers in HS (55%) and MS (40%) didn't use any feed in their *gher*. When they did, they used the tiny amount for MS (0.156±0.17 tonne/ha/year) and HS (0.077±0.037 tonne/ha/year) areas compared to other two sites. Between the two social well-being groups, there were no significant (P>0.05) differences in feed use. The major feed ingredients groups

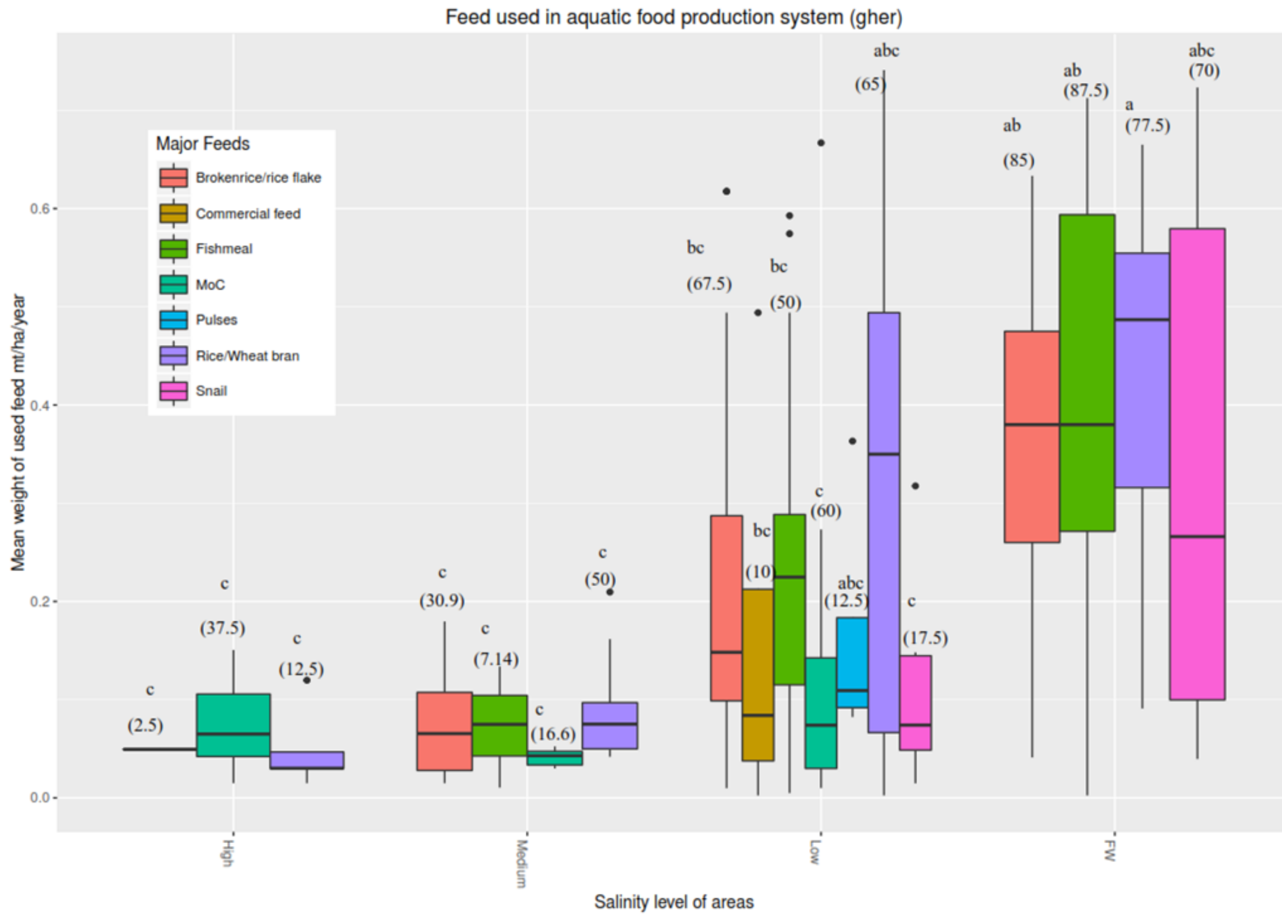


Figure 4.5 Mean feed (tonne/ha/year) used in aquatic farming system across the saline gradients in the S-W Bangladesh [All the feed items are presented on a dry matter basis; the separately plotted points on the chart is the outlier represents a gher; Different letter above the each whisker indicated significant difference (*P*<0.05); number above the each box within the parenthesis is the % of farm utilized specific feed for aquaculture]

used by the farmers are illustrated in Figure 4.5. The amount of feed used and the total yield from the systems were calculated as Food Conversion Ratios (FCR), and it was 1.13 in the freshwater area followed by 0.65, 0.23 and 0.07 in LS, MS and HS areas, respectively. The lower FCR in the higher saline area is linked to the natural productivity of water

4.4.1 HEALTH MANAGEMENT

The major disease occurrence for the research area was White Spot Syndrome Virus (WSSV), yellow head disease, hepatopancreatic necrosis, vibriosis, antenna and rostrum broken, black gill disease and soft shell disease in shrimp. In lower saline areas some less risky diseases like antenna and rostrum broken syndrome in prawn and Epizootic Ulcerative Syndrome (EUS) in finfishes were noted. Most of the farmers did not have adequate knowledge about the disease and causes of aquatic animal mortality. Therefore, regardless of specific disease problems, especially in shrimp, disease was often referred to as white spot viral disease. Some of the farmers were able to define the symptoms of white spot diseases by observing spots on the carapace, aggregation of shrimp and sluggish movements. The size of the *gher* also had an influence on the disease occurrence, *gher* in the higher saline areas were highly affected compared to the *gher* in the lower saline areas (Table 4.3). The absence of shrimp in the freshwater area is one of the reasons for minimum crop loss and disease occurrence.

Table 4.3 Disease occurrence and % of aquatic animal loss (estimated mortality over a year by the farmers) in the aquatic farming systems (*gher*) in S-W Bangladesh

Salinity	Social well-being	% of crop loss mean ±SD	% of *gher* of total *gher* affected (in number)	Disease occurrence frequency ± SD
High	Better-off	21.2 ± 11.03^{b}	55 (11)	$1.7\pm.69^{abc}$
	Worse-off	20.5 ± 7.97^{ab}	85 (17)	$1.94\pm.72^{abc}$
Medium	Better-off	34.32 ± 21.5^{ab}	100 (22)	2.41 ± 1.2^{ab}
	Worse-off	40 ± 21.21^{ab}	90 (18)	2.5 ± 1.04^{a}
Low	Better-off	26.25 ± 18.8^{ab}	20 (4)	1.5 ± 1^{abc}
	Worse-off	52.14 ± 30.1^{a}	35 (7)	$1.28\pm.49^{bc}$
FW	Better-off	20 ± 7.07^{b}	30(6)	1^{c}
	Worse-off	20.5 ± 7.9^{b}	50 (10)	1^{c}

Different superscript letters in each column indicate significant differences ($P<0.05$). The number in the parentheses is indicating the number of *gher* affected.

At least 20-50% aquatic crop loss was recorded across the saline gradients (Table 4.3) and estimated mortality were significantly ($P<0.05$) higher in the MS and LS areas compared to other two sites. However, the disease occurrence frequencies were higher in the higher saline areas and gradually decrease with the decrease of water salinity level. The affected numbers of *ghers* were highest in the MS area and due to this loss farmers got lesser yields compared to the other three sites. Both the better-off and worse-off farmers were affected equally [not significantly different ($P>0.05$)] across the saline areas. Disease occurrence was also linked to water management and water depth of *gher*.

4.4.2 WATER MANAGEMENT

River, canal, underground water and rain were the main sources of water supply for irrigating *gher*. *Gher* water depth and the source of *gher* water sources are presented in Table 4.4.

Table 4.4 Water management in the aquatic farming system in the saline gradient of S-W Bangladesh. Different superscript letters in each column indicate significant differences ($P<0.05$)

Variables	Salinity level of areas			
Water depth and sources	High	Medium	Low	FW
Water depth±SD (cm)	53.8 ± 12.32^{c}	54.5 ± 12.2^{c}	65.9 ± 15.5^{b}	108.1 ± 23.5^{a}
Main water source for aquatic farming				
River	100%	70%	-	-
Water pump (diesel)	-	30%	65%	7.5%
Rain	-	-	30%	95%

Ghers in FW area were maintained greater water depth (mean±SD) (108±23 cm) significantly ($P<0.05$) deeper than any of the saline sites (Table 4.4). Water depth in *ghers* in the LS site (66±15.5 cm) was significantly ($P<0.05$) deeper than MS (54.5±12.17 cm) and HS sites (53.8±12.32 cm), and the latter two locations were statistically similar ($P>0.05$). Water sources in the HS area were mainly dependent on river and canal water as the area had good connection to the *Arpangasia* canal. The MS area was found to toil a bit to get adequate water throughout the year. Therefore, more than 75% farmers were found to use diesel operated hose pump to get water from the adjacent water sources (river/canal). Farmers in the LS and FW area mostly relied on rainwater and also used pumped ground water which was concurrently used for both rice and dyke crop production. No variations were observed for water management issues between better-off and worse-off farmers across the saline gradients. The aquatic and terrestrial crop production systems were mostly driven by the household members, and a tiny number of permanent labourers existed in the higher saline areas. However, it was observed that during the peak season of work like de-watering, harvesting, de-weeding and embankment preparation, temporary labour were hired across the saline zones. The involvement of women in de-weedding works in the higher saline areas was prominent.

4.4.3 Aquatic animal production

The total harvested aquatic animal yield (mean±SD) in the MS area (0.67±0.26 tonne/ha/year) was significantly ($P<0.05$) lower than the three other areas. In the rest of the areas, aquatic yield was 1.14±0.49, 0.97±0.49, and 0.91±0.39 tonne/ha/year in LS, HS, and FW area, respectively. The yield in LS, HS and FW was not significantly different ($P>0.05$).

In between the social well-being group of farmers in the overall four sites the worse-off households were found to produce significantly ($P<0.05$) more aquatic animal than the better-off households farmers. The harvested yields worse-off farmers were at least 18% higher than in better-off households (Figure 4.5).

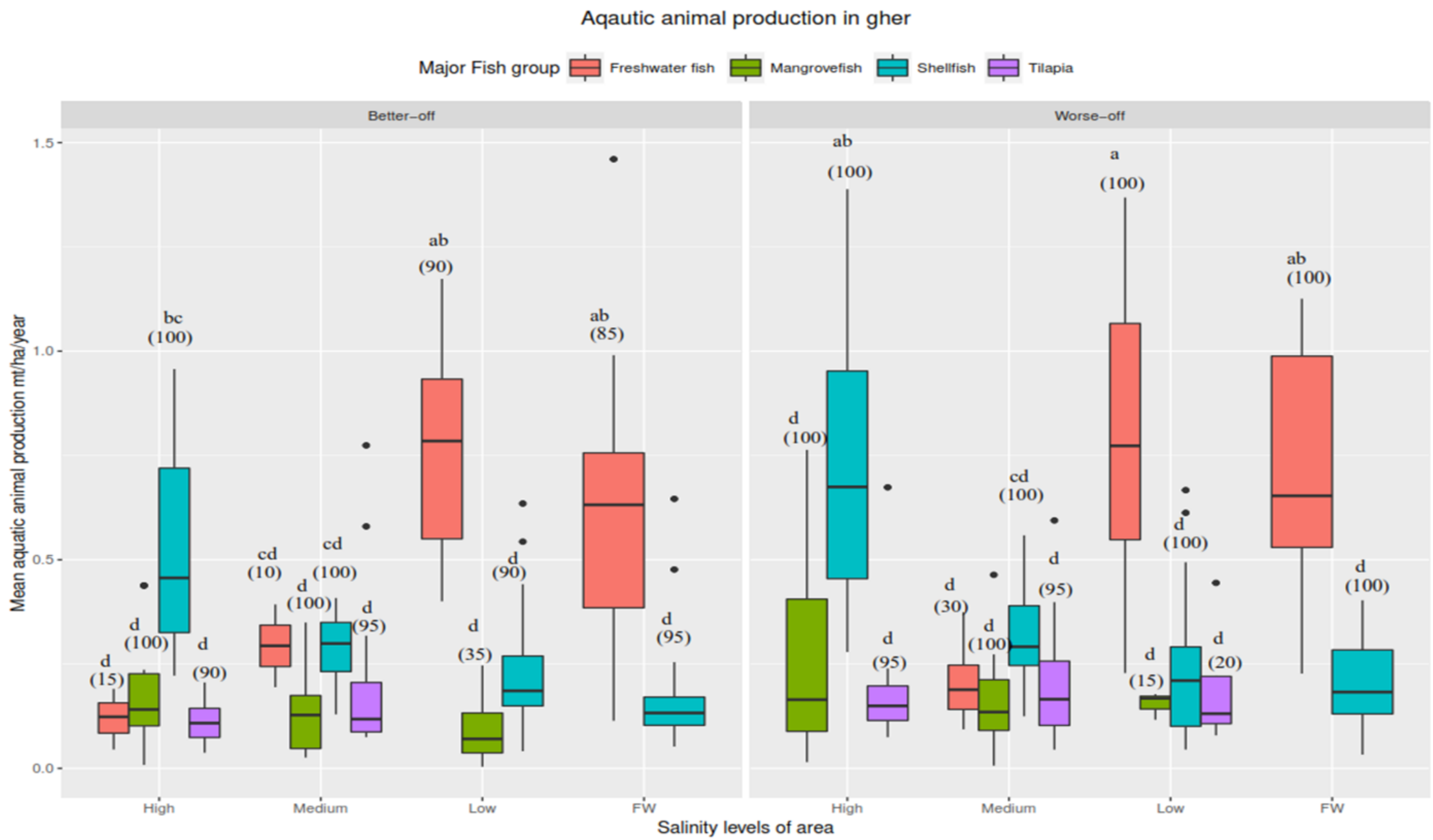


Figure 4.6 Total aquatic animal harvested production (tonne/ha/year) in *gher* system across the saline gradients in the S-W Bangladesh [Different letter above the each whisker indicated significant differences (P<0.05); number above the each whisker within the parenthesis is the % of gher harvested the specific aquatic animals]

Among the four major groups of aquatic animals, shellfish, mainly *bagda* and *golda*, dominated across the saline gradients. The contribution of shellfish was higher in the higher saline area and gradually decreases with the decline the salinity level (Figure 4.7). Shellfish in the HS area comprised about 55% of total production in volume followed by 34% in MS, 18% in LS and 22% in the FW area. The major export product shrimp was common in HS, MS and LS area and prawn in the LS and FW area. Both shrimp and prawn were concurrently cultured in the LS area. The mangrove fish is mostly cultured in higher saline areas and similarly freshwater fish in the lower saline area (Figure 4.7). The core mangrove fish in the proportion of total yield volume to the respective sites was 20% in HS, followed by 16% and 10% in MS and LS respectively, however as expected very negligible amount in the FW area. On the other hand core freshwater species contributed 78% of the total yield in FW area, followed by 58, 26 and 10% in LS, MS and FW area, respectively. Above 90% of *ghers* in higher saline areas had tilapia while it was much less important in lower saline areas. The contribution of tilapia in the higher saline areas was significant and it comprised 13% and 18% of total production volume in HS and MS areas, respectively. About 57 different species of fish and shrimp including mud crab were recorded in the region and are tabulated in Chapter 5 to avoid duplication.

4.4.4 *GHER* SIZE AND PRODUCTIVITY

Total aquatic animal production per unit area and the *gher* size is negatively correlated.

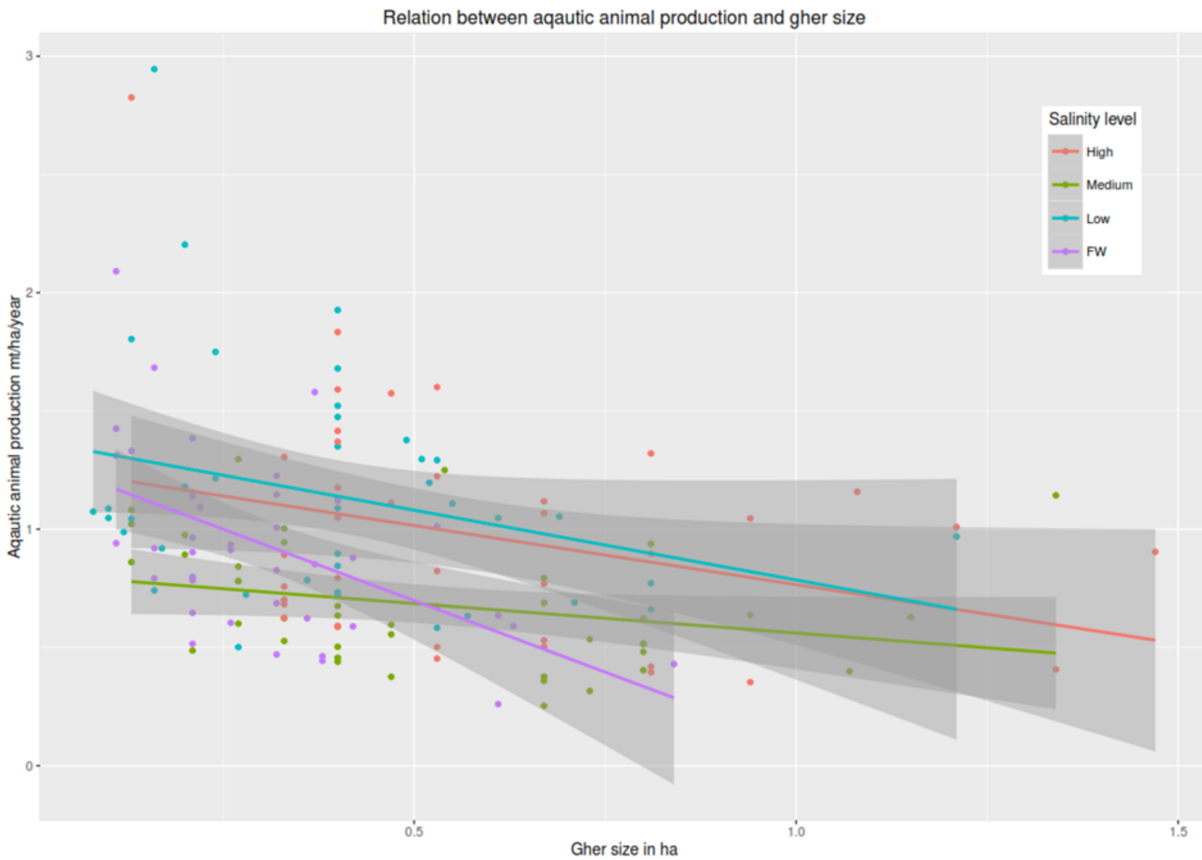


Figure 4.7 Relationship between *gher* size (ha) and the aquatic animal productivity in the aquatic animal production system in S-W Bangladesh

An ANCOVA test confirmed the slope was negatively correlated (Table 4.5) indicating the increase of *gher* size decreased the production in per unit area. The r-squared value indicated the correlation coefficient (R-squared) was 0.24. The differences among the agro-ecologies are presented in Table 4.5.

Table 4.5 Relationship in between the *gher* size and the aquatic animal productivity (derived from ANCOVA) in S-W coastal Bangladesh

Area	intercept	Estimated value	SE	P-value	Significant
High	Productivity	0.78	0.060	>2e-16	***
High	Area in ha	-0.19	0.047	7.4e-05	***
Medium		-0.11	0.057	0.035	*
Low		-0.16	0.055	0.0034	**
FW		-0.29	0.054	2.94e-07	***

Significant codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05

4.4.5 DYKE VEGETABLE PRODUCTION

Systems in LS and FW were far more diversified than in the higher saline agroecosystems. About 97.5% and 87.5% of farmers in LS and FW areas, respectively practised *gher*-dyke cropping. Farmers in the lower saline community were found to produce rice once annually. The year round dyke vegetable and rice production were calculated by considering the total *gher* area during estimation of dyke crop productivity. The dyke crop production in (mean±SD) LS and FW area were 2.7±3.2 and 6.5±4.4 tonne/ha/year respectively. The rice production was about 1.5-2 tonne/ha/year. However, production was unaffected by household well-being status (P>0.05). The variety of dyke vegetables, production, and proportion of *gher* covered the species with statistical analysis are described in Table 4.6.

Table 4.6 Different varieties (variety only those are cultivated >10% of *gher* in sampled *ghers*) of dyke vegetables, produced (mean±SD) in the aquatic farming system in the S-W coastal Bangladesh [% of *gher* practising each variety are presented in parenthesis]

Common name (Local name)	Scientific name	Total production (mean±SD) tonne/ha/year (% of *gher* produced)	
		Low saline	FW
Asparagus bean (*borboti*)	*Vigna sesquipedalis*	1.16±1.38 (43.2)	-
Basil (Green *Puishak*)	*Basella alba*	0.81±1.09 (18.9)	-
Bitter gourd (*karala*)	*Momordica charantia*	1.89±1.45 (48.6)	3.49±2.4 (62.5)
Bottle gourd (*lau*)	*Lagenaria siceraria*	2.23±2.82 (27)	0.90±0.88 (15)
Brinjal (*begoon*)	*Solanum melongena*	0.33±0.28 (43.2)	-
Chili (*jhal morich*)	*Capsicum species/annum*	0.052±0.05 (27)	-
Cucumber (*shasa*)	*Cucumis sativus*	-	4.23±3.37 (74.3)
Kohlrabi (*olkopi*)	*Brassica oleracea var. gongyloides*	0.14±0.10 (29.7)	-
Okra (*dherosh*)	*Abelmoschus esculentus*	0.51±0.39 (24.3)	-
Pumpkin (*misti kumra*)	*Cucurbita maxima*	-	1.88±2.59 (11.4)
Sponge gourd (*dhundul*)	*Luffa cylindrica*	-	0.91±0.93 (28.6)
Tomato	*Lycopersicon esculentum*	0.75±0.97 (64.8)	2.37±2.08 (22.8)
Wax gourd (*chal kumra*)	*Benincasa hispida*	-	4.16±3.81 (17.1)

Other vegetables produced in LS and FW area are listed below with the local/common name and scientific name if not mentioned in the above table.

The other dyke crops produced in LS area are: (1) *pepe*; Papaya (*Carica papaya*) (2) *mula*; Radish (*Raphanus sativus*) (3) *peaj*; Onion (4) *kocu*; Aram (5) *jhinga*; Ribbed gourd (*Luffa acutagula*), (6) Asparagus bean (7) *holud*; Turmeric (*Curcuma longa*) (8) *kola*; Green banana (*Musa* spp), (9) *phulkopi*;Cauliflower (*Brassica oleracea* var. *botrytis*) (10) Cucumber (11) Pumpkin.

The other dyke crops produced in FW are: (1) Brinjal (2) Okra, (3) *jhinga*, (4) *lal shak*; red amaranth) *Amaranthus gangeticus*), (5) *palong shak*; spinach (*Spinacia oleracea*), (7) Bottle gourd (8) Pumpkin

4.4.6 TOTAL AQUATIC ANIMAL, DYKE CROP AND RICE PRODUCTION

Total aquatic animal, rice, and dyke vegetable productions per ha per year across the saline gradients are presented in the following Figure 4.8.

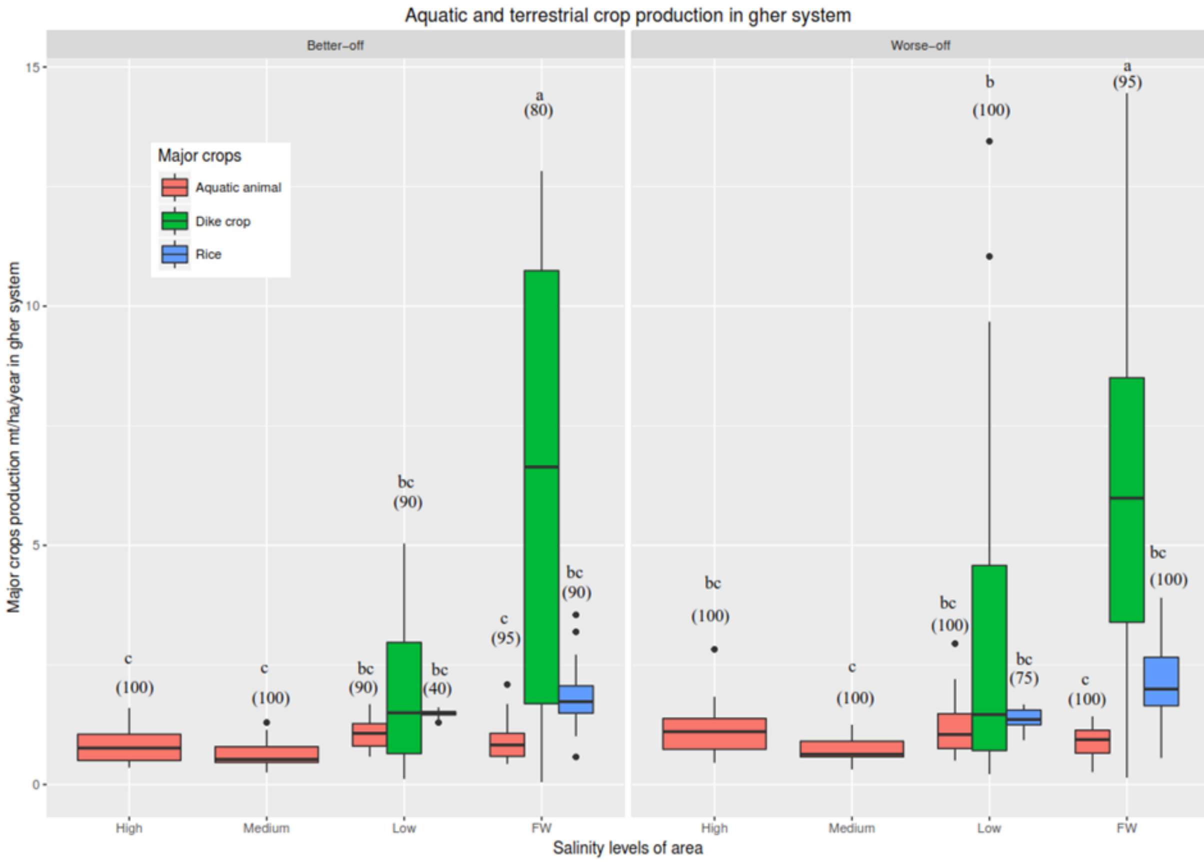


Figure 4.8 Total aquatic animal, rice and dyke vegetable production (tonne/ha/year) in *gher* system across the saline gradients in the S-W Bangladesh [Different letters above the each box indicated significant differences (*P*<0.05); number above the each whisker within the parenthesis is the % of *gher* that harvested the specific class of aquatic animal]

4.4.7 DISTRIBUTION OF *GHER* RAISED AQUATIC ANIMAL, RICE AND DYKE VEGETABLES

Aquatic animals were gifted to kin and kith and the poorer neighbours across the saline gradients. The proportion of aquatic animals gifted was significantly (*P*<0.05) higher in HS (7.4%) than in three other sites (Table 4.6). Gifting levels (mean % of GIFT to total harvested yield) in MS, LS, and FW, were not significantly (*P*>0.05) different. It was observed that the lower value fish, such as tilapia in higher saline areas and Thai sarputi in lower saline areas were mainly gifted to a poorer neighbour (detailed list of available fishes are in Chapter 5). Some high-grade fish (in price) like *vetki*, *parsey* and on some occasion shrimp were given to friends and family. Most of the aquatic animals and other crops were destined to the markets through the various channels. Marketing of perishable item fish is complicated compared to non-perishable terrestrial products. Therefore, a large number of actors like *foria*, *depot* owner, agents were involved in the value chain of seafood both for the local and global market. The lucrative income from the international traded aquatic food items shrimp and prawn opens-up scope for many people in terms of subsistence for their livelihoods. The proportion of aquatic and terrestrial crops market destinations were calculated to the total volume produced per *gher*/year and are presented in Table 4.7.

Table 4.7 Destination of *gher* raised aquatic animals including shrimp and prawn, vegetables, and rice in % (±SD) to total volume in the S-W coastal Bangladesh [Different superscripts in the same row indicate significantly (P<0.05) differ]

Crop	Salinity	Market				Household	Others
		Wholesale (large depot)	Local market	*Farias* (middle man)	Small Depot	Own consumption	GIFT others
Aquatic animal	High	58±36^{b}	-	0.2±2.6^{b}	-	34.3±36.6^{a}	7.4±8.7^{a}
	Medium	62±42^{b}	0.3±3.5^{b}	-	-	34.1±40^{a}	3.3±7.2^{b}
	Low	71±30^{a}	-	4.1±18.7^{a}	-	21.4±24.8^{b}	3.2±6.9^{b}
	FW	55±41^{b}	3.5±1.6^{a}	-	0.3±3.5	38.2±41.1^{a}	2.8±5.7^{b}
Rice	Low	30.87	-	-	-	68.75	-
	FW	53.64	-	-	-	46.35	-
Vegetable	Low	86.46	-	-	-	10.70	2.89
	FW	96.35	-	-	-	2.5	1.6

Household level consumption ranged from 20-35% of total fish produced in the *gher* per year. The consumption proportion was significantly (P<0.05) lower in the LS area compared to the other three areas. About 90% of total vegetables were marketed in local wholesale markets and the rest consumed at the household level. Regarding rice about 30% and 50% of total volume of rice production from LS and FW area, respectively, consumed at the household level and rest destined for the local market.

4.4.8 MONEY LENDING AND CREDIT

Three primary sources: wholesaler, Bank, and NGO were utilised by the farmers for credit. The amount of money and the source of the money along with the proportion of farmers involved are presented in Table 4.8.

Table 4.8 Money lending scenario of households (n=160) over a year across the saline gradients in the aquatic animal farming areas in south-west Bangladesh [Different superscript letters in columns and rows indicate significantly (P<0.05) different; values within the parentheses is the % of the households involved in credit to the total household of each category]

Salinity	Social Well-being	% of HH taking credit	Sources of credit (single/multiple): % of HH taking credit from single source	Amount of credit from sources: Buyer	NGO's	Bank
				Amount BDT in '000' ±SD (% of household involved)		
High	Better-off	50	100	-	19.3±12.4^{b} (45)	100^{ab} (5)
	Worse-off	35	100	-	14.3±5.3^{b} (35)	-
Medium	Better-off	45	100	16±5.6^{b} (10)	20±10^{b} (35)	-
	Worse-off	50	70	16±12.5^{b} (15)	22.4±11^{b} (45)	5^{b} (5)
Low	Better-off	45	88.9	60^{ab}(5)	16.6±11.6^{b} (35)	15^{b} (10)
	Worse-off	20	100	18.5±16.2^{b} (10)	10^{b} (5)	10^{b} (5)
FW	Better-off	70	57.2	113.3±81^{a} (15)	15.2±6.5^{b} (40)	55.5±30^{ab} (45)
	Worse-off	100	71.4	57±51.2^{ab} (35)	14.3±6.4^{b} (30)	32.6±22.6^{b} (70)

1BDT (Bangladeshi Taka) =0.0125US$ or1US$=79.9BDT, December 2014.

The aquatic animal buyers in the wholesale market and the commercial bank appeared to disburse similar amounts of credit to per farmer. However, the amount was, significantly (P<0.05) higher than the amount given by NGO's (Table 4.8). About 70-100 % households in each social well-being group of FW area took credit while the other three sites household ranged from 20-50% of total sampled households. The highest number of farmers was found to engage with NGO's to obtain loans followed by banks and buyers (Table 4.8). There was no significant (P>0.05) difference in credit amount, and frequency between better-off and worse-off. Terms of credit disbursed by wholesalers appears to be simpler and normally based on a verbal commitment to sell fish at a 3-5% commission rate after harvesting. However, bank and NGO's interest rates were higher and based on tighter terms and conditions. Banks demanded repayments to be paid monthly and interest rates of 12-15% on a yearly basis. NGO's ask for weekly or monthly repayments, levying interest rates more than 30% on an annual basis.

4.4.9 ECONOMIC RETURNS OF *GHER* BASED SYSTEM

This section compares the costs and returns for the different aquatic animal farming systems by agro-ecological system and social well-being group of the farmer. The net profits earned by farmers in all areas indicated the contribution of aquaculture activities on their livelihoods. Among cost items seed, feed and fertiliser price have been found the major charge, but water management, labour, harvesting, netting, land rent (if needed) were also important. The cost, return and the net return from aquatic animal and terrestrial crops are presented in Table 4.9. Both HS and LS areas gain a higher profit from their *gher* compared to the MS and FW areas. The worse-off appeared to perform better than better-off regarding getting higher yield from their *gher* production (Table 4.8). However due to the small *gher* size worse-off households gained less actual economic returns compared to the better-off households.

Table 4.9 Cost benefit of aquatic animal and terrestrial crops production system (in '000' BDT±SD) per ha of total *gher* per year across the saline gradients and social well-being in south-west coastal Bangladesh

	Item	Salinity level and social well-being							
		High		Medium		Low		Freshwater	
		BO	WO	BO	WO	BO	WO	BO	WO
Cost	Seed	54.5±42	45±15.6	38.9±18	37.8±19.9	46.7±23.1	56.1±42.7	61.1±55	64.6±28.2
	Fertiliser	4.2±3.6^{abc}	3.9±2.7^{abc}	6.3±5.8^{ab}	7±4.6^{a}	6.5±4.5^{ab}	4.3±3.1^{abc}	2.7±5^{bc}	1.5±2.8^{c}
	Feed	1±1.4^{c}	1±1.4^{c}	2.7±4.7^{c}	2.3±2.9^{c}	13.6±13.3^{bc}	20.3±22.2^{b}	33.3±16^{a}	35±18.4^{a}
	Sub-total	59.7±30	50±24	48±20	47.2±19	67±21	80.7±26.5	97±29	101±31
	Dyke crop	-	-	-	-	8±7.5^{b}	12.8±15^{ab}	22±20^{ab}	24.2±24.7^{a}
	Rice	-	-	-	-	8.8±10^{b}	12.6±9^{b}	22.2±10^{a}	25±11.8^{a}
Return	Fish	250±128^{ab}	323±157^{a}	177±67^{b}	186±66^{b}	255±125^{ab}	274±166^{ab}	212±109^{ab}	215±92^{ab}
	Dyke crop	-	-	-	-	20±19^{ab}	32±37^{a}	55±50^{b}	60.6±37^{ab}
	Rice	-	-	-	-	27.6±1.8^{ab}	25.7±4.3^{b}	35±13.6^{ab}	39±16^{a}
Net return	Fish	190.29^{ab}	272.9a	129.1^{b}	138.8^{b}	188.2^{ab}	193.3^{ab}	114.9^{b}	144^{b}
	Dyke crop	-	-	-	-	12	19.2	33	36.4
	Rice	-	-	-	-	18.8	13	12.8	14
Total net return		190.29^{ab}	272.9^{a}	129.1^{b}	138.8^{b}	219^{ab}	225.5^{ab}	160.7^{b}	194.4^{b}
Contribution of Aquaculture (%)		100	100	100	100	85	85	71	74

Different superscript letters in the same row is significantly (*P*<0.05) different. 1BDT=0.0125US$; 1$=79.9BDT, (BB, December 2014; BDT=Bangladeshi taka)

4.5 DISCUSSION

The results of this chapter confirm that the aquatic animal farming in the south-west Bangladesh is a family-driven, small-scale low input-output polyculture system. Huge arrays of aquatic animal species were found across the saline gradients. Dyke vegetables and rice were commonly found in the lower saline areas. Amongst the aquatic animals, only 2-3 species were destined for international markets and the rest were absorbed into local markets and consumed by the farming household. Regarding terrestrial crops, the major portion was destined for local markets and the rest consumed at the household level. Both aquatic and terrestrial crops were important to mitigate local food security. Disease remained the greatest threat to production and assured economic benefit. Lack of mangrove species and higher mortality in MS and the lower unit value of fish cultured in FW coupled with higher operational costs reduced economic returns compared to the other two sites (HS and LS). This study revealed that polyculture of aquatic animals with particular emphasis on the high market prices, as well as the integration of terrestrial crops, was a viable option for farming households across a range of socio-economic status. However, the underlying resilience of these systems was highly dependent on the local context, natural resource availability, alternative livelihood availability and management techniques like aquatic animal health management.

4.5.1 OUTPUT FROM THE AQUATIC ANIMAL PRODUCTION SYSTEM (*GHER*)

The aquatic animal yield (Figure 4.7) across the saline gradients was similar except in the MS area which was also lower than the average harvested yield (0.72 tonne/ha/year) in *gher* system reported by DoF (2015). However, the total aquatic animals yield in the other three sites are not surprisingly greater, and were similar to those described elsewhere (Ahmed, 2013a; Jahan et al., 2015; Kabir et al., 2015a; Paul & Vogl, 2012). The aquatic animal production in *ghers* has shown an increasing trend due to the market demand, technological development and farmers training (Jahan et al., 2015). Along with these factors population pressure also speeds up intensified production of farm products (Ali, 2007). The dyke crop production also followed the higher trend than the other studies. Howson (2014), found that the farmers in the same survey sites increased their dyke vegetable production at least 300% in volume from 2010-2014. This is due to the increasing trend of land use diversity. Rahman (2016), analysed the land use data and agricultural diversity of 60 years (1948-2008) in Bangladesh and concluded that the land use diversity increasing 0.19% annually and S-W coastal areas were more diverse than the south-east coastal area of Bangladesh. Moreover, integrated rice-fish farming is easily manageable (Mirhaj et al., 2013), providing higher yields (Feng et al., 2016) and appeared more sustainable (Talukder et al., 2015) than non-integrated systems. One important characteristic of integration was that it occurred in lower saline areas where *gher* size is relatively small and managed by household labour. In contrast to lower saline areas, higher saline *ghers* were larger and required more labour for deweeding. Dyke crop production in the current study was also higher than other studies (Ahmed et al., 2007). Dyke crop production was double in FW area than LS area. The yield variation of dyke crops was not linked to investment, which was similar in both areas (Table 4.9) but rather to water salinity variation. Relatively higher water salinity in LS disfavoured dyke crops compared FW area. These findings are supported by Shannon and Grieve (1998), where they observed that salinity reduced crop production significantly. Some commentators like Etienne (1977), also emphasised on the market access *i.e.* good infrastructure enhanced the agricultural production as the farmers can sell products easily in nearer markets. However, in the current study market access in the LS area was much easier than the FW area. (Howson, 2014), also worked in the same region and concluded that salinity had more influence than infrastructure on dyke crop production. In our study, we found a noteworthy difference in the dyke crop variety selection. In the FW area, the climbing vegetables are prominent which required less dyke land and more trellis which is structured horizontally to the canal area of the *gher*. For example, except for tomatoes (Table 4.6) all other vegetables are climbing in nature. On the other hand in LS areas chilli, kohlrabi, and okra are scrambling vine type vegetables needing more dyke area to produce compared to climbing vegetables (Table 4.6). Apart from this another important cause was observed that the farmers in the LS areas were more interested in aquatic species than terrestrial crops as the previous provide a higher economic return. This might be due to the higher price of shrimp and mangrove fish species. The rice production (Figure 4.7) was a bit lower than the findings (5 tonne/ha/cycle) of Ahmed et al. (2007). However, it was similar to that described for shrimp-based rice systems by Alam et al. (2006) and Alam et al. (2007). The actual production in the current system might be 20-25% higher if the dyke and canal area were excluded from the rice yield calculation. Moreover, the variety is also important to determine yield, local varieties tend to produce lower yields compared to the High Yield Varieties (HYV) (Alam et al., 2007).

4.5.2 FACTORS INFLUENCING ON *GHER* OUTPUTS

Aquatic animal production is more complex and diverse compared to the terrestrial crop production. Amongst all water salinity levels, culture duration, *gher* size, stocking density, species diversification, disease occurrences, water management, the livelihood of the farmers and external support like credit are important in an aquatic animal production system. The influence of the each of the variables was assessed and presented in the result section and discussed in the following sections.

4.5.3 DOES *GHER* SIZE HAVE AN IMPACT ON PRODUCTIVITY?

The average *gher* size decreases from higher to lower saline areas. However, this variation did not affect much the worse-off segment across the saline agro-ecologies (Figure 4.1). This type of variation also was reported by Ahmed (2013a). He obtained the total land holding differences in between lower and higher saline was up to 5-8 times; whereas we obtained the individual *gher* size is double in higher saline than lower saline areas. The aquatic animal yield by volume was highest in LS followed by HS, FW, and MS areas (Figure 4.7). In the agricultural activities, *gher* (farm) size is considered as an important indicator to estimate the economic returns (Gordon et al., 2015). The relation in between the *gher* size and the productivity were drawn in Figure 4.6 and in all cases, the inverse relationship were obtained. The relationship of *gher* area and the aquatic animal production also varied from one area to another (Table 4.5). Nevertheless, Townsend et al. (1998) noted that the inverse relationship between farm size and productivity become a 'stylish fact' (Bardhan, 1973) in the economic development literature. The commonly used phrase "small is beautiful" (proposed by economist E.F. Schumacher) gained popularity in contrast with the common economic thinking "bigger is better." The notion noted by Schumacher emphasised the participation of the majority of people. Therefore, small size is desirable and manageable by the small-holders. However, tiny size is a hurdle to gain economic potential (Gordon & Bjørndal, 2009). In the current study the small-holders, were mostly worse-off that normally operate smaller land area compared to the better-off were found more successful. Milstein et al., (2005) also found smaller *gher* productive in the same study area. This higher yield also reported due to the higher survival rate of PL and better management.

On the other hand, some commentators found that smaller farms are not profitable for lack of management skill, but for the size itself (Gordon et al., 2015). Though, bigger farm shrinkage the access of poorer household, the larger farm has a significant distributional and social consequences like charity/gift of farmed products (Gordon et al., 2015). A positive social value was noted in the current study that the farmers in the higher saline zone were inclined to provide more fish to the poorer segment. One of the reasons for this was that farmers could produce and a share a substantial amount of unstocked fish and self-recruited species (SRS) tilapia.

Verschelde et al. (2013) also obtained a positive correlation with the farm size and farm yield which also had an encouraging influence on food security. In prawn based integrated farming system in Bangladesh, it was revealed that the larger *gher* were more likely to be technically efficient compared to the smaller *gher* (Rahman & Barmon, 2012). Ahmed (2010) found that large farms are more beneficiary (both in overall yield and benefit) for prawn farming. Islam et al. (2005) worked on three different type of shrimp *gher* size in the S-W Bangladesh and found the variable cost of inputs and labour was higher in smaller *ghers* compared to larger *ghers*. On a broader geographical scale, work on shrimp farming in the three Asian countries including Bangladesh found that small farms found in the disadvantaged group, not for productivity and managing skill but for the size of the farm (Gordon & Bjørndal, 2009).

The uncertainty of agricultural production and the land and labour market imperfections is considered as the main limitation to determine the farm size and productivity relationship (Bardhan, 1973). Ali and Deininger (2015) showed that smaller farm productivity is higher if labour costs are ignored but the inverse is the case if labour is considered expense. It was beyond the scope of the current study to estimate the actual number of labour days functioned over the year and to give the monetary value. This is because most *ghers* were based on household labour. A rational approach is to identify, a threshold for *gher* size below which incomes are below an attractive level and farmers seek other livelihood options. Some additional issues should consider before fixing such a threshold level like the integration options of other agricultural component, disease occurrence, the scope for the other jobs etc. In S-W Bangladesh Milstein et al. (2005) worked in shrimp farming systems in higher saline areas and counsel for smaller *gher* size for higher productivity. In contrast, Ahmed et al. (2010) reviewed the prawn farming system in lower saline areas and advised the need for bigger *gher* sizes.

Apart from the *gher* size some unquantifiable factors like wild recruitment of mangrove fish and the natural productivity of water determine the aquatic animal production and resultant economic returns. The low feed supply in the higher saline areas reduced the variable cost as the aquatic animal in this system mostly fed on natural food like diatoms and other algae (Belton, 2016). The stocking (Figure 4.2) and yielding (Figure 4.5) graphs in the result sections indicated that mangroves continue to support a wide range of wild species in the HS areas. This wild recruitment ultimately put HS on the upper shelf both in terms of yield and economic return (Table 4.9). At the same time, convenient water salinity in LS area both for mangrove and freshwater species helped to enhance the underwater biodiversity. This species assemblage provided an extra amount of crop and economic return. The contribution of mangrove to coastal aquaculture yield is mentioned in the literature elsewhere (Biswas et al., 2012; Islam & Haque, 2004; Islam & Wahab, 2005). Despite proximity to the mangrove forest, MS areas, water management (Table 4.4) and linking of *gher* to the adjacent natural water bodies were obstructed due to higher elevation which consequently impacted the disease occurrence and availability of mangrove fish. Although the result (Figure 4.6) showed mangrove fish to be proportionally higher in MS compared to LS area, the actual amount was higher in the LS area as the total yield in LS was almost double to MS area. The importance of unquantifiable factors like soil fertility and quality also illustrated elsewhere in the literature (Saini, 1969; Verschelde et al., 2013). Hence, Townsend et al. (1998) suggested research in the agricultural field to be cautious about the perception that smaller farms are more productive than larger farms. They have noted that co-operative activities in farming products, processing and marketing can enhance the economic scale. There are also some advantages of smaller farms whereby small-holders have tried to produce more than one crop at the same time thus accelerating the farm output compared to the larger farm (Saini, 1969). The dedication of small-holders was observed in the current piece of work which put them alongside better-off farmers across the saline gradients. Overall small-holders in Bangladesh on average maintaining the crop production (Turner & Ali, 1996).

Sheng et al. (2015) have suggested that small-holders need to acquire technological advancement to get a higher return from the small areas of their farm. Shrimp farming in Indonesia in extensive systems provided a higher economic return than more intensive systems despite having the technological advancement and involvement of wealthy farmers (Bunting et al., 2013). This suggests most inspirational to the small-holders of S-W Bangladesh where they need to cope with various challenges like climate change and disease outbreaks. At the end of the day, *gher* size is one of the factors of many that are important in gaining success from aquatic animal production. The main attainment concerns the ability to continuously utilise the resources (Ajibefun & Abdulkadri, 2004).

4.5.4 LOW INPUT- OUTPUT SYSTEM

There was an inverse relationship between utilisation of total fertilisation and feed in the aquatic animal production systems across the saline gradients. Fertiliser utilisation was higher in higher saline areas and gradually decreased with the plunging of *gher* water salinity. But the volume of fertilisers used in aquaculture systems in S-W Bangladesh was much lower than the other fertilised agricultural farming systems (Jahan et al., 2015). For the feed utilisation, the scenario was vice-versa. Similar findings were obtained for small scale/extensive shrimp farming in Asian countries (Boyd & Massaut, 1999). Barmon et al. (2006) also found that farmers in lower saline areas used less fertiliser and more feed than higher saline areas in Bangladesh. This is because the intensification and farmers have found that feed works better than fertiliser in this system. As organic fertiliser, *i.e.* cow dung was mostly used and Primavera et al. (1993) also reported the utilisation of cow dung and chicken manure as organic fertilisers in the S-E Asian countries aquaculture. The use of inorganic fertilisers such as urea and TSP are commonly also found elsewhere in the literature (Ahmed et al., 2007). Shrimp in extensive systems feed on naturally available phytoplankton like diatoms and other microalgae. The basis of using fertilisers is to enhance the natural productivity of pond/*gher* (Boyd & Massaut, 1999). In case of inputs provided in the *gher* total nitrogen and total phosphate are mostly derived in the shrimp *gher* from fertilisers. However the major amount might come through the tidal exchange. The major contribution of fertilisers on TN and TP supply in *gher* was also noted by Islam et al. (2004). However, in pond systems only about 5-30% of nutrients are exported to the final product in closed water system (Edwards, 1993) and in *gher* based systems it would be much lower as the water exchange takes place frequently.

Tidal water exchange in *gher* might brings extra benefit due to the presence of mangrove forest which provides e nutrients to aquaculture systems nearby (Islam & Haque, 2004). In this regard, aquatic farming in S-W Bangladesh has benefited from the tidal nutrient supplies from the nearby Sundarbans. Gordon and Bjørndal (2009), described how the addition of feed and labour in the farming system were found to be advantageous in Bangladesh more so than India and Indonesia shrimp farming. The use of formulated feed is rare across the system. This is because the farming system in Bangladesh is of low input and output and if farmers intend to feed the fish they currently rely on commonly available cheap agricultural ingredients and use of it as aqua feed. Tasnoova et al. (2015) found that there was wide use of agricultural ingredients as aqua feeds compared to shrimp farming in Vietnam.

In prawn farming systems farmers relied on relatively higher feed than the shrimp farming system. Ahmed (2013b), noticed that the better-off farmers used pelleted feed and the worse-off farmers mostly relied on snail meat as feed for prawn. In this study, it was found that the farmers, irrespective of their social well-being, utilised snail meat, and rarely used pelleted feed. It was witnessed in the current study that farmers believed that snail meat is easily and quickly transformable to prawn meat compared to other feed and feed ingredients. So, to get fleshy prawn and quick growth farmers tend to use snail meat. Ahmed (2013b) stated a higher amount of snail meat used per unit area in comparison to the current study. This decline might be due to the gradual reduction of snails in nature due to overexploitation. It was also found that snail meat use was context specific for example in the LS area the snail meat utilisation was much lower volume than the FW area. This is also due to the strong marketing network in the FW area. In LS areas farmers were equally involved in shrimp and prawn farming. A tendency among the farmers in the lower saline areas was observed to maximise the shrimp farming even in the almost freshwater area by using artificial salt (Bhowmik, 2016). The lower amounts of feed used in shrimp and higher amount in prawn farming also reflected in the numbers reported in the literature. More prawn feed based research than shrimp feed is evident in the literature (Ahmed, 2013b; Hossain & Paul, 2007; Jahan et al., 2015). The utilisation of lower feed amount and fertilisers in shrimp and prawn farming have proven successful (Chowdhury et al., 2011). One of the reasons is the low stocking densities where less feed is required to support the densities of animals stocked (Boock et al., 2016).

Very limited amounts of chemicals were used in aquaculture systems to treat water, sediment of farm and boost productivity. Use of chemicals in aquaculture system are relatively scarce in the South-east Asian countries shrimp farming (Graslund & Bengtsson, 2001). However, Rico et al. (2013) noted that among the Asian aquaculture producing countries Bangladesh use lesser amount of chemicals in aquatic pond. This is because the majority of the aquatic animal production originated from the extensive and semi-intensive system (Hall, 2004). Ali et al. (2016) also found in S-W Bangladesh chemical utilisation in the *gher* based aquaculture system was confined to the lower saline areas where production systems were more intensive than, the higher saline areas. Hoque (2013), also observed higher utilisation of inputs in the improved farming systems (semi-intensive) in the region. It was observed that in lower saline areas farmers used chemicals to maintain water quality and boost productivity however in the higher saline areas to avoid the devastating disease white spot virus. Nevertheless, chemicals used in aquaculture are less both in volume and frequencies than crop production in Bangladesh (Rahman, 2003). The lesser amount of utilisation of chemicals also established as extensive shrimp farm in Bangladesh was recognised as a sink for solids and nutrients in the water (Wahab et al., 2003) and not sources of pollution as shown for other shrimp farming systems in Asia (Primavera, 2006). Overall this low input-output system also had lower global environmental impacts –which are typically linked to use of formulated feeds based on high impact globally traded feed ingredients. Agricultural activities strongly impact the global carbon (C) cycle (Adhikari et al., 2014) regarding global warming and eutrophication the shrimp-prawn integration is in a better position than the prawn farming along with other fish species (Henriksson et al., 2015). One of the main reasons of chemicals use in S-W Bangladesh aquaculture was an attempt to control disease occurrence in the *gher*.

4.5.5 MAIN THREATS TO GAIN YIELD IN AQUATIC ANIMALS

The disease occurrence in the aquatic farming system and the degree of crop losses are described in section 4.3.6 and Table 4.3. The number of diseases has been reported in the system similar to the report of Alam et al. (2007) and Ali et al. (2016) in the same region. Most of the farmers did not have adequate knowledge about the disease and plan to tackle aquatic animal mortality (Ali et al., 2016). Therefore, regardless of specific disease problems especially in shrimp referred as white spot viral disease. Some of the farmers were able to notify the symptoms of white spot diseases by observing spots on the carapace, aggregation of shrimp and sluggish movements. Karim et al. (2014) noted that more than 50% *gher* in higher saline areas were affected by WSSV. This argument is widely supported by Hossain et al. (2015) where they observed 80% cultured shrimp in high saline and 40-50% in low saline areas were infected by WSSV confirmed by PCR (Polymerase Chain Reaction) test. The size of the *gher* also had an influence on the disease occurrence; bigger *ghers* were more affected compared to smaller *ghers* (Table 4.3). This also agreed with Karim et al., (2012) that larger *gher* tend to be more susceptible on disease occurrence. In lower saline areas some less risky diseases like an antenna and rostrum broken syndrome in prawn and EUS (Epizootic Ulcerative Syndrome) in finfishes was also noted (Ali et al., 2016). The higher crop loss and frequent disease occurrence was reported in the MS area where the water management was comparatively weak. The shallow water depth exacerbates temperature and salinity fluctuations that make the animals more susceptible to disease (Paez-Osuna et al., 2003). The shallow water depth in the higher saline areas was also recognised as a problem by Ahmed et al. (2014). Although, the water sources in lower saline areas were more unstable (rain-fed) than the higher saline areas (river/canal), the size and design of dykes facilitated maintaining the stability of water levels over a longer period. River, canal, and rainwater were also identified as the major sources of *gher* water by Ali et al. (2016) in the same region.

Tendencia et al. (2011) found a positive correlation between disease outbreaks, mortality of the main crop (shrimp) and the extra growth of co-habitat species. However, higher disease occurrence in the MS area did not lead to higher overall yields. It might be due to overall poor management and less access to wild recruited fish species in the system. Alam (2007), rightly cautioned for the better management of shrimp *gher* to obtain sustainable yield and increase the chance of shrimp co-habitat production. Therefore, frequent disease occurrence and crop loss in MS did not provide additional co-habitat fish production (Figure 4.7).

Apart from chemical use to resist diseases multiple stocking was another strategy used by the farmers (Ali et al., 2016). In general, this has been identified as a source of additional risk however in this study increased stocking frequency was positively correlated with the disease incidents (Section 4.3.3 and Table 4.3). This is why all certification schemes required all in and all out strategy and effective biosecurity. The S-W area of Bangladesh is very vulnerable to climate change which might bring more infectious diseases in aquaculture system and preventive measures should be taken to ensure food security (Leung & Sharma, 2000) and gain an economic return. Use of screened (PCR tested) PL and maintenance of proper water depth, lessen the knowledge gap of farmers about the disease and adopt better management practice that can minimise the disease occurrence. However, disease events are not the only factor that alters the yield. Other factors like wild recruitment and contribution of self-recruiting species also had influences on total yield and are depicted in the next section.

4.5.6 RELATION OF STOCKING AND HARVESTED YIELD

The stocking number and stocking frequencies of aquatic animals, mainly shellfish, decreased from higher saline to lower saline areas (Figure 4.2). This gradual decline in shellfish density was correlated with the proportion of shellfish of total harvested aquatic animal yield across the saline gradients. The survival rate, i.e. conversion of PL to harvested shrimp, was low and within the range of 18-50%, similar to the findings of others in the same region (Alam, 2014; Islam et al., 2005). The gradual decline of shellfish contribution in total yield from higher to lower saline areas was also acknowledged by other researchers (Barman & Karim, 2007; Nuruzzaman, 2006). This is because the multiple stocking and multiple harvesting of shrimp and almost year round farming kept high saline system yields higher than those in lower saline areas. The price of shrimp PL is lower than the prawn PL and available most of the time of the culture period that advantaged shrimp over prawn. Another cause also noticed was the shorter culture period of shrimp (120 days) than prawn (>180 days), which kept shrimp yield ahead of prawn, despite the level of direct feeding was insignificant in the former. The late brood maturation of prawn (after May) (Alam, 2014) and dependency on wild PL (Ahamed et al., 2012) which are available mainly during the monsoon period (Ahmed et al., 2008) are the other barriers of prawn farming compared to shrimp. The mangrove fish species also followed a similar trend. For that reason higher saline areas close to mangroves recruited more, and a greater diversity, of natural fish into HS ponds compared to lower saline areas. However, it depends on the connection of the *gher* to nearer canals or rivers as less connectivity to river/canal can give poor recruitment like MS area. Mangrove has a positive impact on the availability of fish (Blaber, 2007).

Freshwater fish species are widely available in the lower saline areas and mangrove fish species in the higher saline areas. Tilapia *spp*. in the high saline area was intentionally stocked in only a negligible number of *ghers* whereas in contrast, intentional stocking is the norm in the MS area. This reflected a relative paucity of recruited wild mangrove fish fry in the MS area and an adaptive strategy by farmers in these areas developing a tilapia/shrimp system to compensate for lower yields of wild mangrove fish. Juvenile wild mangrove fish were traded for stocking in local markets, but the price was unaffordable. Regrettably, not a single mangrove finfish species is being produced by hatcheries on a commercial scale in Bangladesh, but these results suggest the demand. Currently euryhaline tilapia appear to be substituting for mangrove fishes in the higher saline areas of S-W Bangladesh. Tilapias are widespread in *ghers* throughout the higher saline areas. Remarkably farmers in lower saline areas were not interested on tilapia as their priority was prawn and carps. Farmers believed tilapia killed prawn PLs and altered the biomass during overwintering carps and prawn juvenile nursing and they actively excluded tilapia (Professor Dr. Md. Abul Hossain, Noakhali Science and Technology University, personal communication, 2016).

Regarding the total yield of aquatic animals, the proportion of wild recruited species shares has been decreasing day by day as reported by the farmers. This not surprising as the natural resources are declining (Azad et al., 2009). The purposeful stocking of tilapia in MS area can be considered as the response of lower recruitments of wild mangrove fish species. However, the role of wild recruited species remains important in HS systems inevitable. Ensuring the current status, and/or and expanding the capacity for the Sundarbans to act as a natural breeding and nursery resource would be a major safeguard to the current system and future resilience of coastal aquatic farming systems in this part of Bangladesh. Wild biodiversity is a major source of food such as crustaceans and insects along with fish in freshwater rice based aquatic agricultural systems (Halwart et al., 2006).

The variable costs of seed on the balance sheet of aquatic animal production in S-W Bangladesh are balanced exactly. The higher number of shrimp PL of a relatively low price and lower number of prawn PL with a high price balanced the seed cost (Table 4.8). In lower saline areas the stocked freshwater finfishes were mostly overwintered to support adequate growth and returns in the shorter growth window. Higher disease occurrence, less natural recruitment of wild mangrove fish and the comparatively larger amounts of low priced tilapia explained the poorer overall performance of the MS areas. Between the social well-being group, the worse-off households produced higher amounts of aquatic animals per unit area than the better-off farmers. However, regarding production per household, the better-off remained higher than worse-off as the previous group had higher *gher* area.Worse-off farmers were involved in more diversified livelihood options, along with aquatic animal farming they used to sell their labour and/or do lower rank jobs (refer to Chapter 3 livelihood diversity). The poorer has limited alternative livelihood options (Godfray et al., 2010). However, Gautam and Andersen (2016) did not find a positive correlation between livelihood diversification and well-being status. As the financial outcomes of the livelihoods depend on the nature of the work, i.e., trade and salaried jobs, they provide higher economic return than the other jobs. Poorer households most of the time failed to combat the entry barrier and were prevented from getting access to higher salaried jobs. Therefore the poorer in this study were diversely involved in livelihoods, therefore got a similarly skewed effect to that of Gautam and Andersen (2016).

However, poorer people obtained higher yields from their small piece of land. It might be due to the deep intimate knowledge of small-holders about their local ecosystem and their ability to operate a diverse ecosystem (Ali, 2003). Small-holders can get more yield because they have a high level of commitment to production as their livelihoods rely on it (Boselie et al., 2003). The income dependency ratio was also high (Chapter 3) in the worse-off group which means a higher number of family members were involved in active work.However, their contributions are probably less in terms of economic return as they paid less in lower category jobs or work hard in their *gher*. These smallholders play an important role to diversify their farm products in an integrated way.

4.5.7 RESILIENCE OF DIVERSIFICATION AND INTEGRATION

Integrated aquaculture has potential to support food production and broader sustainability (Marques et al., 2016). It also provides a wide range of socio-economic and environmental benefits (Ahmed et al., 2014). Aquatic animal-rice and dyke cropping integration have been shown to improve livelihoods and the reduce vulnerability (Karim et al., 2011) of the households who utilised this technique (Sen, 2011). Integrated crop production intensity varied with the season, and it ultimately improved household-level food production and created food security (Shannon & Grieve, 1998). Kassie et al. (2013) noted that in sub-Saharan Africa crop rotation greatly enhanced land productivity. Tasnoova et al. (2015) comparing shrimp farming between Bangladesh and Vietnam observed that integrated farming of rice-fish was superior in Bangladesh. However, plot tenure, wealth, plot size, and location are important factors to gain success in aquaculture (Kassie et al., 2013). Shrimp-based systems required less labour compared to the prawn based rice-dyke system acknowledged by Barmon et al. (2004). The higher integration in low saline and freshwater area gave higher aquatic and terrestrial crop (Figure 4.7); however, the economic return is largely determined by the price of the product and the input cost. To estimate the overall contribution of aqua-agricultural integration along with the volume of production, the price of the product and the nutritional value are important to measure the sustainability of the system.

4.5.8 ECONOMIC RETURN AND SUSTAINABILITY OF THE SYSTEM

The net return from the aquatic animal production with integrated terrestrial crops varied greatly across the saline gradient. This range in net returns in the study is widely acknowledged in other reports (Ahmed & Flaherty, 2013; Hossain & Paul, 2007; Rahman et al., 2011). The economic return from one area to another area in this study was significantly different. Similarly, Townsend et al. (1998) stated that economic return could vary from region to region. The variable cost, the benefit-cost ratio (BCR), in the current study were similar to other studies in the same region (Ahmed et al., 2007; Ali et al., 2016; Islam et al., 2005). The overall higher yield in the freshwater area did not give higher economic returns as the price of carps was lower than the mangrove fish species. In MS areas, crop loss due to devastating disease and lack of wild recruitment of mangrove fishes kept them in the lower rank. Additional rice and dyke crops in the lower saline areas contributed about 15-30% of total profit of integrated systems thus indicating that aquatic animals are the key factor for economic return. The combination of shrimp-prawn-mangrove fish, freshwater fish along with dyke vegetable and rice gave an extra score to the low saline area. The abundance of mangrove fish along with minimum crop loss due to less disease occurrence advantaged the HS area. The higher feed cost (Table 4.9) in the freshwater area and the lower price of prawn co-habited minor carps and barbs kept the FW area behind despite the higher volume of yield. The higher assemblage mangrove and freshwater fish in LS area provided higher economic return in comparison to all other sites. The underwater biodiversity and the market value of the fish are the important factors to assess the economic return. The high priced mangrove fish availability have proven a benefit of the system (Blaber, 2007). It seems that the success of shrimp and prawn farming is dependent on many factors and not only on the integration. However, Kabir et al. (2015b) found that rice-shrimp system was superior to the rice/non-rice crop production in Bangladesh. Faruque et al. (2016) also found integrated farming in lower saline areas is better than the shrimp in high saline areas. However, geographical locations of the study sites were closer to each other compared to the current study.

For capital, farmers rely on both formal and non-formal sources of credit. The formal moneylenders were wholesalers, bank and NGO’s similar to other reports (Jahan et al., 2015). Shrimp and prawn wholesalers remained as the promoter of farming in the region who provided money to the farmers in advance against the verbal agreement that was established at the early stages of shrimp and prawn farming in Bangladesh (Guimarães, 1989). The interest rate of the bank was lesser than the other sources and the bank also provided a higher amount. The equal access to credit along with specialised training for women is important to reduce income inequality (Gurung et al., 2016). The lower economic return and high investment in the agri-aqua system in FW system involved the farmers in credit flow irrespective of social well-being group. The better-off tended to take a higher amount of loan than the worse-off households which is similar to the findings of Gurung et al. (2016). Large credit flow in feed based shrimp farming in India enhanced the higher productivity from shrimp farming (Ponnusamy & Pillai, 2014). The contribution of credit system for prawn farming was found inevitable in the north-west Bangladesh (Islam et al., 2015) and this trend was also followed in the prawn farming sites in the FW area of the current study. The interest rate of the bank is less than the other sources and the bank also provide higher amounts (Gurung et al., 2016). NGO’s were characterised by extremely high rate of interests and enforced rigid repayment conditions as was also observed by Andersson et al. (2011).

4.6 CONCLUSION

Bangladesh has overcome some environmental challenges noted by Alam and Thomson (2001) in aquaculture development in the last decades. In the case of shrimp and prawn farming, hatchery originated PLs supply increased many folds and the food value chain and market demand also played the key role. However, the feed based shrimp prawn farming is still under developed. Regarding sustainable farming, both shrimp and prawn have some advantages and disadvantages, similar to the mixed results obtained from both systems in technical efficiency tests (Begum et al., 2013; Rahman et al., 2011). However, number issues were identified in the current study; the first one is that the aquatic animal farming system is a small scale family driven polyculture system. Export of two items are given strong financial support to run the system and livelihood options where the adverse salinity does not ideally permit other agricultural activities. Therefore, Bell et al. (2015), argued that expansion of rice will not be profitable in the region while brackish shrimp can provide an equitable and sustainable livelihood. The second issue is the establishment of a proper water management scheme and the construction of a dyke. This is not only for the wide-ranging cropping but also to prepare farmers for the adverse effect of sea level rise due to climatic changes (Bhuiyan & Dutta, 2011). Thirdly, integration of major agricultural components are vital for food production, however the diversity of underwater fish species that can give higher economic returns that are perhaps important with regards to nutrient elements. Agro-biodiversity contributed to human nutrition via many pathways: dietary diversity and quality, generating income, enhancing the resilience of resources (Heywood, 2013).

Therefore, ensuring screened PL supply, proper water management, artificial propagation of few mangrove species or the creation of ‘no catch/ no cut’ zones in the mangrove resource is critical. Conservation of the mangrove resource will be the single most important factor to ensure resilience of current aquatic animal production in the S-W Bangladesh. The nutritional elements of the existing species will provide insights to the policymaker and practitioners to save the diverse system rather than jumping to species-specific aquaculture for food and nutritional security of the people. In the next Chapter, the aquatic animal species were presented from all the culture system and settings and the important nutritional elements analysed for public health development.

5 Chapter 5: Nutrient composition of aquatic animals produced in *gher* based aquaculture in south-west Bangladesh

5.1 Introduction

Fish in Bangladesh is an irreplaceable animal food source and a critical part of maintaining food security. Fish consumption is 18.1 kg/capita/year in Bangladesh, accounting for the supply of more than 60% of animal protein (DoF, 2015), and consumption frequency exceeds that of any other animal food source (Belton et al., 2014). Aquaculture is one of the fastest growing food production sectors in Bangladesh which is linked to the decline of capture fisheries (Belton & Thilsted, 2014). However, aquaculture development focuses on only a few large species that reduces the dietary fish diversity for people (Belton et al., 2014). Some commentators have warned that increased productivity based on only a few species would not meet the nutritional and health targets set and suggest making aquaculture more aligned with a nutrition-sensitive policy (Thilsted et al., 2016). Despite having vast aquatic resources together with improvement in some food and nutrition security indicators many people in Bangladesh are still suffering from malnutrition and different diet-related diseases (IFPRI, 2015).

Malnutrition is mostly caused by micronutrient deficiencies and has emerged as the real public health related challenge for many developing nations (FAO, 2012a). Globally, the direct cost of malnutrition is estimated at $20-$30 billion/year, and annual GDP (Gross Domestic Production) loss is 2-3% in developing countries (Grantham-McGregor et al., 2007). The hidden consequences of micronutrient deficiencies include depressed immune activity, cognitive development, child growth, reproductive performance and work capacity (Underwood, 2000). The problem of diet-related complexities is also a global issue with the consumption of high-fat foods and processed products as well as inappropriate dietary and lifestyle choices (FAO, 2012a).

These challenges can be met if people in the developing world receive adequate nutrient-rich solid foods (Grantham-McGregor et al., 2007). Michaelsen et al. (2009) have recommended identifying a minimum quantity of animal food to support acceptable child growth and development, particularly on essential nutrients. Some analysts have argued for the fortification of essential micronutrients (De Pee & Bloem, 2009). However, fortified foods do not always meet the declared level of micronutrients in developing countries

(Roos et al., 2013). Therefore, fish has attracted considerable attention as important sources of micronutrients in the human diet and for ensuring the food security of poorer people as well as providing essential elements for proper nutritional outcomes. Fish are a rich source of high-value protein, an excellent combination of essential micronutrients, vitamins, and long-chain Polyunsaturated Fatty Acids (LC-PUFA) (Karapanagiotidis et al., 2006). Fish also provide less well-known nutrients such as taurine and choline (FAO, 2014b), and, with some exceptions, is low in saturated fats, carbohydrate, and cholesterol (Sriket et al., 2007). Fish protein is like that of milk, eggs, and meat in the completeness of its amino acid profile (USDA, 2012). A portion of 150 g of fish provides around 50-60% of the daily protein requirement of an adult (FAO, 2012b). Some nutrient-dense fish contain 10-20 times higher levels of vitamin A and calcium respectively than other commonly cultured fish and as much as twice that contained in carrot and spinach (Prein & Ahmed, 2012). Both vitamin A and C can be stored in the liver for 3-4 months. As a result, the consumption of vitamin-rich fish even seasonally can be effective in meeting nutritional demands over longer periods (Haard, 1992).

The consumption of small fish in a traditional dish can achieve 45% of the daily iron requirement of a woman in Cambodia (Roos et al., 2007a). Small fish in Bangladesh tend to contain more micronutrients than larger fish species. At the household level smaller fish are distributed more homogeneously than larger fish and SIS (Small Indigenous Species) are also accessed by the poor (Roos et al., 2003). Small dried fish in a meal can lead to significant increase in iron, zinc, and calcium intakes to meet the needs of children in Malawi (Gibson & Hotz, 2001). Arsenault et al. (2013) worked in rural Bangladesh and found that both women and children are struggling to get adequate amounts of calcium in their diets. In developed countries, dairy products are a source of Ca, whereas in Bangladesh dairy consumption is much lower (HKI, 2014). Nevertheless, consumption of SIS with bones (as whole fish) are a significant source of highly bioavailable Ca (Larsen et al., 2000).

Long-chain n-3 PUFAs (polyunsaturated fatty acids) are important biomarkers to distinguish and characterise species in a given ecosystem (Budge et al., 2002), and can be used to compare the of the nutritional value of wild and farmed fish (Nettleton & Exler, 1992). Wild fish and fish from extensive farming systems contain a higher percentage of long-chain n-3 PUFA (Karapanagiotidis et al., 2006). In contrast, the tissue of intensively farmed fish culture is generally characterised by intraperitoneal fat (Nakagawa et al., 1991). Therefore, high amounts of long-chain n-3 PUFA is included in the feed to enhance the long-chain n-3 PUFA in farmed fish (Stone et al., 2011). Salinity levels of the water in which fish being cultured also influences the amount of fat and long-chain n-3 PUFA in fish (Love, 1988). Along with the agro-ecological impact on fish nutrition, the feed ingredients also had an impact on fish nutrition content (Fry et al., 2016). Climate-induced biochemical ecology change had an impact on the essential fatty acids (EFA) content in fish and consumers (Litzow et al., 2006)

The inclusion of long-chain n-3 PUFA in the human diet is important because consumption of long-chain n-3 PUFA has been shown to result in an inverse relationship with the occurrence of fatal and nonfatal Cardiac Heart Disease (CHD) (Harris et al., 2009). One suggestion for people to lead a healthy lifestyle was to reduce the saturated fat and n-6 fatty acids intake (Mackay et al., 2004). Long-chain n-3 PUFA, especially Eicosapentaenoic Acids (EPA; 20:5n-3) and Docosahexaenoic Acids (DHA; 22:6n-3) are associated with reducing the risk of cardiovascular disease (CVD) (Bragagnolo & Rodriguez-Amaya, 2001; Kris-Etherton et al., 2002) as well as being considered beneficial for infant growth and cognitive development (Koletzko & Cetin, 2007) and enhance the physiological processes (Simopoulos, 1999). Both EPA and DHA, together with Docosapentaenoic Acids (DPA, 22:5n-3), are mostly derived from fish or fish oil. A minimum consumption of 250-500 mg EPA+DHA per day is recommended for healthy life (Mozaffarian & Wu, 2012).

The same enzymes are required for both long-chain n-3 and n-6 PUFA desaturation, elongation and each class of PUFA has a different effect on human health, and an appropriate ratio of these two is important (Strobel et al., 2012). Previous studies suggest that an n-6/n-3 ratio of approximately 1:1 (Simopoulos, 2008) or between 1:1 and 5:1 (Simopoulos, 2002) is beneficial for human health. Based on current observations that ratio has become increasingly skewed with modern diets being rich in n-6. These ratios can be affected by taking supplements rich in long-chain n-3 PUFA, however consuming fish is more efficient (Elvevoll et al., 2006). Moreover, an imbalanced ratio in the human diet has been linked to chronic diseases (Simopoulos, 2002).

Many developing countries have made progress towards improved food and nutritional security. This improvement is mainly due to a better understanding of the role of a balanced nutritional diet, including essential vitamins and minerals, rather than just food production and consumption (Ahmed et al., 1999). Revolutions in information and increasing globalisation of such knowledge has underpinned this particular development platform (Pinstrup-Andersen, 1999). Indeed, Bangladesh has rightly chosen the fish food based approach to confronting food security and nutritional issues (GoB, 2011). The low input and output extensive *gher* based aquaculture in S-W Bangladesh has been shown to be a very complex and diverse system (Chapter 4). Despite the diversity and importance of fish for the local human population, little is known about the nutrient composition of fish from S-W Bangladesh. For linking farming systems with nutritional outcomes, knowledge on the nutrient composition of fish is important (Thilsted & Wahab, 2014).

In reviews on the nutritional composition of fish, references to brackish water aquaculture species in Bangladesh are greatly outnumbered by those dealing with the commercially important freshwater and small indigenous species. In a global context, the commercial freshwater as well as the cold-water marine species, particularly from the north such as Atlantic salmon (*Salmo salar*), tend to attract considerably more interest than brackish and freshwater species from the south. For example, the number of publications from Bangladesh indexed in Medline between 1991-2001 was less than ten indicating that little research is carried out on this topic (Mackay et al., 2004). Fish nutrition data on a species level is helpful to combat malnutrition in developing countries (Roos et al., 2003).

The objective of this chapter was to document the wide-ranging nutritional composition of all the commonly available fish and fishery products from existing culture systems along a saline agro-ecologies in S-W Bangladesh. The study aimed to document inter and intra-species nutrient variation and the impact of feeding and salinity in culture systems on nutrient content. It also aimed to clarify the nutrient contents of locally consumed species in comparison to export-oriented seafood. Processing by-products from the shrimp and prawn value chain are also considered as an almost equal volume of export products remain in Bangladesh as by-products. The identification of specific micronutrient rich fish may help in formulating an effective strategy including production, propagation, and conservation awareness.

The data in this chapter will help academics, dietician, practitioners and health extension workers as well as add value to the existing data sets.

Therefore, the specific research questions are

a) What is the nutritional role of fish and shellfish as a source of long-chain fatty acids (EPA+DHA), macro nutrients and micro nutrients on nutritional security?

b) Are there any environmental (salinity) and ecological impact on inter and intra-species variability of nutrients?

5.2 MATERIALS AND METHODS

Four communities from the aquatic animal farming area of S-W Bangladesh were purposely selected (Figure 2.8). The purposively selected saline areas were: 1) high saline (HS): water salinity >10 ppt; 2) medium saline (MS): water salinity is 5-10 ppt; 3) low saline (LS): water salinity <5 ppt; and 4) fresh water (FW): water salinity ≤0.5 ppt; (Figure 2.8). Three replicates from each site of four saline zones were selected. Culture systems; extensive, semi-intensive, intensive, organic and pocket *gher,* were considered as well. Like the previous Chapter, aquatic animals were categorised into different groups based on type, habitat, size and market orientation. Along with the agroecological settings, this categorization helped to understand the role of fish in local food and nutritional security together with export earnings for sustainable development. In the work focusing, fish type and habitat, aquatic animals were sub-grouped into four clusters: (1) Shellfish; (2) Mangrove fish; (3) Freshwater fish; and (4) By-products. Apart from *gher* raised fish only one wild fish species, *illish*, and its by-product (eggs) were considered. This is because as a single species *Illish* contributes about 13% to the total fish production volume in Bangladesh (DoF, 2015).

All fish collected for analyses were typical of the normal size for consumption. Shellfish covered all the major shrimp and prawn species in the region including mud crab. Freshwater fish and prawn were obtained from the freshwater and lower saline areas and the mangrove fish and shrimp from the higher saline areas. All of these aquatic animals were collected from farmer managed *gher* except *illish.* By-products (shell, head etc.) were largely derived from processing plants and prawn depots. Aquatic animals sampled were also subdivided into two groups based on their body size (1) Small Indigenous Species (SIS) and (2) large fish. Fish with a length less than 25 cm were considered as SIS (Roos et al., 2007b). As the aquatic farming system in S-W Bangladesh is linked to the international market, on the basis of market orientation aquatic animals were divided into two categories (1) export oriented (mainly shrimp and prawn) and (2) locally consumed fish. The sample size for each species from each system was a minimum of four, similar to Cladis et al. (2014) who used 3 samples for each species.

For the energy and micronutrient analysis, each species were pooled with duplication of each sample performed for energy and triplicates for micronutrients. The species collected from each saline culture system together with the sample portion taken for the analysis, including salinity and culture sources, are listed in Table 5.2. Sample portions were collected with the help of the household women which also contributed information about local cleaning processes (Roos et al., 2007a). By-products cleaned from shrimp and prawn was obtained from processing plants and depots after normal processing. The edible portion of the various species samples was homogenised, preserved and shipped under frozen conditions and analysed as detailed in Chapter 2 Sections 2.11.1. All the statistical analyses and graphs presented in this Chapter were performed using R statistical package (R Core Team 2016). Analytical procedures of collected samples used for each nutrient is outlined in Table 5.1.

Table 5.1 The analytical methods and references followed for each nutrient components analysis of aquatic animals in S-W Bangladesh

Parameter	Unit	Methods used	References
Protein	g/100 g	Automated Kjeldahl analysis (Tecator Kjeltec TM 2300 analyser, Foss, Warrington, UK)	(Karapanagiotidis et al., 2006)
Total lipid	g/100 g	Folch	(Folch et al., 1957)
Moisture	g/100 g	Air drying (AOAC 1990-942.05)	(Karapanagiotidis et al., 2006)
Ash	g/100 g	AOAC 1990-942.05	(Karapanagiotidis et al., 2006)
Energy	KJ/g	Bomb calorimeter (Foss, Warrington, UK)	(Doyle et al., 2007)
Fatty acids	g/100 g	GLC	(Karapanagiotidis et al., 2006)
Micronutrients	µg/100 g	Acid digestion, ICP MS	(Wheal et al., 2016) (Nuray Erkan & Özden, 2007)
Selenium	µg/100 g	ICP MS	(Silva et al., 2011)

Table 5.2 Details of aquatic animal collection area, culture systems and parts taken for nutritional composition analysis in S-W Bangladesh

Local Name	Common/English Name	Scientific name	Salinity[¥]	Culture Systems[λ]	Anatomical part analysed
Shellfish					
bagda	Black tiger shrimp	*Penaeus monodon*	1-4	1-4	Muscle
chaka	Indian prawn	*Penaeus indicus*	1-3	1-2	Muscle
chali	Yellow shrimp	*Metapenaeus brevicornis*	1-3	1-2	Muscle
goda	Goda River prawn	*Macrobrachium scabriculum*	1-3, 5	1-2	Muscle
golda	Giant freshwater prawn	*Macrobrachium rosenbergii*	3-5	1-2	Muscle
horina	Speckled shrimp	*Metapenaeus monoceros*	1-4	1-4	Muscle
rosna	Roshna prawn	*Exopalaemon styliferus*	1-3, 5	1-2	Muscle
tiger chingri	Green tiger prawn	*Penaeus semisulcatus*	1	1	Muscle
Mangrove fish					
aamadi	Pointed tail anchovy	*Coilia dussumieri*	1	1	whole fish
ayza	Finny snake eel	*Caecula pterygera*	1	1	Muscle
bele	Tank goby	*Glossogobius giuris*	1-5	1-2	Muscle
bhangon	Flathead grey mullet	*Mugil cephalus*	1-2	1	Muscle
bhola	Pama croaker	*Otolithoides pama*	1	1	Muscle
caine magur	Gray eel-catfish	*Plotosus canius*	1	1	Muscle
choto bele	Knight goby	*Stigmatogobius sadanundio*	1	1	Muscle
cucia	Mud eel	*Monopterus cuchia*	1	1	Muscle
datina	Bluecheek silver grunt	*Pomadasys argyreus*	1-2	1	Muscle
fesa	Gangetic hairfin anchovy	*Setipinna phasa*	1-2	1	Muscle
gaber dana	Spined anchovy	*Stolephorus tri*	1	1	whole fish
gullo/kalo chewa	Bearded worm goby	*Taenioides cirratus*	1	1	Muscle
gullo/lal chewa	Rubicundus eelgoby	*Odontamblyopus rubicundus*	1	1	Muscle
kakra	Mud crab	*Scylla serrata*	1-3	1-2	Muscle & gonad
kakshel	Ray-finned fish	*Barilius barna*	1	1	Muscle
kat koi	Crescent perch	*Terapon jarbua*	1	1	Muscle
khoira	Gizzard shad	*Nematalosa nasus*	1	1	whole fish
khorshola	Mullet	*Rhinomugil corsula*	1-5	1-2	Muscle
nona tengra	Long whiskers catfish	*Mystus gulio*	1-3	1-2	Muscle
parse	Parse	*Liza subviridis*	1-3, 5	1-2	Muscle
payra/chitra	Spotted scat	*Scatophagus argus*	1-3	1-2	Muscle
pora bele	Dusky sleeper	*Eleotris fusca*	5	1	Muscle
shilong	Silond catfish	*Silonia silondia*	1	1	Muscle
taposhi	Paradise Threadfin	*Polynemus paradiseus*	1	1	Muscle
therol/ekthutu	Congaturi halfbeak	*Hyporhamphus limbatus*	1	1	whole fish
vetki	Barramundi/Sea bass	*Lates calcarifer*	1-2	1-2	Muscle

Table 5.2 Details of aquatic animal collection area, culture systems and parts taken for nutritional composition analysis in S-W Bangladesh (Cont'd)

Local Name	Common/English Name	Scientific name	Salinity[¥]	Culture Systems[λ]	Anatomical part analysed
Freshwater fish					
bheda	Gangetic leaffish	*Nandus nandus*	5	2	Muscle
carpio	Common carp	*Cyprinus carpio*	3-5	2	Muscle
catla	Catla	*Gibelion catla*	3-5	2	Muscle
chanda	Asian glass fish	*Chanda nama*	5	2	Muscle
cheng	Gachua	*Channa gachua*	5	2	Muscle
Grass Carp	Grass Carp	*Ctenopharyngodon idella*	3-5	2	Muscle
koi	Climbing perch	*Anabas testudineus*	5	2	Muscle
Mirror carp	Mirror carp	*Cyprinus carpio*	2-3, 5	2	Muscle
mola	Mola carplet	*Amblypharyngodon mola*	5	2	Muscle
mrigal	Mrigal carp	*Cirrhinus cirrhosus*	3-5	2	Muscle
Pangus	Thai pangus	*Pangasius hypopthalmus*	5	2	Muscle
puti	Pool barb	*Puntius sophore*	3-5	2	Muscle
rekha	Silver tiger perch	*Coius quadrifasciatus*	3	2	Muscle
rohu	Rohou labeo	*Labeo rohita*	3-5	2	Muscle
shing	Stinging catfish	*Heteropneustes fossilis*	5	2	Muscle
shoal	Striped snakehead	*Channa striatus*	5	2	Muscle
Silver Carp	Silver Carp	*Hypophthalmichthys molitrix*	3-5	2	Muscle
taki	Spotted snakehead	*Channa punctatus*	5	2	Muscle
tengra	Tengra mystus	*Mystus tengra*	3-5	2	Muscle
Thai sarputi	Silver barb	*Barbonymus gonionotus*	2-3, 5	2	Muscle
Tilapia	Mozambique tilapia	*Oreochromis mossambicus*	1-3	1-2	Muscle
Tilapia (GIFT)	Nile tilapia	*Oreochromis niloticus*	1-3	1-2	Muscle
Wild					
illish	Hilsa shad	*Tenualosa ilisha*	Wild	Wild	Muscle
Snail	Apple snail	*Pila globosa*	Wild	Wild	Muscle
By-products					
bagda head	Tiger Shrimp	*Penaeus monodon*	1-4	1-4	Head
bagda shell	Tiger Shrimp	*Penaeus monodon*	1-4	1-4	Shell
golda brain	Giant freshwater prawn	*Macrobrachium rosenbergii*	3-5	1-2	Brain
golda claw muscle	Giant freshwater prawn	*Macrobrachium rosenbergii*	3-5	1-2	Claw muscle
golda shell	Giant freshwater prawn	*Macrobrachium rosenbergii*	3-5	1-2	Shell
horina shell	Speckled shrimp	*Metapenaeus monoceros*	1-4	1-4	Shell
tiger chingri shell	Green tiger prawn	*Penaeus semisulcatus*	1	1	Shell
illish egg	Hilsa shad	*Tenualosa ilisha*	Wild	Wild	Muscle

Notes: **Collection area Salinity**[¥] 1=high saline, 2= medium saline, 3= Low saline, 4= pocket gher, 5= Freshwater; **Culture systems**[λ]**;** 1= traditional, 2= semi-intensive, 3= intensive, 4= Organic

5.3 RESULTS

The mean value for each nutritional component for each of the species analysed is presented in Tables 5.3-5.6. The comparison of each species for the different culture systems and saline zones are presented in the Supplementary Tables 5.1-5.35 in the Appendix section. In this section, the ranges of the specific nutrient item in the four major fish groups are described.

In the shellfish group across the saline and culture systems, the energy content ranged from 366-892 KJ/100 g raw edible weights; crude protein ranged from 15.2-20.39, total fat 0.73-2.57, dry matter 18.59-21.99, and ash 1.16-3.54 g/100 g raw edible weight. The summary of the macronutrients are present in Table 5.3. However, the macronutrients in a different culture system and saline gradients are presented in supplementary Table (s) 5.1-5.5. In the fatty acids proportion of shellfish saturated fatty acids (SFA) was 29.22-36.21 and EPA, and DHA was 9.54-30.43%. The n-3/n-6 ratio ranged between 0.82-2.23. The fatty acids profiles (% of total fatty acids weight) are presented in Supplementary Tables 5.17-5.21. The mean long-chain n-3 PUFA (EPA+DHA) in mg per 100 g raw edible weight are shown in Figure 5.1.The calcium, iron, zinc and selenium content varied from 60.39-838.16, 0.37-11.2, 1-5.11 mg and 0.12-4.43µg, per 100 g raw edible weight, respectively (Table 5.3). Micronutrients that are not presented in Table 5.3 are also presented in Supplementary Table 5.33.

Among the different saline and culture systems for the mangrove fish group, the energy content ranged from 299.88-1010.13 KJ/100 g raw edible weights. Among the macronutrients crude protein levels ranged from 11.3-20.63, total fat 0.7-7.42, dry matter 17.35-26.34, ash 0.93-3.19 g per 100 g raw edible part (Table 5.4). As for shellfish, the micronutrients across the culture systems and saline zones are presented in Supplementary Tables 5.6-5.10. The saturated fatty acids (SFA) and EPA+DHA ranged 30.3-50.16, and 3.51-30.19%, respectively. The n-3/n-6 ratio ranged between 0.48-3.69 (Table 5.4). The fatty acids profiles in % of total fatty acids weight are presented in Supplementary Table 5.22-5.26 in Appendix 5.1. The mean long-chain n-3 PUFA that is >225 mg/100 g raw edible weight are presented in Figure 5.2. All the mangrove fish n-3 PUFA are shown in Supplementary Table 5.37. The calcium, iron, zinc and selenium content varied from 24.5-1696.8, 0.12-4.1, 0.27-3.0 mg and 0.02-2.68 µg respectively, per 100 g raw edible weight (Table 5.4). Micronutrients that are not presented in Table 5.4 are also presented in Supplementary Table 5.34.

In the freshwater fish group across the saline gradients and culture systems, the energy content ranged from 423.86-927.11 KJ/100 g raw edible weights. Among the macronutrients protein ranged from 15.09-19.07, total fat 0.63-9.76, dry matter 17.11-29.34, ash 0.96-4.89 g per 100 g raw edible parts (Table 5.5). The macronutrients related to specific culture systems and saline zones are presented in Supplementary Tables 5.11-5.15. In the fatty acids proportion of FW fish saturated fatty acids (SFA) was 27.67-48.72, and EPA+DHA were 2.23-19.17% to total fatty acids. The n-3/n-6 ratios were 0.25-3.43 (Table 5.5). The fatty acids profiles in % of total fatty acids weight are presented in Supplementary Table 5.22-5.26. The mean n-3 PUFA (EPA+DHA) that was >115 mg/100 g raw edible weight are presented in Figure 5.3. Moreover, then all of them are shown in Supplementary Table 5.38. The calcium, iron, zinc, and selenium varied from 26.6-1696.6, 0.36-19.6, 0.4-3.3 mg and 0.02-3.4 µg, respectively (Table 5.5). Micronutrients that are not presented in Table 5.5 are also presented in Supplementary Table 5.35.

In by-products group, the energy content ranged from 522-3080KJ/100 g raw edible weights. Among the macronutrients protein ranged from 7.3-23.08, total fat 0.63-46.56, dry matter 21.12-55.52, ash 0.79-10.62% (Table 5.6, and Supplementary Table 5.16). The saturated fatty acids (SFA) was 28.77-35.5, and EPA+DHA content was 0.7-16% in total percent of fatty acids. The n-3/n-6 ratios were 0.2-0.87. The fatty acids profiles in % of total fatty acids weight are presented in Supplementary Table 5.32.The calcium, iron, zinc and selenium content varied from 4.8-5247.1, 0.4-8.7, 22.9-143.5 mg and 0.22-33.5 µg, respectively. Micronutrients that are not presented in Table 5.6 are also presented in Supplementary Table 5.36.

Table 5.3 Nutritional composition (mean± SD) for macro and micronutrients and relative proportion of long-chain n-3 PUFA to total fatty acids in fatty acids content of raw edible portion of 100 g shellfish from the aquatic farming system in S-W Bangladesh

		Macronutrients g per 100 g					Fatty acids (% of FA)				Micronutrients per 100 g			
Species	n	Energy KJ	Fat	Protein	Dry matter	Ash	SFA	n-3 PUFA	n3/n6	EPA + DHA	Calcium mg	Iron mg	Zinc mg	Selenium µg
bagda	48	664±11	0.92±.1	20.4±2	22±2	1.3±.2	30.6±2	21.3±3	.95±0.2	18.2±2.5	104±6	0.37±.03	1.4±.05	0.46±.02
chaka	20	475±20	1.2±.1	20±.7	21±.8	1.2±.09	31±1.6	24±1.4	1.3±.2	20±1.6	60.4±3	1.6±.12	1.2±.06	0.63±.10
chali	20	451±11	1.4±.08	18.6±.7	20.6±1	1.3±.3	33±2	26±1.6	1.5±.14	22.5±1.4	63.3±7	0.94±.09	1±.11	0.26±.02
goda	24	460±13	1.15±.1	17.9±1	19.5±2	1.2±0.2	31±3	18±3	1±.18	14±2.2	76±2.6	1.4±.17	1.4±.16	4.4±.3
golda	12	665±59	1.15±.2	19±.71	21.8±1	1.2±.14	31±1.7	13.9±4	.82±.3	9.5±5	83±7.7	0.87±.07	1.5±.13	0.17±.02
horina	36	430±1	1±.08	18.8±1	20.6±1	1.4±.7	32.5±4	20.5±4	1±.31	16.4±4	95±9	1±.18	1.9±.15	0.12±.02
rosna	24	366±6	1.2±.2	16.8±.8	19±.86	1.3±.35	32.5±2	25.7±3	2±.5	22.7±3	838±11	11.2±1	5.1±.24	4.4±.33
Mud crab	20	892±12	2.6±.2	15±1.6	20.5±2	3.5±1.4	36.2±2	18.2±3	1±.1	13±3	749±37	1±.08	1.5±.08	0.3±.02
tiger chingri	4	451±10	.73±.05	16.2±.1	18.6±1	1.2±.07	29.2±.7	34.2±.3	2.3±.05	30.4±.2	182.7±5	0.86±.11	1.2±.16	2.4±.12

Table 5.4 Nutritional composition (mean± SD) for macro and micronutrients and relative proportion of long-chain n-3 PUFA to total fatty acids in fatty acids content of raw edible portion of mangrove fish from the aquatic farming system in S-W Bangladesh

		Macronutrients g per 100 g					Fatty acids (% of total FA)				Micronutrients per 100 g			
Species	n	Energy KJ	Fat	Protein	Dry matter	Ash	SFA	n-3 PUFA	n3/n6	EPA + DHA	Calcium mg	Iron mg	Zinc mg	Selenium µg
aamadi	4	712.71±3	2.1±0	16.42±	19.3±1	2.7±0.5	45±.2	25.6±0	3.3±.1	20.3±0	838.3±3	3.3±.4	2.52±.2	2.68±.2
ayza[l]	4	637.3±17	2.7±0.1	19.6±.5	23.2±.5	2.2±0.8	39.9±.6	8.2±.4	0.82±0	3.5±.3	549±44	0.58±.1	2.19±.2	0.72±.05
bhangan[l]	8	460.7±26	2.89±.4	19.3±.4	23.7±1	1.16±.2	36.3±.5	26±3.5	3.5±0.9	16.9±3	28.2±2.9	0.63±.05	0.7±0.1	0.36±.05
bhola[l]	4	583.7±87	0.7±.06	11.3±.5	17.5±.4	2.1±.7	30.3±.2	33±0.7	2.1±.04	28.8±.1	24.4±2.3	1.38±.1	0.52±.02	0.14±.02
caine magur[l]	4	299.9±25	6.62±.4	17.9±.3	24.8±.6	1.01±.1	39.3±.2	11.6±.1	0.95±0	4.7±1.5	467±46	0.68±.06	0.65±.09	0.07±.01

Table 5.4 Nutritional composition (mean± SD) for macro and micronutrients and relative proportion of long-chain n-3 PUFA to total fatty acids in fatty acids content of mangrove fish from the aquatic farming system in S-W Bangladesh (Cont'd)

		Macronutrients g per 100 g					Fatty acids (% of total FA)				Micronutrients per 100 g			
Species	n	Energy KJ	Fat	Protein	Dry matter	Ash	SFA	n-3 PUFA	n3/n6	EPA + DHA	Calcium mg	Iron mg	Zinc mg	Selenium µg
cucia[l]	4	617.7±1.7	1.21±.1	18±1	20±.45	2.04±.5	32.8±.9	17±1.5	0.74±0	7.5±1	26.2±2.8	0.71±.02	0.72±.05	0.08±.01
datina[l]	8	648±2.89	4.8±0.9	19.5±.4	24.6±1	1.2±.3	40.7±1	15.3±.8	1.4±.08	7.9±2.2	987±153	3.4±0.2	2.4±0.3	2.08±.3
fesa	8	445±31	3±.6	17.1±.7	21.8±1	2.3±.2	40.9±2	21±2.3	2.8±.2	13.8±3	100±14	0.54±.06	0.71±.06	0.02±0
gaberdana	4	619±5	1.09±0	14.2±.9	17.6±.3	1.84±.1	39.4±.2	34.4±.5	3.4±.04	30.2±.3	1368±41	1.2±.03	3.04±.07	0.41±.04
kakshel	4	441.7±11	1±.03	17±.4	18.8±.1	0.9±.08	34.5±1	19.7±.8	0.8±.01	12.3±.8	310±42	1.3±.13	0.94±.1	0.58±.02
kalogullo	4	357±24	0.7±.05	16.6±.3	19.2±.4	1.4±.6	43.4±1	23.4±2	3.3±.3	17.8±2	593±30	1.33±.2	1.7±0.1	0.9±0.11
katkoi	4	1010±21	4.8±.4	19.6±.9	24.5±.6	1.2±.3	41.7±1	19±3	2.3±.9	12.4±3	195±22	0.86±.08	0.55±.07	0.17±.02
khoira	4	410.4±18	1.07±1	18±.3	21.7±.6	3.4±.5	36.5±.8	32.2±0	2.6±.03	28±.24	140±2	0.74±.12	1.2±0.05	0.53±.08
khorshula	28	491±5	3.3±.8	19±1	23.7±2	1.9±.7	45.3±2	18.3±4	2±.8	7.7±1.7	654±40	0.94±0	1.5±.2	1.4±.2
lalgullo	4	767±32	0.8±.07	17.1±.7	20.1±.5	1.5±.3	41.6±.8	7.9±.3	0.5±.04	4±.12	50.2±6.7	0.12±0	0.27±.03	0.06±.01
nona tengra	20	501±57	5.1±.9	17.8±.6	25±1.6	2.6±1	42.9±7	12±2	1.3±.32	6.5±.7	559±9	0.93±.1	1.9±.2	0.8±.09
parsey	24	637±17	7.4±1	17.5±.9	26.3±2	1.4±.5	43.8±4	14±2	2±.6	7.9±2.7	661±65	2.3±.2	1±.09	0.93±.13
payra	20	539±6	5.8±1	18.5±1	26.3±2	1.9±1	45±2	11.6±2	0.92±.4	6.4±2	637±14	4.1±.2	1.7±.03	1±.02
shilong[l]	4	969±60	2.8±.1	17.4±.2	21±.1	1±.06	43.7±.6	12.1±.1	1.1±.08	8.4±.07	103±9	1.2±.1	0.78±.04	0.2±.02
taposhi	4	581±83	1.8±0	17.3±.2	20.8±.7	1.8±.2	50±.8	12±.9	3.7±.2	9.4±.7	1696±20	1±0.1	1.5±.1	1.6±.2
therol	4	610±33	2.6±.1	18.9±.6	23.2±2	3.2±.5	35±4.5	25.8±3	1.8±.7	9.7±5	34.6±5	0.39±0	0.39±.05	0.02±0
vetki[l]	16	655±19	4±.6	20.6±.3	25.7±.9	1.1±.1	40.5±1	17±.5	1.7±.42	6.4±1	97±2	0.29±0	0.3±.02	0.07±.01

[L] is for large fish, and the rest are Small Indigenous Species (SIS) which measured with bone,

Table 5.5 Nutritional composition (mean± SD) for macro and micronutrients and relative proportion of long-chain n-3 PUFA to total fatty acids in fatty acids content of raw edible portion of freshwater fish from the aquatic farming system in S-W Bangladesh

	Macronutrients g per 100 g						Fatty acids (% of total FA)				Micronutrients per 100 g			
Species	n	Energy kJ	Fat	Protein	Dry matter	Ash	SFA	n-3 PUFA	n3/n6	EPA + DHA	Calcium mg	Iron mg	Zinc mg	Selenium µg
bele	28	718±51	0.7±.2	18.6±.5	19.8±1	1.1±.4	35.6±2	24.6±2	1.4±.5	17.9±3	256±6.6	.64±.1	1.2±.07	0.43±.05
bheda	4	465±22	3±.13	18±.4	22±1.4	1.6±.2	32.5±.1	12.6±.3	0.7±.02	3.8±.1	50.7±3.7	.56±.1	0.94±.12	0.13±.02
catla[l]	12	477±13	0.75±.1	17.7±.5	19.8±.9	1.1±.07	34.6±.9	25.5±3	1.6±.36	19.2±2	1696±19	12.3±1	2.9±.2	2.3±.17
chanda	4	423±12	2.9±.1	16.2±.1	23.3±.6	4.9±.1	38.1±.1	22.6±.1	2.2±.02	13.4±.1	135±5	0.85±.1	0.58±.06	1.7±.12
cheng	4	496±8	0.75±.1	16.3±.3	17.1±.4	.96±.1	36.5±.2	26.6±.5	1.6±.04	19.1±.3	677±64	0.39±0	1.4±.08	1±.12
choto bele	4	821±9	0.69±0	15.1±.4	17.9±.6	1±.05	48.7±2	12±.9	3.4±.09	9.5±.84	77±5	1±.14	1.4±.1	0.17±.02
Common carp[L]	12	812±21	1.3±.4	17.3±1	20.5±1	1±.09	29±1.3	13.2±5	0.5±.17	8.9±4.6	37.4±1.5	0.38±0	0.98±.06	0.09±.01
Grass carp[L]	12	736±61	1.3±.3	17.5±1	19.3±2	1.1±.09	27.7±1	20±11	1.2±.8	7.2±5.6	1128±56	1.6±.1	0.9±.03	2±.23
koi	4	892±12	9.7±1	17±.6	29.3±.6	2.7±.8	33±.2	4.5±3	0.25±.17	2.2±1.6	136±11	0.57±0	1.5±.03	0.24±.02
Mirror carp[L]	12	583±38	1.7±.6	17.2±.8	20±1.4	1.07±.1	36.8±6	8.5±2.2	0.54±.17	4.7±2	987±10	2±.05	2.8±.14	2.2±.29
mola	4	460±18	4.4±.4	16.7±.2	23.7±1	3.2±.7	37.8±.8	22±1.4	2.3±.16	8.2±.6	92.8±8.4	0.7±.09	0.66±.06	0.07±.01
mrigal[l]	12	802±40	1±.37	18±.93	20±.81	1±.13	34±1.6	23±5.8	1.2±.35	16.6±5	138±15	1.5±.1	0.6±.04	0.74±.02
Pangus[L]	4	439±21	2.4±.3	17.4±.4	19.5±2	1.1±.1	39±.7	12.3±.9	0.77±0	8.2±.7	443±38	0.46±0	1±.16	2.5±.3
porabele	4	525±11	0.78±0	16.7±.2	19.3±.8	1.9±.2	37±.08	17.4±.1	0.79±0	10±.1	1286±8	3.8±.3	3.2±.1	3±.2
puti	12	507±16	1.9±.5	17±.6	21.3±.8	3.2±.7	36±2	18.5±3	1.2±.3	10.6±3	54±5	0.43±0	0.6±.05	0.17±0
rekha	4	827±2	2.5±0	17.6±.1	21.5±.3	.97±.1	46±.12	11±1.3	0.99±.1	7.3±1	34±4	1.2±.2	0.75±.1	0.2±.02
rohu[l]	12	466±7	2.2±.6	18.8±2	21±1	1.2±.1	32±1.6	24±1	1±.25	14±4	29.6±.9	0.4±.01	0.6±.02	0.02±0
shing	4	742±12	1.8±.4	16.9±.6	18.8±.8	1.3±.1	33.3±.6	8.8±.3	0.6±.01	5±.14	180±23	0.4±.07	0.7±.08	0.2±.03
shoal	4	916±11	63±.1	18.5±.2	19.3±.3	1.2±.1	35.6±0	20.3±0	1.08±0	16±.01	1042±8	20±2	1.9±.2	3.4±.6

Table 5.5 Nutritional composition (mean± SD for macro and micronutrients and relative proportion of long-chain n-3 PUFA to total fatty acids in fatty acids content) of freshwater fish from the aquatic farming system in S-W Bangladesh (Cont'd)

		Macronutrients per 100 g					Fatty acids (% of total FA)				Micronutrients per 100 g			
Species	n	Energy kJ	Fat(g)	Protein(g)	Dry matter	Ash	SFA	n-3 PUFA	n3/n6	EPA + DHA	Calcium mg	Iron mg	Zinc mg	Selenium µg
Silver carp[L]	12	674±38	1.1±.2	17.4±1	19.5±1	1.1±.1	35.3±3	21.8±6	1.5±.4	13±6	101±13	0.4±.03	0.6±.05	0.5±.04
taki	4	532±12	1±.05	18.6±.5	20±.6	2±1	36.7±.8	18±4.5	1.1±.5	10.7±2	64.8±7	0.5±.02	0.4±.03	0.16±0
tengra	8	873±6	5.3±.6	15.7±.4	23.3±1	1.9±.5	42.5±1	6±3	0.6±.4	3.±2	26.6±4	0.41±.1	0.5±.03	0.17±0
Thai puti	12	927±16	2.9±.5	18±.5	21.7±1	2±.7	40±1.6	10.2±3	0.8±.2	4.3±2	50±7	3.1±.2	0.5±.04	0.24±0
Tilapia[SRS]	20	469±16	2.2±.3	18.7±.5	23.2±1	2.4±.5	39.4±3	18.4±4	1.9±1	7.1±2	83±7.6	0.6±.06	1±.07	0.03±0
GIFT Tilapia[SRS]	20	718±51	2.4±.3	19±1	24.4±1	2.4±.5	38.4±3	14±7	1.3±.7	4.7±1	256±6	0.64±.1	1.2±.1	0.43±.1

[L] is for large fish, and the rest are Small Indigenous Species (SIS) which measured with bone, SRS= Self Recruiting Species

Table 5.6 Nutritional composition (mean± SD) for macro and micronutrients and relative proportion of long-chain n-3 PUFA to total fatty acids in fatty acids content) of raw portion of by-products from the aquatic farming system in S-W Bangladesh

		Macronutrients per 100 g					Fatty acids (% of total FA)				Micronutrients per 100 g			
Species	n	Energy kJ	Fat (g)	Protein (g)	Dry matter	Ash	SFA	n-3 PUFA	n3/n6	EPA + DHA	Calcium mg	Iron mg	Zinc mg	Selenium µg
bagda head	4	820±10	2.3±.20	15±1.4	28±.30	6±.72	32.5±1	13±3.2	0.6±.22	9.2±2	2662±300	6.2±.3	126±18	33±5
bagda shell	4	742±12	1.1±0	17±.3	32±10	8.4±1	30±1.1	20±3	0.9±.2	16±3	4788±547	5±.3	100±11	19±1
golda brain	4	937±10	47±20	7±.07	55±1.7	0.8±.02	35±.9	2±.2	0.2±.01	0.7±.1	16±2	7±.6	66±5	10±1
golda claw	4	800±14	1.8±.20	17.6±.5	22±.80	1.6±.1	28.7±1	9±.24	0.5±.01	7±.1	147±12	0.4±.08	144±10	11±1
golda head	4	3080±13	2±.20	13.5±1	25±1.20	5±2	34±2	12±4	0.9±.4	8±4	1409±153	8.6±1	78±12	8.8±.6
golda shell	4	823±80	1.3±.40	17±.3	31±10	11±.3	32±1	13±3	0.8±.1	9±2	5247±434	8.7±.4	93±3	5±.9
horina shell	4	522±22	2.±.40	14±.5	21±10	7±1	35±.7	14±.1	0.8±.03	8.4±.2	2838±165	4±.1	92±4	0.37±.1
tiger chingri shell	4	1421±30	0.7±.10	15±.8	24±.20	6.7±.4	32.5±1	16±.5	0.74±0	11±.6	4.8±.7	1.5±.1	23±3	0.2±.03
illish[L¥]	4	425±5	18±10	15±.5	37±10	1.4±.1	47±.5	10±.4	4.5±.2	7±.3	4732±160	2.4±.4	55±3	0.09±0
illish egg[¥]	4	820±10	29±2	23±.2	52±1	1.6±0	24±1.5	21.3±1	5.7±.1	18±1	2662±300	6±.25	126±18	33±5
Snail[*]	4	518±22	1.6±.2	9.3±.6	18±.8	3.7±.1	31±1	12±.4	0.5±.02	1.3±0	358±24	1.5±0	1.2±.1	0.2±.01
Total sample (n)	**672**													

[L] is for large fish, and the rest are Small Indigenous Species (SIS) measured with bone, *Snail is not as used as human food, widely used in prawn *gher* as feed. [¥]Wild source;

Table 5.7 Nutrition composition of major fish and fish products in aquatic seafood production system in S-W Bangladesh

Nutrition	Attributes/100 g raw weight	Example of fish and by-products
High fat	>5 g	*golda* brain, *illish* egg, *illish, koi, parsey, payra, caine magur, nona tengra, tengra, datina*
Fatty fish	< 5 g>3 g	*vetki, katkoi, khorshula, mola, fesa, bheda chanda*
Low fat	>1 g<3 g	tilapia, *rohu,* mud crab, *puti, shilong, ayza, therol,* Thai puti, *shing, aamadi, taposhi*
Very low fat	<1 g	*shoal, bele, bagda, catla, mrigal, bhola, horina, golda*
High Protein	>20 g	*illsh, illish* egg, *bagda, vetki, payra, chaka, horina, katkoi, rohu, golda*
Medium Protein	>15 g<20 g	*khorsula,* grass carp, *bele,* tilapia, *datina, bhangan, mrigal, therol,* silver carp, *cucia, chali,* Thai puti, *nona tengra, catla*
Low protein	<16 g	*golda* brain, *bhola,* mud crab, *golda head, illish, choto bele,* silver carp
n-3:n-6	>3	*illish* egg, *illish, bhangan, taposhi, khorshula, parsey,* tilapia, *aamadi, bele, kalo gullo*
n-3:n-6	>1<3	*goda, puti,* mud crab, *shoal, horina, vetki, chaka, payra*
n-3:n-6	<1	*golda* brain, *koi,* common carp, *tengra,* grass carp, *bagda,* Thai puti, *caine magur,* pangus
EPA+DHA	>25%	*tiger chingri, gaberdana, bhola, khoira, rosna,* silver carp
EPA+DHA	>20%	*chali, aamadi, horina, chaka*
EPA+DHA	<10%	*golda* brain, *tengra,* grass carp, Thai *puti,* common carp, *ayza, fesa, golda* head.

TOTAL N-3 PUFA CONTENT COMPARISON

The total long-chain n-3 PUFA content of fish in different clusters was tested and presented in this section. The clusters were then subdivided into different sub-groups depending on the destination and size of the fish, shellfish, and utilisation of by-products.

5.3.1 TOTAL N-3 PUFA (IN WEIGHT) IN SHELLFISH

Almost all of the frozen food that Bangladesh exports belong to this group. Depending on the destination of shellfish two sub-groups were made, exported and locally consumed. Almost all the mud crab and *bagda* were traded on the international market, with just 5% consumed locally. Similarly, 75% of prawns produced were destined for the global market with the remainder, especially undersized prawns, eaten in the domestic markets, big cities, restaurant, etc. Conversely, only 10% of *horina* found its way to international markets (Kabir, 2014).

The mean variations of total n-3 PUFA in mg/100 g raw edible weights of shellfish are presented in Figure 5.1. The mud crab contained a significantly (P<0.05) higher amount of total n-3 PUFA than all other shellfish in the group. This was followed by *chali*, *rosna*, *chaka*, *tiger chingri*, *goda*, *bagda*, *horina* and *golda* in descending order respectively. The locally consumed shrimp contained 100-140 mg total long-chain n-3 PUFA in 100 g raw edible parts, and most surprisingly, two vital export products *bagda* (shrimp) and *golda* (prawn) contained <100 mg (Figure5.1).

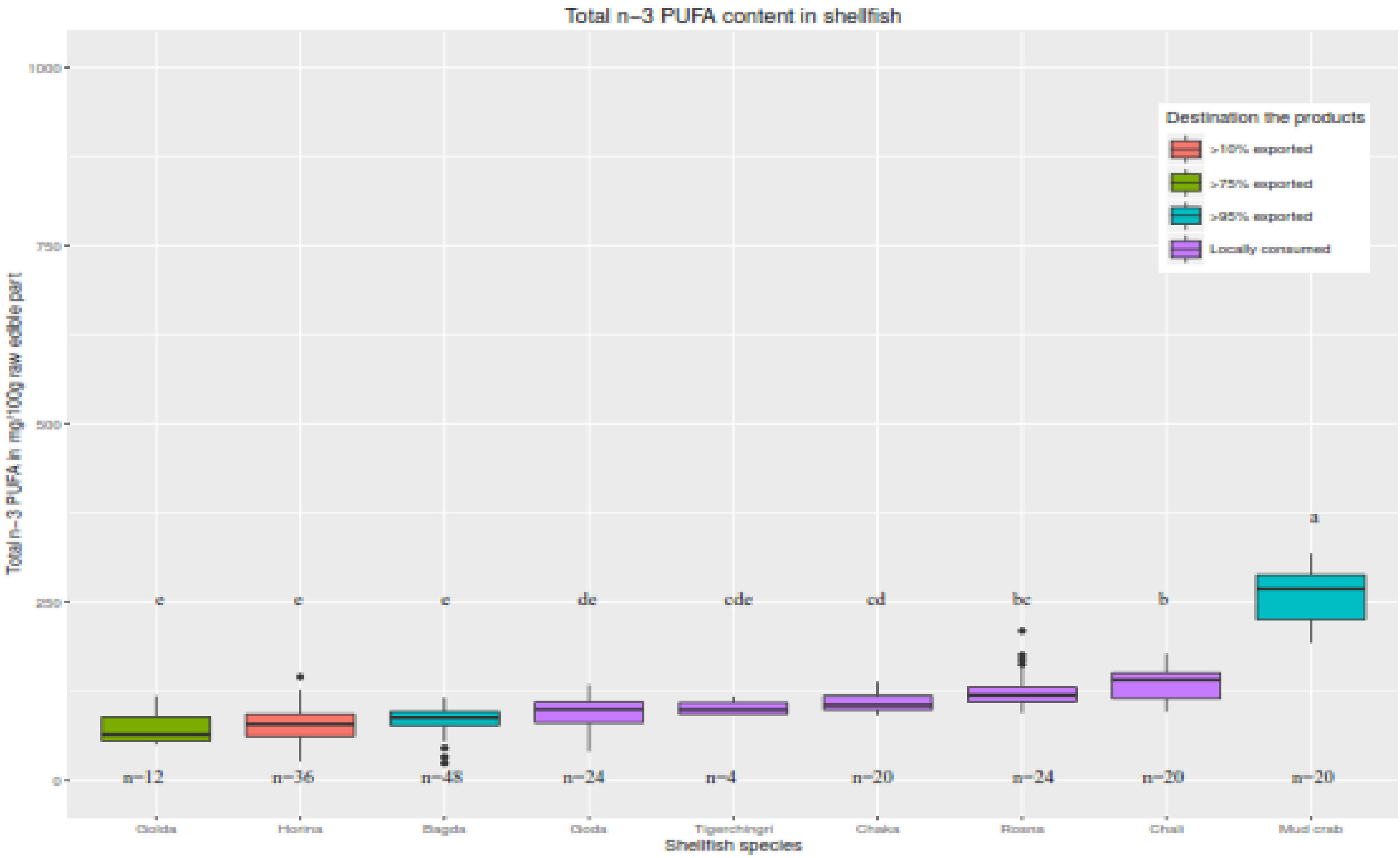


Figure 5.1 Mean total long-chain n-3 PUFA (mg/100 g raw edible parts) in shellfish species in aquatic farming area in S-W coastal Bangladesh [Different superscripts letter above the whisker were significantly different (P<0.05)]

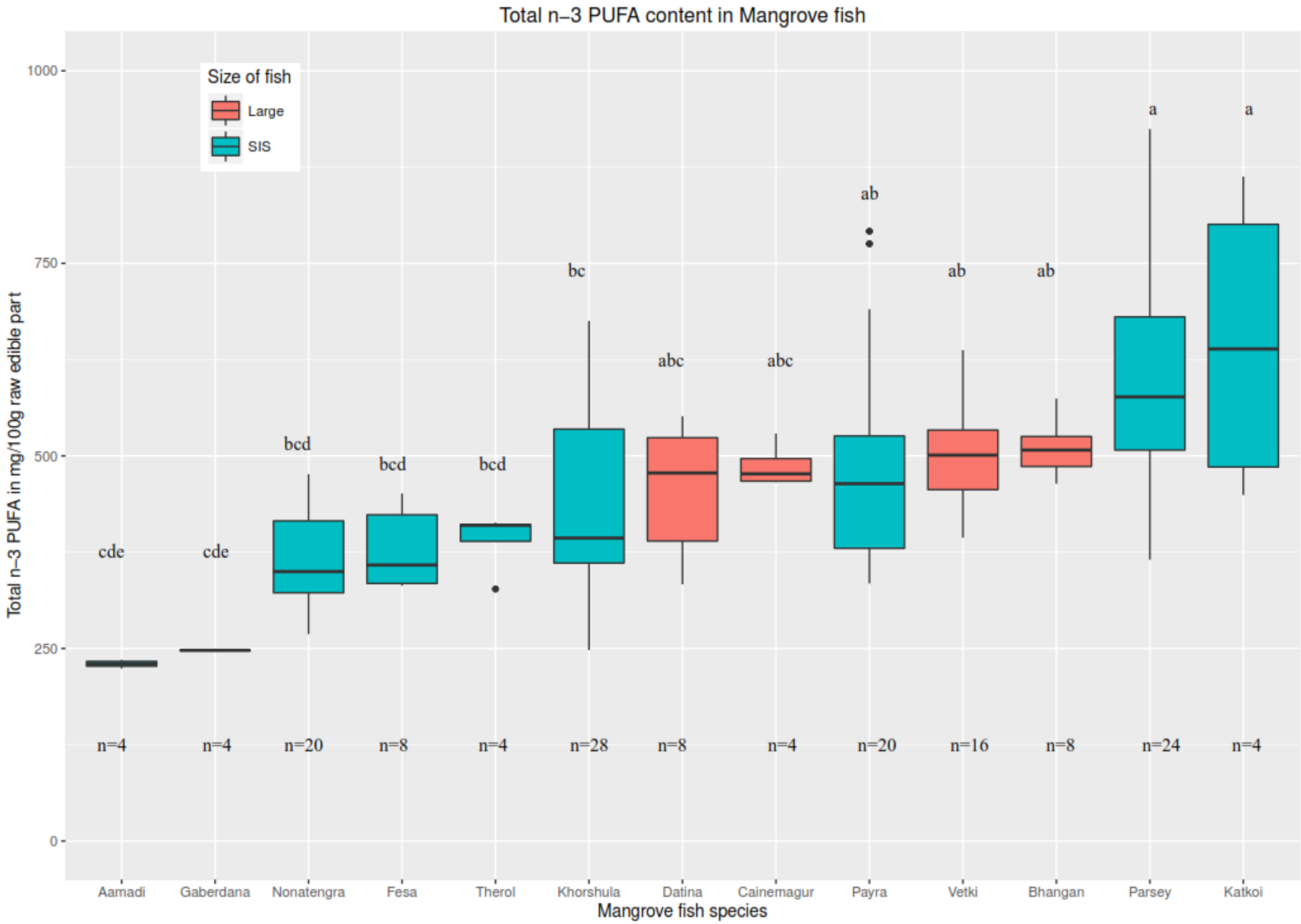


Figure 5.2 Mean total long-chain n-3 PUFA (mg/100 g raw edible part) in mangrove fish (total n-3 PUFA>225 mg) species in aquatic farming areas in S-W Bangladesh [Different superscripts letter above the whisker were significantly different (P<0.05)]

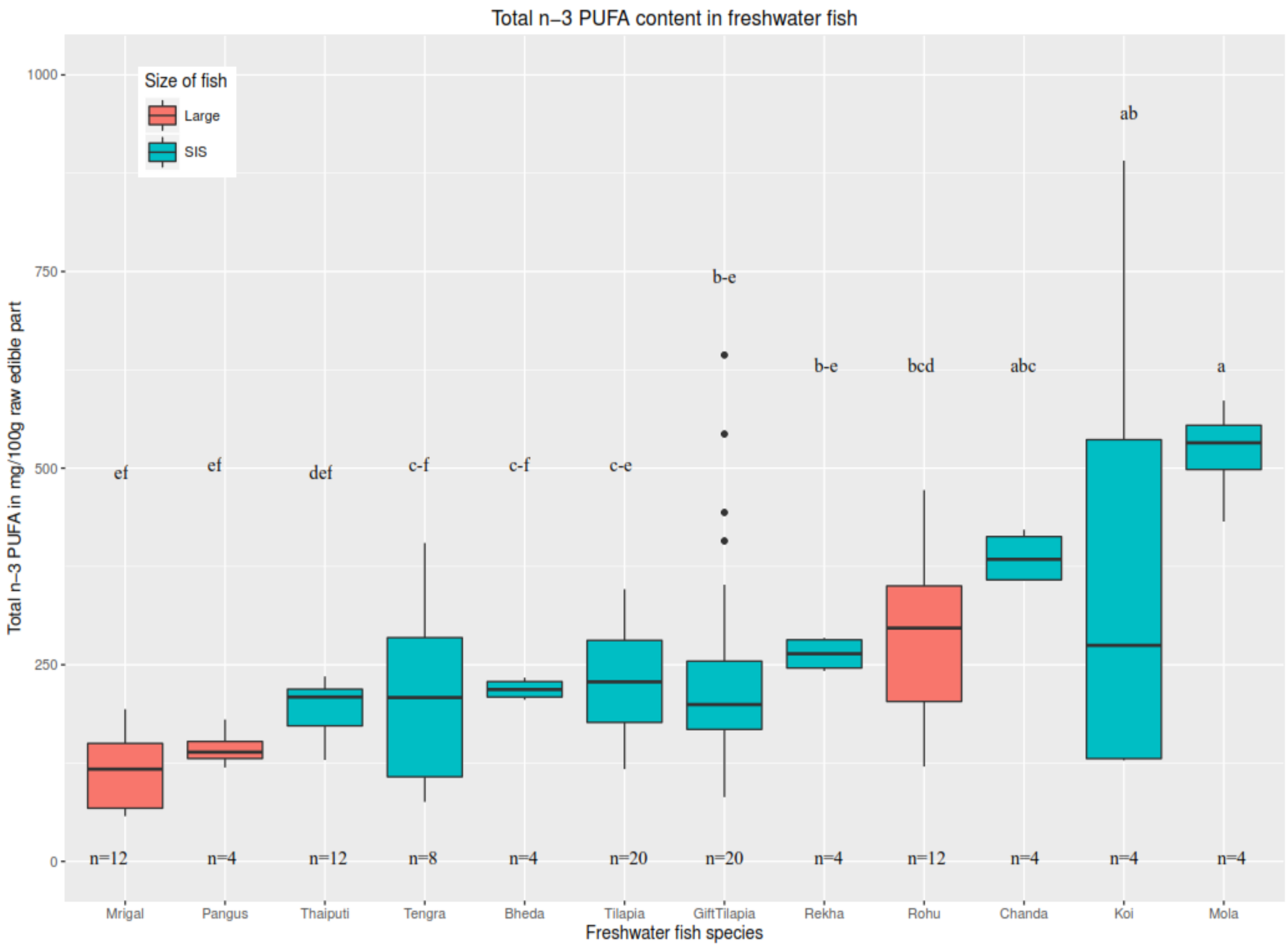


Figure 5.3 Mean total long-chain n-3 PUFA (mg/100 g raw edible part) in Freshwater aquatic species (n-3 PUFA>115 mg) in aquatic farming system in S-W Bangladesh [Different superscripts letter above the whisker were significantly different (P<0.05)]

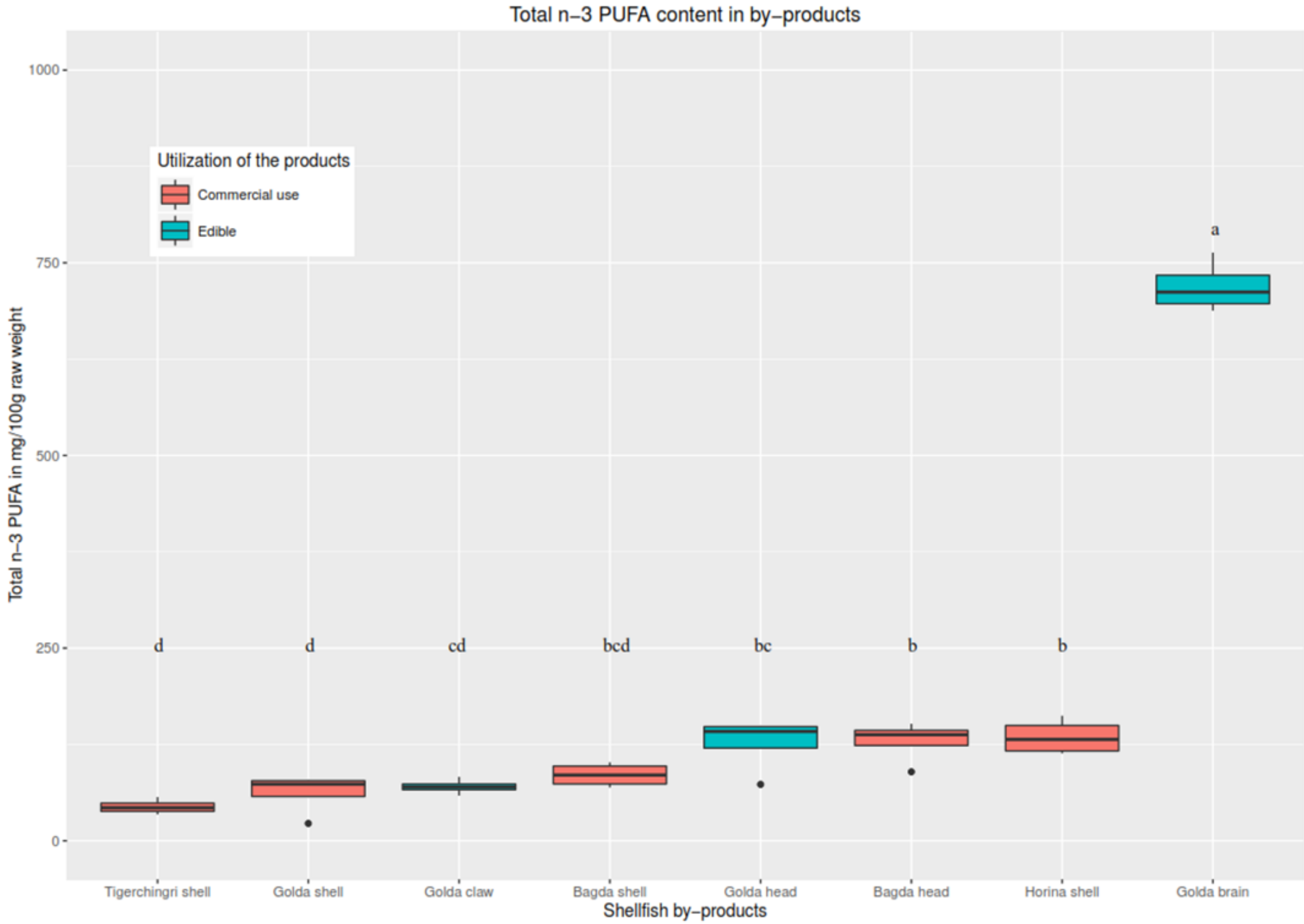


Figure 5.4 Mean total long-chain n-3 PUFA (mg/100 g raw weight) in shellfish by-products (n=4 for each sample) in the aquatic farming system in S-W Bangladesh [Different superscript letters above the whisker were significantly different (*P*<0.05)]

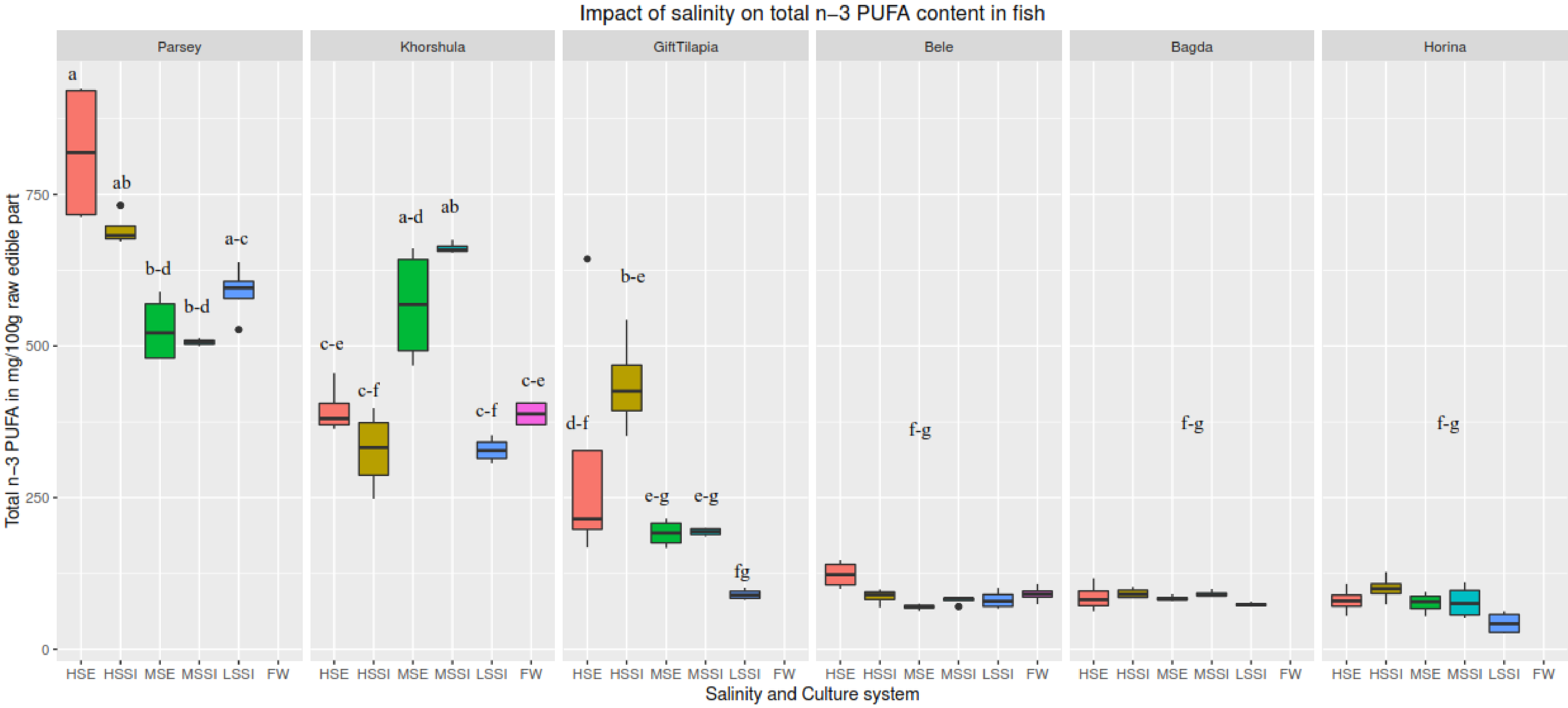


Figure 5.5 Levels of total long-chain n-3 PUFA (mg/100 g raw edible part) measured in selected aquatic animals in a range of culture systems and salinity regimes in S-W Bangladesh [Different superscript letters above the whisker were significantly different (*P*<0.05)] [HSE=High saline Extensive, HSSI=High saline semi-intensive, MSE=Medium saline extensive, MSSI=Medium Saline Semi-intensive, LSSI=Low saline semi-intensive, FW=Freshwater semi-intensive]

The vertical distance from one box to another indicates the mean variation to each other. Mud crab contained a significantly (P<0.05) higher total long-chain n-3 PUFA content than all other shellfish in the group. Among the other shellfish *chali* contained more long-chain n-3 PUFA than *rosna*, *chaka*, *tiger chingri*, *goda*, *bagda*, *horina*, and *golda*, respectively. The locally consumed shrimp contained significantly (P<0.05) higher long-chain n-3 PUFA amounts (100-140 mg) than the exported products with exception to mud crab (Figure 5.1).

5.3.2 TOTAL N-3 PUFA (IN WEIGHT) IN MANGROVE FISH

The shrimp-prawn farming area in S-W Bangladesh is adjacent to the Sundarbans mangrove forest, which is a critical spawning and/or nursery area for most natural stocks of aquatic finfish and shrimp species. The *gher*-raised fish belonging to the mangrove fish group were self-recruited, being largely introduced to the *gher* with the tidal flush or after purchase from fishers. None of the juvenile mangrove fish fry were produced in hatcheries in Bangladesh. Based on the current field work, this group was then further sub-divided into two groups, SIS and larger fish accordingly.

To compare the mean total long-chain n-3 PUFA of core mangrove fish (total n-3 PUFA >225 mg/100 g raw weight), a boxplot was constructed (Figure 5.2). The mean total long-chain n-3 PUFA in mangrove fish species ranged from 25-650 mg/100 g raw weights. Among the 22 mangrove fish species examined over half contained >230 mg/100 g raw weight. Most interestingly fish species in the top of the list are commonly available and frequently consumed by the local and distant households. For example, *parsey, bhangan, payra, datina, khorshula*, *fesa*, *vetki* are the most common. The rest of the species with statistical analysis are not presented in Figure 5.2 are presented in a Supplementary Table 5.37.

5.3.3 TOTAL N-3 PUFA (IN WEIGHT) IN FRESHWATER FISH

To compare the mean total long-chain n-3 PUFA in freshwater fish (Table 5.5) (total long-chain n-3 PUFA >115 mg/100 g raw weight) a boxplot has been constructed (Figure 5.3). Out of the 25 different freshwater fish species examined, the total long-chain n-3 PUFA levels for the top seven species ranged from 250 to 500 mg/100 g raw edible part, except *rohu* which was classed as SIS and SRS (Self-Recruiting Species), descending in total n-3 level in the order of *mola*, *koi*, *chanda*, *rekha*, GIFT tilapia and tilapia (Mozambican). Most interestingly out of the top 13 fish species (Figure 5.3) at least ten were commonly available. Three of them, tilapia, pangus, and *koi* (Thai *koi*), are commercially cultured in

Bangladesh. All of the species under the FW group are also presented in a supplementary Table 5.38.

5.3.4 TOTAL N-3 PUFA (IN WEIGHT) IN SEAFOOD BY-PRODUCTS

To compare the mean total long-chain n-3 PUFA among the shellfish by-products, a boxplot was constructed (Figure 5.4). Amongst the shellfish by-products, *golda* brain contained a significantly (*P*<0.05) higher total long-chain n-3 PUFA content than all other by-products. *Horina* shell, *golda* head, and *bagda* head provided >100 mg n-3 PUFA/100 g raw weight. *Golda* claw delivered around 70 mg of long-chain n-3 PUFA per 100 g raw weight and is considered a delicacy in the local community together with *golda* head and brain. Apart from *golda* by-products the rest of the items are mostly exported to China and other international markets in a dried condition.

The wild fish, *illish* together with its eggs, delivered a significantly higher total n-3 PUFA content than any other aquatic food animals, with the fish flesh providing (mean±SD) 1305.73±78.06 and the eggs almost double at 2348.19±206.2 mg/100 g edible raw part. The long-chain n-3 PUFA content in snail was tested to find potential links with *golda* PUFA levels as snails were mostly used for prawn farming. Both snail and *golda* contained a lower proportion of long-chain n-3 PUFA.

5.3.5 IMPACT OF SALINITY ON N-3 PUFA CONTENT

To determine the impact of salinity on total n-3 PUFA content, six species were selected out of 57 species and nine by-products by their availability in a wider range of agro-ecological zones. The culture systems combined with the salinity level of the agro-ecological zones gave at least 12 different systems (Figure 5.5). Species available in at least five systems were primarily considered with 16 species were found in this group. However, for ensuring the availability and representation from core shellfish, mangrove fish, and freshwater fish groups, at least six species were selected with at least two representation from core shellfish species (*bagda*, *horina*), core mangrove fish species (*parsey*, *khorshula*) and core freshwater fish species (GIFT tilapia, *bele)*.

The variation and effect of the independent factors salinity and culture systems were established by the construction of a boxplot (Figure 5.5). Significant differences (*P*<0.05) were observed between the four saline zones. In the case of intra-species variability, species in the higher saline zones tended to contain more long-chain n-3 PUFA than those in lower salinity environments. For example, *parsey* in the High Saline Extensive (HSE) system showed the largest amount (mean±SD in mg/100 g raw edible weights) of total long-chain n-3 PUFA (818.86±119.57) which was significantly (P<0.05) greater than *parsey* from a low saline area (LSSI) (589.38±46.01). GIFT Tilapia in the MS zone accumulated 329.79±12.66 mg whereas the same species from the LS region gained just 138.25±18.86 mg total long-chain n-3 PUFA. However, this figure was not significantly different indicating that there is a strong tendency to acquire higher total long-chain n-3 while farming in the higher saline area.

5.4 DISCUSSION

In this study, the proximate and nutritional compositions of aquatic food and their by-products from the S-W coastal Bangladesh were analysed and presented. The major export items tended to have smaller amounts of important nutritional components compared to commonly available and locally consumed fish species and by-products of export products that enter local food chains. SIS, which is more accessible to the poor, also contained higher total long-chain n-3 PUFA and micronutrients. In some cases, the nutritional content of by-products exceeded the nutritional content of the main product of that particular species. Higher salinity and extensive culture systems favoured high nutritional valued fish products compared to the lower saline areas.

5.4.1 MICRONUTRIENT CONTENT OF AQUATIC ANIMALS

Micronutrient deficiencies in developing countries like Bangladesh are prominent and widely discussed elsewhere in the literature (FAO, 2014a; Kawarazuka, 2010; UNICEF, 2011). The four micronutrients iron, zinc, calcium and selenium were especially focussed on in the present Chapter, due to their deficiency in the human body (Ahmed et al., 2012).

The iron content was notably higher in *rosna* from the shellfish group, *payra, aamadi and datina* from the mangrove fish group and *shoal* and *catla* in the freshwater fish group. In the by-products group, *golda* by-products provided at least ten times higher iron levels than from the flesh. This is a good sign for the food and nutritional security of the rural poor as much of the *golda* by-products are destined for consumption by the poorer households.

As with iron, *rosna* was found to contain the highest zinc content in the shellfish group. Similarly, *gaberdana, aamdi* and *datina* had the highest zinc levels in the and mangrove fish group and *porabele*, mirror carp and *catla* in the freshwater fish group. By-products appeared to be abundant with zinc with the *golda* claw containing the highest which was at least 100 times higher than the *golda* flesh per 100 g raw weights.

Shellfish flesh was found to be low in calcium (Ca) content, with exception to *rosna*. *taposhi*, *aamadi*, *gaberdana*, *datina* had considerably higher amount compared to other mangrove fish including larger fish. For example, the calcium content in the large fish *vetki* was found to be at least eight times lower than the SIS *aamadi* fish (838 mg/100 g). In by-products of current work, the Ca content in shellfish shell was markedly higher, and the other by-products were in average range except for *golda* claw. The higher content of calcium in shellfish by-products was also noted by Heu et al. (2003).

The range of the above three important minerals content is similar to that found in other studies in Bangladesh except for a few species and by-products that had remained unassessed on such a culture system basis (Bogard et al., 2015; INFS, 2013; Roos et al., 2003).

The selenium content was extremely low compared to other studies for example in some species at least ten times lesser compared to Bogard et al. (2015) in Bangladesh. However, the geographical locations were widely varied with Bogard et al. (2015) which covered countrywide. In the case of Nile tilapia, the current Se content is also lower than Silva et al. (2011) in Brazil. However, the important issue is that Se is being passed on to fish from the water and diet, where diet is considered as primary source of selenium (Janz et al., 2010). The diet used in this piece of work was negligible for Se content (see Chapter 4), which might explain the lower Se content measured in the fish. One other possibility may be related to the fact that only flesh was analysed in the current study, whereas both the intestine and liver are known to be the main storage organs of Se (Misra et al., 2012). However, some smaller sized fish were assessed with liver and intestine didn't provide higher amount of Se. Moreover, Oldfield (1999), made assumptions that the Se content in Bangladeshi flora and soils were low. Hook (2004), worked on the soil Se in Bangladesh and found it to be lower than the instrument (ICP-AES) detection level (50 ng/g). Therefore, further research is needed on Se content along with feed and soil samples.

Amongst the other major micronutrients (Supplementary Table 5.39), sodium, phosphorus and magnesium were found to be higher than the levels reported by Bogard et al. (2015), although the range obtained in the current study are considered safe for human consumption (Ahmed et al., 2015).

The micronutrient contents among the aquatic food produced in S-W Bangladesh were found to be higher in SIS compared to the larger fish. This is rather fortuitous since poorer households more readily access SIS due to the lower price (with few exception like *mola*) they fetch at market. The contribution of SIS to provide micronutrients has been widely acknowledged elsewhere in the literature (Gibson & Hotz, 2001; Larsen et al., 2000; Roos et al., 2007b).

5.4.2 MACRONUTRIENTS AND ENERGY

The energy content and other macronutrients analysed helped to report the contents in nutrient dense fish in order to mitigate the nutrition demand of humans. The energy content of fish is strongly correlated with the fat content of fish, shellfish and their by-products (Bogard et al., 2015). One of the by-products in this study, for instance, *golda* brain whereby half of the sample is fat contained the highest energy. The energy content of mangrove species was higher than freshwater fish and shellfish, which was also linked to the higher fat content. The energy content of samples from the current study were compared with the published datasets of Bangladeshi fish and were found to be similar (Bogard et al., 2015; INFS, 2013).

The ash content in SIS and shellfish were higher compared to the other fish species due to the higher mineral content. The bones of SIS are eaten by consumers and was also analysed here along with the flesh in the study which contributed to the higher ash content in SIS. The fish or fish products with a higher fat content tended to have higher dry matter. So, the moisture content is also indicative of others composition of fish. These findings are also acknowledged by Bogard et al. (2015) and INFS (2013).

The overall crude protein content distribution is not specifically confined to any of the groups of fish examined in this study. The distribution of protein is also heterogeneous between the two subgroups, SIS and large fish. A similar trend was also observed in the other studies on nutritional composition in Bangladesh (Bogard et al., 2015; INFS, 2013). The shellfish species, *bagda*, *golda* and *chaka* contained higher protein levels but had a lower fat content. There is an inverse relationship between the total fat and protein content of aquatic animals (Bogard et al., 2015). The average protein content in fish flesh was higher than the by-products of the fish. In shellfish by-products, the crude protein content was <10% on a weight basis which is slightly higher than that reported by Heu et al., (2003) in Korea. This variation is due to the nutritional content varying between species as well as between regions. Hence, Sachindra et al. (2005) and Sánchez-Camargo et al. (2011) in India obtained almost identical results to the present work.

The total lipid content was generally higher in the commonly available mangrove fish species than both shellfish and freshwater fish. Moreover, shellfish which are consumed locally maintained a higher proportion of fat compared to the export items like *bagda* and *golda*. The lower content of fat in low-lying agricultural land aquaculture systems in the freshwater environment was also acknowledged by Nurhasan et al. (2010) in Laos PDR. The higher content of fat in mangrove fish was also reported by Suganthi et al. (2015) in Muthupet, Tamil Nadu, India. Though, Suganthi et al. (2015) observed a comparatively higher fat content in the same species analysed in the current study, e.g. *parsey*, *nona tengra*, *bhangan*, *payra* and *caine magur*. This is due to the samples from the Tamil Nadu study being taken from wild species which tend to deposit more fat than the cultured species (Suganthi et al., 2015). For example, the wild sample in the current study, *illish* and its eggs contained a higher fat content compared to all other aquaculture samples. However, many farmed fish are fattier than the wild because they are fed a lipid-rich energy diet (Karapanagiotidis et al., 2006). Some SIS for instance such as *katkoi*, *fesa* and *aamadi* from the mangrove fish group and *mola* and *chanda* from the freshwater fish group contained a much higher fat level (>2 g/100 g raw edible weights) than the larger fish group. The higher fat content of SIS in inland freshwater fish species from Bangladesh was also described by Hossain et al. (1999). However, the high fat content is not always correlated with the fatty acids content are discussed in the next section.

5.4.3 FATTY ACIDS CONTENT OF FISH

One of the main aims of this chapter was to describe the fatty acids profiles of aquatic foods available across the saline gradients and culture systems of S-W Bangladesh. The Saturated Fatty Acids (SFA) content (% of total fatty acids) was found to be higher than Monounsaturated Fatty Acids (MUFA) and Polyunsaturated Fatty Acids (PUFA) in most of the species. Though the chronology (SFA>MUFA>PUFA) of fatty acids content varied from species to species and salinity regime. However, this allocation of SFA, MUFA, and PUFA has also been reported in other lipid studies on tropical fish species in Mexico (Hernández-Martínez et al., 2016) and India (Dhaneesh et al., 2012). Among the fatty acids, majority long-chain n-3 PUFA is derived from fish and fish products for human consumption (Arts et al., 2002). The total fat content and the long-chain n-3 PUFA content varied from species to species. For instance, with a low fat content (<1 g/100 g), *Tiger chingri* contained a higher proportion of long-chain n-3 PUFA in total fatty acids compared with the fattier *golda* (>1 g/100 g) that contained at least 2.5 times less n-3 PUFA (Table 5.3). Other examples like the *golda* brain from by-product, koi from freshwater, and *caine magur* from the mangrove fish group (Table 5.4-5.6) contained a higher amount of total fat and a lower proportion of n-3 PUFA. On the other hand, species with a lower amount of total fat sometimes contained a higher percentage long-chain n-3 PUFA for instance *Tiger chingri, bhola, shoal, catla*, and *bele*. The inverse relationships between total lipid and long-chain n-3 PUFA content are not surprising as Strobel et al. (2012) noted that fish with a lower fat such as tuna (*Thunnus spp.*) or pollock (*Pollachius virens*;) provide a considerable amount of long-chain n-3 PUFA for human supply. The variation in total fat and long-chain n-3 PUFA content was also noted in tropical fish species by Karapanagiotidis et al. (2010) and Mohanty et al. (2016) in Thailand and India, respectively. The long-chain n-3 PUFA content and the ratio of n-3/n-6 are intimately related to each other.

The effectiveness of long-chain n-3 PUFA derived from fish for human health development is well recognised (Elvevoll et al., 2006). A higher proportion of n-3/n-6 from fish is always desirable and has been advised to avoid chronic disease (Strobel et al., 2012). The n-3 proportion in the modern diet is skewed towards n-6, and for a balanced diet, fish is expected to provide a higher proportion of long-chain n-3 PUFA compared to n-6 PUFA. Since the pre-fried fish support the imbalance of n-3/n-6, the non-fried fish fillets are advised in western diet (Strobel et al., 2012). The n-3/n-6 ratio in the current study widely varied with the shellfish and freshwater fish having a lower ratio compared to mangrove fish species. In the shellfish group, the locally consumed shrimp species like *rosna* and *tiger chingri* gave a higher n-3/n-6 than the shellfish exported. Among the finfish, both in mangrove and freshwater fish group, SIS such as *aamadi*, *gaberdana*, from the mangrove group and *mola*, *chotobele*, and *chanda* from latter group provided higher n-3/n-6 PUFA ratios than larger fish. As mentioned in the earlier section, long-chain n-3 PUFA related work is very limited both in the freshwater environment as well as in tropical regions. Nonetheless, the current outcomes of n-3/n-6 are lower than the marine fish species (Devadason et al., 2016; Huang et al., 2012). The n-3/n-6 ratios reported in the current study were similar to that of Mohanty et al. (2016) who worked with 39 commercially important fishes in India, as well as Aziz et al. (2013) who analysed marine fish and shellfish from the warm water Straits of Mallcca and Filho et al. (2010) studied 7 freshwater fish in Brazil. The n-3 PUFA and n-3/n-6 ratio in the fish body are dependent upon some factors including water salinity which are described in the next section.

5.4.4 INFLUENCE OF SALINITY ON PUFA CONTENT IN FISH

In this piece of work, the effect of salinity was found to have a negligible effect regarding protein content. However, species harvested from higher salinities have been found to retain more protein (Xu et al., 2010). The long-chain n-3 PUFA content varies from species to species (Strobel et al., 2012). The use of n-3 PUFA biomarkers for the measurement of nutritional composition among the species are widely accepted (Budge et al., 2002). It was found those mangrove fish habitats are in the higher saline areas and also contained higher long-chain n-3 PUFA than shellfish, by-products, and freshwater fish. This location based variation in nutritional content might be due to the differences in natural food composition, for example prey and phytoplankton where artificial feeding is absent or limited (Budge et al., 2002). Intra-species nutritional composition variation also exists, for instance, *parsey* in the High Saline Extensive (HSE) system contained a significantly higher long-chain n-3 PUFA level than fish from a Low Saline Semi-Intensive System (LSSI) (Figure 5.5). Similarly, Nile tilapia (GIFT) reared in the higher saline areas tended to have a higher n-3 PUFA level than those from the lower saline areas. Gan et al. (2016) also found that Nile tilapia (*O. niloticus*) culture in brackish water had an impact on its flesh quality. The trend of a higher long-chain n-3 PUFA content in higher salinities compared to the lower saline areas are mentioned elsewhere in the literature (Devadason et al., 2016). The increment of salinity level was shown to enhance the long-chain PUFA concentration in a study on algae (Nedbalov et al., 2016). This is because freshwater and marine fish display very different essential fatty acids metabolism and requirements. Fonseca-Madrigal et al. (2012) concluded in a study on silverside fish (*Chirostoma estor*) that salinity has an effect on the endogenous biosynthesis of LC-PUFA from its 18-carbon fatty acid precursor. A similar effect of salinity level of long-chain n-3 PUFA was observed in Mesopotamian barb (*Capoeta damascina),* (Fallah et al., 2013), Japanese seabass (*Lateolabrax japonicus*) (Xu et al., 2010) and Rainbow trout (*Oncorhynchus mykiss*) (Haliloğlu et al., 2004).

Diet used for fish cultivation ultimately determine the nutrient content of fish in closed systems (Glencross et al., 2007). Fish from the semi-intensive and intensive systems provided higher protein concentration than the extensive system (Nurhasan et al., 2010). This is because the feed and feed ingredients utilised in the semi-intensive system provide adequate protein. Agricultural ingredients are mostly used in the feed in the shrimp and prawn farming systems in Bangladesh (Rico et al., 2013). The higher content of n-6 in freshwater fish is linked to the utilisation of feed and feed ingredients which tended to be of plant origin where the n-6 content is much higher than long-chain n-3 PUFA (Strobel et al., 2012). Trbović et al. (2013) worked on the diet quality and the nutritional composition of common carp (*Cyprinus carpio*). They observed poor nutritional performance (i.e., lower level of long-chain n-3 PUFA in the flesh) when fed their feed ingredients alone (maize) than when fed an extruded diet. Feed utilisation is mostly confined to the low saline and freshwater areas where *golda* is mainly cultured (Chapter 4). Eutrophication in lower saline areas may also be responsible for long-chain n-3 PUFA deficiencies in the aquatic food web, affecting fish nutrition and physiology (Gomes et al., 2016). Freshwater snails are the main food source used to feed *golda* which has a very low amount of long-chain n-3 PUFA (Table 5.5) is therefore responsible for the lower long-chain n-3 PUFA content in *golda* flesh. It was evident that the diet quality variations are responsible for the differences of long-chain n-3 PUFA on sea bass (*Dicentarchus labrax*) (Alasalvar et al., 2002).

The extensive farming system in higher saline areas, where mangrove fish are more abundant, provided higher levels of long-chain n-3 PUFA. Fish from extensive condition contained a higher percentage of long-chain n-3 PUFA compared to intensive system (Nettleton & Exler, 1992). For example, the cultured sea bass (*Dicentarchus labrax*) contained higher fat with lower percentage of long-chain n-3 PUFA and the wild one had a reverse composition (Alasalvar et al., 2002). However, the wild environment does not always provide the superior nutritional outcomes compared to the cultured one. For instance O'Neill et al. (2015) in yellowtail amberjack (*Seriola lalandi*) and Kaba et al. (2009) in Gilthead seabream (*Sparus aurata*) didn't find a variation on long-chain PUFA content in between wild captured and cultured specimen. Like aforementioned sea bass, tilapia in the extensive system contained a higher percentage of long-chain n-3 PUFA compared to the intensive culture system in Thailand. This explains the recommendation to utilise feeds containing lesser amounts of n-6 PUFA for tilapia culture (Karapanagiotidis et al., 2006).

It was demonstrated that salinity had a more important impact than diet on long-chain n-3 PUFA content revealed in a study on rainbow trout (Haliloğlu et al., 2004). This study also confirmed the effect of salinity on the long-chain n-3 PUFA content in aquatic animals. The wide variation of long-chain n-3 PUFA percentage and the n-3/n-6 among the fish species across saline gradients were observed in this study. Therefore, a wide variety of fish consumption was suggested for human to gain all the possible nutrition in diets

(Strobel et al., 2012). The contributions of fishes on long-chain n-3 PUFA supply to the plate are discussed in the next section.

5.4.5 LONG-CHAIN N-3 PUFA INTAKE FROM AQUATIC ANIMAL

Long-chain fatty acids are beneficiary for human health and well-being (Arts et al., 2001). A minimum consumption of 250 mg of long-chain n-3 PUFA (EPA+DHA) per day is recommended (Mozaffarian & Wu, 2012). From the shellfish group, a 100 g edible portion size from all the species analysed would result in all of them delivering below the threshold of the recommended daily intake of long-chain n-3 PUFA except mud crab. Of the 22 mangrove fish species about half of them were found to provide >250 mg long-chain n-3 PUFA per 100 g edible portion (Figure 5.2). Of these only four are considered as large species with the rest SIS. All of the species are naturally recruited, and/or wild caught released in the *gher*. Conversely, only one-third of the freshwater fish species out of the 25 analysed provided >250 mg long-chain n-3 PUFA per 100 g raw edible weight. In the FW fish group species with higher long-chain n-3 PUFA in percentage were all SIS and SRS except a larger fish *rohu* (Figure 5.3). An important finding of this analysis is that mangrove fish with concentrated long-chain n-3 PUFA remain an important component of aquaculture systems. Thus, applying proper conservation and management techniques could potentially secure these highly nutrient species in local diets. Among freshwater species with higher long-chain n-3 PUFA, about 80% of the species were commonly available. The rapid expansion of aquaculture and selective culture of fish species delimit the availability of species (Belton et al., 2014). Among the by-products, *golda* brain, head and inner muscle of claw provided a substantial amount of long-chain n-3 PUFA which is mostly destined to the poorer households. In Bangladesh *illish* and its eggs contained an exceptionally high amount of long-chain n-3 PUFA, providing 5-9 times the levels of long-chain n-3 PUFA than the recommended intake (250mg) of long-chain n-3 PUFA per day per person.

There are some strong candidate species with high-quality nutrients such as high long-chain n-3 PUFA levels that have been identified including *parsey*, *bhangan*, *payra* and *datina*. The contribution of fish species to supply long-chain n-3 PUFA for dietary consumption was also acknowledged in other tropical environment studies (Aziz et al., 2013; Bogard et al., 2015; Chedoloh et al., 2011; Stein, 2010).

5.5 CONCLUSION

This piece of research work provides novel nutritional information on all the available fish from the *gher* based aquaculture systems in Bangladesh which can inform consumers, dieticians, and fish farmers alike. Inter-species nutritional content variations were higher than the intra-species variations among the aquatic animals. Aquatic animals from the mangrove group in which many were classed as SIS, together with SIS from the freshwater areas had higher proportions of lipid, fatty acids, long-chain n-3 PUFA compared to other freshwater fish and larger fish species as well as the different shellfish species. Some of the by-products such as *golda's* head, brain and claw were identified as the major sources of fatty acids and essential minerals. The export item is higher in protein content and lower in all other nutritional composition in relation to other available species. The higher long-chain n-3 PUFA content fish in the mangrove group is still commonly available, however the freshwater species availability were decreasing due to selective species farming in lower saline areas. This output helps to take programmatic action for conservation, aquaculture, and awareness development for the high-quality fish. The actual impact of this nutrition variation can be understood by looking the food allocation and consumption at the individual level, and their nutritional outcomes are described in the next chapter.

6 CHAPTER 6: INTRA-HOUSEHOLD FOOD ALLOCATION AND CONSUMPTION: IMPACTS ON THE NUTRITIONAL OUTCOMES OF ADOLESCENT GIRLS

6.1 INTRODUCTION

Malnutrition affects billions of people worldwide and is linked to approximately one-half of all child deaths (FAO, 2012a). Survivors are left vulnerable to illnesses as well as stunted growth and intellectual impairment. Malnutrition, poverty, and micronutrient deficiencies are widespread and interconnected, mostly affecting low-income countries (LIC's). Globally, around two-thirds of the undernourished live in seven listed countries including Bangladesh. At the same time, many suffer from obesity and diet-related complexities (FAO, 2012a). Micronutrient deficiencies slow down immune activity, impairs cognitive development and child growth, and undermines reproductive performance and work capacity (Underwood, 2000). It has been acknowledged that malnourished adults earn 20% less compared to healthy adults (Grantham-McGregor et al., 2007) and nutritional interventions have been demonstrated to enhance adult earnings by nearly one half (Hoddinott et al., 2008). In addition to the critical window of 1000 days (-9 to 24 months) of pregnancy and lactation, adolescence (10-19 years) is viewed as the most vulnerable stage in a women's life (USAID, 2006). Adolescents comprise one-fifth of the world population (Thurnham, 2013), and both males and females undergo the last intense phase of their growth when 15-25% of their adult height and 45% of skeletal development occur (Spear, 2002).

Bangladesh is a developing country in the global south of which one-third of the population (27%) is undernourished (FAO, 2010). Around 11-56% of adolescent girls suffer from subclinical vitamin A deficiency and 30-40% is anaemic. The child marriage (age <18) rate in Bangladesh is 66%, which is ranked third on the global list, and 33% have their first pregnancy between 15-19 years of age (WHO, 2013). Such children are at increased risk of developing anaemia during pregnancy, compromising their health as well as that of their offspring. Child malnutrition in Bangladesh is among the highest in the world (Faruque et al., 2008) and about 13–19% of children are severely underweight or stunted; such children suffer from both short-term food deficit and long-term chronic undernutrition. Bangladesh is also ranked second globally in terms of the proportion of infants with a low birth weight (<2500 g) (UNDP, 2001), a situation more severe than poorer countries in sub-Saharan Africa (FAO, 2010). Socio-cultural factors influencing maternal health are believed to explain such poor outcomes and these are now briefly considered.

The social and cultural norms regarding intra-household food allocation in developing countries has long been understood (Gittelsohn, 1991). Male members, including the household head, obtain a higher food share as a token of respect and appreciation (Chimwaza, 1982). This tradition disadvantages many girls from the early phase of life (Henry et al., 1993). Furthermore, the implications of sudden changes in food prices such as those that occurred in 2008 might also be expected to impact on intra-household resource allocation (Bouis et al., 2011). Children with restricted brain development in early life are at risk of later neurological problems, poor school achievement, early school dropout, low-skilled employment and poor care of their children, subsequently accelerating the intergenerational transmission of poverty (Trive, 2012). It is, therefore, essential to ensure that adolescent girls enter pregnancy with an adequate nutritional status (Hyder et al., 2007). Measurement methods such as the summation of diet and nutrient intake in association with health outcomes as opposed to coherent behavioural pattern studies are more reproducible and accurate (Tucker, 2010).

Both Body Mass Index (BMI) and Mid-Upper Arm Circumference (MUAC) are important indicators for the assessment of nutritional status along with other variables of an individual (Choudhury et al., 2000). BMI is a non-invasive, anthropometric indicator widely used in nutritional surveys in developing countries (Khongsdier, 2002). MUAC is mostly used for the nutritional assessment of children (Briend et al., 1989). However, MUAC has recently been used to assess malnutrition in adults and has found to be a better predictor than BMI (Wijnhoven et al., 2010). MUAC is easier to measure and requires less equipment compared to BMI and other weight derived indices (Vlaming et al., 2001). However, both indicators are closely related and simple and can form the backbone of nutritional assessments in developing countries by providing a track record of potential candidates for anthropometric studies (Sultana et al., 2015). Apart from anthropometric measures, the utilisation of biomarkers is increasingly being used in nutritional studies (Bell et al., 2011).

A biomarker can be used is as an indicator of a certain state or condition of biological subjects (Silva et al., 2014). The dietary intake measurement of fatty acids by biological subjects is complicated task (Browning et al., 2012). However, there is a growing interest to know the fate of dietary fatty acids on the human body (Hodson et al., 2009). Moreover, the variation in the fat content in food, its longer half-life over other nutrients as well as being readily accessible to storage depots in the human body has influenced researchers to use biomarkers in fatty acids studies (Arab, 2003). The concentration of specific fatty acids in different matrices (blood, plasma, adipose) are influenced by various factors (Arab & Akbar, 2016). The measurement of EPA and DHA is ideal to best understand the role of oily fish intake in biological samples (human) (Browning et al., 2012). However, the rate of incorporation varies between sample type and time. The metabolic pathways of fatty acids partition over 24 h (Hodson et al., 2009) and incorporation times in different parts of the body can take anywhere from a day to a year (Silva et al., 2014). Whole blood (WB) fatty acids adequately reflect the fatty acids status compared to plasma and blood cells and is recommended to use as specimen assessment (Risé et al., 2007). A drop of blood from a fingertip is adequate to assess the dietary and physiological pattern of a sampled subject (Marangoni et al., 2007). Both plasma and erythrocyte DHAs level are correlated to brain cardiac and other tissue level (Kuratko & Salem, 2009). The long-chain n-3 PUFA; omega-3 fatty acids (EPA+DHA) index calculated from blood serum values is a strong reflection of dietary consumption (Harris, 2007). An omega-3 index level below 4% is considered as undesirable, 4-8% as intermediate and above 8% desirable (Harris & Von Schacky, 2004). The n-3/n-6 PUFA ratio is a major factor for many diseases from inflammatory states to diabetes mellitus up to cancerous state (Tiuca et al., 2015). The proportion of LC n-3 PUFA to total LC-PUFA is a strong indicator of health status (Bibus & Lands, 2015). The dietary n-3/n-6 ratio has a strong correlation with the n-3 blood level. The ratio n-6/n-3 is always expected as 1 however modern diets are characterised by much higher ratios of up to 20 (Simopoulos, 2016).

Developing countries increasingly recognise the role of a nutritionally balanced diet, including critical vitamins and minerals, rather than just food production and consumption in achieving food security (Ahmed et al., 1999). To assess the impact of food consumption more than one item were considered in a study in France (Baudry et al., 2016). In a food security study in Mexican households, all the food items were considered to identify healthy and unhealthy food items (Silva et al., 2015). Along with the nutritional capabilities of food items, the well-being status together with education and other social capitals were also considered (Burchi & De Muro, 2016). Therefore, in addition to the nutritional role of food all other available items and socio-economic assets became an important part of current studies. Fish can be a vital candidate for securing amino acids, peptides, protein, essential Poly Unsaturated Fatty Acids (PUFA) and other useful nutrients

(Sriket, et al. 2007). However, high demand for fish in international markets has been claimed to decrease availability both in local markets and nature (van Mulekom et al., 2006). High prices and reduced supplies of fish in local markets may have serious impacts on the economics and nutrition of low-income people (Kent, 1997). Recent results revealed that both developing and developed countries exchange (export, import) almost equal volumes of fish in trade but that developing countries tended to export high nutritional quality products (Asche et al., 2015). Food security and poverty alleviation viewed through the lens of international trade has been inconsistent. Other major drivers (decentralisation, demographic transition) have often been ignored (Béné et al., 2016).

Food security measured at the household level is problematic in Bangladesh because there is a heterogeneity both in food sharing and manifestation of health outcomes of the family members (Coates et al., 2010). It has been suggested to consider four types of indicators: calories, poverty, dietary diversity and key subjective indicators for the proper measurement of food security (Headey & Ecker, 2013). The 24-hour food recall method has been widely used for dietary consumption, supplementary feeding, fish consumption, and fatty acids consumption in Bangladesh and elsewhere in the world (Ahmed et al., 1998; Gomna & Rana, 2007; Rasheed et al., 2011). Food Frequency Questionnaires (FFQ) in association with/without 24-hour recall method are also widely used (Ahmed et al., 1998; O'Sullivan et al., 2011; Sudo et al., 2004). FFQ were found to be useful in assessing child EPA consumption reported by their parents (Burrows et al., 2013). It is recommended by Ma et al. (2009) that at least 2-3 recall periods are required to obtain quality data. Intra-Household Food Allocation (IHFA) is an integral part of the 24-hour recall. IHFA involves separate measurements of food consumption from all household members before analysing each household member's share of the total. Separate measurements are useful for children (8-11 years) as they reported more accurately than their parents (Burrows et al., 2013) IHFA is considered as the platform for both nutritionist and social scientists alike in revealing the common issue as to who gets what and why (Wheeler, 1991). Therefore, 24-h were incorporated with FFQ and IHFA to understand the food security pattern of individuals at household levels.

Food production, consumption, and public health are intimately linked to each other, but there is a huge research gap regarding their interaction and lack of any integration of relevant data sets in most LMIC's (Low-Middle Income Countries) (Hawkesworth et al., 2010). Linking these sectors could bring better health-driven agricultural changes (Hawkesworth et al., 2010). The current study aims to understand the relationship between farming systems, consumption and nutritional outcomes for communities across the different salinity gradients that are typical of aquatic farming systems in south-west Bangladesh. Specifically, the research addressed the following questions:

a) Are there any influences of intra-household food allocation (IHFA) on consumption profiles, recommended dietary intake and nutritional outcomes of adolescent girls?
b) What impacts, if any, do prevailing agroecology, involvement in food value chain (SFVC) and social well-being have on the nutritional outcomes (both anthropometric and whole blood (RBC) level n-3 PUFA) of adolescent girls?

6.2 MATERIALS AND METHODS

Four communities from the aquatic animal farming area of south-west coastal Bangladesh was purposely selected (Figure 2.7). The selected communities are described in Chapter 2**.** To make the discussion easier in some cases, both high and medium saline areas were grouped together as the higher saline area and low saline and freshwater areas as the lower saline area. A 24-hour food recall method along with food frequency questionnaires and IHFA was developed and validated accordingly (Chapter 2).

The livelihoods of households, individual diet and nutrition consumption, were sampled on two occasions. All the food items were grouped into ten major food groups based on standard approaches (Handa & Mlay, 2006; INFS, 2013). The major food groups were identified as cereals (boiled rice, puffed rice), vegetables (plants, vegetables, leafy vegetables), pulses (pulses and legumes), fish (finfish, shellfish), meat (chicken and meat products), milk (milk and dairy products), beverages (tea, coffee), eggs, fruits and others (ice-cream, chocolate). Fish type (dried, raw and processed) were evaluated separately and converted to a raw weight equivalent. The relationship pattern between the head of the household and the remaining household members were defined as housewife or homemaker was classed as wife, girls as daughter, and boys as son. Although the dietary data from all members of the household was collected only these four members over the age of ten were selected for in-depth dietary analysis.

The intra-household food allocation (IHFA) among the four main family members across the different salinity areas was tested. Household food consumption data was calculated by using the quantitative data on raw food ingredients used to prepare composite meals. The individual level consumption was assessed by considering the quantitive data on the portion size of specific ingredients consumed by the individual within households. First of all, the female who was responsible for cooking was asked about the quantitative amount of food ingredients cooked in their household as well as the portions consumed the household members. With the exception of fish, the nutritional content of all food ingredients were based on secondary data fora ready to cook state (i.e. boiled rice, cooked curry), whereas fish were calculated as presented in Chapter 5 on a raw weight basis. The mean weight of two 24-hour dietary datasets was tabulated, and the weight of the major food groups examined. Four independent factors (1) salinity, (2) social well-being, (3) relationship among family members and (4) household involvement in the seafood value chain (SFVC) were considered for these tests. All the food items were assessed in a ready-to- eat state. The weight food items and consumed by the family members were recorded ingredients wise and then tabulated under major food groups (Table 6.1). By using the food frequency questionnaire along with the 24 h recall method, the consumption pattern of the main food items at household levels over two weeks were assessed (Figure 6.1).

A reference energy consumption level varies with age, sex, BMI and activity level. Therefore, the age, sex and activity level of each household member was recorded. Furthermore, for the activity level, the active mode was considered as the subjects of the study were healthy and active in household work (WebMD, 20016). Reference values for Body Mass Index (BMI), Mid-Upper Arm Circumference (MUAC), total long chain n-3 PUFA (omega-3 index) content in blood, ratio of LC n-3 PUFA to total LC-PUFA, essential micronutrients, protein, and energy were obtained from standard sources (Table 2.10; Chapter 2); (Harris, 2007; Lands, 2003; NIH, 2016; WebMd, 2016; WHO 2011). For omega-3 index the whole blood long chain n-3 PUFA content were transformed to RBC n-3 PUFA using an internally (NAS, UoS) standardisation conversion factor 1.27 (James R Dick, Chief Technician, NAS, University of Stirling UK, personal communication, 2016). The nutritional data of all food items except fish were obtained from secondary sources (INFS, 2013; Islam et al., 2010). Nutritional profiles of aquatic animals were generated from this piece of work (Chapter 5).

The reference value for each variable was subtracted from the respective observed mean value to obtain the residual value. These residual values for energy consumption, MUAC, BMI, total n-3 PUFA consumption, three micronutrients (Ca, Zn, Fe) were tested against the four independent variables to understand their relationships. During the calculation of food item quantity zero figure was ignored as the consumption food amount and frequency of subject consumed specific item were the main objectives. The normality test of data and statistical analysis was carried out using R (R Core Team, 2016). Data were normally distributed.

6.3 RESULTS

6.3.1 FOOD CONSUMPTION FREQUENCY

Food groups consumed daily over a 14 days period were evaluated. Employment within SFVCs and salinity were found to have no influence on food consumption. Among the ten major food groups both rice and vegetables were consumed three times every day (Table 6.3) for both social well-being groups, better-off and worse-off households. In the Figure, 6.1 days consumed over a 2 week period were counted. Food item consumed at least once daily were considered as the food consumed in a day. The two least consumed categories beverage and others (e.g. ice-cream) were excluded from analysis (Figure 6.1).

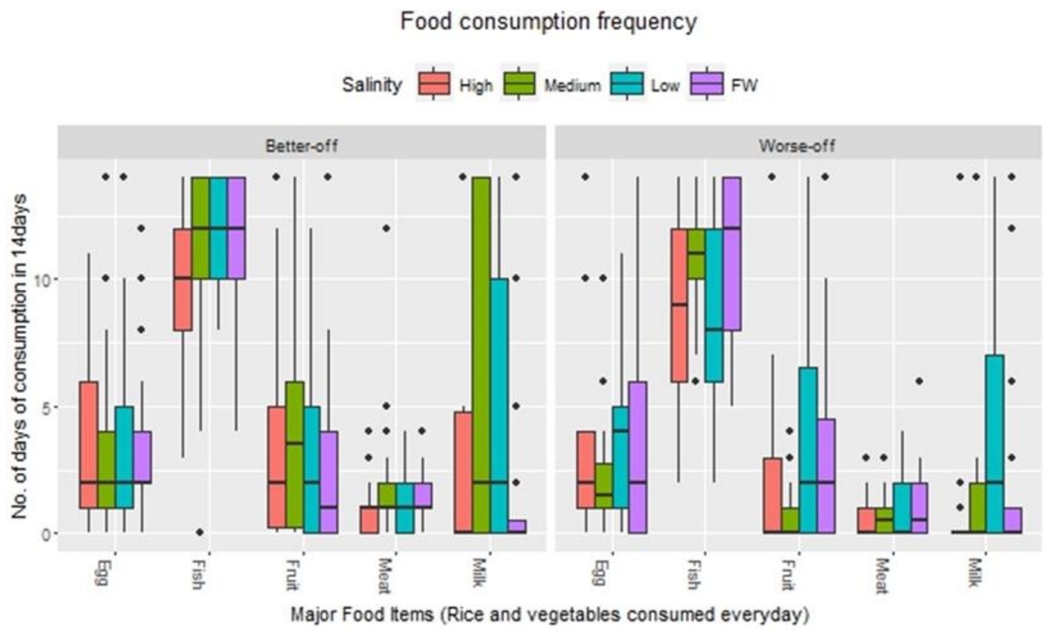


Figure 6.1 Food consumption frequencies (days) in two weeks period along the saline gradients of aquatic animal production area in S-W Bangladesh [Each point in the graph represents an individual household]

Figure 6.1 shows the mean food consumption frequency and variation among the different social groups and food items consumed in households from the different saline areas. Consumption frequency in better-off households was significantly (P<0.05) higher than for worse-off households for all the main food groups. Fish remained the top item in the list followed by eggs, milk, fruit and meat consumption.

6.3.2 INTRA-HOUSEHOLD FOOD ALLOCATION (IHFA)

The mean consumption of the main food items, expressed as in a ready-to-eat format, among the four family members is presented in Table 6.1. The number of respondents also indicates the consumption frequency of a specific item. The number obtained in the cereal category should be considered as an optimal number of respondents as rice is the staple food being consumed in every major meal. Irrespective of household status, approximately 70% of the total foods consumed are cereal or cereal-based, 15% from vegetables, 5% from fish, 3% from meat and the remainder from pulses, beverage, and other food groups.

Table 6.1 Summary of mean (±SD) weight (in g, otherwise mentioned in parenthesis of food groups) of major food group ready-to-eat for all communities and households derived from 24 h recall method across the saline gradients of aquatic farming system in S-W Bangladesh [the number of mean respondents in the parenthesis of each value].

Food groups	Household head	Wife	Son	Daughter
Cereals	2033±616^{a} (219)	1695±520^{b} (233)	1650±613^{b} (130)	1203±422^{c} (289)
Fish	125±85^{a} (202)	103±64^{bc} (219)	125±94^{ab} (117)	101±65^{c} (268)
Vegetables	432±213^{a} (218)	387±184^{a} (230)	400±319^{a} (130)	322±163^{b} (288)
Meat	85±45 (37)	68±30 (36)	87 ±46 (30)	72±43 (39)
Pulses (ml)	235±148^{a} (89)	190±127^{ab} (97)	189±117^{ab} (52)	151±113^{b} (109)
Milk (ml)	138±93 (36)	108±64 (40)	109±61(17)	104±59 (51)
Eggs	35±27 (53)	29±19 (54)	29±18 (36)	31±25 (71)
Fruits	55±51 (28)	48±32 (34)	49±31 (22)	43±27(55)
Beverage (ml)	60±37 (63)	75±25 (3)	64±34 (10)	66±28 (3)
Others*	27±23 (24)	24±17 (19)	20±12 (15)	30±33 (28)

Different superscripts letter in the same row indicated significant differences (P<0.05). [*others is a food group comprised ice-cream, chocolate, etc]

6.3.3 CEREAL CONSUMPTION

Cereals were the most commonly consumed food item in the Bangladeshi diet. Households consumed cereals mainly as boiled rice three times daily. The mean cereal consumption pattern (g/day) is shown in Table 6.2. Excluding the LS area, the household heads from all other regions was found to consume >2000 g cereal per day. However, the wife consumed between 1500-1850 g, similar to that of the son and both were significantly higher than daughter. Better-off (BO) households tended to consume significantly (P<0.05) more cereals (1670 g) than worse-off (WO) (1545 g) households. Households in the LS area consumed significantly (P<0.05) less than the households in the other saline areas.

Participation in seafood value chain (SFVC) had no influence on cereal consumption ($P>0.05$).

Table 6.2 Consumption pattern of ready-to-eat cereals (g) per day among family members (age >ten years) across the saline gradients in aquatic farming systems in S-W Bangladesh

Salinity	Social well-being	Household head	Wife	Son	Daughter
High	Better-off	2157.4 ± 578.1^{ab}	$1790 \pm 473.9^{b\text{-}f}$	$1920.1 \pm 681^{a\text{-}e}$	$1203.5 \pm 382^{g\text{-}i}$
	Worse-off	2378.3 ± 462.4^{a}	$1857.2 \pm 493^{a\text{-}e}$	$1509.6 \pm 438.7^{d\text{-}i}$	$1501.9 \pm 546^{e\text{-}i}$
Medium	Better-off	2230.84 ± 610^{ab}	$1828.2 \pm 546^{a\text{-}e}$	$1554 \pm 608.9^{d\text{-}i}$	$1293.7 \pm 393.5^{f\text{-}i}$
	Worse-off	$2034.9 \pm 670^{a\text{-}d}$	$1617.6 \pm 618^{c\text{-}h}$	$1558.2 \pm 517.9^{d\text{-}i}$	1160 ± 343.7^{hi}
Low	Better-off	$1800.7 \pm 404.5^{b\text{-}f}$	$1560.1 \pm 431^{d\text{-}i}$	$1605.3 \pm 416.4^{c\text{-}i}$	1146.7 ± 322.9^{hi}
	Worse-off	$1645.7 \pm 513^{c\text{-}g}$	$1482.8 \pm 424.7^{e\text{-}i}$	$1239.7 \pm 416.7^{f\text{-}i}$	969.6 ± 363.5^{i}
FW	Better-off	$2119.8 \pm 601^{a\text{-}c}$	$1821.6 \pm 536^{a\text{-}e}$	$1705.8 \pm 609^{b\text{-}g}$	$1257.5 \pm 443.9^{f\text{-}i}$
	Worse-off	$2014 \pm 765.5^{a\text{-}d}$	$1573.4 \pm 558^{d\text{-}i}$	$1806.1 \pm 830.7^{a\text{-}f}$	1093.7 ± 387^{i}

Different superscripts letter in each row and column indicated significant difference ($P<0.05$)

6.3.4 AQUATIC ANIMAL INTAKE

Overall fish consumption at household level was unrelated to agroecology, but household heads consumed the highest amount of fish even if this was not significantly different (Table 6.3). Fish consumption varied from 75-170 g/capita/day. Households in the FW community tended to consume significantly ($P<0.05$) higher levels than in the LS area. However, the FW area was found to be statistically similar to both the MS and HS areas. Fish types consumed at household levels but overlooked in this part in detail are mentioned in Chapter 5. The common pattern is that the proportion of oily fish and the diversity of aquatic animals consumed gradually decreased from HS to FW area. Among the four family members across the salinity gradient, fish consumption was highest for the household head and decreased in order of son, wife and daughter. Fish consumption per day by daughter and wife were significantly ($P<0.05$) lower than the household head. Based on factor analysis better-off households (122 g) consumed significantly ($P<0.05$) more fish than the worse-off households (100 g). There were no differences between the SFVC household and non-SFVC households in fish consumption pattern. The non-SFVC households relied on the local markets for buying fish mostly twice in a week. There were four distinct sources which were identified as the source of aquatic animals which were own *gher* or pond, open water catch, purchased from the market or received gift from others.

Table 6.3 Consumption pattern of ready-to-eat aquatic animals g/day among family members (age >ten years) across the saline gradients of the aquatic farming area in S-W Bangladesh

Salinity	Social well-being	Household head	Wife	Son	Daughter
High	Better-off	137.9 ± 77.7^{ab}	113.5 ± 53^{ab}	169.4 ± 86^{a}	114.4 ± 48.7^{ab}
	Worse-off	107.9 ± 61.6^{ab}	86.1 ± 52.7^{b}	95.4 ± 71^{ab}	86.6 ± 49^{b}
Medium	Better-off	118.5 ± 55.5^{ab}	99.6 ± 59.4^{ab}	100 ± 47.9^{ab}	101.5 ± 54^{ab}
	Worse-off	143.3 ± 96.8^{ab}	108.7 ± 51.4^{ab}	119.6 ± 67.3^{ab}	102.9 ± 57.7^{ab}
Low	Better-off	112.6 ± 78.9^{ab}	89 ± 55.2^{ab}	79.3 ± 54.2^{b}	97.9 ± 59.1^{ab}
	Worse-off	82.9 ± 52.2^{b}	75.3 ± 40.4^{b}	149.8 ± 161.8^{ab}	77.8 ± 41.1^{b}
FW	Better-off	167.8 ± 129^{a}	145.4 ± 96.4^{ab}	133 ± 131.9^{ab}	139.3 ± 108.5^{ab}
	Worse-off	126.2 ± 78.7^{ab}	99.4 ± 70.1^{ab}	120.5 ± 85.3^{ab}	83.7 ± 56^{b}

Different superscripts letter in each row and column indicate significant difference (P<0.05)

6.3.5 VEGETABLE INTAKE

Vegetable consumption at the household level was not related to the agro-ecological setting. Among the household members, based on factor analysis, daughters consumed significantly (P<0.05) fewer vegetables than other household members. Vegetable consumption ranged from 259.7-497 g/capita/day. No significant differences in vegetable consumption (P>0.05) among the four saline areas was found. On factor based analysis the better-off household (400 g) consumed significantly (P<0.05) more than their worse-off (355 g) counterparts. Households in the higher saline areas relied on the local market for vegetables.

6.3.6 CONSUMPTION OF OTHER FOOD GROUPS

Among the four factors for meat consumption, only the saline area had an impact. Meat consumption in the FW area was significantly (P<0.05) higher than that in the MS area. However, there was no significant difference between the FW area and the LS and HS areas. The mean consumption of meat per capita per day gradually decreased from lower saline to higher saline areas, with 92.3±50.5, 83.8±52.2, 74.9±30.9 and 64.7±32 g per capita/day, for LS, MS and HS area, respectively. Although, meat consumption volume did not vary by social well-being, more (double) households in the better-off segment were found to consume meat than those in the worse-off segment.

Consumption of pulses was influenced by the factors relationship and salinity. The household head consumed significantly (P<0.05) more than the daughter, but was similar to their partner and son. The range of pulse consumption was 106.11-311.4 ml/capita/day. Households in the MS area consumed a significantly (P<0.05) higher level than the LS area but did not differ from the FW and HS areas.

Regarding milk consumption, there was no influence from salinity, social well-being, and SFVC. The consumption pattern among the family members was also found not to differ statistically. The consumption amount varied from 47.5-250 ml/capita/day. Surprisingly, household members in the MS (58) area consumed more milk, followed by LS (40), FW (25) and HS (21).

Egg consumption followed the same trend as that of milk and the median amount varied from 16-53 g/capita/day. For fruit consumption, none of the factors had any influence except for salinity. Households in the LS area consumed significantly (P<0.05) more fruit (mean±SD) (63.5±44.5 g) than those in both FW and HS areas. Households from the LS area consumed more fruit than those in FW and HS areas, although they did not differ from the MS area. Both the MS and FW area were similar. The FW and HS area were also similar. The mean fruit consumption (mean ±SD) varied from 15-117 g/capita/day. Fruit type was mainly banana and indigenous fruit. The consumption frequency was almost identical to the milk consumption pattern.

Beverage consumption at household levels was not significantly influenced from any of the four independent factors except salinity, with consumption being higher in the HS region significantly (P<0.05) more than the MS and LS areas but consumed at a similar level to those in the FW area. The mean values of consumption for beverages for households in the

FW, MS, and LS regions were similar. The range of beverage, which consisted mainly of tea, was 27.5-150 ml/capita/day.

The consumption of other items varied significantly with higher intakes in households from the HS area compared to the other three areas. The amount of other products (i.e. ice cream, chocolate) ranged from 4-57 g/capita/day. The other food items were mostly consumed by young children. However, both the frequency and volume were low (Table 6.1).

6.3.7 MAJOR SOURCES OF NUTRITION AND ALLOCATION PATTERN

Fish supplied around a quarter of total protein, approximately 10% of iron, zinc and calories and almost 100% of the total n-3 lipid intake. Fish were a key source of calcium in the diet (>30%). Cereals provided 50% of protein, more than 70% of energy, 20% of calcium, 40% of iron and 60% of zinc in the daily meal. Calculated values suggested that vegetables provided on average 10% of protein and calories, about 30% of calcium and iron, and 15% of zinc (Table 6.4).

Table 6.4 Contribution of the main food groups to provide essential nutrient and calorie supply (mean±SD) in % for individual household members in aquatic farming system of S-W Bangladesh

Group	Nutrients (%)	Household-head	Wife	Son	Daughter
Fish	Protein	23.06±12.89^{b}	23.08±12.83^{b}	25.81±13.42^{ab}	28.33±15.07^{a}
	Calorie	7.50±4.60^{b}	7.40±4.50^{b}	8.95±6.03^{ab}	10.22±6.50^{a}
	Calcium	30.5±26.20	31.4±26.70	33.30±27.07	32.80±26.07
	Iron	8.30±8.30	8.60±8.80	9.50±8.90	10.10±1.00
	Zinc	8.20±7.20	8.40±7.20	9.60±7.50	10.00±8.20
Cereals	Protein	46.96±15.9^{a}	46.62±14.54^{a}	43.69±14.98^{ab}	42.21±14.59^{b}
	Calorie	73.20±11.7^{a}	73.35±10.6^{a}	70.60±11.90^{ab}	69.60±11.50^{b}
	Calcium	23.43±12.2^{a}	22.12±11.56^{ab}	21.04±11.40^{ab}	19.96±11.15^{b}
	Iron	40.36±18.23	39.28±16.86	37.17±16.79	36.91±17.15
	Zinc	58.55±16.44^{a}	58.08±15.22^{ab}	55.88±16.65^{ab}	54.69±15.10^{b}
Vegetables	Protein	10.14±7.30	10.6±6.50	10.37±7.60	11.32±7.50
	Calorie	8.2±4.60^{b}	8.6±4.20^{ab}	9.05±4.90^{ab}	9.7±4.80^{a}
	Calcium	34.68±19.50	36.49±19.83	35.44±20.01	36.71±20.65
	Iron	28.91±17.71	30.12±16.97	30.59±18.09	32.59±18.50
	Zinc	14.75±8.50^{b}	15.67±8.30^{ab}	15.58±9.30^{ab}	17.64±9.60^{a}
Meat	Protein	14.58±8.20	13.85±7.50	17.73±10.48	16.76±10.50
	Calorie	3.6±2.20	3.4±1.90	4.4±2.80	4.5±3.02
	Calcium	0.8±1.10	0.88±1.70	1.01±1.30	0.8±1.20
	Iron	8.8±7.02	8.3±6.06	9.7±6.20	10.08±7.70
	Zinc	8.4±5.70	7.8±4.80	10..57±7.20	10.37±7.50
Milk	Protein	4.4±3.70	3.8±2.80	4±2.20	4.8±3.20
	Calorie	2.9±20	2.6±1.60	2.8±1.60	3.3±1.90
	Calcium	20.3±13.90	19.2±11.80	19.6±10.90	21.8±13.10
	Iron	0.86±.70	0.81±0.66	0.77±.40	0.9±0.60
	Zinc	4.3±3.40	3.8±2.40	3.9±2.10	4.8±3.20
Fruit	Protein	0.9±1.10	1.5±3.30	1.02±.80	1.3±2.70
	Calorie	2.2±2.50	2.5±2.80	2.7±2.80	2.4±2.01
	Calcium	2.09±3.18	1.8±2.40	1.96±3.30	1.6±1.80
	Iron	3.4±60	4±6.30	3±5.40	2.6±3.90
	Zinc	0.85±1.20	0.89±1.20	1.2±1.40	1.08±1.09
Egg	Protein	5.1±4.09	5.4±4.40	5.2±3.60	7.2±6.90
	Calorie	2.1±1.70	2.09±1.60	2.1±1.50	3.07±30
	Calcium	4.2±3.80	4.6±4.70	4.3±3.90	5.7±5.70
	Iron	3.8±3.20	4.2±3.80	4±2.90	5.7±5.80
	Zinc	5.3±4.10	5.3±4.10	5.3±3.70	7.6±6.90

Different superscripts letter in the same row is indicating significant differences (*P*<0.05).

6.3.8 Energy and major nutrition consumption patterns at household level

The heterogeneity of household food allocation has been presented in the previous sections. The nutrition level required may vary depending on various factors including activity level, age, and sex. The gap between actual dietary consumption and Recommended Nutritional Intake (RNI) level determined the food and nutritional security of individual. The observed nutritional and energy consumptions for age group and sex were compared with the RNI values (WebMd, 2016).

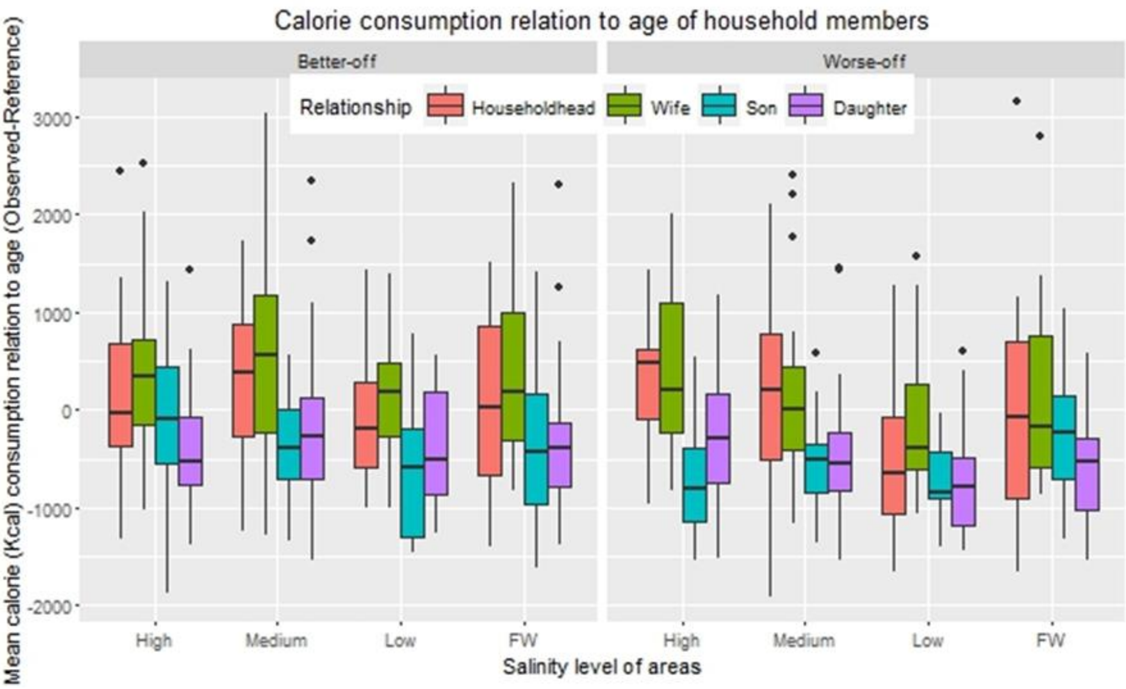


Figure 6.2 Residual energy (Kcal/capita/day) consumption in relation to RNI across the saline gradients of aquatic farming systems in S-W Bangladesh [Each point indicated an individual household member]

6.3.9 Residual (Observed-References) energy consumption

Among the four study sites, household members in the HS area consumed significantly ($P<0.05$) more energy than the LS area. Nevertheless, consumption in the HS area was statistically equal to the MS and FW area. The calorie consumption in relation to an average threshold level (for daughter and wife 2300 Kcal and son and household head 2900 Kcal) among the family members showed that both the household head and his wife consumed more than their daughter and son. The Household head and the wife consumed at least 3 and 8.5% above threshold levels, respectively. In contrast sons and daughters consumed 14 and 18% less than threshold levels, respectively. For the saline area, the threshold level was fixed as 2600 Kcal (the average value for four members (2300×2+2600×2)÷4). The energy consumption pattern across the saline gradients were 2,4, 6 and 16% less than the threshold level in HS, MS, FW and LS area, respectively. In social well-being groups, the worse-off consumed a significantly (P<0.05) lower amount of calories than better-off households, with the variation between these two social groups being around 10%.

6.3.10 Residual (Observed-References) micronutrients consumption pattern

The consumption patterns of the three essential micronutrients, zinc, calcium, and iron, among household members in the four different saline zones were tested. Among the four independent factors only SFVC had no influence on micronutrient consumption (Table 6.5).

Among the four different sites, zinc consumption was found to be 20-50% higher than the RNI. Households in FW regions consumed significantly (P<0.05) more than households in the MS region, but were equal to the other two areas. Also, the better-off households consumed more than, the worse-off households across the agro-ecologies. The household head and wife consumed a significantly higher level of zinc in compared to the threshold than the son and daughter (Table 6.5).

For calcium, people from the FW area consumed a significantly higher (P<0.05) amount than all other sites. HS consumed more than the LS area, although this was similar to the MS area. Both the MS and LS areas were statistically similar. Better-off households were significantly (P<0.05) higher in terms of calcium consumption compared to worse-off households. Among the household members, the daughter consumed a significantly lower amount than both the household head and son but a similar amount when compared to wife. The intake value for the daughter was more than 50% lower than the RNI (Table 6.5).

Iron consumption did not differ significantly among the four sites. The FW region consumed the most iron followed by HS, MS and LS areas. With regards to the social well-being groups, better-off households had a significantly (P<0.05) higher iron intake than the worse-off households. Among the household members, a significant difference was observed among the four members, with the household head consuming the most iron followed by the son, wife, and daughter. Furthermore, the daughter was found to receive

15% less than the reference value, while male members consumed 60-80% more than their requirement (Table 6.5).

Table 6.5 Results showing factors affecting mean micronutrients consumption of household members in relation to the average reference value in the aquatic farming system in S-W Bangladesh.

Minerals	Factor	Group	Mean residual	SD	% above (+) or below (-) the threshold level	Significance
Zinc	Salinity	HS	3.6	5.1	36.0	ab
		MS	3.5	5.9	35.6	b
		LS	2.3	4.7	23.0	ab
		FW	3.9	5.8	39.0	a
	Social Well-being	Better-off	3.9	5.4	39.4	a
		Worse-off	2.8	5.4	27.8	b
	Relation	Household head	4.5	6.0	45.5	a
		Wife	4.9	5.3	49.0	a
		Son	2.1	5.2	20.6	b
		Daughter	1.8	4.5	18.5	b
Calcium	Salinity	HS	-586.2	328.7	-53.3	b
		MS	-607.3	313.1	-55.2	bc
		LS	-707.5	250.6	-64.3	c
		FW	-84.8	796.5	-7.71	a
	Social Well-being	Better-off	-446.9	549.9	-40.6	a
		Worse-off	-533.7	492.7	-48.5	b
	Relation	Household head	-340.4	602.9	-30.9	a
		Wife	-515.9	475.4	-46.9	bc
		Son	-417.5	564.8	-37.9	ab
		Daughter	-609.4	445.6	-55.4	c
Iron	Salinity	HS	4.06	10.4	33.8	a
		MS	2.75	9.5	22.9	a
		LS	2.01	9.5	16.7	a
		FW	4.49	10.3	37.4	a
	Social Well-being	Better-off	4.3	10.1	36.4	a
		Worse-off	2.3	9.8	18.8	b
	Relation	Household head	10.1	9.9	84.0	a
		Wife	1.4	8.8	11.9	c
		Son	7.3	8.6	60.9	b
		Daughter	-1.9	7.8	-15.8	d

Different letters (last column) in rows under each factor row indicated significant differences ($P<0.05$).

6.3.11 TOTAL N-3 PUFA CONSUMPTION PATTERN

SFVCs had no influence on the n-3 PUFA consumption at the household level (Figure 6.3). However, households involved in open water fishing, confined to few in the HS area, consumed higher n-3 PUFA than others.

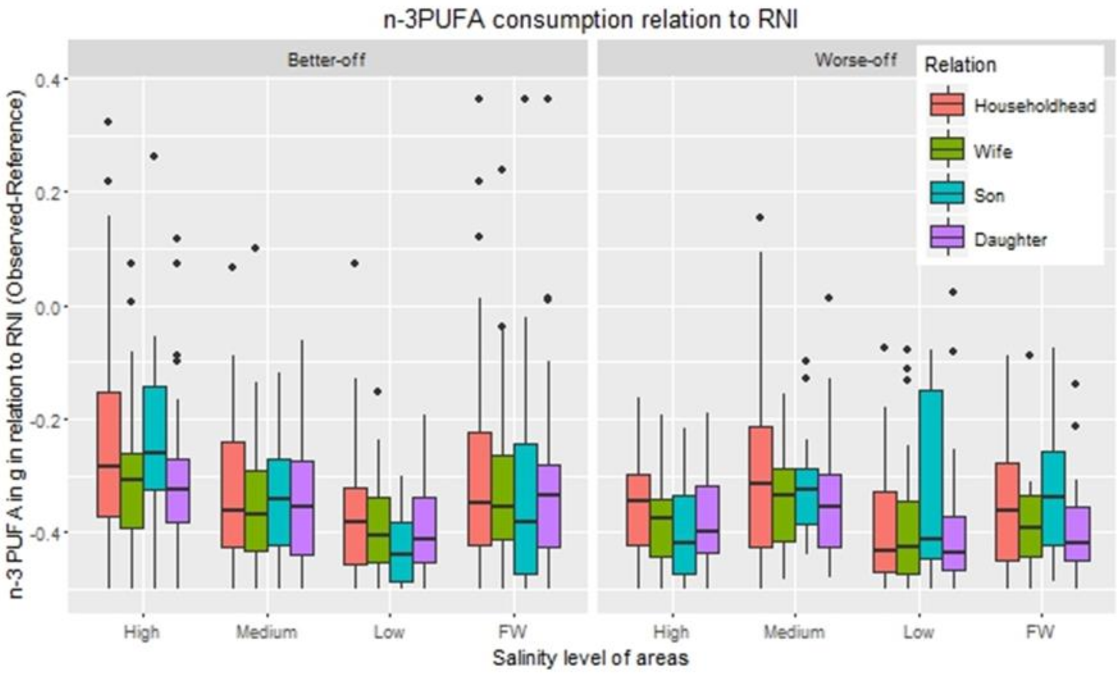


Figure 6.3 Residual total n-3 PUFA (g/capita/day) consumption in relation to RNI along the saline gradients of aquatic farming system in S-W Bangladesh [Each point indicated members at household level]

Households in the LS region consumed a significantly lower (*P*<0.05) amount of n-3 PUFA compared to all other areas. In addition, better-off households had a significantly higher n-3 PUFA intake than their worse-off counterparts. The household head consumed a higher n-3 PUFA level than both the wife and daughter but consumed an equal level to the son. The consumption pattern between the wife, daughter and son were similar. The standard optimal dose of 500 mg per day per capita has been considered here (ISSFAL, 2004).

6.3.12 BODY MASS INDEX (BMI) OF ADOLESCENT GIRLS

SFVCs had no influence on the BMI values of adolescent girls (Figure 6.4).The residual BMI in the HS area was found to be significantly (*P*<0.05) higher than the other three sites. LS and FW regions were statistically similar although both were higher than the MS area. Adolescent girls from the better-off households had a significantly (*P*<0.05) higher BMI than those from worse-off households. Nevertheless, the overall BMI was found to be 10-20% below the reference level.

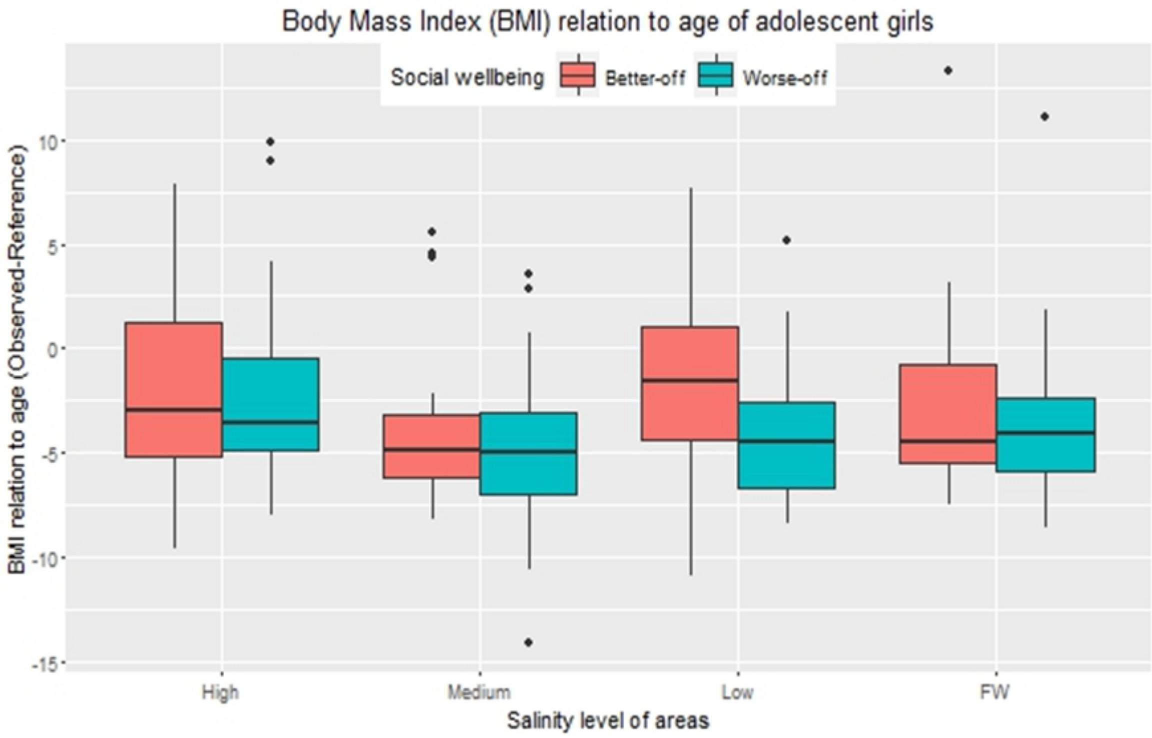


Figure 6.4 Residual (Observed-Reference) BMI (Body Mass Index) of adolescent girls (10-19 years) in relation to age across the saline gradients of aquatic farming systems in S-W Bangladesh

6.3.13 Residual (Observed-References) Mid-upper arm circumference (MUAC)

The MUAC of adolescent girls from the HS area was significantly ($P<0.05$) higher than that observed in adolescent girls from both the MS and FW regions. Girls from the LS area had a significantly higher MUAC than girls from the FW region, although no differences were found between the LS and MS areas. Both the MS and FW areas remained in the bottom cohort. The mean MUAC level was found to deviate up to 25% lower from the reference level (Figure 6.5).

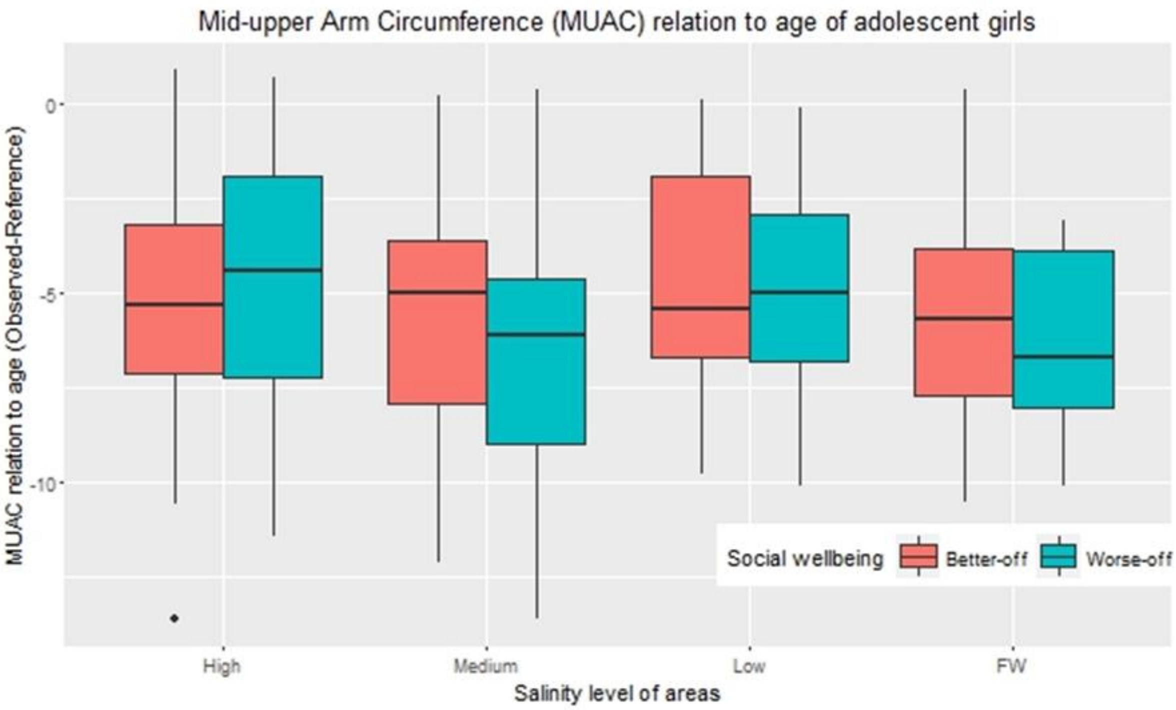


Figure 6.5 Residual (Observed-Reference) MUAC (Mid-upper Arm Circumference) of adolescent girls (10-19 years) in relation to age across the saline gradients of aquatic farming system in S-W Bangladesh

6.3.14 Total n-3 PUFA content in whole blood of adolescent girls

The total n-3 fatty acids (EPA+DHA) as a percentage of total fatty acids were obtained from the blood samples of adolescent girls. The total n-3 PUFA content in RBC (transformed from whole blood) was tested against three independent factors: salinity, social well-being, and participation in SFVCs. Total n-3 PUFA in adolescent's blood was unaffected by participation in SFVCs and social well-being. However, the total n-3 PUFA content was significantly affected by salinity level, with the HS area significantly higher (4.63±0.7) than all other areas. Girls from the MS area had significantly higher (3.96±0.8) total n-3 content than girls from both the LS (2.96±0.8) and FW (2.77±0.6) area (Figure 6.6). Furthermore, no significant differences (*P*>0.05) were found between girls from the LS and FW sites. The total n-3 in blood gradually decreased with the progression towards less saline environments.

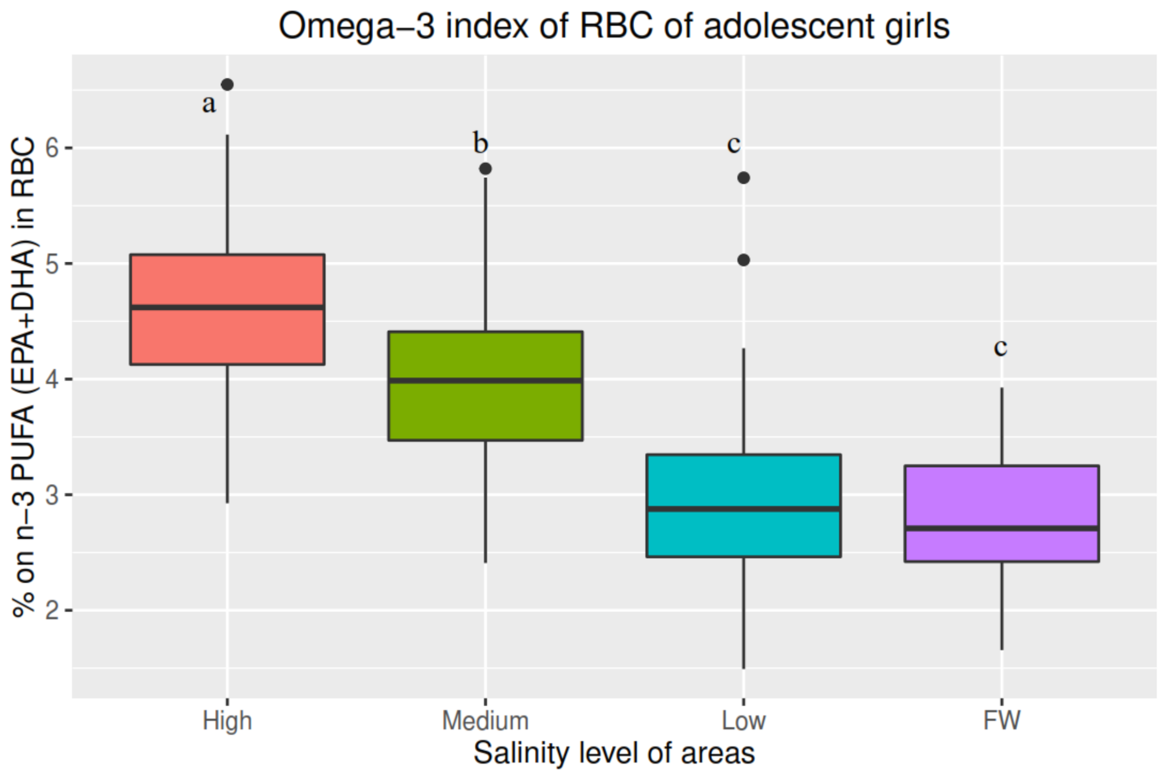


Figure 6.6 % of total n-3 PUFA (EPA+DHA) in RBC of adolescent girls (10-19 years) across the saline gradients of the aquatic farming system in S-W Bangladesh

6.3.15 TOTAL N-3 LC-PUFA AND LC-PUFA RATIO IN WHOLE BLOOD OF ADOLESCENT GIRLS

The n-3 LC-PUFA/total LC-PUFA in the whole blood of adolescent girls was tested against the three independent factors salinity, social well-being, and SFVC. As with total n-3 PUFA content, there were no influences from neither social or well-being nor SFVC factors at the same scale in the same statistical model. The pattern of n-3 LC-PUFA/total LC-PUFA followed the same trend of omega-3 index of adolescent girls. The n-3 LC-PUFA content in relation to total LC-PUFA in the whole blood sample is drawn and presented in Figure 6.7. The long-chain n-3 PUFA proportion in whole blood was not related to social well-being. Salinity gradients followed the trend HS (32.1±3.1) was equal to MS (30.9±3.7) > LS (24.2±3.7) > FW (22.5±2.3), significantly (*P*<0.05) (Figure 6.6).

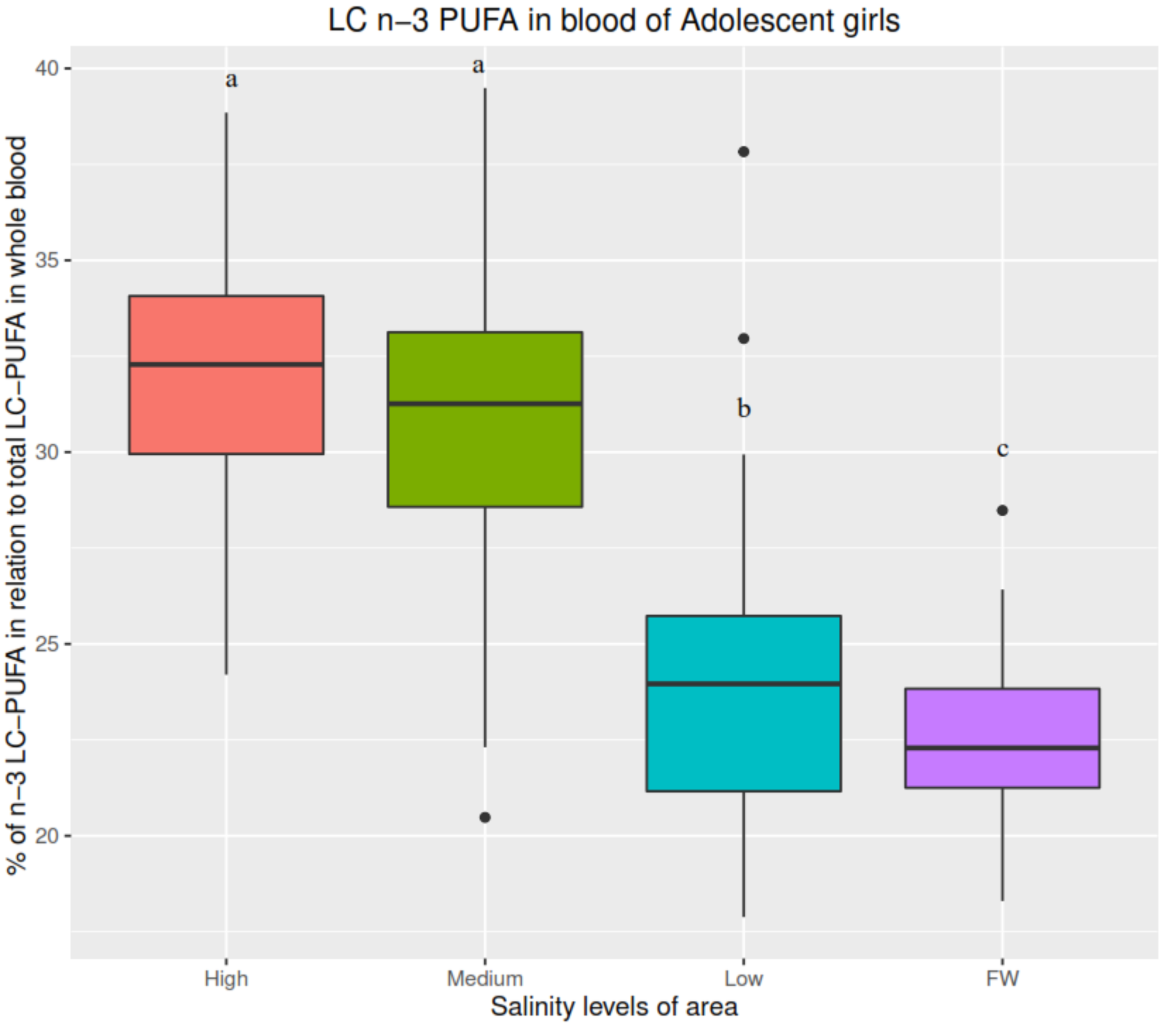


Figure 6.7 % of n-3 LC-PUFA in relation to total LC-PUFA in whole blood of adolescent girls (10-19 years) across the saline gradients of the aquatic farming system in S-W Bangladesh [Green portion of the body represents % of n-3 LC-PUFA content]

6.4 LINKING NUTRIENT CONSUMPTION TO HEALTH OUTCOMES

6.4.1 DIETARY TOTAL N-3 PUFA LINKED TO WHOLE BLOOD N-3 PUFA

The dietary consumption of nutrients from the two 24 h recall studies correlated to the nutritional and health outcomes of adolescent girls. The relationship between dietary and total n-3 PUFA blood levels are shown in Figure 6.8.

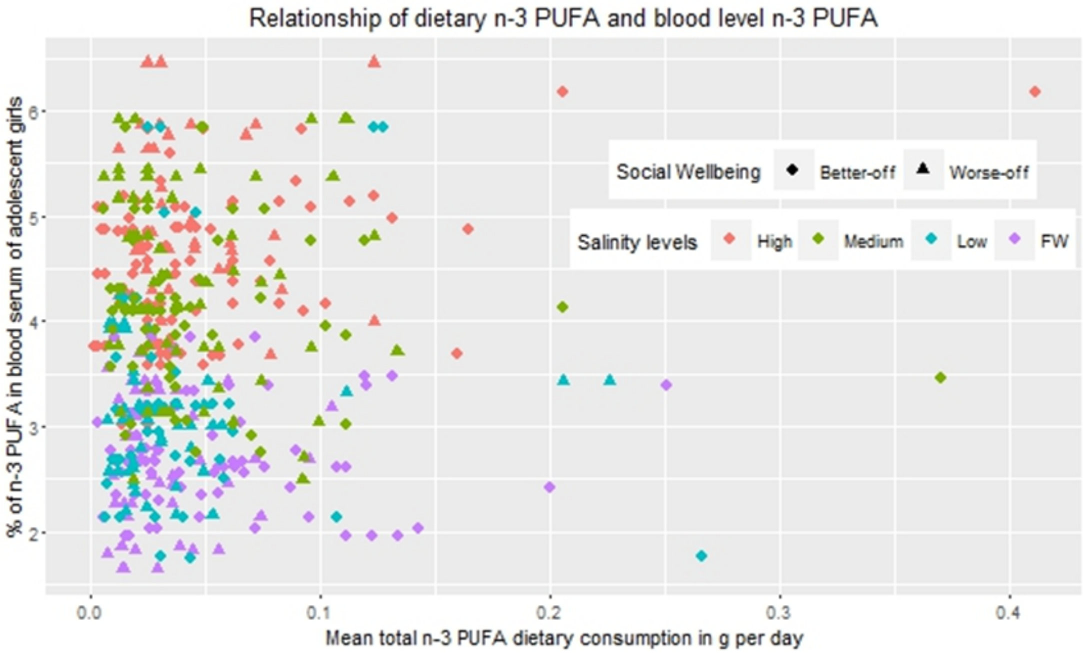


Figure 6.8 Scatterplot of mean total n-3 PUFA consumption (EPA+DPA+DHA) in relation to total n-3 PUFA (EPA+DHA) in whole blood of adolescent girls across the saline gradients of aquatic farming system in S-W Bangladesh [Each data points is representing n-3 PUFA value for adolescent girls]

No strong correlations (r=0.002) were obtained from the dietary fatty acids consumption and the total n-3 levels in blood samples from adolescent girls (Figure 6.8). Based on the nutritional composition of the various fish species presented in Chapter 5 (Table 5.5), the present results indicate that people from the higher saline areas consume more n-3 PUFA content through their fish intake compared to lower saline households.

6.4.2 Dietary total protein consumption linked BMI of adolescent girls

Protein consumption may impact the anthropometric outcomes. The mean protein consumption in relation to the RNI of adolescents was tested against their BMI value. In most of the adolescent girls, protein consumption level was found to be 2-3 times higher than the required amount for all sites and social well-being groups. However, the protein consumption and the BMI values are not correlated. Apart from receiving adequate protein the daughter from the households was found to be vulnerable in receiving adequate amounts of food compared to others family members.

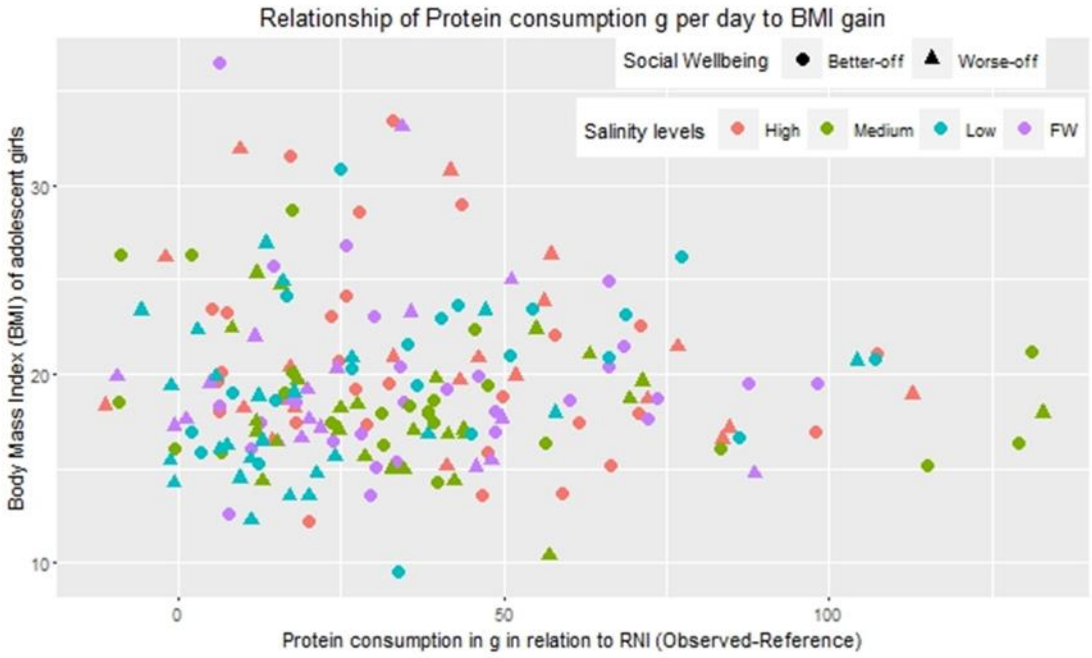


Figure 6.9 Scattered plot of mean protein (g/capita/day) consumption in relation to RNI against Body mass Index (BMI) of adolescent girls across the saline gradients of aquatic farming system in S-W Bangladesh [Each data points is representing value for adolescent girls]

6.5 DISCUSSION

The results presented in this chapter confirm that the nutritional outcomes of adolescent girls vary across the saline gradients. The anthropometric outcomes varied across the saline gradients as well as social well-being. The n-3 PUFA in the RBC of adolescent girls accurately reflects the access and availability of oily fish. The clearer pattern of n-3 PUFA in blood shows how diet (fish) quality governs the nutritional outcomes, irrespective of social well-being. The fish-based HS area also showed a clear consistency in terms of energy consumption and anthropometric outcomes. The inadequate livelihood options (Chapter 3), from both the MS and FW areas, reflected on the anthropometric outcomes of adolescent girls through a lower MUAC value. The present study expected to observe a disparity in fish consumption levels in non-aquaculture households as issues surrounding the food security of people in this group has been raised elsewhere in the literature (Gomma & Rana, 2007). However, increased access to food, food production, social safety nets and charitable services has enhanced the food consumption of poorer social groups. The old social custom of food allocation disparity still exists at household levels depriving women, in particular adolescent girls, of fish distribution.

6.5.1 IMPACT OF INTRA-HOUSEHOLD FOOD ALLOCATION (IHFA)

Intra-household food allocation among family members varied significantly across the different saline gradients and social well-being groups. The household head tended to eat a higher amount compared to the other family members. The daughter often received a smaller share compared to their counterparts. This finding is similar in nature to that of Hill et al. (1996) and Koenqig (1986), who identified this form of disparity at the household level in Bangladesh. This view persists and was revealed in a study in Bangladesh (Roos et al., 2007b). Fish consumption patterns per day per capita was found to be higher in this study compared to others (Bogard et al., 2016), and could possibly be linked to the survey area (most of the households are fish farmers) and harvesting season (December- the peak harvesting time). Regarding food allocation, fish was found to vary greatly with the household head and male members obtaining a major share whereas the wife and daughter received less. For example, the daughter was found to get at least 25% smaller share on a ready-to-eat fish weight basis compared to the household head and the other male members. Nevertheless, these amounts of fish consumed by the girls were above the RNI level. However, in Nigeria, where the male heads of household generally consume 59% more fish by weight than the wife and children, the gap in fish consumption per unit body weight revealed that the average fish consumption was 0.27 for male and 0.17 kg/kg body weight/year for the wife and children (Gomna & Rana, 2007). One reason for this may be related to the hierarchy within a household. For instance, as the housewife distributes the food among family members she may view the male household head as the household member who deserves the largest share of the meal since he is the breadwinner regarding earnings. Indeed, Chimwaza (1982), noted that, as the household head, the male received a greater share of food than the remaining family members, which was most likely as a token of respect and appreciation. Similarly, Sen and Sengupta (1983), argued that both women and children obtain a smaller share of nutrient rich food as they remain in the lower status of the household, especially in South Asian countries. This study also confirmed that adolescent females, and to some extent other female members of the household, were deprived of frequently consumed food items such as cereals, fish, and vegetables (Tables 6.1). The quantitative consumption variation may not provide the exact scenario as the nutrition content of food items and requirements by the subjects are widely varied. Therefore, the nutrition consumption among the subjects and health outcomes are discussed in next section.

6.5.2 NUTRIENT CONSUMPTION AND ANTHROPOMETRIC OUTCOMES

Dietary consumption does not always reflect the health outcomes. For example, males have a higher energy intake compared to females, but the BMI values between the two sexes of an adult were identical. Since the male members of the household are involved in labour-intensive work, this would suggest that they expend more energy (Sudo et al., 2004). The BMI and MUAC values of adolescent girls were below the reference values for their respective age groups (Figure 6.4 & 6.5). The results of the present study are perhaps better in nature to that of Shahabuddin et al. (2000), who found that the BMI of two-thirds of 17-year-old adolescent girls were in the third percentile in Bangladesh. Adolescent girls aged between 15-19 have been found to be underweight compared to their counter sex in Bangladesh (NIPORT, 2013). The MUAC value in the present study follows the same trend as BMI. Sultana et al. (2015) also found a significant positive correlation between BMI and MUAC in Bangladesh. The source of macronutrients is important in determining their utilisation within the human body.

In this study, cereals provided around 70% of the energy, whereas fish and vegetables provided 10%. Other than cereals and vegetables, which were found on average to be consumed 3 times every day reflecting the findings of Sudo et al. (2004), fish were the next most frequently consumed food item. This is in agreement with the study of Belton et al., (2014) in Bangladesh. The contribution of cereals is higher than that reported in some other studies performed in Bangladesh. For example, Ahmed et al. (1998) found that cereals provided 57% of the calories, whereas Sudo et al. (2004) noted that rice alone contributed 60% and NIPORT (2013), reported that both cereals and roots provided 80% of the energy. The importance of these macronutrient sources were found to be similar to others. Energy allocation among household members showed that both the household head (2988 Kcal), wife (2496 Kcal) and son (2484 Kcal) are getting higher than the national (2481 Kcal/capita/day) (Figure 6.2) intake level reported in 2009 (NIPORT, 2013). It therefore appears that aside from adolescent girls (1877 Kcal) the other family members have a sufficient energy intake level. This is most likely due to the increase in rice production in Bangladesh. This argument is firmly supported by Hels et al. (2003) who stated that Bangladeshi households are enjoying the growing trend of fish vegetable and energy consumption.

While considering the WebMd (2016), reference value the active level were considered for energy consumption estimation of household members. The calorie intake of the household head and wife was found above the ceiling whereas both the son and daughter remained below the RNI level. This argument is supported by Hill et al. (1986) who observed a 13% deficit in calories in members from rural households in Bangladesh with no teenage boys or girls fulfilling their requirement. A similar level of energy deficit among the urban adolescent college girls was also reported by Kabir et al. (2010). Both in energy consumption and anthropometric outcomes adolescent girls remained in the unfavourable condition.

The reduced total energy intake accelerates weight loss, regardless of the macronutrient consumption of the diet (Shay et al., 2012). A lower energy intake coupled with higher cereal consumption has been shown to lower the BMI value in adults (age 40-59) in the US (Shay et al., 2012). A similar inverse relationship between higher cereal intake and BMI was also observed in school children in Chile (Valenzuela et al., 2015). Therefore, a lower energy intake associated with a higher consumption level of cereals might be linked to lower BMI.

A reduced consumption and consumption frequency of eggs, milk and other items than fish based food also appeared to be responsible for a low weight gain (Table 6.1). The consumption of fish-rich diets led to weight loss in European adults (Thorsdottir et al., 2009). In contrast, the consumption of high levels of milk and eggs resulted in an enhanced body weight in a cross-sectional study of children in Estonia and Sweden (Villa et al., 2007). The consumption of other food items, such as chocolate and ice-cream, at the expense of nutritionally dense food is also responsible for weight gain (Hanning et al., 2007).

Despite a reduced consumption of meat, eggs, milk and other foods by the adolescent girls, compared to other household members, the overall protein intake was found to be well above the RNI (Figure 6.9) with a major amount of protein derived from fish. In this study, protein of fish origin was 50% higher than the global context where Tacon and Metian (2013), noted that aquatic animal products accounted for 16.6% of the animal protein supplied. In this study over two-thirds of the animal protein consumed was derived from fish. This result is in accordance with the national context of Bangladesh (Ahmed et al., 1998; DoF, 2015). The protein consumption level in adolescent girls was found to be 2-3 times higher (Figure 6.9) than the recommended nutritional intake level. This level of higher protein intake in meals is common in many countries (Mamerow et al., 2014). In contrast, in some cases, the amount of animal protein intake has been reported to be extremely low, e.g. 9 g/capita/day in Bangladesh (NIPORT, 2013). Also, Ahmed et al. (1998) found that only 17% of adolescent girls met their protein requirement in urban areas of Bangladesh (Ahmed et al., 1998). A lower protein consumption and poor BMI level were found in readymade garments factory workers in Bangladesh (Khan & Ahmed, 2005). However, this current level is not thought to be harmful since the WHO/FAO/UNU (2007) all suggest a protein intake level of 0.83 g/kg of body weight/day and that exceeding this recommendation by up to 3-4 times is considered safe. A higher protein consumption was also reported among the affluent adolescent girls in Delhi, India (Chugh & Puri, 2001). However, all of these nutrients are not equally available for digestion and absorption. As the protein digestibility of Indian rice-based diet is lower (77%) than in the western diet (95%) (WHO/FAO/UNU, 2007).

Macronutrient consumption pattern and BMI were not always correlated. Lean girls can have a higher protein intake than overweight girls. For instance, Lepe et al. (2011) reviewed the impact of high protein diets on BMI and noted that half of the reviewed studies revealed that the high protein dietary pattern was responsible for the weight loss. The higher protein consumption is not exceptional as Hassapidou et al. (2006) also obtained 1.5-4 time higher than RNI (0.83 g/kg body weight/day) level of protein consumption of adolescent girls in Greece.

In addition to higher protein consumption, some consumption behaviours also regulate the anthropometric outcomes. Adolescent girls in the current study consumed food three times in a day and food volume were almost equally distributed. This might be the cause for the reduction in weight of the girls due to the high protein intake at breakfast (Baum et al., 2015). Regular consumption of food in the morning has been linked to reduced body weight (Leidy et al., 2013). A meal frequency of 3 times in a day also ensured the equal distribution of energy consumption which can avoid weight gain (Dubois et al., 2009). Although, the active level threshold from WebMD (2016) has been considered here to compare the energy consumption at individual level. However, some researchers could not find any relationship in diet consumption and activity level of children (9-10 years) in the UK (Vissers et al., 2012).

Here, the higher protein consumption might be linked to the seasonality. The current study was conducted during the peak season for fish harvest and thus fish consumption might have been elevated compared to levels for the rest of the year. Morales (2007), found that the dietary intake of fresh aquatic animals at inland locations in three South-east Asian countries varied by food and nutritional factors (good taste, easy to cook), abundance (availability, ease of catching) and economic value (good price). Moreover, the consumption by households was also related to agro-ecological zones, with sites and months reflecting the different availability of aquatic animals.

Thus, Bibiloni et al. (2015) noted that the role of dietary macronutrients on the body weight gain is indecisive. For example, Elliott et al. (2011) studied 5-17 years old subjects in Australia and found no conclusive evidence that percentage of macronutrient intake influenced BMI. Therefore, Villa et al. (2007) concluded that the dietary macronutrient intake and weight gain are country-specific and local contexts should be considered in intervention projects addressing anthropometric status. Higher protein consumption has been linked to a lower body weight gain (Soenen et al., 2012). Meal pattern and food choice are also important indicators for nutrient consumption in adolescent girls (Sjöberg et al., 2003).

6.5.3 LINKING BETWEEN N-3 PUFA IN DIET AND BLOOD

Total n-3 PUFA levels in the RBC of adolescent girls gave a very clear distinction between the saline areas. This accurately reflects the importance of oily fish (Chapter 5) harvested from the *ghers* in the higher saline areas compared to lower saline sites, as the availability of oily fish gradually decreases with the decline in *gher* water salinity levels from south-west to the northeast area in S-W Bangladesh. Shellfish was lower compared to other fish in supplying n-3 PUFA (He et al., 2013). Both the HS and MS areas fall into the intermediate stage of the omega-3 index (Harris, 2004) with the remaining areas categorised as the undesirable stage of the omega-3 index in blood. Households in the higher saline areas tended to eat a more oily mangrove fish species due to their easy access. This view also agrees with the views of others whereby the omega-3 index is highly correlated with oily fish consumption (Vidgren et al., 1997).

The omega-6 and omega-3 (n-6/n-3) fatty acids ratio are opposite to the total n-3 PUFA content in RBC, i.e. the lower saline areas had a higher ratio of n-6/n-3 than the higher saline areas. This would most likely be related to the lower consumption levels of oily fish in the lower saline areas. Moreover, dyke crops such as, rice are produced in high volume in the lower saline areas giving easy access to the people for plant-based diets. However, in the current study, a similar trend in vegetable consumption across the agro-ecologies was observed. This might be due to the seasonality. Plants are higher in omega-6 fatty acids and are devoid of LC-PUFA such as EPA and DHA. Although there was no sharp difference obtained on plant-based food consumption, however, there was a trend in lower saline areas to consume more vegetables and fruit in general. This is supported by the fact that the diet in the lower saline areas is also believed to be more plant based, which may well contribute to the higher n-6 content in blood. This argument has also noted by Michaelsen et al., (2011), who studied 13 LMIC's where the population diet was largely plant-based and found that maternal mothers had a lower level of DHA in their breast milk compared to countries consuming more fish. Compared to omnivores, vegetarians have a significantly higher n-6 PUFA and n-6/n-3 ratio in blood plasma (Yu et al., 2014), leading some (e.g. Li, 2011) to suggest that the vegans needed to enhance their dietary n-3 PUFA consumption.

Apart from dietary causes some non-dietary factors such as age, adiposity, exercise (Burdge et al., 2002), sex (Marangoni et al., 2007) and smoking (Bradbury et al., 2011) also affect the fatty acids composition of human blood. The potential health impact also depends on the cooking method i.e. fried fish is inferior compared to non-fried fish (He et al., 2013). In the present piece of work the non-dietary causes might be a factor, although subjects were non-smokers, single sex, and mostly school goers who supported their mother in the household chores. The cooking method at household level might be a factor. However, the cooking method was identical among households from the same geographical area. Cooking methods may nevertheless modify the benefits of fish consumption and there is a further need to explore the optimal way of cooking in future research (He, 2009). Milk consumption was also negligible (about 15% of adolescent girls consumed milk of the total girls studied; Table 6.1) and showed an inverse relationship with the n-3/n-6 PUFA ratio in the whole blood. This finding was similar to a study on adolescent children (10-15yrs) in Japan (Fukushima et al., 1999). It is expected that at the childbearing age most of the adolescent girls will show more DHA as estrogen has an increased effect on the conversion of alpha-linolenic (18:3n-3) to DHA (Burdge et al., 2002). Moreover, the ability of young women to partition fatty acids towards ketone body production rather than VLDL-TAG (Very Low-Density Lipoprotein-Triglycerol) put them in advantageous metabolic position compared to young men (Marinou et al., 2011).

In a recent global survey report, the n-3 PUFA content from Bangladesh was excluded (Stark et al., 2016) which further emphasises the importance of the current study. The average value of EPA and DHA in RBC is close to 4 and the higher saline areas are above the threshold of low level. This result is slightly higher than in the neighbouring country, India (Stark et al., 2016).

6.5.4 MICRONUTRIENT CONSUMPTION

In Bangladesh among the micronutrients iron, zinc, and calcium deficiencies are high (Ahmed et al., 2012) along with vitamin A and iodine. Zinc consumption at household levels was observed to be higher than the reference level across all saline gradients, with an improvement of 20-50% higher than the RNI level. This result differs from that of ICDDR'B et al. (2013), where they reported that the national level of zinc deficiency affects around 45% of preschool children and 57% of non-pregnant/non-lactating women. This might be linked to higher fish consumption and bioavailability of zinc sourced from fish. The bioavailability of micronutrients varies widely (Bogard et al., 2015). Combs et al. (2008) also found sufficient zinc consumption in the south-east coastal area of Bangladesh.

The pattern of calcium consumption was particularly low throughout all saline gradients and social well-being groups. Household members, irrespective of sex and position, had a 30-55% lower calcium intake than the RNI. The situation deteriorated towards the higher saline areas where the intake level was more than 50% lower than the required amount. This might be explained by the lower consumption of dairy products in more saline areas which is believed a major source of Ca. Moreover, both livestock and milk production has reduced significantly over the year due to shrimp farming which limits the amount of land available for grazing (Rahman et al., 2002). Moreover, the current study showed that fish consumption contributed only about 30% of the required amount. Small fish eaten whole including the (soft) bones are a particularly valuable source of Ca (Roos et al., 2003). This is by no means surprising as a similar situation was described by Combs and Hassan (2005) who found that there was a calcium intake deficit in the south-east coastal area of Bangladesh. Arsenault et al. (2013) worked in rural Bangladesh and found that women and children struggled to get adequate amounts of calcium in their diets. In developed countries, dairy products are a source of Ca. However, in Bangladesh dairy consumption is much lower (HKI, 2014). The consumption of SIS provided adequate micronutrients, appears to have decreased day by day due to the expansion of monoculture of aquatic animals (Belton & Thilsted, 2014).

Iron consumption was found to differ among the four household members. The intake of both the male members of the household (i.e. household head and son) was more than 60-80% of their requirement, whereas the wife only obtained around above 10% of the reference level. The daughter, however, for whom this nutrient is essential, received at least 15% less than the required level. As cereals and vegetables and fish are supposed to be the rich source of iron (Table 6.1), a minimum share of all of the items kept the girls in an iron deficit situation. It has been reported that 77% of adolescent girls consume less iron than the required level (Ahmed et al., 1998). It was also discovered that two-thirds of girls aged between 13-18 were found to be affected by anaemia, and about one-third of anaemia is reputably linked to the iron deficiency in Myanmar (Htet et al., 2013).

The present study described the consumption level of three essential micronutrients but did not necessarily confirm the impact of micronutrients on nutritional status of the body.

6.5.5 INFLUENCE OF SOCIAL WELL-BEING AND INVOLVEMENT IN AQUATIC ANIMAL VALUE CHAIN

The socio-economic positions have influences on the anthropometric outcomes of people in in the middle–income countries (Batty et al., 2009). Adolescent girls from better-off households had a significantly higher BMI and MUAC values than worse-off households, although both were below the threshold. The consumption frequency in households that were better-off was much higher than their worse-off counterparts as the former group tended to have more land, money as well as more access to resources. The better-off households tended to consume more food and nutrients compared to worse-off households throughout all saline areas. This finding is largely agreed upon from other studies carried out across Bangladesh. For example, Shahabuddin (2010), noted that the poorest people in Bangladesh did not meet the minimum nutritional requirement to maintain their health. The anthropometric outcomes (e.g. underweight, stunting) of neonatal subjects, up to the age of 24 months, also showed that better-off households performed significantly better than those worse-off (Saha et al., 2009). In poorer households, fish were found to be consumed less often than in richer households. This argument is supported elsewhere in the literature, with the poorest quartile consuming 39% less of the richest (Dey et al., 2010). In Nigeria, fish consumption was found to be two times lower in non-fishing households than those involved in fishing (Gomna & Rana, 2007). Similarly, those fishing households catching a considerable amount of fish mitigate their demand for buying fish from the market (Thompson et al., 2007). This behaviour indicates the disposal of higher value species and the purchase of lower value ones (Belton et al., 2011). During the harvesting season, households utilise all the fish from their *gher*. Moreover, in most cases the low priced fish were consumed at the household level with the remainder sold on the market. Capture fisheries provide nutritionally valuable fish which are often accessible by the poorer household (Belton & Thilsted, 2014). Fish originating from open waters in Bangladesh contained higher levels of micronutrients compared to fish from aquaculture systems (Bogard et al., 2016). Moreover, households involved in fish related livelihoods enhance food security through direct consumption, enhancing purchasing power as well as empowering women through their involvement in fish processing and trade (Kawarazuka & Béné, 2010). More than 70% of households in the S-W coastal region were directly involved in aquaculture, and almost all were better-off households. Wealthier households tend to engage in fish farming. However, the engagement of poorer household in any scale of farming can enhance the household level of fish consumption by even more than the national average level (AFSPAN, 2015).

Another excellent cause for having better food intake at better-off households as they retain more food for consumption rather than selling to the market. Age, income, and education (Choudhury et al., 2000) have all been considered as positive indicators of a more healthy dietary pattern (Kant, 2004) along with nutritional knowledge (Vijayapushpam et al., 2006) and land holding (Rammohan & Pritchard, 2014). Despite the better-off position and living in proximity to the cities, households in the lower saline areas failed to provide adequate nutritional food to their children. Better-off girls in lower saline sites manifested lower n-3 PUFA in their blood compared to girls in worse-off households in higher saline areas. Food quality had a major influence on n-3 PUFA in blood. This piece of research has produced empirical evidence on food production systems, food quality, food allocation, and its health impact. Now, media and health professional should be made aware of these findings (Rahmawaty et al., 2013)

6.6 CONCLUSION

Social well-being and diet quality across the saline gradients appeared to influence the nutritional outcomes of adolescent girls. Both social well-being and diet quality are enhanced the health and nutritional outcomes of adolescent girls in general, although local context had a strong influence (Lassi et al., 2015). It was expected that the more integrated rice-fish-vegetable production in the lower saline areas provides better nutritional outcomes for the people of the community. The shrimp-based ecological settings in the high saline area, which are believed to be the worst for local food security, gave quality outcomes in all aspects of food and nutritional security indicators. Ecological conditions (Erkan & Cagiltay, 2011) played the major role in food supply and nutrition intake at the household level (Yu, 2012). Integrated aquaculture-agriculture systems, most concentrated in less saline areas did not result in overall better diets and nutritional outcomes than in communities in more salinised environments. Nevertheless the suggestions for the production of nutrient-rich crops, by incorporating vegetables and aquaculture can potentially improve both nutritional consumption and health outcomes (Pandey et al., 2016). The results also signal that global food security is impacted by a wide range social, environmental and economic factors that need to be considered through building an integrated approach (Lang & Barling, 2012) rather than concentrating on the international trade of food items.

7 CHAPTER 7: GENERAL DISCUSSION

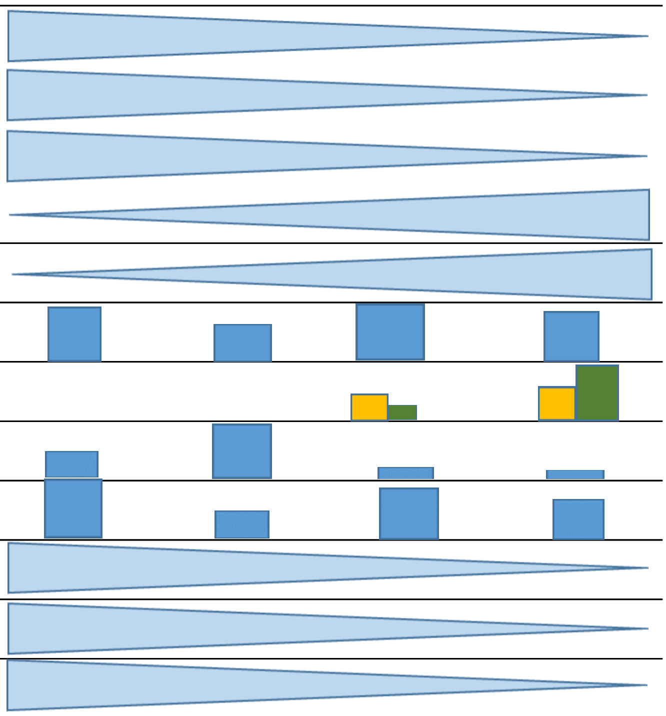
This thesis explored the impacts of aquatic animal farming on food and nutritional security of coastal producer communities in south-west (S-W) Bangladesh. This chapter focuses on the main hypothesis ‘export-oriented shrimp and prawn based aquatic animal farming in low-lying coastal floodplain has positive and diverse impacts on rural livelihoods and food & nutritional security’. In the early stage of this thesis, relevant articles were reviewed to generalise the development of farmed seafood production and identify existing knowledge gaps. The following sections sum up the findings and link the aquaculture activities on livelihoods, aquatic farming, food allocation at household levels and nutritional outcomes. Methodologies were tested that brought data from the domain of social science, aquaculture, analytical science and public health. Finally, the recommendation is made for the future research, utilisation of this research for policy formulation and pragmatic action.

7.1 OVERALL DISCUSSION

Farming systems are dynamic processes. Livelihood options, farm yields and diet quality of the aquatic animals produced varied across the salinity and the social well-being of producers. Aquatic animal farming in these agro-ecosystems was based on family-driven, low input and output polyculture system where the disease was a major barrier to sustaining yields. Limited livelihood opportunities in both medium saline (MS) and freshwater (FW) areas pushed more households into an ultra-poor category. Distance from the mangroves and big cities reduced the livelihood options for the poor. Moreover, the poor aquaculture returns evident in the MS community and comparatively low net returns in the freshwater (FW) area limited the participation of poor, who usually could not absorb disease risks nor organise financial capital. The involvement of the poor was less dependent on some pre-requisites like land ownership and aquaculture experience but important than a willingness to become involved in aquaculture. The majority of

Table 7.1 Summary of the shrimp-farming system and linkage to health outcomes of adolescent girls [▭=Rice; ▭= Dyke vegetables; density of box/shape is indicated the intensity of variables; HS=High saline, MS=Medium saline, LS=Low saline, FW=Freshwater].

Item	Variables	Area			
		HS	MS	LS	FW
Inputs	Water salinity				
	Seeds (PLs, fry)				
	Fertilizer				
	Feed				
Cost	Operational cost				
Yield	Fish yield				
	Rice and vegetables				
Gher management	Disease occurance				
Benefit	Net Return				
Nutritional quality of fish	Oily fish				
Health outcomes of adolescent girls	Total n-3 PUFA in blood				
Market orientation	Export items				



households in communities researched located across the saline gradient were directly or indirectly linked to Seafood Value Chain (SFVC). Aquatic animal productivity (per unit area) was nearly 20% higher among poorer producer households. However, the total production was greater in better-off households as they had larger *gher* areas. The poorer had an intimate linkage to farming directly linked to their limited range of alternative livelihoods (either cash or natural capital related) and were under pressure to use their land more intensely to try and boost their limited income.

Mangrove SRS (Self-Recruiting Species) and SIS (Small Indigenous Species) fishes were seen as a gift of nature that delivered double benefits to the high saline (HS) communities i.e. a higher market price and concentrated source of dietary nutrients (like long chain n-3 PUFA). The MS area was also close to mangrove, however, it had limited wild recruits due to poor connectivity of *ghers* to tidal water channels. This limitation appears to explain their reliance on introduced tilapias as a response to limited availability of wild mangrove-derived recruits.

The nature of inputs used and level of intensification varied across the saline gradient. Use of feed and fertilisation were inverse to each other, from higher (both HS and MS) to lower (both LS and FW) saline areas. More seed was stocked, more frequently in higher than lower saline areas. Apart from the economic benefit, higher saline areas contained a higher proportion of mangrove oily fish which also contained higher long-chain n-3 PUFA and essential micronutrients. Shellfish was higher in protein but very low in the other key nutrients compared to the other co-habited finfish and shellfish species. There was a tendency for a larger portion (45-80% by weight) of *gher*-produced aquatic animals, to be consumed locally, with the balance destined to the global value chain.

If the exported items were considered, only around 50% (by weight) remained in Bangladesh as by-products. Prawn by-products were widely used as local food while the rest are exported as dried by-products to international markets for industrial purposes.

Both rice and dyke vegetables provided 15-30% of economic return from *gher*-based systems in lower saline areas, indicating that aquatic animals were the main source of profit. At household levels, fish and other food item consumption were higher in better-off household compared to the worse-off household. However, adolescent and adult females consumed a lower share of food compared to male members in intra-household food allocation irrespective of social well-being and agro-ecologies. Adolescent females from better-off households were in a better position anthropometrically (BMI, stunting and wasting), than worse-off households. However, the anthropometric outcomes were similar throughout the saline gradients. In the biomarker study on the omega-3 index and n-3/n-6 of adolescents whole blood, there were no differences between the better-off and the worse-off girls across the saline gradients. However, for both omega-3 index (Harris, 2007) and the LC n-3-PUFA/LC-PUFA (Lands, 2003), adolescents in HS had higher values that gradually decreased with prevailing water salinity across agro-ecologies.

The strong link between the prevailing aquatic animals nutrient contents (long-chain n-3 PUFA) and girls' blood level LC n-3 PUFA, demonstrating that local food production could influence the health outcomes of dependent communities, irrespective of the social well-being.

The relatively undesirable levels of the omega-3 index (EPA+DHA in RBC) in the lower saline areas were noteworthy. As the majority of female adolescents entered into their in-laws household and gave birth to their first child at this stage, there is a huge probability of intergenerational malnutrition during the critical 1000 days. More informed diet choice, exchange of diet, conserve mangrove oily fish, declared ‘no cut no catch zone’ in the mangrove and practising sustainable polyculture system could potentially help to mitigate these challenges.

The food production system in S-W coastal Bangladesh is dynamic, with interacting processes embedded in the social, economic, agro-ecological context. The full set of food production systems, level of participation by member of the community and food security outcomes were understood in a holistic way. The export-oriented primary products (both shrimp and prawn) can promote social, economical and ecologically sustainability and the co-habited species can mitigate the local food demand. However, worst case scenarios from both the academic literature and media reports (e.g. Lovatt, 2016) suggest that salinisation, environmental degradation, social conflict, hunger, and malnutrition have been strongly linked to export-oriented shrimp and prawn farming and increase peoples’ vulnerability. However, Little (2010), noted that over-sensationalisation of some of the problems encountered in aquaculture had created obstacles in the process of sustainable development. The reorientation of the debate from seafood farming in saline environment towards the more holistic notion of food security outcomes is captured in the core part of this thesis.

In the introductory chapter it opens the discussion by introducing the shrimp and prawn farming systems, historical perspectives, major stakeholders, the foremost driving force of the development process, major impacts on socio-economic and environmental conditions. It closes with a call for analysis agro-ecological settings and the trade-off in between local food security outcomes and farming pattern.

In materieals and methods part it proceeded to demonstrate how water salinity affected aquatic animal farming systems. This analysis also supported understanding of the spatial scale of the farming pattern and helped to identify the various agro-ecologies on diversity and productivity. The interdisciplinary approach and analytical framework encompassed social science, aquaculture, food nutrition and public health.

The social well-being part it dealt with the socio-economic issues and the complex set of interactions of food production. This also identifies the major stakeholders and the major activities linked to the aquatic animal farming. This Chapter also goes to understand the level of participation of worse-off households in aquatic animal farming.

In farming system it assessed the major activity the farming of aquatic animals and production of other agricultural components of *gher*-based systems. This helped to understand the role of mangroves and other natural resources (salinity, wild recruit of juveniles) on farm productivity.

In nutritional content part it explored the impact of different level of inputs and environmental variations on the nutritional attributes of the aquatic animals. This Chapter documented nutritional profiles of a wide range of aquatic species from different agro-ecological landscapes. This analysis contributed to understanding the trade-offs in nutritional content of export and locally consumed items and the specific sources (species/location/culture system) of essential macro and micronutrients. The variation of nutritional profiles in between small and large fish, mangrove and freshwater fish also gave evidence for policy makers to take steps for conservation of natural resources and, and promotion of nutritionally sensitive aquaculture.

The intra-household level study it described the social customs of food allocation at household levels, indicating how adolescent girls are deprived of getting an adequate share of food. The nutritional profiles of aquatic foods allowed an evaluation of the nutrient distribution among family members and comparison with the recommended nutritional intake (RNI) by age and gender. The food security outcomes, both in anthropometric and biomarker tools assists in identifying both exposed and hidden hunger of adolescent (the most vulnerable segment at household levels). The estimation of adolescent girls health outcomes with some associated factors like social well-being and agro-ecological settings, give an idea about the casual factors of the differences.

The outcomes of this thesis are:

(a) An improved understanding of social well-being and the livelihoods of the aquatic animal farming communities.

(b) Various type of culture systems, their complexity and the important role prevailing saline areas and proximity to mangrove natural resources exert on them.

(c) A broader understanding of *gher*-based aquatic animal production systems across the agro-ecologies.

(d) The factors affecting yields and economic return in *gher* based aquaculture were identified.

(e) The nutritional content of aquatic animals from different agro-ecologies were described and the factors responsible for the nutrition differences.

(f) An understanding of the intra-household food distribution among the household members and the nutritional outcomes for the most vulnerable group, adolescent girls.

The following subsections attempt to sum up the research outcomes in relation to the questions stated in the early stage of this thesis.

7.2 CONTRIBUTION AND IMPACT OF THIS RESEARCH

The role of aquaculture in the global food supply is increasing day by day. Both the aquaculture and fisheries are playing a vital role for securing livelihoods of poor households and directly and indirectly supporting food security (Figure 1.7). However, the nutritional contribution of fish and fishery products on food and nutritional security were ignored in the internal debate. Therefore this piece of work was designed to provide adequate information on about fish and fishery products nutrition and their eventual role in the food and nutritional development. Biomarker was used as a tool to understand the role of fish and it was manifested how the aquaculture system and nutritional profiles of the animals impacted on the health outcomes of adolescent girls. All the four communities were more or less fish dependent however the nutrient content of fish was largely determine the food and nutritional outcomes. These research findings is particularly important in the LMIC's where aquaculture in its commercial form is developing importance. The research outcomes would have value to development agencies and policy makers assessing strategies for other coastal and or saline affected areas in terms of maintaining agricultural yield and the quality of food system for a vulnerable population.

7.3 CRITIQUES OF THE METHODS

The necessity for interdisciplinary research for food security is now well accepted (Liverman & Kapadia, 2010). In bridging disciplines, we must recognise the framing of social science, aquaculture, food chemistry, and public health when development strategies and policies. The identity of key issues of seafood farming was important before selecting the analytic framework of this research. In-depth analysis of such important issues and a clear focus on the major elements helped to decide the research boundaries. A range of stakeholders are involved in many stages of seafood production. In smallholder farming, the producer communities were a significant stakeholder in the system. Understanding their role, farming practice, bioeconomic return, household level consumption and food security outcomes were vital.

The selection of cases study sites can be politically, and scientifically complex. Therefore clear criteria are a must. The best approach was practised to select sites that lie along saline gradients. The site also should provide adequate representation of the agro-ecologies and major farming system. Case studies across the agro-ecologies of a system are highly complex and heterogeneous. It was important to understand the complexity and the primary target of their farming system. Quantifying yield from different angles like in weight, monetary value, nutritional value, labour intensity affecting the science-policy relationship. On many occasions, researchers observed the harvesting, catch composition, and its eventual distribution which helped to draw a factual picture. Some of the farmers tried to show overcapitalization and higher crop loss in order to secure government subsidies and relief. However, researchers were cautious to collect these points by exploring from different angles and repeating the objective of this work. For example aquatic animal samples were collected from *gher* rather than marketplace given the accuracy of the sampling framework and comparison of the systems.

A focus on adolescent girls within household level food security is complex. The clear criteria for household selection, and the consideration of equal numbers of better-off and worse-off households for the study, helped to ensure support from all groups within the community and avoid in adevertent alienation. Higher educated female enumerators from urban origins got special attention from rural households. Describing the possible outcomes of the research and the importance of blood samples to use as biomarker inspired the parents and the girls to participate in the programme.

Estimation of consumed food, weight and validation among the enumerators was time-consuming and complex. Co-planning helped all enumerators to grasp the key concepts and implementation realities. The plate-waste amount was not possible to record as we used recall method, therefore, consumption of fish might be lower than the presented value. However, the similar trends were followed across the agro-ecologies. Considering all the consumed food ingredients to evaluate the consumption pattern (both quantitative and nutritional quality) produced a more comprehensive picture allowing the role of fish on household food security outcomes to be more realistically assessed.

This multi-disciplinary research overcomes many challenges and adopted standardised methods from the various domains of biological and social sciences. This standardised metrics can be a potential way to link the impact of aquatic animal farming in a fragile environment to the food security outcomes of the community people. A focus on a specific vulnerable population- the adolescent girls- whose sufficient nutrition supply is vital to tackle intergenerational malnutrition especially during the critical 1000 days was considered particularly valuable to prioritise in communications to policy-makers.

7.4 LIMITATION

The logistics were complicated and did not meet up to the expectations for example observation of seasonal variation in household food consumption pattern due to political disturbance and limitation of resources.

7.5 RECOMMENDATION

The addition of longitudinal household consumption and nutritional profile and labour migration during the hungry months should be the next step of this research. Adding a few more micronutrients biomarker (Ca, iron, and selenium) is also recommended. Understanding the nutritional knowledge of women is an important aspect.

7.6 CONCLUSION

Therefore, sustainable aquaculture development in the south-west Bangladesh is likely a dynamic process that is challenged by a wide range of biophysical and socioeconomic factors at both the household level and macro level of policy makers. Limited livelihood options in some areas coupled with poverty, disease occurrence, lack of natural recruitment species are the major challenges for the sustainable development. The involvement of the resource poor households is not a dream; the willingness is vital here for whom who dare to defeat the viral disease. The shrimp-prawn sector is highly valued, however, lower in nutritional value compared to locally consumed fish. The holistic scenario suggested shrimp farming is a family driven small scale polyculture where varieties of aquatic foods are produced both for global and local value chains. The nutritional content analysis of the existing aquatic animals from related culture systems from a major aquaculture system is unique and largest of its kind in Bangladesh. Also dealing with the n-3 PUFA in whole blood of the vulnerable cohort; adolescent girls from both segments of the social well-being is a first in the country. This study is confident that the champion multidisciplinary tools are an appropriate metrics to link the aquaculture interventions and the nutritional outcomes of vulnerable population in a fragile environment. This study is opening an opportunity to relevant stakeholders to share their knowledge and formulate an effective strategy for the sustainable development seafood farming in developing countries.

8 BIBLIOGRAPHY

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9 APPENDIX

Appendix 1 (2.1) One-off questionnaire for the community census in the SW coastal aquatic food production area in Bangladesh

Questionnaire were developed both in Bengali and English, however, field level data were collected in the form of Bengali language

Household id derived from KI sessions.	Farmers name	Father's name	the social group ranked by KI's	HH size (family members)	No. of Females (10-19) with age	No. of males (10-19) with age	No. of *gher*	*Gher* area (in ha)	Property right (Ownership status)	Engagement of labour	Dike vegetable production (Y/N)	Major Aquatic species	House type (building materials)	HH area (living space and adjacent area)	Education level of household head

….rows continued up to 1082; total number of households in four communities

Appendix 2 (2.2) Questionnaire to aquatic food production systems (*gher*) across the saline gradients in the S-W coastal Bangladesh

Questionnaire were developed both in Bengali and English, however filed level data were collected in the form of Bengali language

Questionnaire for Aquatic food production systems in S-W Bangladesh

University of Stirling, UK

Household number with social group (given in KIs sessions): _______

1. Name of the farmer:_________________________ 2.Age:_______ 3.Religion:_________

4. Education level: _____ 5.Village. 6. Sub-district: 7. District:

8. Mobile No.:

9. Family Size:_______ 10.Family Type: Joint/Nuclear 11.No. of family member involved fish farming:

12. Male member: Female member:

13. Total land area:_______ decimal

14. Farm area:_______ 15.Own:_______ 16. Rent: _____17.Leased_______

18. Cultivable land:

19. Land owner: within the community/outsider 20.

Farmer**:** within the community /outsider

21. GPS: ________________________

22. History of farm:

23. Water salinity:_____ppt (range:________ ppt)

24. Culture type: Monoculture/Polyculture; 25.Culture system: Extensive (No feed) /Semi-intensive/Intensive/organic

26. Average water depth in *gher*: ______cm (~) Water Source: …………..

27. Stocking density of PL (post larvae) and fingerlings in number with weight of finfish

Name of the species	Steps	No. of Pl/fry	Sources	Stages of nursing	Average size	cost

28. Fertilisers and chemical applied in *gher*

Item	Amount (kg)	frequency	Total amount (kg)	cost (BDT)
Lime				
Fertiliser (name)				
Fertiliser (name)				
Fertiliser (name)				
Chemicals (name)				
Chemicals (name)				
Chemicals (name)				

29. Feed/ingredient applied in *gher*

Feed/ingredients (Name)	Amount	Frequency	Total amount (kg)	Phase of feeding	Target species	cost (BDT)

30. Seasonal calendar of shrimp-prawn-rice-dike vegetables production with major activities

Months	Bengali Month	Major activities
January		
February		
March		
April		
May		
June		
July		
August		
September		
October		
November		
December		

31. *Gher* output: Shrimp-prawn and fish production with destination and price per kg

Species	Destination (kg)						Total (Kg)	Value (BDT)
	Wholesale	Local market	Agents	Local Depot	Household	Gift		
Total								

32. Labour for harvesting

Type	Household member	Individual labour	Individual fisherman (*Bagdi*)	Fishing group	Others
Man days					
Cost					

34. Source of water: Ground water/river, canal water/rain water

35. Pump ownership: own/hire 36. Horsepower: 37. Cost:

38. Rice and dike vegetable production and destination

Species/Variety	Amount (kg)	Destination			Cost (BDT)	Return (BDT)
		Market	Household	Gift		
Total						

39. Net return:………….. 40. Benefit-cost Ratio (BCR): _____,

41. Disease occurrences:

Name of diseases	frequency	Affected Species	% of loss of the crop

42. Dadon or credit

Sources	Bank	NGO	Agent	Wholesaler	others
Amount					
Repayment					
% of interest					

43**.** Problem 44. Comments

Signature of the interviewer

Appendix 3 (2.3) Consent form for the anthropometric study and blood sample collections from adolescent girls in aquatic food production systems in S-W Bangladesh

[approved from ethical committee (BMRC) accordingly]

Consent Form

We are here from the University of Stirling, UK to collect data as the part of PhD research on food and nutritional security at the household level of the south-western coastal belt of Bangladesh. We will transform your personal information into the code and keep it confidential and destroy after finishing the research. During the blood sample collection from the finger tip of adolescent girls and nutritional outcomes study female health assistant/experienced women will deploy. It will take at least 3-4 hours, and your information should be accurate and if you wish you can withdraw your participation from this volunteer survey work. Your participation and information may help the policy makers to formulate strategies which eventually provide benefit to the mass people.

Interviewer of this research work has clearly explained the aim and objectives of this survey, and I can withdraw my participation at any moment if I wish. I have the right to know anything relevant to this survey work.

Does the interviewee agree?		Doesn’t agree	
Name of the interviewee:		Signature:	

The interviewee came to know about the aim and objectives of this survey and willingly participate and giving his/her consent by signing in respective space.

Name of the Interviewer:		Signature	

Contact Person:

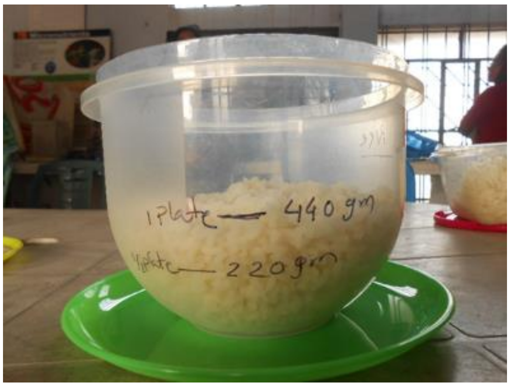
Abdullah-Al Mamun, Assistant Professor

Department of Fisheries and Marine Science, Noakhali Science and Technology University

Sonapur, Noakhali-3814, Bangladesh

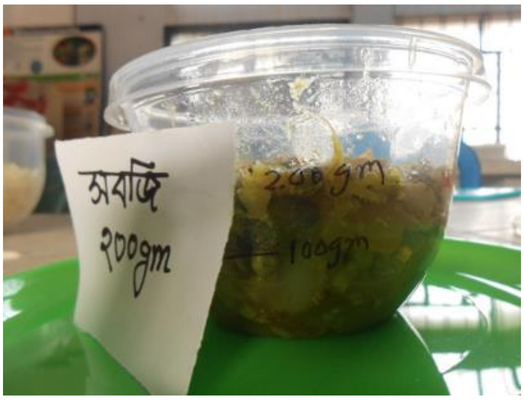
Cell: +8801712928710, E-mail: mamun_au22@yahoo.com

Appendix 4 (2.4) Food photography for intra-household food allocation study in S-W Bangladesh

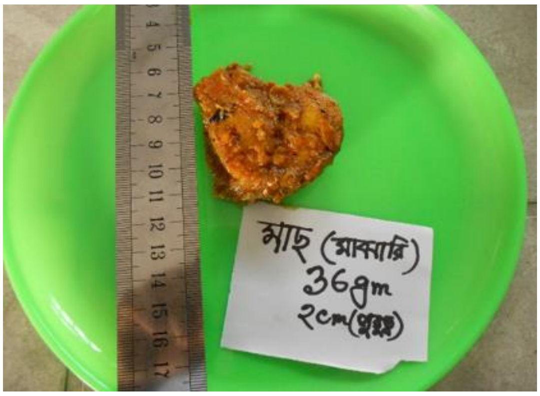


Supplementary Plate 2.1 Boiled rice

Supplementary Plate 2.2 Plain bread



Supplementary Plate 2.3 Mixed vegetables

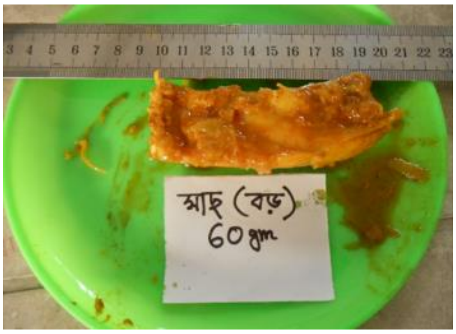


Supplementary Plate 2.4 Fish fillet (dorsal portion)

Supplementary Plate 2.5 Fish fillet (abdominal)

Supplementary Plate 2.6 Fish fillet (cutlets)

Appendix 4 (2.4) Food photography for intra-household food allocation study in S-W Bangladesh (Cont'd)



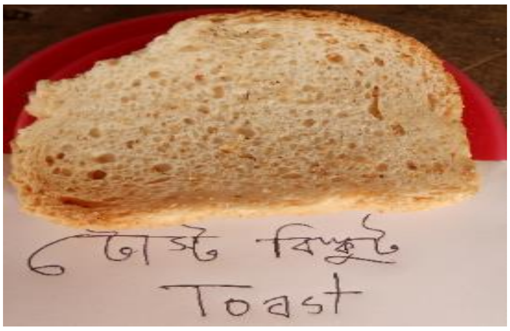
Supplementary Plate 2.7 Fish fillet (large portion)

Supplementary Plate 2.8 Vegetables (potato, cauliflower)

Supplementary Plate 2.9 Chicken (drum steak, breast)

Supplementary Plate 2.10 Lentil soup (pulses)

Supplementary Plate 2.11 Traditional cake



Supplementary Plate 2.12 Biscuit

Appendix 5 (2.5) Questionnaire on Food and Nutritional Security at Household level of south-west Coastal region of Bangladesh

1.	Household No.			Holding No.			2. Village & Codes		
3.	Cluster			4.	Location of the House(Distance from Highway)		Yard	House type: Building/half-building/tin/tin-bamboo/edbestor-tin/katcha/katcha-tali/mud	
5.	Sub-district		Code		6.	District		Code	
7.	GPS								
8.	Name of Household Head Mobile No:								
9.	Father/Husband Name of Household Head								
10.	Name of the respondent: Relationship with Household Head								
11.	Is this family related to fish/fish related activities? Code: 12. Is there any permanent labour?								
13.	No of farm: Farm area		dec.	14.	Rented area of farm:			dec.	
15.	Leased area of farm;		dec.	16.	Cultivable area:			dec.	
17.	Homestead area:	Dyke cropping: Y/N No of income persons: 1 (code…..)/ 2 (code……)							
17.	Income from Agri/others		Tk.	18.	Income from Fisheries			Tk.	
19.	Source of drinking water	Tk.		20.	Distance of Home from Source of water			Yard	
21.	The amount of raw fish consumed/day: gm Weekly: kg 22. Yearly: Kg								

23. Family expenditure

Type	Food	Education	Medicine	Transport	Accommodation	Dress	Agriculture	Fisheries	Others
Cost									

24. Are there any members of the family affected by any disease in the last 15 days? Member ID:

25. Disease: Diarrhoea/ Pneumonia/Fever

26. Which member of the family is responsible for shopping?   Member ID:

27. Which member of the family is responsible for cooking?   Member ID:

28. Toilet: Open/Katcha/Pakka

29: Burner: Traditional/Improved/Bondhu/Gas/Electric

30. Refrigerator=Yes/ No

31. Which food items has taken at family level in the last 14 days

Item	Leafy vegetables	Fish	Meat	Milk	Egg	Fruit
Days						

32. The amount of fish required in each week?   Own farm: kg   Market: kg

33. Rank the fish that taken at household level

Rank	Name of fish	Rank	Name of fish
1		6	
2		7	
3		8	
4		9	
5		10	

34. Family Information: Religion:

ID	Name of the Household Members	Relationship with HH Head	Sex *	Age		Marital Status*	Education class & code *	Occupation*		Weight		Height (cm)	MUAC (mm)	Blood sample pad id No.
				Year	Month			1st	2nd	Empty Stomach	Full of Stomach			
1.														
2.														
3.														
4.														
5.														
9.														
10														

*Code from the code sheet

[Number of rows were added dependent on household members including number of guests eaten in the same household]

35. 24 Hours Recall Method of family food consumption (Morning)

Description of Food	Name of Food	Menu Code	Food ingredients	Family Measure ment	Cooked Weight (g)	Source Code	Type Code	Price (Tk)
Leftover food from last day & Morning food								

No. people took meal?							
No. people did not take meal?							
Member ID							
Guest	Age						
	Sex						
	Age						
	Sex						

Source code: 1=Own, 2=Collected, 3=Common pools 4= Depot, 5=Processing plant, 6=Bye-product, 7=Gift, 8=Market/ Type code:1=Fresh, 2=Dried, 3=Smoked, 4= Bye-product, Fish code in code page

24 Hours Recall Method of family food consumption (Lunch)

Description of Food	Name of Food	Menu Code	Food ingredients	Family Measure ment	Cooked Weight (g)	Source Code	Type Code	Price (Tk)
Lunch								

No. people took meal?							
No. people did not take meal?							
Member ID							
Guest	Age						
	Sex						
	Age						
	Sex						

Source code: 1=Own, 2=Collected, 3=Common pools 4= Depot, 5=Processing plant, 6=Bye-product, 7=Gift, 8=Market/ Type code:1=Fresh, 2=Dried, 3=Smoked, 4= Bye-product, Fish code in code page

24 Hours Recall Method of family food consumption (Dinner)

Description of Food	Name of Food	Menu Code	Food ingredients	Family Measurement	Cooked Weight (g)	Source Code	Type Code	Price (Tk)
Dinner								

No. people took meal?							
No. people did not take meal?							
Member ID							
Guest	Age						
	Sex						
	Age						
	Sex						

Source code: 1=Own, 2=Collected, 3=Common pools 4= Depot, 5=Processing plant, 6=Bye-product, 7=Gift, 8=Market/ Type code:1=Fresh, 2=Dried, 3=Smoked, 4= Bye-product, Fish code in code page

24 Hours Recall Method of family food consumption (between breakfast and lunch)

Description of Food	Name of Food	Menu Code	Food ingredients	Family Measurement	Cooked Weight (g)	Source Code	Type Code	Price (Tk)
Food took between breakfast and lunch 1=Yes 2=No b. Food took between lunch and dinner 1=Yes 2=No c. Food took between dinner and breakfast 1=Yes 2=No d. Food gifted to others e. Food got from others f. Food intake outside g. Excess food for next day								

Consumption Unit		
Item Number		

Adult equivalent			

Intra-household Food Allocation using 24 h recall at individual level

Name of the Member: Date: 1st visit: 2nd visit:

Member IDt			Family ID:		

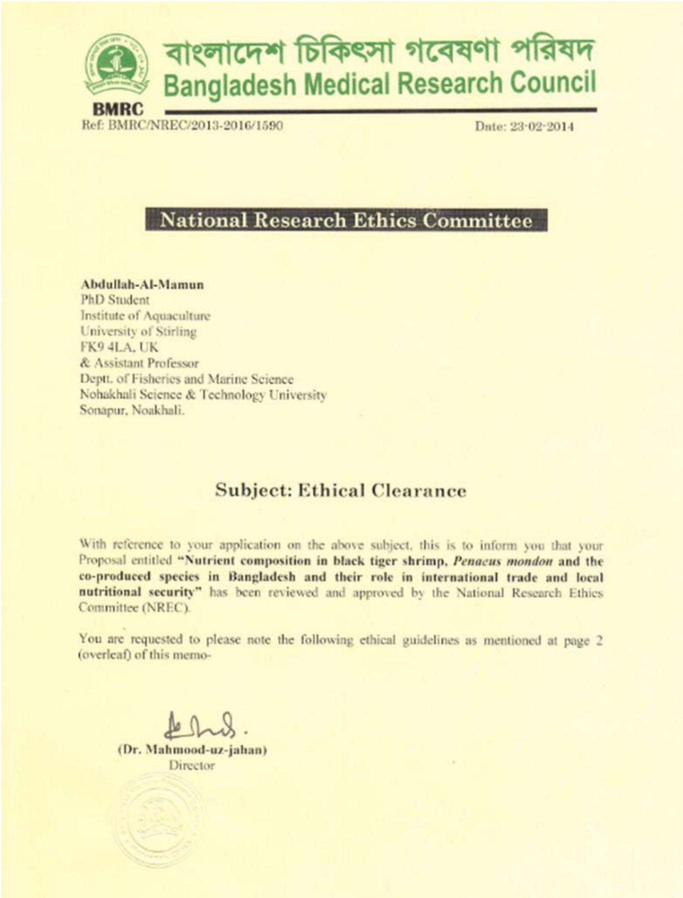
Time	Food/Menu	Description of food	Family Measurement	Actual Cooked weight (g)	Where took food	Food code
Morning						
Lunch						
Dinner						
Others						

Place of food intake; 1=Own home, 2=House of Lord where selling labour, 3=other house, 4=Hotel/market, 5=absent, 6=Didnot eat// Guest code=101, Others=201, Animals=301, Excess=401

[This sheet number was added depending on the number of household members; each sheet for an individual member at a time]

Appendix 6 (2.6) Ethical Certificate from Bangladesh Medical Research Council (BMRC)

Ethical Certificate



বাংলাদেশ চিকিৎসা গবেষণা পরিষদ
Bangladesh Medical Research Council
BMRC

Ref: BMRC/NREC/2013-2016/1590

Date: 23-02-2014

National Research Ethics Committee

Abdullah-Al-Mamun
PhD Student
Institute of Aquaculture
University of Stirling
FK9 4LA, UK
& Assistant Professor
Deptt. of Fisheries and Marine Science
Nohakhali Science & Technology University
Sonapur, Noakhali.

Subject: Ethical Clearance

With reference to your application on the above subject, this is to inform you that your Proposal entitled **"Nutrient composition in black tiger shrimp, *Penaeus mondon* and the co-produced species in Bangladesh and their role in international trade and local nutritional security"** has been reviewed and approved by the National Research Ethics Committee (NREC).

You are requested to please note the following ethical guidelines as mentioned at page 2 (overleaf) of this memo-

(Dr. Mahmood-uz-jahan)
Director

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THE ETHICAL GUIDELINES TO BE FOLLOWED BY THE PRINCIPAL/ CO-INVESTIGATORS

- ❒ The rights and welfare of individual volunteers are adequately protected.
- ❒ The methods to secure informed consent are fully appropriate and adequately safeguard the rights of the subjects (in the case of minors, consent is obtained from parents or guardians).
- ❒ The Investigator(s) assume the responsibility of notifying the National Research Ethics Committee (NREC) if there is any change in the methodology of the protocol involving a risk to the individual volunteers.
- ❒ To immediately report to the NREC if any evidence of unexpected or adverse reaction is noted in the subjects under study.
- ❒ Project may be supervised by BMRC authority periodically.
- ❒ This approval is subject to P.I.'s reading and accepting the BMRC ethical principles and guidelines currently in operation.
- ❒ You are required to submit a report to the BMRC periodically and after completion of the research work.

Appendix 7 (2.7) Material Transfer Agreement (MTA) with BMRC

Material Transfer Agreement

Bangladesh Medical Research Council

BMRC Bhaban, Mohakhali, Dhaka-1212, Bangladesh. Telephones: 8819311, 8828396
Fax: 880-2-8828820 Email: info@bmrcbd.org Website : www.bmrcbd.org

Application for Transfer of Human Biological Material/s Abroad for Research Purpose

Material Transfer Agreement (MTA)

1. **Principal Investigators :**

A. Bangladeshi : Abdullah-Al Mamun
PhD student, Institute of Aquaculture,
University of Stirling, FK9 4LA, UK.
Phone: +4407438265137,
E-mail: a.m.mamun@stir.ac.uk
& Assistant Professor,
Department of Fisheries and Marine Science,
Noakhali Science & Technology University,
Sonapur, Noakhali, Bangladesh, Phone: +880 1712928710,
E-mail: mamun_au22@yahoo.com

B. Foreign : Professor Gordon Bell, PhD
Head of the Nutrition Group, Institute of Aquaculture, School of Natural Sciences
University of Stirling, Stirling FK9 4LA, Scotland, UK
Email: g.j.bell@stir.ac.uk, Tel +44 1786 467997, Fax +44 1786 472133
http://www.aqua.stir.ac.uk/nas/

2. **Title of the Research Study:** Nutrient composition of black tiger shrimp, *Penaeus monodon* and the co-produced species in Bangladesh and their role in international trade and local nutritional security

3. **Duration :** 3 years (October 2013 to September 2016)

4. **Funding Agency:** Global project SEAT, EU FP7 Sustaining Ethical Aquaculture Trade, Institute of Aquaculture University of Stirling, Stirling FK9 4LA, Tel: +44 (0)1904 635954, fjm3@stir.ac.uk, (www.seatglobal.eu) &

Commonwealth Scholarship Commission in the UK, c/o The Association of Commonwealth Universities,Woburn House, 20-24 Tavistock Square, London WC1H 9HF, United Kingdom Telephone: +44 (0)20 7380 6797, Vanessa.Worthington@cscuk.org.uk, www.acu.ac.uk www.dfid.gov.uk/cscuk

5. **Institution where material/s is/are to be sent:** Nutrition Group, School of Natural Sciences, Institute of Aquaculture, University of Stirling, Stirling FK9 4LA, Scotland, UK

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Appendix 8 (3.1**)** Table (Supplementary) 3.1 Mean average residual for each KI and standard deviation (SD) residual for each KI in aquatic animal production areas of S-W Bangladesh

Salinity	Key informants	Mean residual	SD residual
High	K1	-0.007326007	0.3417253
	K2	0.032967033	0.342001
	K3	-0.025641026	0.3127105
Medium	K1	0.181964573	0.3407856
	K2	0.123993559	0.3478688
	K3	-0.305958132	0.4317521
Low	K1	0.031111111	0.2209626
	K2	-0.35555556	0.3159260
	K3	0.004444444	0.2600251
Freshwater	K1	-0.113612004	0.3943469
	K2	0.219185423	0.4609402
	K3	-0.105573419	0.4148036

Appendix 9 (3.2) Table (Supplementary) 3.2 Consistency test well-being group executed through KIs and community census in aquatic animal production areas of S-W Bangladesh

Coefficients:

	Estimate.	Std Error	t value	Pr(>|t|)	
(Intercept)	0.4157	0.2117	1.964	0.051145	.
wealth_group Poor	-0.6638	0.3093	-2.146	0.033297	*
wealth_group Rich	1.4299	0.3851	3.713	0.000277	***
wealth_group Ultrapoor	-1.2058	0.4503	-2.678	0.008137	**

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.732 on 170 degrees of freedom
Multiple R-squared: 0.178, Adjusted R-squared: 0.1635
F-statistic: 12.27 on 3 and 170 DF, p-value: 2.635e-07

Appendix 10 (3.3) Table (Supplementary) 3.3 Correlation between aquaculture index and wealth index in aquatic animal production areas of S-W Bangladesh

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	0.955833	0.317969	3.006	0.00306	**
aquaScore	0.021835	0.010455	2.088	0.03829	*
areaHigh saline	-1.041266	0.481513	-2.162	0.03201	*
areaLow saline	-0.564647	0.473888	-1.192	0.23515	
areaMid saline	-0.465997	0.597505	-0.780	0.43656	
aquaScore:areaHigh saline	-0.009610	0.014299	-0.672	0.50249	
aquaScore:areaLow saline	- 0.003849	0.014610	-0.263	0.79251	
aquaScore:areaMid saline	-0.033405	0.014526	-2.300	0.02271	*

Signif. Codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1					

Residual standard error: 1.861 on 166 degrees of freedom
Multiple R-squared: 0.07429, Adjusted R-squared: 0.03526
F-statistic: 1.903 on 7 and 166 DF, p-value: 0.07198

Appendix 111 (3.4) Table (Supplementary) 3.4 Correlation between aquaculture index and aquaculture experiences (in year) in aquatic animal production areas of S-W Bangladesh

Coefficients:					
	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-25.55289	9.98079	-2.560	0.011353	*
experience	0.73942	0.87183	0.848	0.397591	
area High saline	50.30177	14.79063	3.401	0.000841	***
area Low saline	37.03466	14.90602	2.485	0.013963	*
area Mid saline	61.39803	13.54004	4.535	1.1e-05	***
experience : area High saline	-0.97943	1.39186	-0.704	0.482615	
experience: area Low saline	- 1.28834	1.34683	-0.957	0.340171	
experience :area Mid saline	-0.05983	1.17157	-0.051	0.959330	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1					

Residual standard error: 28.4 on 166 degrees of freedom
Multiple R-squared: 0.4316, Adjusted R-squared: 0.4076
F-statistic: 18 on 7 and 166 DF, p-value: < 2.2e-16

Appendix 12 (3.5) Table (Supplementary) 3.5 Correlation between wealth index and aquaculture experiences (in year) in aquatic animal production areas of S-W Bangladesh

Coefficients:					
	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-0.53515	0.66553	-0.804	0.4225	
experience	0.10484	0.05814	1.803	0.0731	.
areaHigh saline	0.23739	0.98626	0.241	0.8101	
areaLow saline	0.60146	0.99396	0.605	0.5459	
areaMid saline	0.50622	0.90287	0.561	0.5758	
experience:areaHigh saline	-0.05190	0.09281	-0.559	0.5768	
experience:areaLow saline	-0.05868	0.08981	-0.653	0.5144	
experience:areaMid saline	-0.10283	0.07812	-1.316	0.1899	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1					

Residual standard error: 1.894 on 166 degrees of freedom
Multiple R-squared: 0.04106, Adjusted R-squared: 0.000625
F-statistic: 1.015 on 7 and 166 DF, p-value: 0.4222

Appendix 12 (3.6) Table (Supplementary) 3.6 Correlation between ownership and leased-in *gher* farmer in S-W Bangladesh

Coefficients:				
	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.209556	0.477576	0.439	0.661
aquaScore	0.001866	0.004052	0.461	0.646
ownOwn	0.129007	0.500024	0.258	0.797

Residual standard error: 1.831 on 141 degrees of freedom
Multiple R-squared: 0.001909, Adjusted R-squared: -0.01225
F-statistic: 0.1348 on 2 and 141 DF, p-value: 0.874

Appendix 13 (5.1) Supplementary (S) Table 1. Macronutrients content (g/100 g raw edible part; mean±sd) in shellfish (*bagda*) from different culture systems along the saline gradients in S-W Bangladesh

Culture system	HSE	HSI	HSO	HSSI	LSI	LSO	LSSI	MSE	MSI	MSO	MSSI	Pocket
Lipid	0.92±0.14	0.99±0.04	0.88±0.12	0.91±0.07	0.95±0.02	0.98±0.06	0.94±0.02	0.86±0.05	1.04±0.06	0.91±0.12	0.95±0.04	0.71±0.14
Protein	20.4±0.84	22.4±0.23	20.56±0.23	19.84±2	20.39±2.39	21.52±0.26	20.73±1.62	19.52±1.03	21.11±0.37	21.92±0.22	19.77±1.27	16.54±0.54
Ash	1.19±0.42	1.48±0.08	1.37±0.06	1.22±0.2	1.46±0.06	1.38±0.05	1.27±0.19	1.22±0.11	1.14±0.06	1.41±0.07	1.31±0.11	1.35±0.12
Moisture	78.34±1.35	75.24±0.09	77.78±0.07	78.97±2.25	76.99±1.17	76.34±0.12	77.89±2.71	79.23±1.27	77.77±0.22	77.35±0.22	78.55±1.37	81.69±1.15

Appendix 14 (5.2) Supplementary (S) Table 2 Macronutrients content (g/ 100 g raw edible part; mean±sd) in shellfish from different culture systems along the saline gradients in S-W Bangladesh

Culture system	HSE	HSSI	LSSI	MSE	MSSI	HSE	HSSI	LSSI	MSE	MSSI
Species	*chaka*					*chali*				
Lipid	1.26±0.04	1.16±0.1	1.13±0.07	1.13±0.1	1.14±0.13	1.33±0.12	1.33±0.07	1.41±0.03	1.37±0.08	1.38±0.11
Protein	19.35±0.42	19.34±0.28	20.63±0.23	20.52±0.35	19.47±0.34	19.08±0.23	17.34±0.16	18.69±0.32	19.19±0.08	18.87±0.17
Ash	1.23±0.06	1.17±0.04	1.17±0.04	1.3±0.05	1.07±0.03	1.77±0.39	0.99±0.12	1.2±0.02	1.24±0.03	1.22±0.12
Moisture	79.25±0.78	78.34±0.22	78.41±0.24	78.6±0.42	80.22±0.13	78.87±0.88	81.14±0.4	78.72±0.16	78.56±0.41	79.66±0.62

Appendix 15 (5.3) Supplementary (S) Table 3 Macronutrients content (g/ 100 g raw edible part; mean±sd) in shellfish from different culture systems along the saline gradients in S-W Bangladesh

Culture system	FW	HSE	HSSI	LSSI	MSE	MSSI	FW	LSSI	Pocket
Species	*goda*						*golda*		
Lipid	1.13±0.11	1.11±0.04	1.03±0.08	1.09±0.12	1.25±0.15	1.29±0.08	1.25±0.05	1.25±0.08	0.94±0.05
Protein	16.52±0.23	18.13±0.71	16.59±0.3	18.66±0.47	19.01±0.38	18.43±0.29	20.02±0.1	19.72±0.42	18.59±0.4
Ash	1.1±0.04	1.14±0.04	1.12±0.13	1.03±0.09	1.36±0.03	1.23±0.34	1.19±0.07	1.27±0.03	1.1±0.21
Moisture	80.3±0.18	80.05±0.31	83.59±4.83	80.2±0.42	78.49±0.19	80.3±1.1	76.81±0.35	78.33±0.18	79.53±0.47

Appendix 16 (5.4) Supplementary (S) Table 4 Macronutrients content (g/ 100 g raw edible part; mean±sd) in shellfish (*horina*) from different culture systems along the saline gradients in S-W Bangladesh

Culture system	HSE	HSO	HSSI	LSO	LSSI	MSE	MSO	MSSI	Pocket
Lipid	1±0.06	0.98±0.04	1.05±0.02	0.99±0.04	1.01±0.07	1.03±0.16	0.93±0.05	1.01±0.1	1.05±0.08
Protein	17.91±1.96	18.39±0.24	19.1±0.22	20.33±0.15	18.84±0.42	18.35±2.6	18.78±0.17	18.94±0.4	18.83±0.15
Ash	1.48±0.76	1.18±0.12	1.17±0.3	1.17±0.09	1.01±0.04	1.24±0.21	1.17±0.05	1.23±0.09	1.38±0.04
Moisture	79.95±2.01	78.45±0.48	79.3±0.49	79.71±1.68	79.87±0.66	79.89±2.68	79.06±0.95	79.19±1.2	79.27±0.65

Appendix 17 (5.5) Supplementary (S) Table 5 Macronutrients content (g/ 100 g raw edible part; mean±sd) in shellfish from different culture systems along the saline gradients in S-W Bangladesh

Culture system	HSE	HSSI	LSSI	MSE	MSSI	FW	HSE	HSSI	LSSI	MSE	MSSI	Wild
Species	Mud crab					*rosna*						*tiger chingri*
Lipid	2.49±0.08	2.76±0.23	2.66±0.18	2.6±0.15	2.35±0.07	1.15±0.04	1.08±0.13	1.03±0.14	1.14±0.07	1.06±0.14	1.54±0.1	0.73±0.05
Protein	15.81±1.32	16.45±0.63	15.96±0.19	13.71±2.36	14.07±0.65	16.08±0.15	16.52±0.28	16.12±0.23	17.9±0.27	17.78±0.45	16.27±0.24	16.42±0.12
Ash	2.93±0.45	4.32±0.39	3.71±0.49	2.58±1.23	3.38±1.68	1.16±0.04	1.31±0.52	1.16±0.06	1.53±0.18	1.25±0.06	1.64±0.61	1.21±0.07
Moisture	80.05±0.46	78.04±1.34	77.44±1.72	81.91±4.07	79.87±0.9	80.17±0.08	81.61±1.05	81.82±1.24	80.65±0.49	80.73±0.28	80.71±0.22	81.41±1.22

Appendix 18 (5.6) Supplementary (S) Table 6. Macronutrients content (g/ 100 g raw edible part; mean±sd) in mangrove fish from different culture systems along the saline gradients in S-W Bangladesh

Culture system	HSE	HSE	FW	HSE	HSSI	LSSI	MSE	MSSI	Pocket	HSE	MSE	HSE
Species	*aamadi*	*ayza*	*bele*	*bele*	*bele*	*bele*	*bele*	*bele*	*bele*	*bhangan*	*bhangan*	*bhola*
Lipid	2.1±0.05	2.73±0.15	0.71±0.06	0.94±0.17	0.89±0.08	0.64±0.08	0.57±0.02	0.71±0.11	0.65±0.05	3.01±0.44	2.76±0.21	0.7±0.06
Protein	16.42±0.25	19.6±0.54	18.42±0.55	18.76±0.09	19.3±0.47	18.91±0.23	18.1±0.59	18.79±0.21	18.24±0.2	19.57±0.17	18.96±0.32	11.3±0.47
Ash	2.69±0.52	2.19±0.79	1±0.1	1.32±0.87	1.19±0.31	1.08±0.15	1.14±0.08	1.06±0.42	0.9±0.03	1.24±0.29	1.08±0.05	2.11±0.69
Moisture	80.66±1.35	76.84±0.5	79.86±0.45	79.35±2.2	79.71±0.92	80.63±0.64	81.56±0.41	80.07±0.39	79.87±0.25	77±0.98	75.59±0.6	82.45±0.35

Appendix 19 (5.7) Supplementary (S) Table 7 Macronutrients content (g/ 100 g raw edible part; mean±sd) in mangrove fish from different culture systems along the saline gradients in S-W Bangladesh

Culture system	HSE	HSE	HSE	MSE	HSE	MSE	HSE	Wild	HSE	HSE	HSE	HSE
Species	*cainemagur*	*cucia*	*datina*	*datina*	*fesa*	*fesa*	*gaberdana*	*hilsa*	*kakshel*	*kalogullo*	*katkoi*	*khoira*
Lipid	6.62±0.37	1.21±0.1	4.03±0.66	5.55±0.1	3.52±0.22	2.49±0.03	1.09±0.04	18.28±1.35	1.06±0.03	0.72±0.05	4.79±0.39	1.07±0.09
Protein	17.95±0.33	18.03±1.03	19.19±0.14	19.78±0.23	17.47±0.45	16.75±0.84	14.18±0.9	15.11±0.53	17.04±0.42	16.57±0.32	19.57±0.9	17.96±0.35
Ash	1.01±0.11	2.04±0.56	1.32±0.47	1.08±0.02	2.25±0.23	2.35±0.23	1.84±0.13	1.39±0.07	0.93±0.08	1.18±0.38	1.19±0.26	3.38±0.48
Moisture	75.14±0.56	80.1±0.45	76.1±0.7	74.72±1.09	78.94±2.06	77.43±0.33	82.43±0.32	63.41±1.32	81.19±0.13	80.75±0.42	75.47±0.66	78.33±0.66

Appendix 20 (5.8) Supplementary (S) Table 8. Macronutrients content (g/ 100 g raw edible part; mean±sd) in mangrove fish from different culture systems along the saline gradients in S-W Bangladesh

Culture system	FW	HSE	HSSI	LSSI	MSE	MSSI	Pocket	HSE
Species	*khorshula*							*lal gullo*
Lipid	3.66±0.1	3.95±0.11	2.69±0.53	3.67±0.1	3.61±0.69	3.81±0.04	1.5±0.06	0.88±0.07
Protein	19.68±0.48	19.73±0.29	19.78±0.1	19.97±0.25	18.04±0.32	18.87±0.74	17.57±0.49	17.08±0.71
Ash	1.83±0.15	2.82±1.06	1.94±1.07	1.5±0.48	1.81±0.56	1.51±0.8	1.86±0.48	1.5±0.31
Moisture	75.86±0.94	74.65±0.48	76.62±1.12	75.86±2.57	75.47±1.08	76.54±2.42	78.95±0.56	79.92±0.53

Appendix 21 (5.9) Supplementary (S) Table 9. Macronutrients content (g/ 100 g raw edible part; mean±sd) in mangrove fish from different culture systems along the saline gradients in S-W Bangladesh

Culture system	HSE	HSSI	LSSI	MSE	MSSI	HSE	HSSI	LSSI	MSE	MSSI	Pocket
Species			*nona tengra*						*parsey*		
Lipid	4.85±0.95	6.3±0.38	4.46±0.36	4.23±0.85	5.68±0.07	7.97±0.16	6.48±0.42	8.32±0.55	8.72±0.27	6.86±0.27	6.19±0.33
Protein	18.43±0.27	18.21±0.56	18.38±0.23	17.41±0.18	16.96±0.17	18.1±1.17	17.97±0.82	18.02±0.29	17.04±0.67	17.62±1.24	16.31±0.3
Ash	4.23±0.18	1.68±0.24	1.59±0.19	2.33±0.09	3.06±0.17	1.63±0.73	1.46±0.8	1.41±0.39	1.34±0.8	1.39±0.26	1.22±0.37
Moisture	72.48±0.34	73.92±1.31	75.8±0.48	76.29±0.1	75.43±0.65	73.78±2.56	74.92±0.79	72.75±2.5	70.93±2.83	73.51±0.13	76.11±0.55

Appendix 22 (5.10) Supplementary (S) Table 10 Macronutrients content (g/100 g raw edible part; mean±sd) in mangrove fish from different culture systems along the saline gradients in S-W Bangladesh

Culture system	HSE	HSSI	LSSI	MSE	MSSI	HSE	HSE	HSE	HSE	HSSI	MSE	MSSI
Species			*payra*			*shilong*	*taposhi*	*therol*			*vetki*	
Lipid	6.61±1.07	5.01±0.57	4.68±0.77	5.61±1.3	7.13±0.6	2.78±0.13	1.78±0.06	2.56±0.1	3.24±0.15	3.9±0.44	4.23±0.19	4.63±0.23
Protein	19.27±0.19	20.38±0.49	17.2±0.24	17.07±0.47	18.5±0.42	17.36±0.19	17.35±0.19	18.94±0.64	20.56±0.17	20.51±0.22	20.52±0.36	20.93±0.23
Ash	2.29±1.1	1.35±0.65	2.04±0.1	1.92±1.13	2.19±1.76	0.98±0.06	1.83±0.2	3.19±0.55	1.13±0.08	1.1±0.04	1.21±0.04	0.97±0.1
Moisture	72.86±2.45	74.16±2	75.46±0.63	74.35±2.23	71.81±2.15	78.95±0.11	79.2±0.68	76.76±1.75	74.6±0.1	74.65±0.59	73.65±1.75	74.18±0.24

Appendix 23 (5.11) Supplementary (S) Table 11 Macronutrients content (g/100 g raw edible part; mean±sd) in freshwater fish from different culture systems along the saline gradients in S-W Bangladesh

Culture system	FW	FW	FW	LSSI	Pocket	FW	FW	LSSI	FW	LSSI	Pocket
Species	*bata*	*bheda*	*catla*			*chanda*	*cheng*	*choto bele*	Common carp		
Lipid	3.36±0.35	2.96±0.13	0.85±0.06	0.77±0.04	0.64±0.03	2.98±0.08	0.75±0.06	0.69±0.03	1.49±0.06	1.5±0.05	0.74±0.08
Protein	18.35±0.67	18.1±0.36	18.08±0.39	17.78±0.35	17.18±0.16	16.23±0.11	16.32±0.28	15.09±0.41	18.01±0.16	18.02±0.31	15.81±0.71
Ash	1.02±0.08	1.57±0.2	1.13±0.02	1.07±0.08	1.19±0.04	4.89±0.13	0.96±0.11	1.02±0.05	1.09±0.03	1.07±0.04	1.05±0.15
Moisture	76.46±0.95	78.02±1.35	79.35±0.16	80.34±0.77	80.98±0.95	76.73±0.56	82.9±0.43	82.09±0.63	78.41±0.24	79.19±0.67	80.99±1.04

Appendix 24 (5.12) Supplementary (S) Table 12 Macronutrients content (g/100 g raw edible part; mean±sd) in freshwater fish from different culture systems along the saline gradients in S-W Bangladesh

Culture system	FW	LSSI	Pocket	FW	FW	LSSI	Pocket	FW	FW	LSSI	Pocket
Species	Grass carp			*koi*	Mirror carp			*mola*	*mrigal*		
Lipid	1.5±0.09	1.45±0.38	0.94±0.03	9.76±1.57	2.36±0.21	1.09±0.05	1.68±0.1	4.4±0.35	1.45±0.32	0.88±0.16	0.73±0.08
Protein	18.37±0.43	18.46±1.02	15.75±0.45	16.98±0.61	17.88±0.27	17.49±0.84	16.28±0.43	16.67±0.21	19.02±0.51	17.55±0.9	17.56±0.48
Ash	0.99±0.06	1.15±0.06	1.11±0.03	2.76±0.83	1.09±0.08	1.13±0.07	1.01±0.06	3.18±0.73	1.06±0.04	0.98±0.1	1.2±0.11
Moisture	79.89±0.53	78.5±0.9	82.14±0.74	70.66±0.65	78.46±0.21	79.42±0.98	81.48±0.3	76.32±1.17	78.77±0.38	80.05±0.14	80.03±0.91

Appendix 25 (5.13) Supplementary (S) Table 13 Macronutrients content (g/100 g raw edible part; mean±sd) in freshwater fish from different culture systems along the saline gradients in S-W Bangladesh

Culture system	FW	FW	FW	LSSI	Pocket	FW	FW	LSSI	Pocket	FW	FW
Species	Pangus	*porabele*		*puti*		*rekha*		*rohu*		*shing*	*shoal*
Lipid	2.35±0.34	0.78±0.03	2.14±0.06	2.15±0.5	1.4±0.13	2.5±0.04	2.48±0.4	2.8±0.14	1.46±0.24	1.87±0.37	0.63±0.1
Protein	17.39±0.39	16.76±0.2	17.44±0.27	17.48±0.43	16.3±0.4	17.59±0.15	19.89±0.24	20.06±0.58	16.67±1.21	16.93±0.66	18.46±0.18
Ash	1.09±0.16	1.94±0.17	2.77±0.43	3.4±1.09	3.32±0.44	0.97±0.09	1.15±0.02	1.16±0.2	1.16±0.09	1.34±0.07	1.16±0.12
Moisture	80.47±1.8	80.67±0.86	78.55±0.41	78.04±0.35	79.63±0.71	78.48±0.26	79.47±0.4	77.72±0.92	80.25±0.74	81.2±0.88	80.66±0.31

Appendix 26 (5.14) Supplementary (S) Table 14 Macronutrients content (g/100 g raw edible part; mean±sd) in freshwater fish from different culture systems along the saline gradients in S-W Bangladesh

Culture system	FW	LSSI	Pocket	FW	FW	LSSI	FW	LSSI	MSSI
Species		Silver carp		*taki*	*tengra*			Thai puti	
Lipid	1.36±0.08	1.04±0.05	0.86±0.1	1±0.05	5.74±0.29	4.79±0.39	3.45±0.19	2.63±0.2	2.5±0.11
Protein	18.46±0.22	17.65±1.02	15.99±0.38	18.58±0.49	15.57±0.33	15.82±0.47	18.39±0.15	18.03±0.77	17.9±0.49
Ash	0.99±0.05	1.23±0.06	1.12±0.03	1.96±1.01	1.92±0.55	2.11±0.62	2.26±0.42	1.19±0.36	2.67±0.17
Moisture	80.22±1.82	79.96±1.08	81.34±0.6	79.75±0.61	75.78±1.93	77.7±0.07	79.05±0.93	77.66±0.83	78.08±2.01

Appendix 27 (5.15) Supplementary (S) Table 15 Macronutrients content (g/100 g raw edible part; mean±sd) in freshwater fish from different culture systems along the saline gradients in S-W Bangladesh

Culture system	HSE	HSSI	LSSI	MSE	MSSI	HSE	HSSI	LSSI	MSE	MSSI
Species	Tilapia					Tilapia (GIFT)				
Lipid	2.12±0.13	2.72±0.14	1.98±0.25	1.99±0.06	2.06±0.06	2.24±0.2	2.38±0.35	2.08±0.16	2.57±0.11	2.87±0.11
Protein	18.5±0.6	18.72±0.51	18.72±0.7	18.85±0.27	18.78±0.17	18.67±0.18	19.54±0.52	19.73±0.47	17.63±0.61	19.79±0.23
Ash	2.27±0.18	3.26±0.14	2.11±0.22	2.19±0.3	2.18±0.34	3.01±0.53	2.82±0.46	2.01±0.21	2.16±0.22	2.17±0.11
Moisture	75.88±0.91	76.32±0.71	76.09±1.39	76.56±0.33	78.98±0.83	74.93±0.07	76.42±0.45	74.75±0.18	76.29±2.52	75.54±1.17

Supplementary (S) Table 16. Macronutrients content (g/ 100 g raw edible part; mean±sd) in By-products from the aquaculture area of S-W Bangladesh

Appendix 28 (5.16) Supplementary (S) Table 16. Macronutrients content (g/100 g raw edible part; mean±sd) in by-products from the aquaculture area of S-W Bangladesh

Culture system	*Gher*						Wild	*Gher*	Feed	*Gher*
By-products	*bagda* head	*bagda* shell	*golda* brain	*golda* claw	*golda* head	*golda* shell	*illish* egg	*horina* shell	snail	*tiger chingri* shell
Lipid	2.26±0.19	1.1±0.03	46.56±2.13	1.87±0.18	2.12±0.21	1.25±0.39	29.23±2.31	2.04±0.35	1.6±0.22	0.69±0.12
Protein	15.07±1.39	17.41±0.31	7.3±0.07	17.66±0.45	13.51±1.15	17.43±0.28	23.08±0.21	14.4±0.49	9.29±0.64	15.25±0.8
Ash	6.57±0.24	10.43±0.37	0.79±0.02	1.58±0.05	6.31±0.83	10.62±0.26	1.6±0.04	6.73±1.26	3.74±0.14	6.77±0.4
Moisture	72.35±0.33	67.94±1.08	44.49±1.67	77.92±0.86	75.16±1.17	69.19±0.89	48.13±1.03	78.88±1.03	81.91±0.78	75.85±0.22

Appendix 29 (5.17) Supplementary (S) Table 17 The content of important fatty acids (% of total FA) in *bagda* from different culture systems along the saline gradients of S-W Bangladesh

Culture System	HSE	HSI	HSO	HSSI	LSI	LSO	LSSI	MSE	MSI	MSO	MSSI	Pocket
C14:00	0.55±0.03	0.41±0.03	0.72±0	0.46±0.11	0.83±0.03	0.43±0.02	1.02±0.01	0.68±0.04	0.42±0.03	0.4±0.04	0.83±0.13	0.86±0.07
C16:00	16.25±1.25	20.91±0.6	15.63±1.43	15.99±3.08	20.31±1.03	16.12±0.3	15.94±0.17	16.57±0.32	19.2±0.17	15.61±0.05	16.13±0.2	14.44±1.91
C18:00	10.9±1.17	11.35±0.1	12.3±1.3	10.66±0.59	10.06±0.19	12.66±0.31	13.11±0.26	10.81±0.03	11.9±0.01	12.66±0.44	10.94±0.18	11.52±2.58
∑SFA	28.81±2.65	34±0.59	30.83±2.6	28.45±3.27	32.47±1.26	30.77±0.43	31.71±0.63	29.55±0.37	33.14±0.36	29.88±0.52	29.45±0.17	28.54±3.69
C18:1n-9	11.55±0.56	13.85±0.2	11.92±0.15	11.9±0.3	14.99±0.46	8.84±0.45	11.95±0.44	9.64±0.24	14.09±0.57	11.68±0.07	10.34±0.92	11.37±1.96
∑ MUFA	17.33±0.83	17.75±0.23	19.32±0.18	16.71±1.38	19.6±0.44	15.3±0.73	21.15±0.2	17.26±0.54	17.77±0.97	16.92±0.03	18.8±1.3	18.72±1.04
C18:2n-6	10.55±0.56	16.14±0.12	9.72±0.28	10.87±2.66	15.92±0.96	7.47±0.11	4.23±0.08	7.94±0.02	14.92±0.21	12.38±0.15	6.12±0.04	5.31±1.5
C20:4n-6	11.23±0.43	3.6±0.08	9.75±0.18	10.58±1.67	3.88±0.17	12.73±0.17	11.5±0.14	10.11±0.09	4.51±0.07	10.94±0.03	10.21±0.25	15.32±5.11
∑n-6 PUFA	25.32±0.58	21.57±0.2	22.93±0.04	24.96±4.43	21.47±1.22	24.85±0.33	18.81±0.22	22.42±0.17	21.33±0.31	26.85±0.37	19.66±0.29	23.23±5.26
C20:5n-3	10.19±1.56	9.53±0.31	9.35±0.79	11.02±1.3	8.91±0.38	10.09±0.21	10.22±0.27	11.64±0.07	9.84±0.3	9.04±0.16	12.06±0.33	11.99±2.42
C22:5n-3	1.77±0.55	0.43±0.08	1.39±0.2	1.48±0.37	0.55±0.04	2.49±0.05	1.16±0.03	1.61±0.01	0.48±0.02	1.73±0.06	0.92±0.02	0.75±0.87
C22:6n-3	7.45±0.34	11.13±0.26	6.97±0.94	6.37±1.09	10.87±0.25	6.4±0.05	5.46±0.08	6.07±0.06	10.58±0.43	7.55±0.3	7.56±0.29	7.6±4.15
∑ n-3 PUFA	20.75±2.33	21.66±0.47	18.7±2.03	21.62±0.58	21.23±0.45	22.27±0.21	19.08±0.52	23.38±0.15	21.44±0.73	19.83±0.49	23.19±0.57	22.38±7.81
∑ 16:00	1.73±2.31	0.18±0.02	1.21±0.05	0.67±0.42	0.23±0.01	0.51±0.11	2.43±0.02	0.6±0.09	0.51±0.29	0.45±0.15	1.57±0.7	1.72±0.58
∑ PUFA	47.79±4.51	43.41±0.56	42.84±2.02	47.25±4.83	42.93±1.63	47.63±0.45	40.31±0.74	46.4±0.21	43.27±1.32	47.13±0.71	44.43±1.52	47.33±3.62
∑ DMA	6.07±2.02	4.85±0.39	7.01±0.61	7.59±0.59	5±0.84	6.3±0.18	6.83±0.4	6.79±0.34	5.82±0.12	6.08±0.22	7.33±0.49	5.41±0.95
n.3:n.6	0.82±0.08	1±0.02	0.82±0.09	0.89±0.15	0.99±0.04	0.9±0	1.01±0.02	1.04±0.01	1±0.02	0.74±0.01	1.18±0.01	1.06±0.57
EPA+DHA	17.63±1.69	20.66±0.51	16.33±1.74	17.39±2.38	19.78±0.61	16.49±0.19	15.68±0.36	17.71±0.11	20.42±0.73	16.59±0.46	19.62±0.62	19.59±6.58
EPA+DPA+DHA	19.41±2.22	21.08±0.49	17.71±1.94	18.87±2.72	20.32±0.59	18.97±0.25	16.84±0.38	19.32±0.11	20.9±0.75	18.32±0.52	20.54±0.64	20.34±7.43

Appendix 30 (5.18) Supplementary (S) Table 18 The content of important fatty acids (% of total FA) in Shellfish from different culture systems along the saline gradients of S-W Bangladesh

Culture System	HSE	HSSI	LSSI	MSE	MSSI	HSE	HSSI	LSSI	MSE	MSSI
Species			*chaka*					*chali*		
C14:00	0.76±0.13	1.01±0.22	0.68±0.03	0.71±0.12	0.73±0.06	0.85±0.21	0.82±0.14	0.53±0.03	0.59±0.1	1±0.57
C16:00	17.04±0.67	17.87±1.25	18.52±0.02	17.04±1.31	17.79±1	17.98±0.61	18.92±0.5	18.61±0.9	17.4±0.74	18.7±0.66
C18:00	10.23±0.74	9.59±0.26	11.31±0.15	10.44±0.88	10.7±0.78	11.65±1.58	11.96±0.18	11.5±0.72	12.57±0.55	10.58±0.63
∑SFA	29.63±0.81	30.1±0.95	32.49±0.2	29.82±1.91	30.9±1.9	33.49±1.91	34.46±1.01	32.04±1.42	32.59±2.43	32.3±1.16
C18:1n-9	11.95±2.12	12.01±1.21	8.67±0.12	10.75±2.5	9.75±2.12	7.39±1.05	8.27±1.44	9.32±1.08	7.29±0.99	9.63±1.3
∑ MUFA	20.89±1.6	21.11±0.72	17.96±0.3	19.88±2.06	19.19±1.7	17.02±1.75	18.67±1.59	18.75±0.57	17.11±1.91	18.83±1.47
C18:2n-6	8.94±0.87	6.93±2.79	6±0.07	8.06±1.61	6.93±1.67	3.97±0.88	4.15±0.05	6.37±1.23	4.86±0.23	6.1±1.48
C20:4n-6	7.8±0.73	8±0.66	7.26±0.1	7.74±0.67	7.72±0.72	9.7±0.27	8.81±0.35	7.92±0.09	8.75±0.78	8.07±0.6
∑n-6 PUFA	20.42±0.14	18.88±1.71	16.7±0.28	19.49±1.79	18.19±1.68	17.46±0.39	15.82±0.64	17.34±0.96	16.82±0.87	17.26±0.79
C20:5n-3	10.66±0.56	12.02±1.93	13.27±0.11	11.27±1.51	12.58±1.59	11.07±0.57	11.46±0.28	12.45±1.27	12.15±1.92	11.85±0.75
C22:5n-3	1.64±0.02	1.78±0.4	1.8±0.11	1.64±0.02	1.8±0.19	1.1±0.32	0.94±0.01	0.87±0.1	1.16±0.21	0.87±0.12
C22:6n-3	7.97±0.19	7.8±0.12	8.07±0.08	7.98±0.14	8.14±0.28	11.66±1.94	11.01±0.8	10.27±0.41	9.86±0.15	10.46±0.33
∑ n-3 PUFA	23.02±0.46	24.33±1.74	25.34±0.11	23.55±1.19	25.01±1.63	26.1±2.26	25.89±1.16	26.77±1.26	25.83±2.41	26.34±1.13
∑ 16:00	0.84±0.06	1.07±0.31	0.78±0.03	0.9±0.12	0.85±0.06	1.76±0.12	0.74±0.1	1.13±0.64	1.77±0.17	0.86±0.43
∑ PUFA	44.28±0.58	44.29±0.39	42.83±0.42	43.94±0.71	44.05±1.14	45.32±2.15	42.45±1.76	45.24±0.91	44.42±1.64	44.46±0.87
∑ DMA	5.2±0.4	4.5±0.62	6.72±0.04	6.37±0.48	5.86±0.36	4.18±2.04	4.42±0.36	3.97±0.13	5.88±1.05	4.41±0.75
n.3:n.6	1.13±0.02	1.3±0.21	1.52±0.02	1.22±0.19	1.39±0.19	1.5±0.14	1.64±0.02	1.55±0.15	1.54±0.21	1.53±0.13
EPA+DHA	18.64±0.74	19.82±1.84	21.35±0.09	19.25±1.6	20.72±1.8	22.73±2.42	22.48±1.04	22.71±1.08	22.01±1.89	22.31±0.93
EPA+DPA+DHA	20.28±0.72	21.59±2.07	23.15±0.03	20.89±1.6	22.51±1.92	23.83±2.11	23.41±1.05	23.58±1.17	23.16±1.69	23.18±1.02

Appendix 31 (5.19) Supplementary (S) Table 19 The content of important fatty acids (% of total FA) in Shellfish from different culture systems along the saline gradients of S-W Bangladesh

Culture System	FW	HSE	HSSI	LSSI	MSE	MSSI	FW	LSSI	Pocket
Species	*goda*						*golda*		
C14:00	1.63±0.11	1.43±0.26	1.32±0.12	1.69±0.34	1.59±0.12	1.94±0.37	1±0.09	1.19±0.32	1.37±0.15
C16:00	17.87±0.9	17.93±1.27	17.82±1.07	18.35±3.42	18.5±1.12	18.96±3.22	18.55±1.76	19.14±1.75	18.45±0.46
C18:00	9.08±1.13	8.35±0.32	8.59±0.43	9.56±1.7	8.03±0.39	9.08±1.67	9.85±0.3	9.17±1.37	9.17±1.43
∑SFA	30.92±1.53	29.46±1.62	30.16±2.1	32.63±4.8	29.86±0.88	32.42±4.97	30.75±2.03	30.78±1.72	30±1.68
C18:1n-9	15.08±0.75	13.8±0.47	13.19±0.42	14.64±1.93	14.69±0.66	14.41±1.92	5.26±10.52	9.45±10.96	20.04±3.86
∑ MUFA	25.28±3.68	23.72±0.94	21.41±1.89	26.63±3.32	25.97±1.98	27.65±1.98	31.11±2	30.07±3.36	31.14±3.69
C18:2n-6	6.14±0.77	5.46±0.11	5.72±0.42	5.36±0.91	5.85±0.46	5.31±0.77	9.2±3.69	12.41±1.5	6.19±1.57
C20:4n-6	9.46±2.6	9.47±2.02	10.49±0.65	8.61±3.09	7.81±0.63	6.81±0.65	7.59±2.99	5.59±1.74	6.85±0.56
∑n-6 PUFA	18.47±2.96	17.55±2.2	18.57±0.72	17.71±3.35	16.45±0.8	15.61±1.72	18.12±0.88	19.42±1.59	14.81±0.72
C20:5n-3	9.14±0.19	10.97±1.22	11.25±0.76	7.75±1.68	9.66±0.79	8.55±2.43	7.5±2.25	4.07±4.75	6.62±4.86
C22:5n-3	0.75±0.17	0.85±0.18	0.69±0.05	0.82±0.62	0.94±0.14	1±0.46	0.38±0.2	0.47±0.34	1.01±0.5
C22:6n-3	4.15±0.2	4.73±0.19	4.88±0.31	4.44±1.61	4.52±0.46	5.15±1.44	2.94±1.28	3.54±3.18	3.97±1.1
∑ n-3 PUFA	16.74±1.21	19.73±1.2	21.05±1.22	15.1±3.19	18.88±1.45	17.68±4.25	12.36±3.65	13.11±4.74	16.36±4.78
∑ 16:00	1.82±0.51	1.56±0.12	1.37±0.13	1.69±0.42	1.62±0.11	1.41±0.14	0.46±0.15	0.7±0.36	1.06±0.4
∑ PUFA	37.03±2.62	38.84±3.01	40.98±0.76	34.49±5.5	36.95±1.85	34.7±5.47	30.93±3.7	33.23±6.08	32.24±4.54
∑ DMA	6.77±0.12	7.98±0.55	7.45±0.47	6.24±1.72	7.22±0.49	5.23±0.61	7.21±0.46	5.91±1.92	6.63±0.82
n.3:n.6	0.93±0.18	1.13±0.11	1.14±0.1	0.86±0.17	1.15±0.09	1.13±0.23	0.68±0.21	0.67±0.22	1.12±0.37
EPA+DHA	13.29±0.26	15.7±1.22	16.12±0.53	12.19±2.66	14.17±1.22	13.7±3.43	10.44±3.52	7.6±7.3	10.58±5.76
EPA+DPA+DHA	14.04±0.4	16.55±1.17	16.81±0.57	13±3.08	15.11±1.34	14.7±3.7	10.82±3.72	8.07±7.64	11.6±6.23

Appendix 32 (5.20) Supplementary (S) Table 20 The content of important fatty acids (% of total FA) in *horina* from different culture systems along the saline gradients of S-W Bangladesh

Culture System	HSE	HSO	HSSI	LSO	LSSI	MSE	MSO	MSSI	Pocket
C14:00	1.09±0.3	0.76±0.15	0.87±0.27	0.49±0.21	0.93±0.14	1.15±0.16	0.57±0.01	0.93±0.1	1.04±0.24
C16:00	14.68±1.52	15.75±0.16	16.11±0.84	15.23±0.14	19.68±1.9	17.72±2.33	17.4±0.07	19.72±2.78	15.93±0.61
C18:00	12.54±1.58	13.02±0.35	10.78±0.35	11.99±0.66	13.84±1.29	12.26±1.97	13.17±0.11	13.46±4.7	11.05±0.69
∑SFA	31.45±3.63	32.19±0.35	30.22±0.94	30.4±0.75	35.59±3.29	32.81±3.78	33.35±0.12	36.24±7.83	30.64±0.29
C18:1n-9	8.56±3	9.33±1.62	7.76±1.46	10.91±2.36	7.15±0.28	7.95±0.21	8.82±0.19	9.24±0.37	8.28±0.06
∑ MUFA	17.62±4.11	17.8±1.38	16.82±0.8	16.31±2.85	23.15±1.58	20±1.9	15.92±0.33	18.42±2.48	17.17±0.31
C18:2n-6	5.24±3.3	7.2±0.39	6.68±2.52	10.16±0.38	6.29±0.04	4.38±1.81	10.35±0.35	8.58±1.65	5.83±2.11
C20:4n-6	10.66±1.28	10.3±0.55	9.8±0.84	11.85±1.24	9.43±1.25	10.71±0.09	11.74±0.26	8.54±1.6	10.76±0.48
∑n-6 PUFA	19.34±4.44	21.1±0.25	20.47±3.24	25.83±1.14	18.52±1.25	17.77±1.28	26.29±0.12	19.73±4.79	20.76±1.73
C20:5n-3	12.59±1.4	10.27±0.34	12.17±1.38	9.77±0.8	7.68±1.54	11.6±3.23	8.68±0.38	9.8±0.18	11.36±0.2
C22:5n-3	1.29±0.23	1.17±0.07	1.42±0.42	2.02±0.15	0.63±0.18	0.93±0.17	1.64±0.07	1.48±1.34	1.74±1.04
C22:6n-3	8.06±1.16	7.17±0.22	8.04±1.3	5.41±0.4	2.61±0.58	6.15±2.77	4.58±0.26	3.97±1.36	7.55±2
∑ n-3 PUFA	23.64±2.86	20.7±0.54	24.9±3.2	19.88±1.12	13.45±2.76	21.72±6.32	17.01±0.78	19.24±3.85	23.59±3
∑ 16:00	2.17±0.93	2.34±0.17	1.99±0.9	1.43±0.05	4.37±0.25	2.32±0.79	1.94±0.31	1.24±0.84	2.64±0.6
∑ PUFA	45.15±4.13	44.13±0.8	47.35±1.43	47.15±2.31	36.35±4.25	41.81±5.82	45.23±0.51	40.2±9.47	46.99±0.93
∑ DMA	5.78±2.57	5.88±0.9	5.61±0.34	6.14±1.06	4.91±0.99	5.38±0.41	5.5±0.45	5.13±0.92	5.2±0.72
n.3:n.6	1.27±0.32	0.98±0.03	1.25±0.34	0.77±0.01	0.72±0.1	1.24±0.43	0.65±0.03	0.98±0.04	1.15±0.24
EPA+DHA	20.65±2.5	17.45±0.56	20.21±2.69	15.17±1.19	10.3±2.11	17.75±5.99	13.27±0.63	13.78±1.53	18.91±2.12
EPA+DPA+DHA	21.93±2.72	18.62±0.63	21.63±2.86	17.19±1.35	10.92±2.3	18.68±6.1	14.91±0.7	15.26±2.87	20.66±3.15

Appendix 33 (5.21) Supplementary (S) Table 21 The content of important fatty acids (% of total FA) in shellfish from different culture systems along the saline gradients of S-W Bangladesh

Culture System	HSE	HSSI	LSSI	MSE	MSSI	FW	HSE	HSSI	LSSI	MSE	MSSI	Wild
Species	Mud crab					*rosna*						*tiger chingri*
C14:00	3.16±0.05	2.6±0.12	1.95±0.01	2.51±0.01	2.74±0.03	1.46±0.17	1.52±0.09	1.05±0.62	2.2±0.13	1.38±0.02	1.77±0.11	0.75±0.01
C16:00	20.4±0.26	21.53±0.36	20.48±0.08	20.4±0.47	23.6±0.26	19.81±0.58	18.51±1.55	18.91±0.97	18.35±0.16	18.68±0.09	21.78±1.64	15.48±0.52
C18:00	9.85±0.07	8.79±0.17	8.27±0.06	7.89±0.25	7.31±0.17	10.19±0.92	10.64±0.32	10.17±0.58	8.11±0.05	8.99±0.07	8.25±0.43	10.76±0.4
∑SFA	37.02±0.75	39.16±1.21	34.55±0.1	34.27±1	36.07±0.57	33.55±1.48	32.97±1.41	32.55±1.79	30.67±0.15	31.8±1.78	33.47±1.12	29.22±0.74
C18:1n-9	8.76±0.07	10.5±0.18	16.56±0.25	16.2±0.4	11.16±0.25	9.93±0.18	10.86±1.35	10.74±0.67	12.51±0.39	11.82±0.3	11.69±1.07	6.36±0.14
∑ MUFA	19.22±0.88	25.03±0.53	28.31±0.42	27.9±0.16	22.59±0.23	21.57±1.56	20.59±1	20.04±0.41	24±0.5	20.15±0.24	23.44±1.21	13.62±0.17
C18:2n-6	8.89±0.04	5.42±0.14	5.91±0.01	7.25±0.04	7.99±0.12	3.01±0.44	3.11±0.52	3.3±0.14	4.53±0.3	5.56±0.27	4.13±0.73	2.29±0.15
C20:4n-6	5.86±0.44	7.01±0.22	5.84±0.1	4.28±0.2	4.88±0.06	6.24±0.63	6.08±0.62	6.81±0.31	9.43±0.19	7.81±0.04	5.31±0.05	7.95±0.06
∑n-6 PUFA	18.65±0.49	16.77±0.29	15.79±0.12	17.11±0.97	16.87±0.22	11.73±0.23	11.5±0.43	12.51±0.62	16.86±0.26	15.77±0.41	11.47±0.59	15.32±0.45
C20:5n-3	11.04±0.21	6.47±0.18	6.11±0.1	7.31±0.45	5.51±0.08	13.33±0.96	13.85±1.16	14.68±1.74	11.18±0.25	13.54±0.15	12.09±1.92	13.89±0.12
C22:5n-3	1.77±0.05	1.25±0.05	1.48±0.04	1.59±0.14	2.54±0.16	0.57±0.07	0.69±0.13	0.64±0.15	0.65±0.03	0.39±0.01	0.53±0.09	1.44±0.06
C22:6n-3	7.3±0.3	3.69±0.15	5.66±0.1	5.81±0.12	5.79±0.13	10.81±0.98	11.59±0.43	10.38±1.01	5.98±0.13	7.84±0.95	10.93±0.45	16.54±0.04
∑ n-3 PUFA	21.56±0.62	14.34±0.34	16.93±0.17	16.76±1.12	21.3±0.44	26.96±2.35	28.09±1.04	27.7±1.46	20.37±0.41	24.79±1.13	26.34±2.84	34.16±0.27
∑ 16:00	1.21±0.03	1.08±0.84	1.73±0.12	0.7±0.02	1.33±1.08	1.18±0.34	1.14±0.23	1.43±0.11	1.01±0.1	0.62±0.01	3.92±0.29	2.16±0.09
∑ PUFA	41.42±1.11	32.19±0.56	34.45±0.37	34.56±1.85	39.5±1.6	39.87±1.97	40.73±1.05	41.64±2	38.24±0.28	41.19±1.27	41.73±2.45	51.64±0.8
∑ DMA	2.34±1.36	3.62±0.23	2.7±0.06	2.83±0.19	1.83±1.02	5.01±1.09	5.72±0.3	5.77±0.18	7.09±0.3	6.86±0.64	1.36±0.24	5.52±0.24
n.3:n.6	1.16±0.01	0.86±0.01	1.07±0	0.98±0.06	1.26±0.01	2.3±0.24	2.45±0.16	2.21±0.01	1.21±0.04	1.57±0.08	2.3±0.3	2.23±0.05
EPA+DHA	18.34±0.5	10.16±0.31	11.76±0.2	13.13±0.57	11.3±0.17	24.14±1.61	25.45±0.94	25.05±1.11	17.16±0.38	21.37±1.09	23.02±2.36	30.43±0.15
EPA+DPA+DHA	20.12±0.55	11.41±0.33	13.25±0.24	14.72±0.71	13.84±0.32	24.71±1.66	26.14±1.05	25.69±1.22	17.81±0.38	21.76±1.1	23.55±2.45	31.88±0.21

Appendix 34 (5.22) Supplementary (S) Table 22 The content of important fatty acids (% of total FA) in mangrove fish from different culture systems along the saline gradients of S-W Bangladesh

Culture System	HSE	HSE	FW	HSE	HSSI	LSSI	MSE	MSSI	Pocket	HSE	MSE	HSE
Species	*aamadi*	*ayza*				*bele*				*bhangan*		*bhola*
C14:00	3.44±0.03	4.07±0.08	0.87±0.1	1.26±0.48	0.89±0.22	0.8±0.29	1.28±0.1	0.9±0.07	2.53±2.29	5.06±0.65	4.83±0.92	0.83±0
C16:00	28.48±0.11	29.44±0.54	22.95±1	22.59±0.55	22.4±2.11	21.21±0.71	20.07±0.06	21.47±1.43	21.87±1.49	24.13±0.5	25.36±1.77	16.01±0.07
C18:00	9.84±0.07	5.33±0.02	11.29±0.72	10.07±1.01	11.91±0.38	10.13±0.98	11.14±0.21	11±0.36	8.88±2.52	4.8±0.12	4.67±0.21	11.05±0.06
∑SFA	45.08±0.19	39.95±0.63	36.55±1.83	36.23±0.63	36.75±2.56	33.5±0.84	34.05±0.19	34.5±1.48	37.57±4.62	36.24±0.54	36.44±0.43	30.3±0.16
C18:1n-9	7.77±0.16	21.58±0.1	9.16±0.93	10.49±1.09	10.12±1.19	10.81±1.79	12.61±1.14	9.79±0.93	9.77±3.24	6.9±3.45	5.58±1.91	7.3±0.32
∑ MUFA	19.58±0.06	41.03±0.1	16.63±1.14	18.78±1.28	16.57±1.66	18.47±1.2	19.34±1.25	16.09±0.91	21.44±3.38	26.7±2.81	22.99±1.46	16.5±0.65
C18:2n-6	1.77±0.04	4.49±0.09	2.55±0.25	3.82±1.41	2.33±0.28	3.38±0.09	2.36±0.07	3.05±0.42	2.44±1.15	2.2±0.79	1.85±0.39	2.82±0.06
C20:4n-6	2.82±0.04	2.59±0.01	10.54±0.69	9.25±1.7	11.07±2.13	11.65±0.98	11.3±0.3	11.08±0.22	7.02±6.01	3.39±0.67	2.67±0.18	8.18±0.06
∑n-6 PUFA	7.79±0.19	9.97±0.22	18.52±1.66	17.99±1	19.45±4.54	21.58±1.5	19.89±0.38	20.75±1.61	14.05±9.25	8.49±2.37	7.19±0.9	15.3±0.14
C20:5n-3	7.89±0.02	1.31±0.13	4.45±0.47	5.34±1.19	3.34±0.39	3.92±1.42	1.89±0.02	3.75±1.19	4.74±2.29	8.76±4	9.13±3.59	13.49±0.48
C22:5n-3	1.25±0.02	1.48±0.05	4.49±0.29	4.12±0.19	3.94±0.59	6.95±4.79	3.34±0.11	4.1±0.7	3.52±0.84	4.9±0.89	4.38±1.51	1.41±0
C22:6n-3	12.43±0.02	2.2±0.19	15.04±0.23	12.32±3.09	15.23±0.83	10.81±5.31	17.73±0.45	16.84±2.28	10.12±6.11	6.47±0.8	9.4±4.17	15.35±0.63
∑ n-3 PUFA	25.56±0.08	8.22±0.45	26.23±0.59	25.02±1.02	24.76±1.45	24.26±1.51	24.2±0.55	26.8±0.64	21.28±2.48	23.87±2.81	28.61±2.61	32.9±0.76
∑ 16:00	1.98±0.4	0.83±0.13	2.07±0.32	1.98±0.09	2.47±0.25	2.19±0.15	2.53±0.14	1.86±0.09	5.67±3.92	4.7±2.35	4.77±2.31	5±0.05
∑ PUFA	35.34±0.15	19.03±0.54	46.82±1.15	44.99±1.66	46.68±3.5	48.03±2.01	46.61±1.06	49.41±2.15	40.99±7.82	37.06±2.8	40.57±1.18	53.2±0.81
n.3:n.6	3.28±0.07	0.82±0.03	1.43±0.16	1.39±0.08	1.34±0.36	1.13±0.12	1.22±0.01	1.3±0.08	2.12±1.23	3.06±1.18	3.99±0.18	2.15±0.04
EPA+DHA	20.32±0.05	3.51±0.33	19.49±0.3	17.66±2.07	18.57±0.88	14.73±3.99	19.62±0.47	20.58±1.14	14.86±3.85	15.23±3.21	18.53±0.59	28.84±1.1
EPA+DPA+DHA	21.57±0.04	4.99±0.38	23.98±0.5	21.79±2.06	22.51±1.22	21.68±1.18	22.95±0.58	24.68±0.6	18.38±3.07	20.13±4.1	22.91±0.93	30.25±1.1

Appendix 35 (5.23) Supplementary (S) Table 23 The content of important fatty acids (% of total FA) in Mangrove fish from different culture systems along the saline gradients of S-W Bangladesh

Culture System	HSE	HSE	HSE	MSE	HSE	MSE	HSE	Wild	HSE	HSE	HSE	HSE
Species	*caine magur*	*cucia*	*datina*		*fesa*		*gaberdana*	*illish*	*kakshel*	*kalogullo*	*katkoi*	*khoira*
C14:00	2.49±0.02	1.64±0.07	2.09±0.04	1.88±0.18	2.5±0.17	3.7±0.04	2.04±0.03	8.19±0.33	1.13±0.04	4.6±0.13	2.01±0.4	1.25±0.08
C16:00	28.33±0.15	20.47±0.59	27.88±2.87	27.94±2.82	30.97±1.19	25.94±0.14	25.11±0.13	30.42±0.23	21.25±0.6	28.61±0.87	29.04±0.41	22.54±0.48
C18:00	7.13±0.01	9.54±0.35	9.13±1.44	9.25±1.17	7.2±0.37	7.61±0.05	9.55±0.09	7.39±0.09	10.75±0.3	7.88±0.21	8.76±1.16	10.14±0.6
∑SFA	39.33±0.18	32.79±0.93	40.85±1.19	40.51±1.86	42.42±2.14	39.47±0.16	39.44±0.2	46.74±0.53	34.49±1.1	43.4±1.42	41.68±1.03	36.55±0.83
C18:1n-9	22.78±0.1	15.29±0.74	19.52±1.02	21.73±1.57	19.9±0.46	13.37±0.06	6.29±0.07	20.84±0.49	13.44±0.15	12.88±0.36	15.39±2.03	8.26±0.76
∑ MUFA	35.3±0.04	24.56±0.99	30.37±1.79	32.76±1.05	31.36±0.47	27.49±0.32	14.49±0.37	38.64±0.25	19.87±0.6	24.96±1.02	28.59±0.96	15.65±0.73
C18:2n-6	5.92±0.09	7.9±0.13	4.98±0.02	3.47±1.7	1.21±0.1	2.4±0.03	2.07±0.03	0.61±0.01	9.59±0.04	1.83±0.01	2.18±0.56	1.8±0.06
C20:4n-6	2.72±0.02	7.06±0.34	3.7±1.01	3.54±0.83	3.06±0.15	3.71±0.03	4.14±0.05	0.98±0.02	9.42±0.57	1.8±0.14	3.11±0.53	5.53±0.07
∑n-6 PUFA	12.22±0.03	22.95±0.37	11.72±1.5	10.82±0.53	6.39±0.28	8.7±0.06	10.12±0.12	2.13±0.01	24.03±0.73	6.98±0.09	9.33±2.67	12.42±0.15
C20:5n-3	1.07±0.01	0.68±0.13	2.77±1.44	2.46±1.1	6.71±0.76	3.55±4.1	8.53±0.07	6.04±0.25	3.57±0.23	3.79±0.38	4.56±1.38	6.82±0.31
C22:5n-3	2.99±1.38	3.61±0.33	2.35±0.26	3.15±0.73	1.86±0.1	1.5±0.08	1.56±0.54	1.27±0.06	2.59±0.11	1.54±0.15	3.23±0.38	1.29±0.09
C22:6n-3	3.66±1.44	6.84±0.9	5.35±1.1	5.3±1.07	7.91±0.41	9.6±0.12	21.66±0.2	1.06±0.06	8.78±0.58	14.07±1.69	7.86±3.7	21.11±0.54
∑ n-3 PUFA	11.59±0.09	16.9±1.49	15.77±0.98	14.86±0.3	19.03±1.4	22.95±0.1	34.44±0.49	9.68±0.38	19.77±0.79	23.36±2.35	19.1±3.05	32.21±0.05
∑ 16:00	1.56±0.13	2.8±0.06	1.3±0.48	1.04±0.2	0.8±0.01	1.4±0.35	1.51±0.07	2.81±0.1	1.84±0.18	1.29±0	1.3±0.34	3.17±0.27
∑ PUFA	25.37±0.22	42.65±1.91	28.78±2.92	26.72±0.83	26.22±1.69	33.04±0.24	46.07±0.51	14.62±0.28	45.64±1.7	31.63±2.44	29.73±0.52	47.8±0.11
n.3:n.6	0.95±0.01	0.74±0.05	1.36±0.1	1.38±0.07	2.98±0.09	2.64±0.02	3.4±0.04	4.55±0.18	0.82±0.01	3.34±0.3	2.26±0.97	2.59±0.03
EPA+DHA	4.73±1.45	7.52±1.03	8.12±2.54	7.76±2.16	14.62±1.17	13.15±3.99	30.19±0.26	7.1±0.31	12.35±0.81	17.86±2.07	12.41±3.43	27.93±0.24
EPA+DPA+DHA	7.72±0.07	11.13±1.36	10.47±2.28	10.91±2.89	16.48±1.26	14.65±3.92	31.75±0.61	8.37±0.36	14.94±0.92	19.4±2.22	15.64±3.1	29.23±0.15

Appendix 36 (5.24) Supplementary (S) Table 24 The content of important fatty acids (% of total FA) in Mangrove fish from different culture systems along the saline gradients of S-W Bangladesh

Culture System	FW	HSE	HSSI	LSSI	MSE	MSSI	Pocket	HSE	HSE	HSSI	LSSI	MSE	MSSI
Species				*khorshula*				*lalgullo*			*nona tengra*		
C14:00	2.66±0.07	6.19±0.16	5.62±0.26	4.49±0.1	7.31±0.14	5.45±0.13	2.6±0.09	1.92±0.02	4.77±3.43	12.03±0.34	2.55±0.3	2.47±0.15	1.92±0.17
C16:00	32.78±0.37	31.29±0.16	30.4±1.26	31.06±0.94	28.73±0.74	33.37±0.47	32.79±0.38	25.04±0.27	28.33±2.51	29.63±0.14	24.86±2.58	24.61±0.42	27±0.75
C18:00	7.85±0.09	5.67±0.69	6.52±0.16	6.48±0.26	4.6±0.1	5.68±0.04	7.86±0.11	11.05±0.02	10.25±1.27	10.57±0.06	8.61±0.92	9.21±0.24	8.89±0.33
∑SFA	46.88±0.56	46.87±0.84	44.17±1.74	43.76±1.28	42.99±0.51	45.64±0.63	46.84±0.66	41.57±0.79	44.86±7.38	53.75±0.14	38.16±3.11	38.59±0.71	39.24±0.81
C18:1n-9	12.53±0.78	6.79±1.82	11.21±1.89	13.59±0.08	9.47±0.31	7.62±0.1	12.54±0.78	15.65±0.52	20.05±8.33	8.92±0.49	22.19±4.01	19.04±4.38	27.44±0.18
∑ MUFA	24.3±0.62	24.66±2.02	23.6±2.21	26.05±0.47	27.19±1.44	19.24±0.35	24.26±0.69	30.2±0.29	32.39±9.96	25.57±0.34	38.48±1.96	31.97±3.21	39.02±2.45
C18:2n-6	2.27±0.15	2.04±0.96	3.81±0.36	9.73±0.07	3.99±0.44	4.06±0.04	2.27±0.15	5.07±0.22	3.16±0.2	1.58±0.28	4.21±1	7.53±1.17	5.9±3
C20:4n-6	2.58±1.48	2.85±0.5	2.01±0.07	1.98±0.07	2.29±0.15	1.34±0.04	2.58±1.49	5.28±0.18	3.05±0.34	2.58±0.08	2.44±0.66	3.08±0.25	2.64±0.15
∑n-6 PUFA	8.78±1.12	8.1±0.92	9.4±0.14	14.51±0.38	8.71±0.26	7.35±0.1	8.8±1.14	16.48±0.59	8.93±0.53	7.2±0.22	9.07±0.77	13.5±0.94	11.03±3
C20:5n-3	1.48±0.13	2.94±0.9	1.54±0.11	0.7±0.03	3.3±0.06	1.91±0.11	1.48±0.13	2.51±0.11	2.64±0.78	3.31±0.05	2.41±0.52	2.59±0.32	2.05±0.2
C22:5n-3	3.06±0.19	3.83±0.99	2.28±0.07	1.61±0.07	2.93±0.08	2.34±0.11	3.06±0.2	1.92±0.06	1.5±0.14	1.83±0.11	0.9±0.36	1.24±0.05	1.19±0.21
C22:6n-3	7.45±0.2	4.4±2.18	7.43±0.19	3.41±0.26	4.16±0.41	6.73±0.36	7.45±0.2	1.48±0.01	4.08±0.54	4.24±0.12	3.21±0.66	4.16±0.42	3.98±0.6
∑ n-3 PUFA	17.27±0.95	15.94±3.79	21.26±0.45	12.26±0.6	17.63±0.29	26.77±0.83	17.33±1.01	7.96±0.3	12.53±1.9	11.88±0.26	11.85±1.23	13.96±2.55	9.85±1.06
∑ 16:00	2.77±0.1	4.44±1.87	1.56±0.14	3.43±0.18	3.48±0.59	1±0.09	2.77±0.11	3.78±0.78	1.29±0.21	1.59±0.44	2.44±1.97	1.98±0.24	0.86±0.34
∑ PUFA	28.82±1.17	28.48±2.84	32.23±0.49	30.2±0.82	29.82±1.13	35.12±0.95	28.9±1.35	28.23±0.49	22.75±2.61	20.67±0.48	23.36±1.51	29.45±3.22	21.74±1.75
n.3:n.6	2±0.33	1.95±0.23	2.26±0.08	0.84±0.02	2.03±0.03	3.64±0.11	2±0.33	0.48±0.04	1.4±0.13	1.65±0.09	1.32±0.25	1.03±0.12	0.97±0.36
EPA+DHA	8.93±0.32	7.34±1.31	8.97±0.27	4.11±0.29	7.46±0.41	8.64±0.46	8.92±0.32	3.98±0.12	6.71±0.27	7.55±0.07	5.62±0.14	6.75±0.73	6.03±0.42
EPA+DPA+DHA	11.99±0.51	11.17±0.53	11.25±0.34	5.72±0.36	10.39±0.47	10.99±0.57	11.98±0.52	5.9±0.18	8.21±0.41	9.38±0.18	6.52±0.48	8±0.77	7.22±0.63

Appendix 37 (5.25) Supplementary (S) Table 25 The content of important fatty acids (% of total FA) in Mangrove fish from different culture systems along the saline gradients of S-W Bangladesh

Culture System	HSE	HSSI	LSSI	MSE	MSSI	Pocket	HSE	HSSI	LSSI	MSE	MSSI	HSE
Species				*parsey*					*payra*			*shilong*
C14:00	5.08±0.19	3.74±0.13	6.3±0.29	4.06±0.03	3.98±0.08	5.87±0.05	1.54±0.66	0.95±0.08	1.36±0.05	2.71±0.37	3.12±1.83	2.52±0.07
C16:00	25.82±0.19	22.77±0.07	34.91±0.39	35.03±0.52	29.34±0.36	31.08±0.84	34.52±2.61	36.34±1.37	37.8±1.33	34.82±1.57	32.23±0.68	30.56±0.45
C18:00	4.62±0.09	5.48±0.07	3.94±0.08	4.71±0.07	5.4±0.03	4.35±0.29	6.79±0.19	9.22±3.21	6.41±0.07	7.82±1.23	8.03±1.4	9.04±0.14
∑SFA	41.25±0.13	37.46±0.06	46.84±0.76	49.32±0.72	44.56±0.53	43.46±1.06	43.67±3.28	47.65±2.65	45.98±1.22	46.64±1.48	44.72±0.82	43.76±0.59
C18:1n-9	8.25±2.21	7.27±1.94	8.24±0.02	7.46±0.16	10.01±2.05	7.2±0.02	11.54±0.96	11.54±1.54	13.88±0.46	14.82±0.53	13.63±2.65	18.26±0.2
∑ MUFA	28.37±2.08	26.94±1.82	30.38±0.2	26.71±0.23	30.53±2.23	30.93±1.44	25.3±2.63	21.92±1.54	27.65±0.34	30.12±3.49	30±3.38	32.13±0.38
C18:2n-6	1.54±0.11	1.84±0.04	3.44±0.03	2.6±0.04	1.71±0.13	1.51±1.24	3.08±2.1	1.14±0.04	1.34±0.08	2.9±2.31	4.95±4.38	2.76±0.12
C20:4n-6	2.86±0.26	3.6±0.19	2.23±0.05	2.4±0.06	2.55±0.18	1.62±1.35	5.47±5.02	9.41±0.64	7.41±0.25	1.35±0.18	1.58±0.27	3.8±0.03
∑n-6 PUFA	6.42±0.29	8.11±0.31	8.03±0.26	7.06±0.13	6.24±0.32	5.99±2.07	15.52±5.3	18.93±0.83	14.83±0.3	9.43±2.26	12.45±5.18	10.73±0.83
C20:5n-3	7.59±0.61	7.34±0.39	2.48±0.12	3.13±0.06	5.07±0.34	5.53±0.05	2.99±2.55	3.82±0.93	3.95±0.04	1.1±0.45	2±0.73	3.15±0.04
C22:5n-3	2.81±0.27	2.91±0.18	1.05±0.04	1.12±0.01	1.97±0.13	1.24±0.64	2.47±1.22	2.79±0.67	2.86±0.04	1.88±0.41	2.51±1.01	1.9±0.04
C22:6n-3	2.68±0.24	4.78±0.28	2.71±0.08	1.44±0.01	2.68±0.13	2.23±0.5	3.39±1.37	3.11±0.34	3.4±0.49	3.77±0.3	4.49±1.35	5.22±0.03
∑ n-3 PUFA	16.32±0.09	18.04±1.04	11.7±0.25	11.06±0.08	12.95±0.78	15.16±0.42	13.46±1.24	10.5±1	10.88±0.82	12.04±2.88	11.27±2.16	12.09±0.11
∑ 16:00	7.63±1.99	9.45±0.47	3.05±0.14	5.85±0.32	5.72±0.76	4.47±0.05	2.05±0.79	1±0.27	0.67±0.1	1.77±1	1.56±0.21	1.29±0.03
∑ PUFA	30.37±2.17	35.6±1.82	22.78±0.62	23.97±0.51	24.91±1.71	25.62±2.5	31.03±5.8	30.42±1.56	26.37±1.16	23.24±4.39	25.28±3.25	24.11±0.97
n.3:n.6	2.54±0.13	2.22±0.04	1.46±0.03	1.57±0.02	2.07±0.05	2.76±0.88	0.93±0.25	0.55±0.04	0.73±0.04	1.28±0.02	1.1±0.63	1.13±0.08
EPA+DHA	10.28±0.84	12.12±0.66	5.19±0.19	4.57±0.06	7.74±0.47	7.76±0.54	6.38±3.92	6.93±0.75	7.35±0.47	4.87±0.61	6.49±2.07	8.37±0.07
EPA+DPA+DHA	13.08±1.11	15.03±0.84	6.24±0.22	5.68±0.07	9.71±0.61	9±1.17	8.85±5.14	9.72±1.4	10.22±0.5	6.76±1.02	9±3.08	10.27±0.11

Appendix 38 (5.26) Supplementary (S) Table 26 The content of important fatty acids (% of total FA) in Mangrove fish from different culture systems along the saline gradients of S-W Bangladesh

Culture System	HSE	HSE	HSE	HSSI	MSE	MSSI
Species	*taposhi*	*therol*	*vetki*			
C14:00	4.43±0.08	1.66±0.68	6.26±0.07	6.26±0.06	4.03±2.01	5.21±0.17
C16:00	33.14±0.88	24.61±3.49	26.83±0.07	26.81±0.03	28±0.72	27.11±0.64
C18:00	10.78±0.46	7.6±0.5	6.24±0.13	6.24±0.13	6.52±0.54	5.8±0.37
∑SFA	50.16±0.79	35.17±4.53	41.21±0.05	41.18±0.1	39.75±1.95	39.68±0.97
C18:1n-9	21.74±0.7	14.24±6.7	11.98±0.17	11.98±0.17	14.22±1.67	13.47±0.24
∑ MUFA	33.77±0.62	22.27±3.29	29.58±0.14	29.58±0.12	27.43±1.79	30.04±1.24
C18:2n-6	0.63±0	10.75±5.01	2.93±0.02	2.93±0.01	7±1.69	5.66±0.22
C20:4n-6	1.39±0.02	2.28±0.52	2.17±0.05	2.17±0.04	2.82±0.16	2.4±0.12
∑n-6 PUFA	3.26±0.1	15.85±4.53	7.82±0.12	7.85±0.11	13.94±2.5	11.55±0.59
C20:5n-3	4.36±0.34	1.29±0.77	1.84±0.2	1.84±0.2	1.44±0.07	0.6±0.7
C22:5n-3	1.86±0.22	1.89±0.67	6.21±0.14	6.21±0.15	2.58±1.12	3.15±0.19
C22:6n-3	5.04±0.35	8.41±4.19	5.45±0.15	5.45±0.15	4.8±0.11	4.2±0.23
∑ n-3 PUFA	12.03±0.95	25.78±3.23	16.86±0.12	16.89±0.13	17.41±0.83	16.91±0.03
∑ 16:00	0.78±0.1	0.92±0.21	4.52±0.22	4.51±0.22	1.47±0.3	1.82±0.89
∑ PUFA	16.08±1.14	42.56±1.35	29.2±0.17	29.24±0.2	32.82±3.48	30.27±0.32
n.3:n.6	3.69±0.2	1.78±0.71	2.16±0.04	2.15±0.04	1.27±0.17	1.47±0.07
EPA+DHA	9.4±0.69	9.7±4.96	7.28±0.19	7.29±0.2	6.24±0.18	4.81±0.47
EPA+DPA+DHA	11.26±0.91	11.59±5.64	13.49±0.29	13.5±0.3	8.82±0.94	7.96±0.28

Appendix 39 (5.27) Supplementary (S) Table 27 The content of important fatty acids (% of total FA) in freshwater fish from different culture systems along the saline gradients of S-W Bangladesh

Culture System	FW	FW	LSSI	Pocket	FW	FW	LSSI	FW	LSSI	Pocket
Species	*bheda*		*catla*		*chanda*	*cheng*	*choto bele*		Common carp	
C14:00	1.62±0.03	1.53±0.02	1.96±0.48	0.86±0.13	1.99±0.05	1.36±0.06	4.85±0.03	0.74±0.13	1.11±0.05	0.75±0.14
C16:00	21.99±0.08	22.84±0.09	22.83±0.24	20.88±0.32	27.19±0.12	23.36±0.13	32.07±1.79	19.7±0.92	20.98±0.14	19.7±0.91
C18:00	7.28±0.05	8.55±0.14	8.61±0.19	11.09±0.27	7.33±0.02	10.37±0.06	10.46±0.78	8.75±0.35	5.34±0.12	8.75±0.37
∑SFA	32.53±0.14	34.35±0.18	35.48±1.25	34.03±0.18	38.14±0.08	36.48±0.24	48.72±2.66	30.33±1.13	28.39±0.16	30.31±1.12
C18:1n-9	22.62±0.08	14.92±0.14	11.55±3.88	10.8±0.08	13.42±0.12	11.69±0.06	22.99±0.91	17.27±2.15	27.03±0.26	17.31±2.18
∑ MUFA	34.71±0.15	24.31±0.2	21.36±3.41	19.79±0.05	27.4±0.14	18.68±0.11	35.02±1.31	23.85±0.59	41.88±1.01	23.86±0.63
C18:2n-6	11±0.06	4.49±0.11	3.16±1.54	3.27±0.1	2.57±0.05	2.38±0.03	0.65±0.03	5.87±3.27	11.94±0.08	5.88±3.29
C20:4n-6	3.12±0.06	7.73±0.05	6.96±0.82	9.53±0.19	4.84±0.07	7±0.06	1.46±0.1	11.56±0.93	4.8±0.11	11.56±0.95
∑n-6 PUFA	17.99±0.15	16.87±0.17	14.79±2.25	17.21±0.18	10.35±0.14	16.15±0.11	3.5±0.37	27.33±0.54	21.03±0.04	27.27±0.45
C20:5n-3	0.28±0	4.12±0.02	5.94±2.07	9.13±0.16	4.68±0.08	1.9±0.03	4.29±0.34	3.13±0.02	0.93±0.04	3.13±0.01
C22:5n-3	1.5±0.03	1.96±0.03	2.62±0.77	3.43±0.07	5.29±0.01	4.78±0.08	1.8±0.14	2.79±0.1	0.81±0.04	2.77±0.09
C22:6n-3	3.57±0.1	13.09±0.02	13.54±0.43	11.67±0.14	8.67±0.01	17.24±0.3	5.2±0.5	8.85±0.17	1.82±0.11	8.94±0.15
∑ n-3 PUFA	12.58±0.26	22.56±0.12	26.1±4.03	27.79±0.78	22.57±0.07	26.64±0.45	11.98±0.97	16.91±0.1	5.63±0.12	16.95±0.23
∑ 16:00	2.19±0.04	1.91±0.31	2.27±0.46	1.17±0.81	1.55±0.05	2.05±0.01	0.78±0.04	1.58±0.1	3.07±0.95	1.61±0.18
∑ PUFA	32.76±0.28	41.34±0.02	43.17±2.25	46.18±0.21	34.46±0.22	44.83±0.34	16.26±1.36	45.82±0.54	29.73±0.86	45.83±0.5
n.3:n.6	0.7±0.02	1.34±0.01	1.83±0.55	1.61±0.06	2.18±0.02	1.65±0.04	3.43±0.09	0.62±0.01	0.27±0.01	0.62±0.01
EPA+DHA	3.85±0.11	17.22±0.01	19.48±2.5	20.8±0.3	13.35±0.09	19.13±0.27	9.49±0.84	11.98±0.16	2.75±0.14	12.06±0.14
EPA+DPA+DHA	5.35±0.13	19.18±0.04	22.1±3.27	24.23±0.37	18.64±0.07	23.91±0.36	11.29±0.98	14.78±0.25	3.56±0.18	14.84±0.2

Appendix 40 (5.28) Supplementary (S) Table 28 The content of important fatty acids (% of total FA) in freshwater fish from different culture systems along the saline gradients of S-W Bangladesh

Culture System	FW	LSSI	Pocket	FW	FW	LSSI	Pocket	FW	FW	LSSI	Pocket	FW	FW
Species	Grass carp			*koi*	Mirror carp			*mola*	*mrigal*			Pangus	*pora bele*
C14:00	1.24±0.07	1.6±0.08	0.71±0.06	1.14±0.05	2.05±0.05	1.43±0.22	2.03±0.1	5.68±0.41	1.36±0.58	1.77±0.65	0.95±0.1	3.06±0.16	1.02±0.07
C16:00	21.53±0.33	20.74±0.24	22.2±0.55	24.27±0.28	22.48±0.14	29.2±1.44	22.19±0.69	25.18±0.23	23.51±0.39	22.45±3.08	21.43±2.24	25.86±0.4	22.72±0.05
C18:00	4.49±0.05	3.18±0.01	5.29±0.1	7.21±0.15	6.56±0.04	13.94±0.72	6.47±0.2	5.15±0.48	9.2±0.12	7.77±3.41	9.68±0.29	9.14±0.24	11.04±0.11
∑SFA	28.09±0.32	25.96±0.14	28.96±0.58	33.37±0.2	32.65±0.91	45.72±2.27	32.22±1.58	37.87±0.88	35.57±0.39	33.69±0.8	33.49±2.41	39.17±0.69	36.99±0.08
C18:1n-9	22.84±0.06	39.73±0.3	15.65±0.15	36.52±5.63	32.97±0.44	19.21±0.87	32.54±0.74	13.42±1.54	13.91±4.66	15.01±7.8	8.33±1.62	23.05±1.3	11.76±0.12
∑ MUFA	30.09±0.23	52.29±0.31	22.06±0.28	44.85±6.18	43.83±0.62	27.05±2.13	43.25±0.97	26.17±0.15	22.18±5.09	26.66±12.44	15.96±1.55	31.21±1.64	21.71±0.04
C18:2n-6	17.06±0.24	11.64±0.09	9.19±0.2	11.85±2.99	10.7±0.22	5.09±0.21	10.56±0.25	4.05±0.26	3.52±0.84	5.21±2.57	4.25±1.75	7.38±0.03	5.45±0.07
C20:4n-6	2.95±0.06	2.08±0.22	3.34±0.04	1.84±0.48	2.7±0.03	6.08±0.74	2.66±0.06	2.5±0.09	7.86±3.98	6.82±3.33	10.99±0.61	4.82±0.31	11.43±0.18
∑n-6 PUFA	22.01±0.14	15.67±0.12	14.64±0.42	16.69±2.38	15.73±0.48	16.11±2.15	15.51±0.42	9.69±0.12	16.74±4.77	17.62±3.21	22.57±1.69	15.99±1.29	21.95±0.17
C20:5n-3	1.27±0.16	0.16±0.01	3.92±0.06	0.29±0.15	0.13±0.15	3.28±0.56	0.13±0.15	2.37±0.86	3.89±0.67	4.02±1.94	4.14±0.5	2.41±0.14	3.53±0.07
C22:5n-3	0.79±0.03	0.36±0.03	1.61±0.02	0.57±0.5	0.63±0.01	1.57±0.25	1.96±2.65	1.21±0.06	2.69±0.47	2.71±1.6	3.32±0.29	1.7±0.16	4.69±0.05
C22:6n-3	3.87±0.2	1.8±0.18	10.56±0.28	1.93±1.48	3.31±0.16	3.92±0.98	3.27±0.22	5.86±0.33	12.96±2.2	9.64±5.47	15.11±0.26	5.82±0.59	6.5±0.04
∑ n-3 PUFA	19.24±0.24	5.7±0.33	33.49±0.46	4.55±3.5	6.91±0.18	10.3±2.12	8.16±2.39	22.03±1.36	23.89±0.41	19.76±9.7	25.72±1.42	12.29±0.94	17.44±0.14
∑ 16:00	0.57±0.01	0.39±0.01	0.86±0.06	0.53±0.3	0.88±0.01	0.82±0.16	0.86±0.03	4.23±0.66	1.62±0.35	2.27±0.22	2.26±0.83	1.35±0.5	1.91±0.32
∑ PUFA	41.81±0.12	21.76±0.43	48.98±0.85	21.78±6.05	23.52±0.29	27.23±0.15	24.53±2.22	35.96±0.79	42.25±5.46	39.65±12.77	50.56±3.83	29.62±2.04	41.29±0.06
n.3:n.6	0.87±0.02	0.36±0.02	2.29±0.03	0.25±0.17	0.44±0.02	0.66±0.22	0.53±0.16	2.27±0.16	1.52±0.41	1.07±0.36	1.14±0.03	0.77±0	0.79±0
EPA+DHA	5.14±0.35	1.96±0.19	14.48±0.34	2.23±1.61	3.44±0.31	7.2±1.54	3.4±0.36	8.24±0.66	16.85±2.87	13.66±7.41	19.25±0.63	8.23±0.73	10.03±0.1
EPA+DPA+DHA	5.93±0.38	2.32±0.22	16.09±0.35	2.8±2.11	4.07±0.32	8.77±1.79	5.36±2.4	9.45±0.7	19.54±3.34	16.37±8.92	22.57±0.42	9.93±0.88	14.71±0.15

Appendix 41 (5.29) Supplementary (S) Table 29 The content of important fatty acids (% of total FA) in freshwater fish from different culture systems along the saline gradients of S-W Bangladesh

Culture System	FW	LSSI	Pocket	FW	FW	LSSI	Pocket	FW	FW	FW	LSSI	Pocket
Species		*puti*		*rekha*		*rohu*		*shing*	*shoal*		Silver carp	
C14:00	2.24±0.73	2.02±0.45	3.38±0.41	2.67±0.19	0.78±0.11	0.85±0.05	1.66±1.13	2.25±0.12	0.96±0	3.74±0.27	2.84±1.05	1.87±0.28
C16:00	22.51±1.45	22.8±1.12	23.52±1.57	30±0.13	21.99±1.62	20.98±0.84	20.94±0.56	22.16±0.37	22.58±0.03	22.96±0.57	22.95±0.99	23.39±3.37
C18:00	8.19±0.93	8.75±0.47	7.62±0.37	12.08±0.25	9.16±0.39	8.81±1.26	8.18±0.82	7.22±0.12	10.66±0	6.41±0.05	6.95±0.69	9.23±1.63
∑SFA	35.23±1.82	36.04±1.83	36.96±2.15	46.05±0.12	33.47±2.45	31.84±0.67	32.26±1.02	33.26±0.56	35.64±0.03	35.15±0.74	34.72±1.54	36.04±5.73
C18:1n-9	15.13±1.3	18.87±4.84	11.61±2.79	20.76±1.02	9.62±0.4	10.01±1.28	9.97±0.38	17.95±0.17	13.56±0.01	15.97±0.66	14.94±1.27	12.02±1.88
∑ MUFA	28.79±2.32	30.26±3.25	24.59±2.37	30.36±0.91	17.57±0.85	20.86±0.88	19.94±2.23	41.02±0.05	22±0.02	29.91±1.39	26.4±4.19	21.32±3.82
C18:2n-6	7.6±1.23	6.88±0.26	7.2±2.91	4.13±0.28	8.85±7.02	14.13±0.23	8.89±7.01	3.97±0.02	4.76±0.01	4.93±0.36	5.47±0.67	3.73±0.32
C20:4n-6	4.34±1.61	4.57±1.47	3.49±0.19	4.39±0.02	8.22±3.8	4.03±0.51	5.98±1.21	5.59±0.09	8.48±0.01	4.46±0.12	4.87±0.54	5.36±1.05
∑n-6 PUFA	15.51±1.44	15.36±1.98	14.99±3.08	11.22±0.5	23.01±2.23	22.76±0.78	20.32±5.31	14.29±0.22	18.84±0.03	14.14±1.18	15.07±1.4	13.86±1.85
C20:5n-3	2.65±0.08	2.78±0.16	4.95±2.02	3.48±0.32	2.96±1.96	2.05±0.13	3.57±2.7	1.45±0.04	1.3±0	3.6±0.04	4.64±1.27	6.24±2.06
C22:5n-3	1.64±0.08	1.59±0.13	2.09±0.24	1.99±0.03	2.8±0.33	2.73±0.58	3.08±0.73	1.05±0.02	2.77±0	1.45±0.06	1.44±0.11	1.37±0.34
C22:6n-3	6.66±2.37	6.53±2.92	8.24±0.54	3.84±0.83	12.5±3.07	9.7±0.61	11.44±1.82	3.44±0.1	14.65±0.01	5.27±0.41	7.17±2.41	12.91±5.49
∑ n-3 PUFA	17.87±2.83	16.11±2.51	21.43±1.73	11.07±1.29	24.33±0.55	23.14±0.91	24.93±1.15	8.87±0.28	20.29±0.01	17.04±1.11	21.39±5.28	27.12±8.08
∑ 16:00	2.6±0.24	2.22±0.57	2.03±0.66	1.3±0.01	1.62±0.28	1.4±0.02	2.55±1.15	2.56±0.03	3.23±0.02	3.75±0.17	2.42±1.54	1.65±0.38
∑ PUFA	35.98±4	33.7±4.92	38.45±2.54	23.59±0.8	48.96±2.02	47.3±0.45	47.8±3.21	25.72±0.52	42.37±0.02	34.93±2.13	38.88±5.09	42.64±9.55
n.3:n.6	1.15±0.11	1.05±0.06	1.48±0.37	0.99±0.16	1.07±0.11	1.02±0.07	1.3±0.39	0.62±0.01	1.08±0	1.21±0.02	1.41±0.24	1.92±0.33
EPA+DHA	9.31±2.33	9.31±2.8	13.19±2.29	7.31±1.14	15.46±4.94	11.75±0.72	15.01±4.45	4.9±0.14	15.95±0.01	8.87±0.36	11.81±3.66	19.15±7.55
EPA+DPA+DHA	10.95±2.37	10.9±2.92	15.28±2.52	9.3±1.16	18.26±5.27	14.47±0.18	18.09±5.16	5.95±0.16	18.72±0.01	10.32±0.43	13.25±3.69	20.52±7.89

Appendix 42 (5.30) Supplementary (S) Table 30 The content of important fatty acids (% of total FA) in freshwater fish from different culture systems along the saline gradients of S-W Bangladesh

Culture System	FW	FW	LSSI	FW	LSSI	MSSI	HSE	HSSI	LSSI	MSE	MSSI
Species	*taki*	*tengra*		Thai puti			Tilapia (Mozambican)				
C14:00	1.3±0.04	1.55±0.13	1.88±0.4	2.63±1.06	3.17±0.33	3.42±0.08	3.69±0.01	3.93±0.31	4.52±0.12	8.05±0.61	8.89±0.3
C16:00	24.16±0.86	29.38±1.11	28.47±1.3	27.54±2.37	29.62±0.66	25.62±0.53	23.15±0.01	23.84±0.18	30.33±0.08	27.29±1.17	25.72±0.22
C18:00	9.56±0.26	9.71±0.54	10.42±1.03	9.2±1.63	7.6±0.9	8.29±0.19	5.71±0.04	5.59±0.1	7.02±0.38	5.43±0.38	4.87±0.02
∑SFA	36.69±0.79	42.1±1.82	42.95±1.74	40.69±1.41	41.31±1.07	38.37±0.66	34.81±0.04	35.9±0.73	43.02±0.2	42.51±1.27	40.86±0.34
C18:1n-9	15.71±1.52	30.03±1.39	26.79±3.88	27.35±9.75	31.97±4.17	26.02±0.07	14.6±0	14.95±0.54	17.91±0.87	8.83±0.41	9.32±0.09
∑ MUFA	25.25±0.84	41.14±1.33	38.28±3.8	33.86±8.79	38.09±3.64	33.99±0.33	28.31±0.03	28.11±0.17	34.02±1.66	28.56±2.82	24.9±0.29
C18:2n-6	6.15±2.85	8.26±0.58	5.32±3.41	9.18±3.97	9.04±3.83	10.21±0.02	10.18±0	10.46±0.42	5.19±0.01	2.64±0.52	3.34±0.03
C20:4n-6	6.03±0.3	1.31±0.47	2.72±1.66	2.62±1.64	1.52±0.36	1.96±0.02	2.65±0	2.59±0.07	2.08±0.27	1.9±0.39	1.34±0.01
∑n-6 PUFA	17.73±4.2	11.33±1.52	10.25±1.64	14.05±6.42	12.65±4.8	14.04±0.09	16.01±0.01	16.15±0.32	10.53±0.73	7.25±0.06	7.02±0.14
C20:5n-3	1.37±0.7	0.62±0.25	1.76±1.34	0.77±0.74	0.5±0.18	1.22±0.02	1.65±0	1.57±0.07	0.61±0.06	1.67±0.24	1.39±0.01
C22:5n-3	3.43±1.62	0.42±0.32	1.06±0.66	1.09±0.64	0.46±0.11	0.93±0.03	3.36±0	3.21±0.14	1.85±0.18	3.2±0.42	2.67±0.02
C22:6n-3	9.37±1.76	1.56±1.09	2.54±1.32	4.33±2.51	1.85±0.48	4.27±0.06	7.07±0	6.54±0.55	3.63±0.58	5.02±0.99	6.37±0.04
∑ n-3 PUFA	18.16±4.51	4.64±1.84	7.64±3.46	10.48±3.14	7.27±0.69	12.81±0.23	18.95±0.02	18.13±0.77	11.39±0.71	18.56±4.31	24.74±0.06
∑ 16:00	2.18±0.06	0.56±0.12	0.88±0.35	0.94±0.52	0.67±0.2	0.79±0.21	1.92±0.01	1.71±0.19	1.05±0.04	3.13±0.77	2.48±0.12
∑ PUFA	38.06±0.52	16.53±3.45	18.77±3.26	25.46±10.04	20.59±4.42	27.64±0.35	36.88±0.04	35.99±0.65	22.96±1.47	28.94±3.98	34.25±0.09
n.3:n.6	1.12±0.52	0.4±0.11	0.78±0.43	0.79±0.14	0.66±0.3	0.91±0.02	1.18±0	1.12±0.07	1.08±0.01	2.56±0.59	3.52±0.07
EPA+DHA	10.74±2.46	2.18±1.34	4.3±2.49	5.1±2.81	2.35±0.51	5.49±0.07	8.72±0	8.11±0.62	4.24±0.64	6.69±0.93	7.77±0.05
EPA+DPA+DHA	14.17±4.07	2.6±1.65	5.36±3.12	6.2±3.43	2.81±0.61	6.42±0.1	12.08±0.01	11.32±0.76	6.09±0.8	9.89±0.95	10.44±0.04

Appendix 43 (5.31) Supplementary (S) Table 31 The content of important fatty acids (% of total FA) in freshwater fish from different culture systems along the saline gradients of S-W Bangladesh

Culture System	HSE	HSSI	LSSI	MSE	MSSI
Species	Tilapia (GIFT)				
C14:00	6.51±0.31	2.77±0.29	3.63±0.11	5.18±0.09	3.57±0.12
C16:00	29.66±0.37	26.32±0.54	25.01±0.16	26.71±0.69	27.9±0.12
C18:00	5.02±0.03	4.47±0.19	6.07±0.03	7.12±0.32	5.45±0.09
∑SFA	42.59±0.68	34.62±0.79	35.54±0.06	41.26±0.95	38.04±0.09
C18:1n-9	10.61±0.05	14.43±0.14	31.86±0.23	14.86±0.09	23.91±0.13
∑ MUFA	31.86±0.4	26.56±0.75	43.39±0.39	30.34±0.2	39.08±0.17
C18:2n-6	4.32±0.05	7.41±0.13	11.2±0.11	4.92±0.14	8.23±0.05
C20:4n-6	1.12±0.07	1.37±0.16	0.9±0.01	2.78±0.05	1.54±0.03
∑n-6 PUFA	7.58±0.06	11.11±0.58	14.68±0.25	12.13±0.08	12.62±0.09
C20:5n-3	1.27±0.39	1.06±0.06	0.32±0.1	0.85±0.14	0.45±0.12
C22:5n-3	3.35±0.22	2.94±0.15	1.28±0.02	2.23±0.06	1.65±0.01
C22:6n-3	3.56±0.23	5.14±0.68	2.58±0.04	4.91±0.08	3.55±0.05
∑ n-3 PUFA	14.33±0.37	26.8±0.88	5.99±0.23	13.79±0.57	9.64±0.43
∑ 16:00	3.64±0.6	0.91±0.08	0.4±0.04	2.48±0.62	0.62±0.28
∑ PUFA	25.55±0.31	38.82±1.54	21.07±0.44	28.4±1.15	22.88±0.13
n.3:n.6	1.89±0.06	2.41±0.05	0.41±0.01	1.14±0.05	0.76±0.04
EPA+DHA	4.83±0.24	6.2±0.74	2.9±0.1	5.77±0.07	3.99±0.17
EPA+DPA+DHA	8.18±0.32	9.14±0.88	4.18±0.12	8±0.06	5.65±0.18

Appendix 44 (5.32) Supplementary (S) Table 32 The content of important fatty acids (% of total FA) in by-products from different culture systems along the saline gradients of S-W Bangladesh

Culture System	BP	BP	BP	BP	BP	BP	Wild	BP	Feed	BP
Species	*bagda* head	*bagda* shell	*golda* brain	*golda* claw	*golda* head	*golda* shell	*illish* egg	*horina* shell	snail	*tiger chingri* shell
C14:00	1.09±0.19	0.69±0.08	3.08±0.29	0.96±0.11	1.51±0.18	0.99±0.19	7.26±0.97	2.08±0.06	2.6±0.64	1.25±0.07
C16:00	19.64±1.44	15.07±0.48	23.48±0.1	17.5±0.84	20.46±1.73	18.4±1.3	11.71±0.43	20.12±0.68	17.49±0.57	17.64±0.45
C18:00	8.81±0.16	11.62±0.41	7.03±0.1	8.51±0.19	9.9±1.04	11.32±0.56	4.92±0.08	8.79±0.04	3.94±0.11	9.63±0.67
∑SFA	32.46±1.32	29.66±1.11	35.5±0.89	28.77±0.97	33.71±1.8	32.1±0.94	24.29±1.46	34.6±0.7	30.73±0.97	32.53±1.2
C18:1n-9	15.98±2.39	11.63±0.88	29.93±0.7	27.59±0.96	22.05±3.18	22.03±2.29	23.76±0.24	10.26±0.07	9.07±0.26	13.6±0.32
∑ MUFA	25.19±0.87	20.53±0.26	51.07±0.51	37.23±1.94	33.58±4.18	32.75±3.72	48.31±0.14	27.67±0.32	26.54±0.43	25.07±2.37
C18:2n-6	13.1±3.61	8.07±1	8.16±0.17	6.71±0.23	7.28±1.79	8.18±1.19	0.8±0.01	6.11±0.04	12.51±0.49	10.65±0.34
C20:4n-6	8.1±0.54	11.4±0.2	0.69±0.03	8.22±0.29	5.8±0.34	6.87±1.87	1.79±0.08	7.56±0.28	6.3±0.17	7.19±0.26
∑n-6 PUFA	24.38±4.09	22.73±0.98	10.17±0.24	16.71±0.59	14.87±1.91	16.81±0.89	3.75±0.16	17.61±0.58	25.03±0.91	21.36±0.55
C20:5n-3	5.74±1.33	10.04±1.69	0.32±0.02	4.35±0.08	4.8±2.3	5.6±1.08	10.19±0.59	5.89±0.18	1.08±0.52	7.17±0.39
C22:5n-3	0.91±0.16	1.19±0.19	0.1±0.01	0.47±0.02	0.95±0.36	0.89±0.3	1.74±0.16	1.09±0.11	0.35±0.02	1.04±0.08
C22:6n-3	3.48±0.77	5.96±1.38	0.38±0.04	2.85±0.07	3.34±1.27	3.68±1	7.38±0.51	2.5±0.01	0.2±0.01	3.99±0.22
∑ n-3 PUFA	13.09±3.2	19.72±3.01	2.04±0.17	8.99±0.24	12.27±4.25	12.95±2.62	21.31±1.19	14.4±0.11	12.09±0.37	15.79±0.55
∑ 16:00	1.87±1.05	1.99±0.62	0.42±0.05	1.03±0.03	0.97±0.2	0.63±0.04	2.33±0	3.1±0.13	1.52±0.82	1.73±0.14
∑ PUFA	39.34±1.46	44.45±1.63	12.63±0.36	26.74±0.86	28.11±3.19	30.38±3.53	27.39±1.35	35.11±0.75	38.64±1.09	38.88±0.99
∑ DMA	3.01±1.35	5.37±0.38	0.8±0.09	7.26±0.22	4.6±0.78	4.76±0.7	0±0	2.62±0.24	3.92±0.11	3.52±0.38
n.3:n.6	0.56±0.22	0.87±0.17	0.2±0.01	0.54±0.01	0.86±0.38	0.77±0.12	5.69±0.09	0.82±0.03	0.48±0.02	0.74±0.02
EPA+DHA	9.22±2.07	16±3.06	0.7±0.06	7.2±0.15	8.13±3.55	9.28±2.08	17.57±1.09	8.38±0.18	1.28±0.52	11.16±0.61
EPA+DPA+DHA	10.13±2.05	17.2±2.97	0.8±0.07	7.68±0.17	9.08±3.9	10.17±2.36	19.31±1.11	9.47±0.11	1.63±0.5	12.2±0.69

Appendix 45 (5.33) Supplementary (S) Table 33 Shellfish micronutrients content per 100 g raw weight

Species	Sodium mg	Magnesium mg	Phosphorus mg	Potassium mg	Copper mg	Vanadium µg	chromium µg	manganese µg	Cobalt µg	Arsenic µg	Cadmium µg	Led µg
bagda	154.38±3.82	31.15±0.72	259.93±7.12	320.39±9.52	0.72±0.05	0.91±0.14	1.96±0.22	46.37±2.33	1.05±0.12	11.96±0.96	0.72±0.12	0.16±0.03
chaka	117.60±4.23	32.86±1.56	281.48±11.16	315.50±11.74	0.53±0.03	4.12±0.11	13.55±1.62	161.86±7.83	1.93±0.11	1.61±0.26	2.99±0.66	1.15±0.13
chali	89.97±11.82	24.42±2.48	225.21±22.60	269.77±30.34	0.76±0.13	2.06±0.24	5.34±0.73	43.03±5.39	1.03±0.09	3.18±0.50	0.87±0.09	11.40±0.92
goda	47.58±2.99	23.64±1.74	197.22±9.51	168.52±13.13	0.57±0.04	2.48±0.28	15.18±2.66	140.73±19.16	1.16±0.17	13.42±2	65.76±9.02	48.23±4.30
golda	107.87±10.19	26.70±2.70	265.22±24.25	323.44±30.87	0.80±0.07	1.84±0.26	9.87±1.03	119.01±12.58	1.59±0.16	2.69±0.57	1.98±0.16	2.06±0.39
horina	190.37±18.72	47.46±5.25	354.83±34.82	404.22±41.29	0.82±0.05	2.51±0.33	3.21±0.42	93.50±7.88	1.89±0.16	7.42±1.13	3.07±0.31	0.55±0.08
Mudcrab	276.68±13.40	62.82±4.31	271.50±12.80	366.92±16.54	1.41±0.06	17.33±1.26	30.86±3.21	1994.92±277.43	5.25±0.41	1.55±0.21	3.98±0.45	8.65±0.48
rosna	92.17±0.89	22.12±1.53	128.41±3.91	119.15±3.69	1.28±0.17	1.18±0.14	1.93±0.21	129.74±17.32	0.98±0.18	7.75±1.21	4.10±0.56	9.85±1.37
tiger chingri	90.24±10.25	24.81±2.39	227.24±23.72	271.05±30.36	0.76±0.11	2.06±0.28	5.36±0.74	43.61±5.55	1.06±0.14	3.22±0.48	0.87±0.09	11.29±0.88

Appendix 46 (5.34) Supplementary (S) Table 34 Mangrove fish micronutrients content per 100 g raw weight

8	Sodium mg	Magnesium mg	Phosphorus mg	Potassium mg	Copper mg	Vanadium µg	Chromium µg	Manganese µg	Cobalt µg	Arsenic µg	Cadmium µg	Led µg
aamadi	52.52±4.86	30.76±3.15	635.44±64.05	226.5±21.42	0.18±0.02	10.46±0.31	7.82±1.14	345.91±38.3	3.42±0.4	5.88±0.64	2.26±0.35	6.13±0.91
ayza	38.52±3.64	19.54±1.8	444.61±38.62	245.33±28.93	0.21±0.02	7.87±0.69	3.57±0.42	121.49±9.5	1.24±0.14	6.86±0.89	1.2±0.17	2.63±0.4
bele	57.84±5.26	22.94±3.59	197.3±33.13	421.52±67.71	0.06±0.01	0.59±0.08	57±7.13	24.21±3.32	0.79±0.1	0.32±0.06	0.89±0.1	0.46±0.07
bhangan	55.35±4.52	26.12±2.44	270.96±26.85	544.93±42.82	0.27±0.02	2.38±0.41	75.91±7.43	35.12±5.47	1.3±0.09	2.44±0.37	0.7±0.13	3.83±0.6
bhola	34.41±2.81	15.2±1.31	321±46.96	124.94±18.85	0.04±0	2.71±0.46	4.27±0.4	109.41±15.05	0.64±0.05	4.98±0.7	2.14±0.36	4.33±0.33
caine magur	41.2±1.4	19.01±0.91	183±8.41	297.05±16.49	0.06±0	0.97±0.11	1.88±0.16	39.42±2.64	1.88±0.14	4.85±0.64	1.3±0.09	5±0.67
cucia	51.09±7.81	29.14±2.97	636.01±77.9	210.9±4.38	0.14±0.01	35.85±2.63	6.13±1.08	615.95±40.88	1.58±0.24	9.4±0.38	1.02±0.12	9.31±0.99
datina	79.13±5.85	21.45±1.63	234.01±9.59	347.63±31.4	0.17±0.01	1.19±0.08	7.18±0.46	43.97±4.03	1.5±0.18	0.72±0.09	0.91±0.1	0.53±0.08
ekthutu	60.47±1.11	43.5±0.73	906.13±21.02	322.86±6.19	0.08±0	1.85±0.13	5.29±0.16	420.03±11.25	1.43±0.07	7.68±1.08	2.05±0.25	6.82±1.08
fesa	37.99±3.34	23.65±3.24	324.27±25.82	326.21±49.3	0.09±0.01	1.71±0.12	92.69±14.06	138.26±17.84	0.81±0.09	2.82±0.4	0.64±0.07	4.95±0.53
gaberdana	37.79±3.84	25.26±2.32	397.12±29.25	89.56±10.46	0.14±0.02	2.83±0.35	28.2±1.42	250.8±18.94	3.15±0.36	8.55±1.42	2.09±0.23	0.74±0.08
illish	26.73±2.28	14.4±1.25	223.37±30.42	268.71±26.97	0.07±0.01	18.19±2.06	2.39±0.21	141.4±17.06	1.31±0.22	21.54±3.25	1.83±0.31	4.79±0.68
kaksel	51.5±3.73	18.11±1.53	169.28±14.46	129.31±1.89	0.27±0.03	0.45±0.04	15.71±1.91	114.7±15.91	1.33±0.15	4.56±0.28	3.68±0.3	15.52±2.42

Appendix 47 (5.34) Supplementary (S) Table 34 Mangrove fish micronutrients content per 100 g raw weight (cont'd)

	Sodium mg	Magnesium mg	Phosphorus mg	Potassium mg	Copper mg	Vanadium µg	Chromium µg	Manganese µg	Cobalt µg	Arsenic µg	Cadmium µg	Led µg
kalo gullo	51.55±1.32	24.87±0.5	492.17±22.79	314.87±5.8	0.19±0.01	72.64±3.87	6.91±0.38	581.35±15.94	7.61±0.23	5.68±0.8	2.43±0.28	11.96±1.1
katkoi	18.94±0.8	3.17±0.34	48.73±4.2l	53.4±4.26	0.02±0	0.15±0.02	1.44±0.14	13.76±1.39	0.16±0.03	0.65±0.13	0.18±0.02	0.94±0.14
khoira	68.32±2.83	33.33±2.33	583.91±33.85	290.44±24.84	0.13±0.01	12.08±0.74	9.29±0.48	214.22±10.27	2.67±0.28	5.4±0.73	2.63±0.29	5.21±0.71
khorshula	45.57±5.18	24.55±1.86	473.46±18.59	342.76±46.17	0.16±0.02	14.75±0.92	7.03±1.01	332.09±27.03	1.31±0.16	0.72±0.03	0.79±0.1	7.84±0.69
lalgullo	35.27±2.08	21.91±1.46	438.59±28.36	163.79±13.78	0.08±0.01	27.16±1.66	10.04±0.64	1669.89±102.92	4.15±0.48	5.14±0.38	0.94±0.05	7.83±0.79
nona tengra	32.83±0.65	22.59±0.47	441.25±11.86	201.01±4.52	0.1±0	19.52±0.7	125.71±9.87	236.09±2.88	2.5±0.08	2.35±0.27	1.5±0.24	7.53±1.17
parsey	132.01±6.9	29.93±1.99	294.71±18.31	472.07±22.76	0.13±0	3.86±0.49	41.67±4.13	51.33±6.37	1.83±0.15	2.53±0.37	0.89±0.07	1.5±0.24
payra	55.1±4.24	35.78±3.15	989.6±97.33a	189.11±16.57	0.1±0.01	15.82±1.84	12.27±1.93	655.3±77.54	2.92±0.19	3.19±0.42	2.33±0.28	11.76±1.35
shilong	70.24±10.56	18.61±2.13	158.81±18.56	228.24±16.1	0.17±0.02	0.7±0.06	12.41±1.81	92.35±6.47	1.32±0.12	8.04±0.38	7.65±0.43	4.34±0.57
taposhi	23.22±1.29	11.47±0.66	137.65±5.59	185.97±11.8	0.08±0.01	1.46±0.08	4.84±0.75	49.89±0.71	0.52±0.04	35.89±2.95	0.71±0.11	1.31±0.21
vetki	40.42±0.7	20.37±1.95	277.38±16.83	314.54±12.36	0.08±0.01	4.08±0.62	9.2±0.62	242.83±24.84	1.44±0.21	6.46±0.87	3.32±0.31	14.06±3.06

Appendix 47 (5.35) Supplementary (S) Table 35 Freshwater fish micronutrients content per 100 g raw weight

Species	Sodium mg	Magnesium mg	Phosphorus mg	Potassium mg	Copper mg	Vanadium µg	Chromium µg	Manganese µg	Cobalt µg	Arsenic µg	Cadmium µg	Led µg
bheda	46.13±3.76	22.63±1.19	287.9±10.97	303.65±14.64	0.14±0.01	0.16±0.02	3.07±0.44	116.5±13.62	1.2±0.17	5.2±0.19	0.58±0.06	0.41±0.04
catla	52.47±5.41	21.64±3.08	213.47±26.5	359.13±54.3	0.14±0.02	1.73±0.19	3.86±0.64	29.86±4.45	1.66±0.27	4.41±0.57	0.46±0.02	2.54±0.29
chanda	44.96±3.65	38.35±3.49	969.62±102.7	233.14±21.4	0.09±0.01	31.55±2.09	30.92±3.69	693.71±49.47	5.81±0.53	16.16±2.62	2.85±0.44	14.73±1.75
cheng	25.89±1.31	18.96±2.03	185.9±5.26	206.04±20.58	0.14±0.02	1.19±0.16	61.51±6.61	119.89±15.37	0.9±0.08	9.79±0.65	0.74±0.11	2.16±0.1
choto bele	45.42±3.26	26.04±2.03	486.78±37.23	227.42±21.87	0.08±0.01	2.52±0.35	4.31±0.14	392.61±40.92	1.13±0.13	1.98±0.26	4.37±0.34	20.05±2.1
Common carp	74.68±7.88	16.41±1.46	179.85±13.53	257.96±24.12	0.06±0.01	4.63±0.34	4.76±0.48	67.03±7.06	1.2±0.19	3.82±0.71	0.63±0.08	0.41±0.06
Grass carp	46.29±1.45	18.74±0.73	188.84±6.56	284.26±12.81	0.08±0	0.57±0.06	2.73±0.19	32.16±2.06	6.95±1	4.04±0.47	0.63±0.06	0.61±0.08
koi	40.7±1.88	25.67±1.3	695.64±34.16	267.43±15.18	0.07±0	9.7±0.96	5.23±0.66	982.91±23.03	1.83±0.16	9.43±1.49	1.52±0.23	4.37±0.69
Mirror carp	106.24±4.84	26.7±1.15	316.77±5.71	477.36±24.93	0.09±0	4.15±0.22	3.69±0.32	42.52±1.49	1.57±0.08	5.76±0.74	0.63±0.09	2.67±0.23
mola	28.47±1.97	27.88±1.71	612.43±31.61	231.29±17.54	0.06±0.01	59.56±2.12	4.48±0.32	573.28±32.95	1.22±0.13	14.6±2.14	1.1±0.21	2.41±0.34
mrigal	60.54±9.27	20.26±2.43	219.34±26.68	352.25±35.63	0.09±0.01	3.2±0.51	4.07±0.56	38.3±4.96	0.99±0.12	2.81±0.47	0.41±0.05	0.76±0.08
Pangus	70.31±2.54	17.74±0.61	242.39±27.16	334.37±22.18	0.04±0	10.31±0.46	5.62±0.72	107.04±7.72	2.21±0.24	3.54±0.6	0.73±0.11	6.7±1.14
pora bele	41.27±3.15	20.24±2.9	341.64±17.38	265.29±24.52	0.15±0.01	8.94±1.1	2.91±0.49	138.24±6.31	3.48±0.12	5.6±0.89	1.92±0.25	7.67±0.86

Appendix 48 (5.35) Supplementary (S) Table 35 Freshwater fish micronutrients content per 100 g raw weight (cont'd)

Species	Sodium mg	Magnesium mg	Phosphorus mg	Potassium mg	Copper mg	Vanadium µg	Chromium µg	Manganese µg	Cobalt µg	Arsenic µg	Cadmium µg	Led µg
puti	55.82±4.59	36.86±2.56	840.78±48.15	279.04±12.83	0.12±0.01	21.2±1.42	6.68±0.67	285.75±39.91	2.15±0.34	8.85±1.3	0.52±0.04	2.41±0.28
rohu	30.98±3.33	23.74±1.99	228.53±21.49	379.41±26.67	0.1±0	0.79±0.06	5.1±0.2	52.67±2.67	2.1±0.16	4.4±0.7	0.45±0.06	2.41±0.38
shing	74.21±3.41	18.65±2.95	197.08±31	351.61±50.91	0.07±0.01	0.7±0.09	2.32±0.19	34.43±2.84	0.47±0.03	3.83±0.59	0.45±0.07	2.36±0.4
shoal	42.59±2.2	22.79±0.61	209.31±7.73	379.1±2.7	0.07±0.01	0.17±0.01	2.02±0.18	54.77±7.56	1.84±0.1	2.62±0.33	0.64±0.07	2.32±0.29
Silver carp	62.25±7.13	19.47±2.57	260.75±32.08	315.99±29.93	0.07±0.01	1.84±0.12	1.95±0.26	107.32±18.16	1.91±0.27	4.28±0.3	0.44±0.05	2.07±0.17
Snail	14.28±1.9	89.61±11.97	99.25±11.6	155.01±14.77	0.33±0.04	13.19±1.62	21.35±2.74	7669.04±936.9	45.65±5.92	58.01±5.59	1.4±0.27	6.38±0.77
taki	31.98±3.56	18.79±1.68	200±17.92	330.36±23.24	0.05±0.01	0.69±0.1	2.05±0.08	120.2±16.38	0.46±0.05	3.9±1.16	0.63±0.09	0.26±0.02
tengra	33.98±2.48	21.49±1.67	344.48±23.1	298.36±16.63	0.09±0.01	7.93±0.83	6.62±1.24d	81.42±6.27	3.33±0.22	5.04±0.7	0.71±0.13	3.72±0.6
Thai Sarputi	23.37±1.49	18.85±1.18	188.52±15.42	331.86±19.34	0.05±0	2.68±0.25	3.18±0.26	36.33±4.42	0.53±0.08	12.08±0.86	0.46±0.07	2.15±0.36
Tilapia	44.02±3.51	15.85±1.58	131.95±12.25	254.59±21.1	0.09±0	1.96±0.31	24.92±1.7	75.31±8.16	1.06±0.12	2.54±0.34	0.29±0.03	0.75±0.13
Tilapia (GIFT)	68.9±4.99	22.74±1.81	228.67±16.96	448.07±31.17	0.11±0.01	9.24±0.51	416.74±55.22	93.56±8.88	3.36±0.33	1.98±0.43	0.48±0.1	1.35±0.26

Appendix 48 (5.36) Supplementary (S) Table 36 By-products minerals content per 100 g raw weight

Species	Sodium mg	Magnesium mg	Phosphorus mg	Potassium mg	Copper mg	Vanadium µg	Chromium µg	Manganese µg	Cobalt µg	Arsenic µg	Cadmium µg	Led µg
bagda head	126.24±18.33	82.1±12.05	455.77±59.38	192.22±25.99	4.74±0.39	14.69±2.34	18.19±2.91	739.99±47.68	5.57±0.22	40.2±6.39	2.95±0.33	2.73±0.26
bagda shell	100.97±11.79	121.42±13.83	671.68±71.27	127.45±12.59	1.8±0.18	8.98±1.37	18.04±1.76	991.41±91.07	2.78±0.33	82.67±9.47	2.4±0.36	1.45±0.21
golda brain	66.36±4.98	5.37±0.45	112.31±7.98	140.27±10.87	1.95±0.17	1.9±0.21	631.97±55.23	182.34±21.35	1.45±0.13	5.48±0.68	170.65±13.59	0.61±0.1
golda claw	143.51±9.83	30.62±2.36	243.37±16.94	242.17±11.39	0.83±0.02	0.23±0.04	5.21±0.62	144.89±8.58	0.66±0.03	16.29±1	8.07±0.69	1.87±0.23
golda head	78.16±11.92	48.9±5.06	418.2±55.84	86.64±9.2	2.09±0.09	10.97±1.21	25.04±0.99	1315.39±142.9	4.24±0.56	11.94±1.1	11.23±1.01	1.78±0.23
golda shell	92.96±2.99	113.47±8.04	680.03±28.82	129.46±6.9	1.8±0.06	18.02±1.73	27.86±1.16	4466.36±150.41	6.54±0.62	33.55±2.75	5.16±0.36	4.22±0.3
horina shell	92.29±4.14	63.93±3.09	469.35±22.66	134.84±3.42	5.05±0.27	6.79±0.52	11.44±0.7	1693.7±64.23	4.28±0.2	21.83±2.21	2.56±0.37	9.78±0.78
illish egg	22.92±3.1	7.98±1.08	267.67±16.88	198.78±13.23	0.09±0.01	5.07±0.42e	4.09±0.53	156.35±12.18	1.74±0.13	36.01±5.06	1.34±0.22	0.63±0.03
tiger chingri shell	55.43±3.49	76.89±4.17	520.65±22.49	68.51±6.96	0.83±0.06	4.07±0.35	12.94±2.21	605.63±54.28	3±0.59	43.22±12.71	1.14±0.81	4.77±1.79

Appendix 49 (5.37) Supplementary Table 5.9 Results showing a variation of the mean±SD total n-3 PUFA content of mangrove fish in the aquatic food production area, S-W Bangladesh

Species (local name)	Mean	±SD	Significant
amadi	229.95	4.9	c-e
ayza	142	13.4	de
bhangan	509.5	37.02	ab
bhola	82.2	7.7	e
caine magur	487.08	29.34	a-c
cucia	91.73	11.2	e
datina	454.4	86.8	a-c
fesa	377.7	50.45	b-d
gaberdana	226.7	24.1	c-e
kakshel	139.84	25.16	de
kalogullo	108.66	15.9	e
katkoi	647.4	204.6	a
khoira	147.25	14.3	de
khorshula	403.9	161.9	bc
lalgullo	27.06	2.2	e
nona tengra	355.6	66.04	b-d
parsey	598	139.6	a
payra	493.4	137.4	ab
shilong	190.3	12.7	de
taposhi	153.5	17.08	de
therol	390.14	41.97	b-d
vetki	496.4	69.06	ab

The significance code different letter indicates significantly different ($P<0.05$)

Appendix 50 (5.38) Results are showing variations of the mean±SD total n-3 content of freshwater fish in the aquatic food production system, S-W Bangladesh

Species (local name)	Mean	±SD	Significant
bele	86.16	21.4	f
bheda	219.05	13.4	c-f
catla	94.47	18.1	ef
chanda	386.89	33.9	a-c
cheng	107.58	11.4	ef
choto bele	57.98	3.4	f
Common carp	68.84	30.9	f
GIFT Tilapia	244.55	154.3	b-e
Grass carp	129.75	55.2	ef
koi	392.16	359.1	ab
Mirror carp	69.11	31.7	f
mola	520.58	64.9	a
mrigal	117.94	48.6	ef
pangus	144.39	25.9	d-f
porabele	70.2	2.3	f
puti	180.92	26.5	d-f
rekha	263.59	22.05	b-e
rohu	286.19	104.5	b-d
shing	84.22	84.2	f
shoal	61.52	9.5	f
Silver carp	101.36	30.4	ef
taki	93.99	22.16	ef
tengra	217.99	129.6	c-f
Thaiputi	196	32.04	d-f
Tilapia	229.82	70.6	c-e

The significance code different letter indicates significantly different ($P<0.05$)