Impacts and responses to environmental change in coastal livelihoods of south-west Bangladesh

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Abstract

Aquatic ecosystems are of global importance for maintaining high levels of biodiversity and ecosystem services, and for the number of livelihoods dependent on them. In Bangladesh, coastal and delta communities rely on these systems for a livelihood, and the sustainability of the productivity is seriously threatened by both climate change and unsustainable management. These multiple drivers of change shape the livelihood dependence and adaptation responses, where a better understanding is needed to achieve sustainable management in these systems, while maintaining and improving dependent livelihoods. This need has been addressed in this study in the region of Satkhira, in the southwest coast of Bangladesh, where livelihoods are highly dependent on aquatic systems for food supply and income. Traditional wild fish harvest in the rivers and aquaculture systems, including *ghers*, ponds, and crab points have been changing in terms of the uses and intensity of management, and suffering from climate change impacts as well. By means of six focus groups with 50 participants total, and validated by expert consultations, we conduct an analysis to understand the main perceived impacts from climate and human activities; and the adaptation responses from the aquatic system livelihoods. We find that biodiversity has decreased drastically, while farmed species have increased and shrimp *gher* farming turned more intensive becoming the main source of income. All these changes have important implications for food supply in the region and environmental sustainability. Dramatic responses taken in the communities include exit the fisheries and migration, and more adaptive responses include species diversification, crab fattening and working more on the pond and *gher* infrastructure. This study evidences the results of the combination of multiple stressors in productive systems and the barriers to adaptation in aquatic ecosystem dependent communities.

Keywords: adaptation, focus group discussions, gender inequality, Bangladesh, coastal ecosystems, aquaculture.

Introduction

South Asian (SA) countries in the Arabian Sea, Bay of Bengal and East of Indian Ocean share similarities in its fisheries environment, socio-economic characteristics and problems (Stobutzki et al., 2006). These countries fall in the region of heavy rainfalls in the monsoon belt. As a result, they are endowed with many rivers, frequent floods and river bank erosion in delta regions. These factors contribute to ecosystems of high biodiversity and natural capital richness (ecosystem services) such as mangroves, wetlands and coral reefs (Tittensor et al., 2010), and also contribute to the vulnerability of people living in these areas (Allison et al., 2009; Barange et al., 2014).

Bangladesh is a salient example of vulnerable livelihoods dependent on aquatic systems, that are impacted by climate change and where fishing and aquaculture have evolved rapidly in the last decades with important consequences for sustainability (Faruque et al., 2017). The countryis on the top ten national economies most vulnerable to the impacts of climate change on fisheries and aquaculture (Allison et al., 2009). Despite being ranked first among countries vulnerable to climate change (Ahmed et al., 2009), research and development programs might have contributed to reduce its vulnerability rating to the current sixth position (Kreft et al., 2016).

In Bangladesh, aquatic ecosystems supply fish and other aquatic resources to 160 million Delta inhabitants. The country is ranked fourth for inland fisheries production in Asia, behind China, Myanmar and India (FAO, 2016). Many aspects of the Bangladeshi culture, economy and tradition are rooted on fishing and fish culture activities. Fish is a natural complement to rice in the national diet, giving rise to the adage "*Machhe Bhate Bangali*", literally meaning – 'fish and rice make a Bangladeshi'. Fish contributes about 60% of the total animal protein intake in the diet of the people from Bangladesh (DoF, 2013), while the integrated coastal and freshwater systems contribute to household food security, nutrition and income (Faruque et al., 2017). The fisheries sector provides full-time employment to an estimated 1.2 million fishers and an estimated 10 million households, where as much as 64% are partly dependent on fishing (e.g. part time fishing for family subsistence in flooded areas) (DoF, 2015). Among the employments associated with the fish sector in the country, only 10% are occupied by women (Islam et al., 2016). However, when considering fish processing plants and fish drying centres in the coast, women occupy 80% of the jobs (Hossain et al., 2013a).

The rich aquatic biodiversity of Bangladesh has been attributed to one of the world's largest wetlands (Bengal Delta) and the aforementioned three large river systems (Bart, 2002). Fisheries are important in the deltaic regions, and contribute nearly to 3.65% to the Gross Domestic Product (GDP), to 23.81% of gross agriculture products and 1.97% to the total export earnings (DoF, 2017). Coastal Bangladesh (47,211 km^2) covers 32% of the country and extends over nineteen districts out of a total sixty-four (Shamsuddoha and Chowdhury, 2007).

Bangladesh is at high risk from climate change and the country economy will face the biggest risk from global warming in the next 30 years (Caesar et al., 2015; Kay et al., 2015; Whitehead et al., 2015). The country is susceptible to a range of climate change impacts, from extreme events like cyclones (GoB, 2008) to slow onset processes like sea level rise (Hossain et al., 2012). In addition to Cyclone Aila in 2009, the southeast coast was hit by other high impact cyclones, including cyclone Bijli in the same year, cyclone Rashmi in 2008, and cyclone Sidr, a category 4 cyclone in also in 2008 causing extensive damage to life and property. Since 1970, the country has experienced thirty-six cyclonic storms resulting on over 450,000 deaths and immeasurable economic losses (UNDP, 2010). Events and processes like cyclone, flooding, riverbank erosion, and salinity intrusion in the coast of the country may intensify and become more recurrent and spatially expanded in the 19 districts situated in the coastal zone of Bangladesh (IUCN, 2012). Sea level rise would exacerbate these effects along the coastal margin by altering erosion rates, causing saline waters to intrude further inland, shrinking protective barriers and increasing flooding by cyclone and storm surges (Ericksen et al., 1993).

In addition to climate change, directly human induced impacts come from aquaculture in the coastal waters. Fish biodiversity and catches are adversely impacted by faulty post-larval shrimp (PL) collection, together with water pollution from the industry and agriculture that are causing high fish seed mortality. There is a huge by-catch[1] associated with intensive fishing for PL shrimp to supply shrimp farms in coastal Bangladesh, with hundreds of non-target fish and shellfish removed in this activity (Bhattacharya et al., 1999; Hoq et al., 2001; Toufique, 2002). PL shrimp bycatch could be contributing to the decline in finfish populations and diversity noted by Gain et al. (2005). Additionally, the indiscriminate use of insecticides and pesticides in the crop fields by the farmers are one of the major causes to turn many wild fishes once abundant in the rivers and floodplains to be now threatened (Mazid, 2002). In addition, a range of chemicals were found to be used in the shrimp aquaculture[2] (Shamsuzzaman and Biswas, 2012; Ali et al., 2016), causing an alarming decrease in population of local fish and shellfish species (Ali et al., 2014; Hossain and Hasan, 2017).

[1]The by-catch consists of seeds of many different cyprinids, eels, anchovies, Bombay duck, marine and coastal catfish, gobies, eel gobies, crabs, snails, mussels, bivalves and many other species.
[2]Including potassium permanganate, sumithion, melathion, formalin, bleaching powder, malachite green and a number of different antibiotics

In this study, we explore the recent trends in aquatic ecosystems of the coast of Bangladesh by looking at its aquatic diversity, aquaculture practices and productivity, and a number of associated livelihood changes. For this we use focus group discussions and household surveys in the district of Shyamnagar Upazila in Satkhira, southwest coast of Bangladesh. This case study is selected due to the importance of the natural ecosystems of the Satkhira coast in Sundarbans and the risk of climate change impacts and high livelihood dependence on water resources in the area.

The investigation covers the period of 2002-2012 and includes qualitative and quantitative data from primary and secondary sources. The study provides new evidence on the changes and responses in aquatic ecosystems-dependent livelihoods in Bangladesh.

2. Methodology

To study the coastal livelihoods and their dependence on aquatic systems, climate change and management practices in Bangladesh we follow a series of methodological steps depicted in Fig. 1. First is the selection of the case study area based on preliminary consultations, expert evaluation and literature review. Second is the presentation of the characteristics of the study area (section 2.1) and the identification of the main issues for aquatic systems dependent livelihoods. This step involves an in depth literature review and interactions with stakeholders in order to understand the main concerns in the area from an exploratory perspective. Different methodologies including interviews, focus groups and questionnaires were planned following previous studies in the literature and good practices in qualitative social research (Reed, 2008; Young et al., 2018). Based on this evidence, third is the design of a questionnaire to collect information on the main issues identified in the region (appendix 1). Fourth is the data collection through implementation of the series of focus group discussions, field observation and interviewing key informants in the study area in order to address the objectives of the study (section 2.2). Finally, data analysis allows us to understand perceptions, impacts and responses and a report is shared among stakeholders within the DECCMA project (Hill et al., this issue).

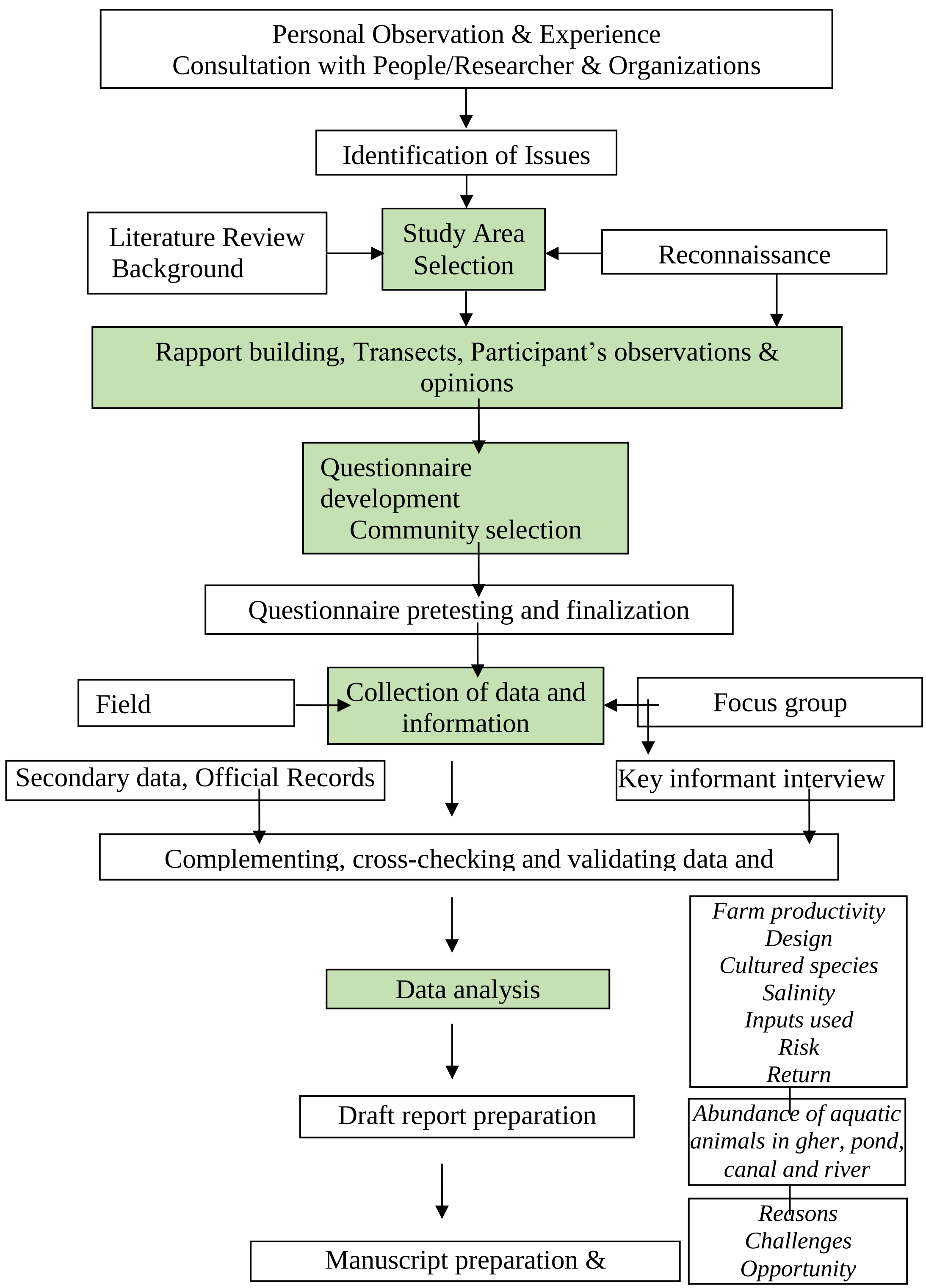

Fig. 1. Methodology of the study leading to this publication. Green boxes represent the main methodological steps in the process and white boxes represent the specific tasks and processes. .

2.1 Study Area

Through the past experience of the authors and consultation with researchers, a reconnaissance survey was made to select the study area, study participants, and the key informants and to build rapport with the study participants (Fig. 1). The selected study area is the Union Atulia of Shyamnagar upazila (sub-district) in the Satkhira district (Fig. 2) in south-west Bangladesh. This area has been selected due to its natural ecosystems with high conservation value and the risks and vulnerability of inhabitants to climate change and water resources (Ullah and Rahman, 2014). The area was extensively damaged and devastated by cyclones - Sidr and Aila during 2008-09 (UN, 2010). Coastal Bangladesh is particular for its highly irregular deltaic coastline (710 km long), fissured by many rivers and streams flowing into the Bay of Bengal. Formed by a deltaic plain, Bangladesh is virtually the only drainage outlet for a vast complex river basin made up of the Ganges (local name the Padma), the Brahmaputra and, and the Meghna rivers. The study area is located in the floodplains, which in total cover 80% of the country area. The region can be considered a coastal wetland, composed by freshwater marshes, swamps, coastal rivers, estuaries and includes part of the Sundarbans, the world’s largest contiguous mangrove forest (Rashid, 2000).

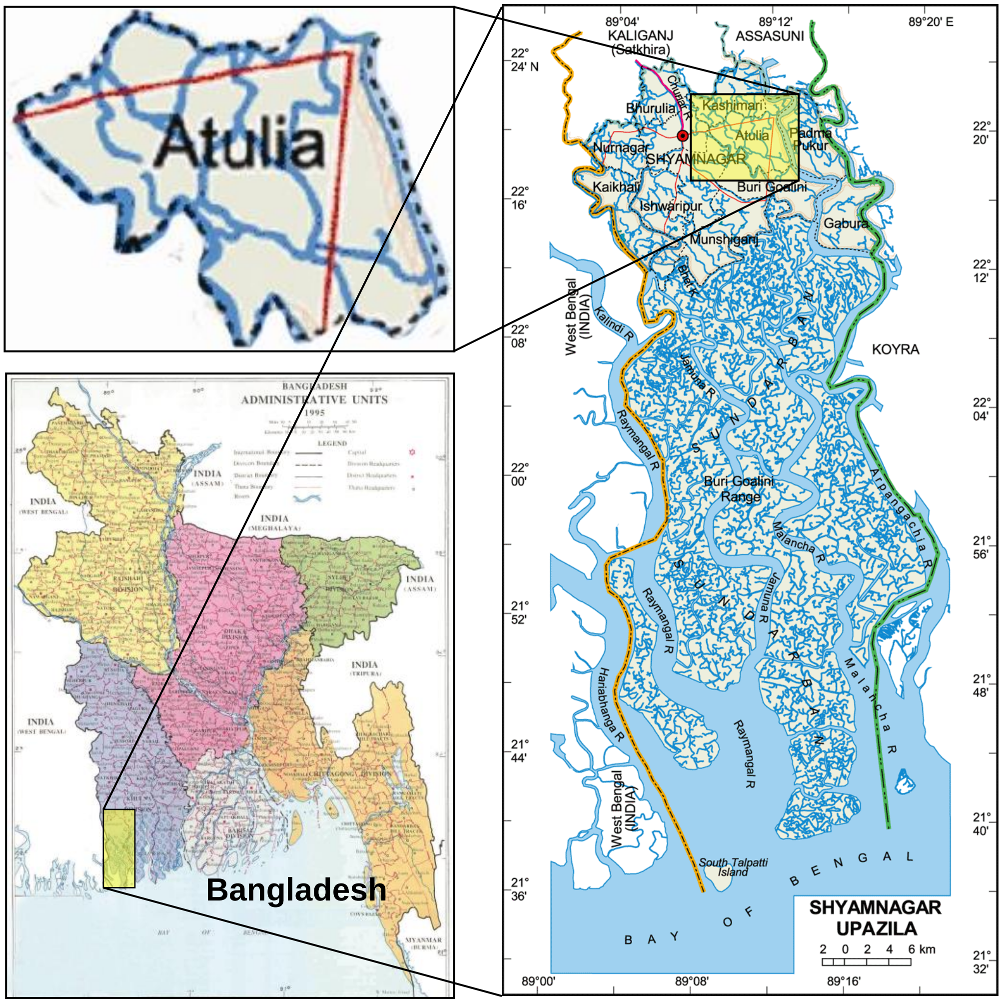

Fig. 2. Map of the study area – Union Atulia under Upazila (Sub-district) Shyamnagar, Satkhira, Bangladesh (curtsey- www.banglapedia.org).

Bangladesh waterbodies are known to be the habitat of 293 freshwater fishes, 475 marine fishes, 24 exotic fishes (Hossain, 2010; IUCN Bangladesh. 2015; Hossain et al., 2015) and a number of other vertebrates and invertebrates (Fig. 3). The natural ecosystems of the Satkhira coast in Sundarbans have been greatly destroyed in the last years, causing extinction of 21 species of reptiles and 23 species of fish (Khan, 2014).

Satkhira district is the easternmost coastal district in Bangladesh (Fig. 2). The coast of Bangladesh is different from the remaining parts of the country not only because of its unique geo-physical characteristics but also for the different socio-political consequences that often limit people access to endowed resources and perpetuate risk and vulnerabilities. Livelihood conditions of the costal people depend on what resources are available at the household level in terms of ownership and access (Maroof and Jahan, 2010). Direct observations and discussion with the villagers revealed that, in terms of exploited ecosystems, the major aquatic ecosystems available in the four villages of the case study are – small to medium sized *gher* (shrimp/prawn farming pond), small homestead freshwater ponds (water used for drinking, bathing, washing and cleaning and for freshwater fish farming), crab points (man-made saline small ponds – used for crab fattening), the river Kholpetua, the Sundarbans along with natural canals and manmade canals (inlet channel from river to *gher*), and inundated rice fields.

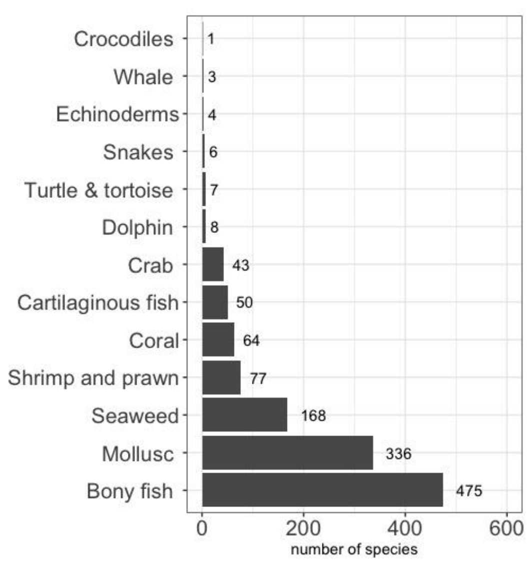

Fig. 3. Marine fauna and flora diversity of Bangladesh (total=1,242). Source: After Hossain, 2010; IUCN Bangladesh. 2015; Hossain et al., 2015.

2.2 Focus Groups Discussions (FGD)

In order to study the perceived trends on impacts, biodiversity, productivity and livelihood activities over time a series of focus group discussions were organized in the region. The main objective of the FGDs is to identify: 1) the perceptions on the changes in biodiversity in the aquatic production systems in the coast; 2) their productivity and livelihood dependence; 3) the main perceived impacts from climate and human activities; and, 4) the adaptation responses from the aquatic system livelihoods. For this, data on specific quantifiable factors were collected from the participants including productivity, average size of the system, species composition (number of species and abundance under each species), input cost (seed, feed, fertilizer and other chemical), profitability, salinity, erosion, input used, risk and return). The FGDs were complemented with interviews with four key informants (a high school teacher, a female NGO worker, an upazila fisheries officer and a UP member – all four living and working in the area for more than 10 years with thorough knowledge on the community and livelihood patterns) and direct observations from local authors in four villages – Boro Kupot, Chhoto Kupot, Atulia and Boyarshing, within the Union Atulia of Shyamnagar upazila (sub-district)in the Satkhira district (Fig. 2). The draft questionnaire was pre-tested through interviews with the key informants (stakeholder representatives sin the areas) and fishers. The modifications were carried out to overcome the gaps and ambiguities and the questionnaire was finalized. A detailed questionnaire on its final form is available in Appendix 1.

The final questionnaire was used to conduct a total of 6 Focus Group Discussions (FGD) with fishers, fish farmers and retired fishers who have thorough knowledge on the changes and trends of production systems, biodiversity and impacts. Each focus group was composed of 8-10 people including men and women as we wanted to have gender representation. Completely different groups of people took part in different FGD sessions. Each session lasted between 2-3 hours. During the FGD, the participants were asked to comment on the perceived changes in the production systems starting from 2002 up to 2012, which is the period that covers the cyclone major events in the area. Specific information was collected from the literature for four different aquatic farming systems: shrimp *ghers*, fish ponds, crab points and the river. The information was collected included productivity, aquatic farm design, species combinations, salinity, use of inputs, risks, return, household dependency and the trend in abundance of aquatic animals.

In the FGDs, participants were asked to make a list of all the aquatic animals and plants available in and around their villages and on the surrounding aquatic systems. The FGD participants also ranked the important fish and shellfish species based on their overall impact on their livelihood, and discussed the adaptation strategies. In addition to FGDs, primary data were also collected through field observations and interviewing the key informants. The key informants also assisted in cross-checking and validating the data and information collected in the FGDs. The data was also validated using official records from Department of Fisheries, FAO, IUCN and other secondary literatures. With all the collected information a qualitative analysis is conducted to understand the main impacts and their consequences for local livelihoods.

3. Results

The main perceptions and information from coastal livelihoods depending on aquatic systems obtained from the FGDs and interviews are presented in this section. First we show the stakeholders' perceptions on the aquatic systems in the study area (section 3.1), including: the perceived biodiversity levels; the livelihood dependence in terms of jobs, species and gears; and the productivity of the different systems. Then we analyse the major changes over time in the aquatic systems and livelihoods (section 3.2). Finally, we present the adaptation responses (section 3.3).

3.1 Perceptions on the aquatic systems

3.1.1 Biodiversity levels

Participants identified a number of species related to each of the four aquatic systems in the coast: shrimp *ghers*, ponds, crab points and rivers. Eighty-four organisms/groups were identified by the participants (Fig. 4), and a large number of species give support to the village livelihoods. Wild aquatic systems have greater levels of species diversity, specially fish, as stakeholders identified (Fig. 4). Wild species identified are amphibian, mollusc, mammals, plant, fish, crustaceans and reptile species, while only fish and crustacean species are farmed (Fig. 4). According to the perceptions of the participants, rivers hold the highest biodiversity followed by *ghers* (Fig. 4). In the farmed systems, ponds have the highest number of species and these are all fish. The complete list of species identified is available in Appendix 2.

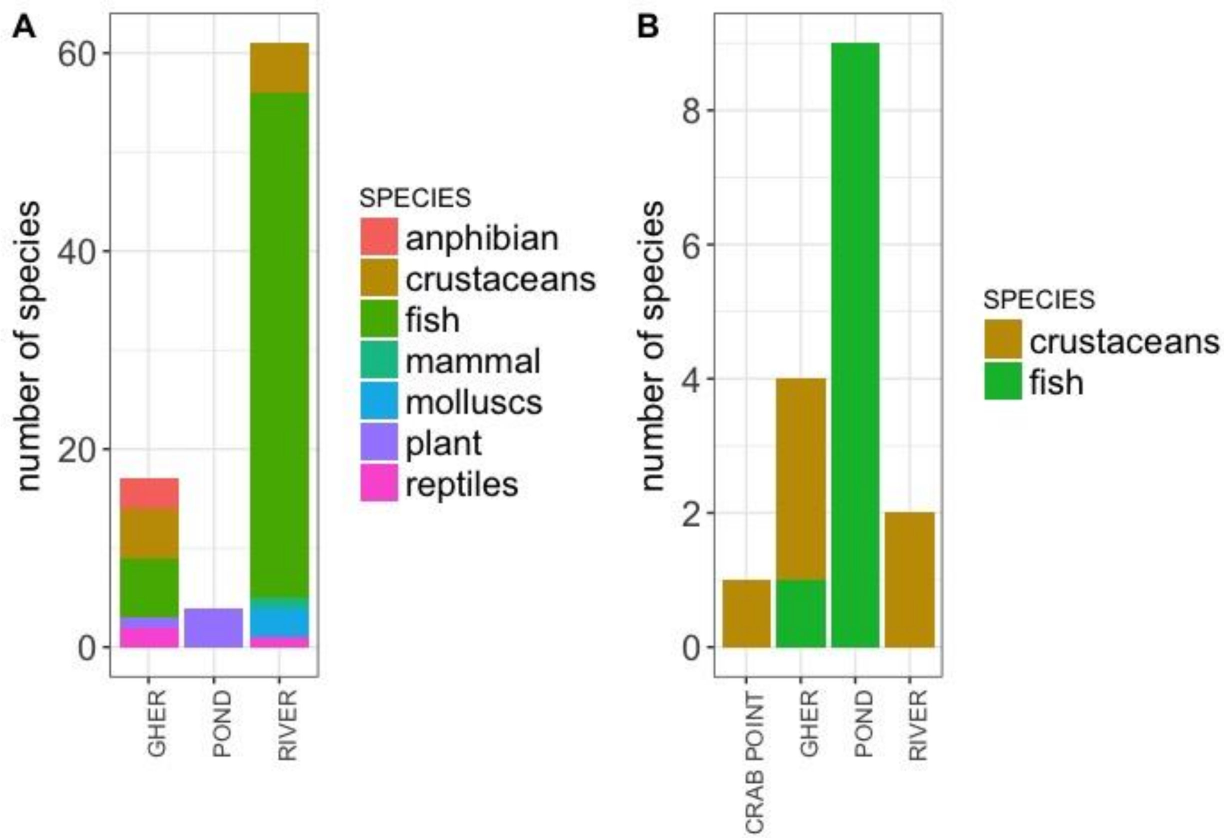

Fig. 4. Diversity of species in aquatic systems: A) wild species; and, B) farmed species. Note scales on y-axis differ.

3.1.2 Livelihood dependence

Table 1 summarizes the aquatic systems in the study area and the main livelihoods associated with them as resulting from the consultation.

Table 1

Aquatic systems dependent livelihoods in the study area.

Ecosystem	**Main resources**	**Directly dependent livelihoods**	**Indirectly dependent livelihoods**	**Other livelihoods**
Sundabarns:	Honey, wood, shrimp/prawn PL,	Collector, PL harvester, Seller	Pirate,	Rickshaw puller,

Mangrove forest and channels	*Golpata*, cooking fuel		credit provider, NGO worker, input supplier, coast guard, housewives	*Nasiman*, motor cycle rental, shopkeeper, wood collector, fish drying worker, boatmen, NGO worker, brick kiln worker, migrant worker, street vendors, doctor, teacher
River Kholpetua	Shrimp/prawn PL, fish, shrimp, prawn, mollusc	PL harvester, fisher, nurserer, supplier, boat fish trader		
Rice field	Agriculture	Farmer, farm labour		
Gher	Shrimp, fish	Soil labor, owner, *gher* farmer, middlemen, depot holder, Shrimp processor, net/trap maker		
Pond	Fish	Fish farmer, fish seed supplier, fisher, fish retailer, fish wholesaler, net maker, boat maker, fish trader		
Crab point	Crabs	Crab fattener, net/trap maker, crab depot owner, transporter, middlemen		

More than 60% interviewees are dependent (either part-time or full time) on the Sundarbans mangrove forest for their livelihoods, mainly through the collection of wood, and the harvest of crab, fish and shrimp. We classify the aquatic related livelihoods in two main categories that where identified: shrimp and crab farming, and wild fishing (Table 2). Farming livelihoods are mainly dedicated to g*her* farmer/labour (22%), Post-larvae (PL) collector (27%), crab fattener (19 %) and earth labour in *gher* (17 %). The wild fishing livelihoods are mainly composed of Fishers (27 %), Fish farmers (8%) and Fish retailers (6 %) (Table 2).

Table 2

Livelihoods of the respondents in the study area.

Farming		**Wild fishing**	
livelihoods	**% of respondents**	**Livelihoods**	**% of respondents**
Shrimp *gher* owner	11	Fish farmers	8

g*her* farmer/labour	22	Net makers	2
Post-larvae (PL)collector	27	Fishers	27
Post-larval nurserer	5	Trap makers	2
Post-larvae supplier	7	Fish seed supplier (*Patilwala*)	4
Earth labour in *gher*	17		6
Shrimp middlemen (*Foira*)	2	Fish retailers	
Depot holder	3.5	Fish wholesaler	2
Crab fattener	19	Boat makers	1.5

Note: percentages do not sum up to 100% since many individuals have various livelihoods.

Every person is often involved in two major livelihoods/professions, e.g., same person works for six months as PL collector and for the rest of the year works as an earth worker. Many of the fishers, if there is not enough fish in the river, work as PL collectors. Livelihoods not directly dependent on aquatic systems but that rely on other directly dependent livelihoods are - Pirate (they swoop down the fishers fishing in Sundarbans, snatch the catch, nets, and other valuables and kidnap fishers for ransom; no statistics but villagers believe that almost every village has pirates in disguise and are known only when they are caught), Credit (*Dadon*) provider (3 %), NGO worker (Trainer/Credit provider 5 %), Input supplier (to shrimp/fish farm/shop owners) (2 %) and Coast guard (only 1% from study villages, mostly outsiders). Non-aquatic system-based livelihoods include Housewives (32 %), Rickshaw puller (12 %), *Nasiman* (tri-wheeler) driver (9 %), Motor cyclist (rental – 3 %), Shopkeeper (3 %), Wood collector (18 %), Brick kiln worker (15 %), Agriculture farmer/labour (20 %), Migrant worker (outward - 15 %), Street vendor (4 %), Doctor (Quack – without any proper medical degrees or education also includes people who practice herbal and other alternative medicine like traditional healer or *kaviraj* – less than 1 %), School teacher (3 %), Cooking fuel collector/seller (straw, 7 %), *Golpata* (*Nypa fruticans*, used popularly as roof building materials) collector/seller (13 %) and honey collector (6 %).

The key aquatic species for livelihoods ranked by the focus group participants are listed in Table 3. The table shows the result of the ranking of each species according to the FGDs results, explaining the reason for ranking that species and the perceived trend in the period assessed. In the first FGD held in the Boidyopara, Boro Kupot, a mix group of four women and six men ranked 10 important fishes/shellfishes starting from 1 to 10 (most important to least ones). In the later five FGDs, people were asked to rank the same listed 10 species (the name of the fish revealed) without revealing the ranks made by other groups of FGD participants.

Table 3
Important fish and shellfish species, ranks and reasons of importance.

Rank mentioned in six FGDs						Mean rank	Name	Reason	Trend
1	1	1	1	1	1	1	Tilapia	Available, cheap, easy access	Increasing
2	2	3	4	2	3	2	Mud Crab	High price, cash crop	Increasing
3	3	2	3	4	2	3	Bagda Chingri	High price, cash crop	Decreasing
4	5	4	2	3	4	4	Harina Chingri	Available, medium price	Increasing
5	4	6	5	5	7	5	Bhetki	High price, cash crop	Stable
6	8	5	7	8	5	6	Parse	Available, eaten, sold	Stable
7	6	9	6	7	6	7	Paira	Less available, eaten, sold	Decreasing
8	7	10	8	6	9	8	Chaka Chingri	Medium price, cash crop	Decreasing
9	10	8	9	9	8	9	Baila	Less available, eaten, sold	Decreasing
10	9	7	10	10	10	10	Bhangon	Less available, eaten, sold	Decreasing

Tilapia is ranked first in all the FGDs. It is an exotic species introduced in 1954 in the (back then) East Pakistan from Thailand. The villagers said that more than 40% of the fish they consume was tilapia. The fish was cheap (Tk. 30-90/kg based on the size; the bigger the size, the higher the price) and affordable and could be grown even in their semi-saline and saline ponds and *ghers* where no other freshwater fish could be grown. The villagers also used small sized cheap tilapia as crab feed. Mud crab, bagda chingri and harina chingri rank 2nd, 3rd and 4th position, because these species were sold rather than consumed as subsistence stock because of their market value. Bhetki (5th), parse (6th), paira (7th) and chaka chingri (8^{h}) were used mainly as cash crop but sometimes villagers ate or offered these species to their guests. Baila (9th) and bhangon (10th) were also used for both purposes (market and food) depending on the size. The large sizes of these two species were for sale and smaller sizes for household consumption.

Respondents gave information about the main fishing gears they use. The main method of shrimp collection in the *gher* is *goi* method: harvesting shrimp in an outlet drain through dewatering the *gher*. Nearly 60% *gher* owners use the method and the remaining40% use the *atul* method: small bamboo trap placed in the *gher*. People use many different types of nets to catch fish and crab in the four studied villages. The major gears used by the villagers are *khepla jal* (cast net), *ber jal* (seine net), *current jal* (gill net), *net jal* (mosquito net), *moi jal* (pull net), *tinkona jal* (triangular push net), *bakso jal* (box net trap), *borsi* (hook and line), *borsa/fala* (wounding gear) and by hand. Though banned by the government, shrimp post-larvae collection using both pull net and push net and destruction of hundreds of non-target eggs, spawns and fry of fish, shellfish and molluscs has been going on. Fishing with destructive methods like poisoning or the use of explosives, although reduced, is still in practice inside the Sundarbans. More than 10% of the participants confessed that they used poison or explosive to catch fish several times inside the Sundarbans in the last six months. Nearly 60% of women in four study villages were found to be skilled at throwing cast nets and pushing and pulling other nets alone or in a group with other men and women.

3.1.3 Productivity of the aquatic systems

Participants identified the key productivity factors in each of the aquatic systems studied in the area, together with the main impacts and responses. Table 4 summarizes these results and what follows is a detailed description of the productivity changes per aquatic system.

Table 4

Results on the aquatic systems productivity changes.

System	Productivity factors	Perceived Impacts		Livelihood responses
		From Cyclone	**From Management**	
Shrimp *gher*	Size (+) Species richness (+) Input costs (+) Profitability (+)	Silt increase Depth decrease Unavailability of prawn	Intensification Decrease in *gher* size Shrimp disease Increase in input costs	Species diversification
Fish pond	Water depth (-) Species composition (-) Input costs (-) Profitability (-)	Wild fish destruction Water depth decrease Salinity increase	Tilapia increase Stocked culture fish decrease	Stock valuable fish in pond Re-excavate ponds Change pond water more frequently
Crab point	Size (+) Input costs (-) Profitability (+)	Crab point destruction Decrease natural catch	Intensification Feeding small sized tilapia to crab	New comers to crab fattening Increase crab consumption
River	Depth (-) Species composition (-) Salinity (+ -) River erosion (+)	Silt increase Salinity increase	Decrease in fish diversification Decrease in catch per unit effort	Fishers changed their livelihood strategies to agriculture/shrimp farm labour, migrant brick klin worker or rickshaw puller

Shrimp gher

FGD participants enlisted the following key factors for the *gher* productivity (measured as shrimp kg/unit area): 1) size of the *gher*, 2) species composition (number of species and abundance under each species), 3) input cost (seed, feed, fertilizer and other chemicals) and 4) profitability (see

Table 3). The major changes in the shrimp *gher* as identified by the participants were –a) *gher* became heavily silted after Aila cyclone in 2009, the water depth in *gher* decreased substantially (due to high expense, the poor and marginal *gher* owner could not remove the silt); b) unlike in the pre-Aila period, there were hardly any prawn found in the *gher*; c) *gher* size decreased (division of parental property among inheritors seemed the major cause); and d) frequency of shrimp disease increased substantially due to intensifying culture method (very high stocking density) coupled with poor management.

The productivity of *gher* decreased greatly following the Aila, but since then it has been gradually increasing with an upward trend due to the intensification of the farming system. Species composition was more or less similar over the years with a recent increasing trend, as many *gher* owners started stocking the so called *sada machh* (white fish), like carps, bhetki (giant perch) or bata (flathead mullet) in their *gher* to compensate the ever-decreasing profit from shrimp sale. The input cost has been gradually increasing and the increased productivity cannot compensate the increasing cost; particularly farmers were concerned with the fast growing price of good quality shrimp post larvae (PL) feed and other inputs. Many farmers wanted to stock good quality PL and to provide feed in the shrimp *gher*, but could not do so, because of the lack of cash capital. Although *gher* productivity was showing an increasing trend, profitability was decreasing gradually due to high production cost involved in shrimp farming. The low profitability was also a result of frequent outbreak of diseases and, in many cases, farmers lost all the shrimp in the *gher* within a very short period of time of the disease outbreak.

Fish pond

The key factors for the pond systems enlisted were productivity (kg/unit area), water depth, species composition (number of species and abundance under each species), input cost (seed, feed, fertilizer etc.), pond water salinity and profitability. The major changes in the freshwater fish ponds were – a) Aila destroyed all the valuable freshwater wild fish species people used to catch for their household consumption and to distribute among the neighbours[3]; b) tilapia increase: very few during pre-Aila period, and a considerable increase in the culture ponds afterwards; and c) stocked culture fish (Indian major carps, Chinese carps, silver barbs) not growing well.

The productivity of the pond system went down heavily after Aila, recovering with a slightly rising trend but still much lower than pre-Aila productivity. The water depth in the pond has been gradually decreasing over time. Many villagers re-excavated their ponds, mainly to remove the saline bottom mud. Villagers were very unsure if all the tasty freshwater fishes would live again in the ponds. As in a shrimp *gher*, the input cost in the fish pond was also increasing because of high cost of fry/fingerling and fish feed. Pond salinity reached a peak during Aila and killed almost all freshwater animals and plants. Since then, the salinity has been slowly decreasing and villagers have been trying hard to reduce soil and water salinity by removing bottom mud and frequently replacing the water. It will take many more years to normalize the situation and go back to pre-Aila salinity levels. Pond culture was not profitable as the growth rate of cultured fish was very slow, even after fertilizer use and fish feed. Often it was not worth to stock valuable culture fish in the pond.

Crab point

[3]Like – tengra – *Mystus* sp., magur – *Clarias batrachus*, shing – *Heteropneustes fossilis*, boal – *Wallago attu*, taki – *Channa punctatus*, shol – *Channa striatus*, puti – *Puntius* sp., mola – *Amblypharyngodon mola*, darkina – *Esomus danricus* etc.

The key factors selected for the crab points[4] included productivity (kg/unit area), average size of the crab point, species composition, input cost (seed, feed) and profitability (Table 3). The major changes in the crab culture system were – a) Aila destroyed substantial number of crab points; b) natural catch of crab decreased substantially; and c) over the last 2-3 years (post Aila), hundreds of people became involved in crab fattening; d) crab consumption by villagers of all religions and castes was showing an increasing trend.

There was not much crab fattening activities 10 years ago, as this activity started in the pre-Aila period during years 2007 and 2008. Aila destroyed many crab culture points, but the number of crab farmers has multiplied afterwards. Therefore, almost all the factors (productivity, profitability, size of crab point) were found to have an increasing trend. Despite a number of crab species are available in the coast, people are only involved with fattening giant mud crab, *Scylla serrata*, mainly because of its high demand and price in the overseas markets of China, Hong Kong and Thailand (Ferdoushi and Xiang-guo, 2010). The crab exports has grown many folds over the last 3-4 years, and as the industry heavily depends on wild catch, both natural production and diversity of crabs in the Sundarban mangrove forest have decreased alarmingly.

River

The key factors for the coastal river fishery included productivity (catch), river depth, species composition (diversity and abundance), salinity and river erosion (Table 3). The major changes in the coastal river were: a) the diversity of the coastal fish drastically decreased and once highly

[4]Crab pond is known as crab point locally.

abundant fish and shellfishes (prawn, shrimp and crab) were not available in the river, mainly due to anthropogenic activities like overfishing, destructive fishing, faulty harvesting of shrimp/prawn post larvae, pollution, water withdrawal at the upstream, etc. ; b) catch per unit effort in the river greatly decreased; and c) river became silted resulting on a very low water depth.

Silted riverbed, river erosion and the resulting ever-decreasing water depth impacted coastal fish and crustacean diversity, affecting catches, and was of big concern for the locals. Both fulltime and part-time fishers along with all other participants complained about the diminishing catches in the river Kholpetua. River salinity increased during Aila but since then it has been gradually decreasing. The productivity and species composition of the river Kholpetua in the study villages decreased gradually over the years mainly due to destructive practices and overfishing. Many important, popular and common fish and shrimp species once abundantly available in the river throughout the year became rare or disappeared altogether. Even five years ago, it was very easy for a fisherman to catch 2-3 kg fish with a simple gear like *khepla jal*, *thela jal*, *tinkona jal* in an hour. Because of the very low fish abundance in the river, nowadays, a fisher could catch even less than 1kg of fish in 6-8hours. Fishers were having problems to maintain their families and many were switching to other livelihood strategies like agriculture/shrimp farm labour, migrant brick klin worker or rickshaw puller, not without serious difficulties.

3.2 Major changes in aquatic systems and livelihoods

The participants in the FGDs identified the major events over the last 10 years that shaped their aquatic systems regarding system design, species composition, use of inputs, and trade off – fish as cash crop and family consumption. There are two main types of livelihood changes: those happening to the productivity of the aquatic systems, and those affecting the wellbeing of dependent livelihoods. Table 5 portrays the key changes affecting the productivity of aquatic systems. According to the participants, cyclone Aila killed almost all plants (cereal crops, vegetables, fruits and timbers), made the land and water salinized and reduced the fertility of soil and water. Even after a number of years after Aila, the villagers were having problems in growing any plants in the soil and farming freshwater fish in the ponds. Therefore, among others, the 2009 Aila cyclone was considered almost in every response by the villagers concerning the changes in systems, organisms and practices over the selected period.

Table 5
The major events over the last 10 years affecting aquatic systems productivity.

Factors	**2002**	**2007**	**2012**
Farm design and practice	• Large *ghers* • Proper water depth in *gher*s and ponds	• Large *ghers* • Water depth decreased in *ghers* and ponds due to siltation	• Smaller and divided *gher* • Water depth further decreased in *ghers* and ponds due to siltation and Aila
Species abundance	• Rich diversity of freshwater wild fishes in ponds • High diversity of coastal fishes in rivers • No aquaculture fish in ponds	• Introduction of tilapia (*Tilapia mossambicus*) in ponds and *ghers* • Indigenous and exotic carps stocked in ponds, good production • River diversity decreased	• Wild fish disappeared from ponds • River diversity decreased further • Indigenous and exotic carps stocked in ponds, poor production • Introduction of monosex tilapia (*Oreochromis niloticus*) in ponds and *ghers* • Stocking of coastal white fish - bhetki, bata etc. in *gher*
Input used	No feed, fertilizer in shrimp *gher*	• No feed, fertilizer in fish ponds • Feeding the shrimps with snail meat, use of yeast	• No feed, fertilizer in fish ponds • Many *gher* owners try to prepare the *gher* – removing bottom mud,

		–molasses mixture, lime and other fertilizer in shrimp *gher* • Chopped tilapia and kuchia for crab	liming and feeding shrimp with feed pellet • Chopped tilapia and other low-value fish for crab
Trade off – fish as cash crop and family consumption	• No selling of FW pond fish, mainly used for HH consumption, sharing with and gift to neighbours and relatives • Abundant coastal fish and shrimp in rivers, used both for selling and HH consumption	• No selling of FW pond fish • Catch and diversity of fish and shrimp decreased in rivers • More selling and less eating	• No wild fish in ponds, cultured fish mostly for selling, sometimes eating in the HH, no sharing, no gift • Almost all the fish are expensive and mostly for selling • Occasionally low value and low quality fish for homestead consumption

*HH: household; FW: freshwater.

The main impacts and changes affecting non aquatic based livelihoods identified by the villagers are the availability of potable water; the shortage of cooking fuel; and the gender biased wage. Almost all the coastal households have a long way to go to ensure the minimal quantity of drinking water for the family members, that is often the duty of the household females. Some of the families are fortunate enough to have sweet water tube-well, pond-side aquifer tube-well or rain water harvest facilities with the help of different organizations. However, that doesn’t ensure all year round the supply of drinking water. Women along with their daughters often travel everyday 1-2 km for 1-2 buckets of drinking water, sometimes twice a day. Waterborne diseases like jaundice and diarrhea are very common among the villagers, especially women and children.

Collection of cooking fuel in rural Bangladesh has always been a problem, especially in the coast. The people of Atulia have been suffering from acute shortage of cooking fuel. Almost 90% of the households only cook once a day. Yet they suffer continuous agony over managing the fuel for cooking. The men in the households almost ignore this problem and cooking fuel collection is always done by housewives and their daughters. As most of the paddy fields have now been converted to shrimp *gher*, the rice straw the women used to collect for free has now been stopped. Aila killed almost all timber trees and bamboos thickets. People cannot keep domestic animals like cows for the same reason, that could have helped them supplying cooking fuel as dried cow dung is used by villagers in other parts of the country.

Women and children daily spend 1-2 hour seeking for cooking fuel in and around the villages, travelling 2-3 km. A little better-off households purchase the rice straw after rice harvest from the rich owners at 800 taka (US$ 10)/bigha (33 decimals≅1335.18 m^2), sufficient for 2-3 months for a medium size family. Other poor households cannot afford even that, and buying cooking wood from market is beyond their capacity. According to the FGD participants, women in coastal villages are also involved in some laborious waged work, unlike in most other areas of the country where women generally don't. These laborious work includes earth cutting (soil labour) in the *gher* and ponds, dyke repairing, collecting shrimp PL, fishing (casting, pushing and pulling nest, and angling), working in the crop fields for transplanting rice, weeding, and harvesting. However, when it comes to the wages particularly for earth work and working in the crop field, women always receive less wage than men for doing exactly the same wok for the same duration of time. Fig. 5 shows the comparison of daily wages among women and men before and during the 2008-2012 period. These figures go in line with recent estimates of wage imbalance in Bangladesh, where Kapsos (2008) found that women in Bangladesh earned an average of 21% less per hour than men, raising to a 23.1% gap when considering occupational segregation.

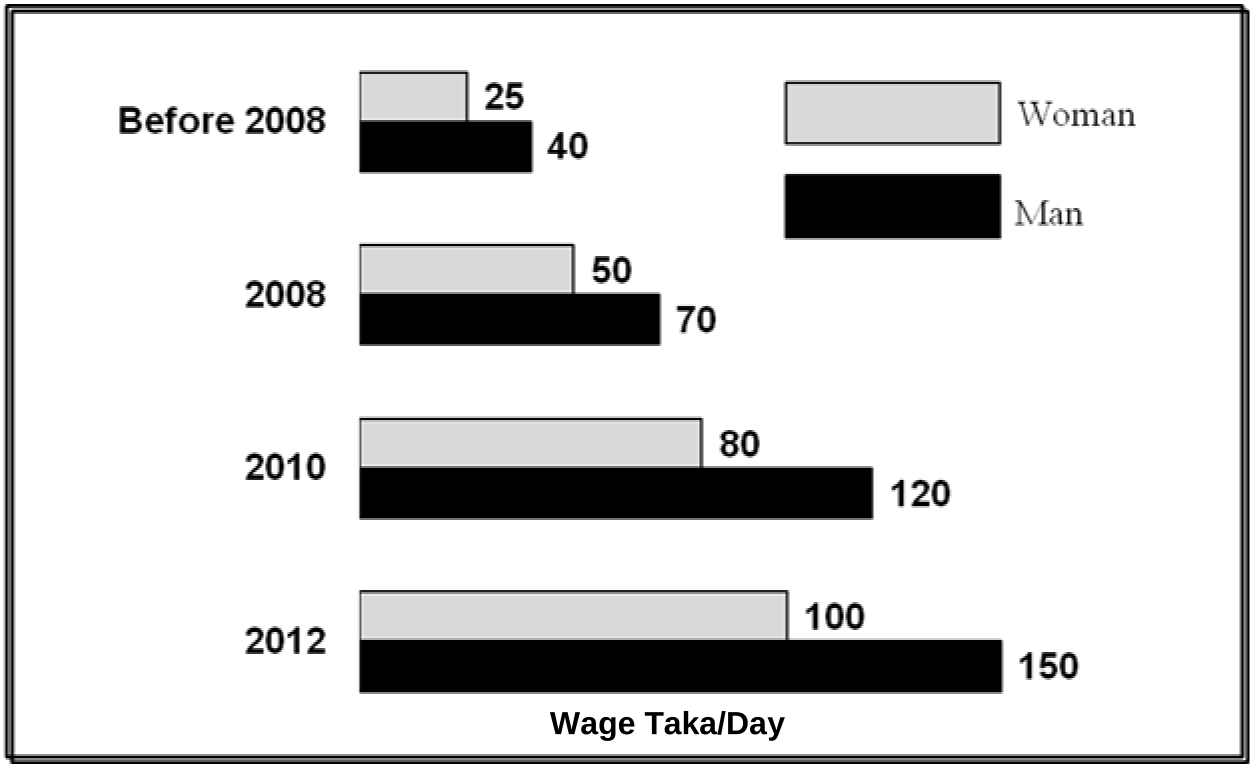

Fig. 5. Comparison of daily wages of men and women in Atulia, Shyamnagar, Stakhira (data collected from field visits, interviews with men and women and cross-checked by key stakeholders in the areas).

3.3 Local adaptation responses

Tropical cyclones and tidal surges not only kill people but damages vital livelihood assets -houses, boats, fish landing jetties, roads and other physical assets that make the fishers more vulnerable. Cyclone Aila was the most devastating along with a number of other cyclones coupled with anthropogenic factors like overfishing, destructive catching of shrimp/prawn post larvae (PL), and unsustainable shrimp expansion finally led to outward migration as a result of a loss of livelihood opportunities. These also exerted long-term implications on food security as fisheries were greatly affected and freshwater supplies diminished in the wake of increased salinization. In response to the adverse impacts, affected communities adopted a variety of coping strategies (Table 3), some of which, however, led them to be worse off than they were before. For instance, children in some households were taken out of school so that they could contribute to income generating activities and help to sustain the livelihood of their families, an erosive coping strategy that can cause an intergenerational leaning towards poverty and vulnerability.

For most coastal fishers, fishing is the only livelihood option they know and are comfortable with, and economic diversification with other alternate income generating activities is not possible. However, finding no way out, many fishers in this area exit the fisheries and start jobs like rickshaw pulling, furniture making, or petty business. Also a few go to work for the garments factories in Dhaka. *Kartik* to *Falgun* (October – January) is the most critical time for the fishers and poor fish farmers in the study area. There is the lowest fish catch in coastal rivers and floodplains and virtually there are no activities in the shrimp farms this time and hardship begins. Almost all the fisher families, including poor shrimp farmers and farm workers, have reduced the number and the size of their daily meals, they go after cheaper food, and when possible borrow money from local moneylenders, NGOs and wholesalers with high interest. They also get advance loans (*dadon*) from the wholesalers and even if the profit is a bit less, later on during fishing season, they are forced to sell their catch to that wholesalers. Most of the fishers can never pay the whole debt to the wholesalers and the cycles go on and on.

Children particularly the boys of most of the fisher families cannot continue their education, because of shortage of money and involvement in fishing at an early age. Most fishers would avoid hiring other fishers or neighbours as it costs money so they employ their children to help them in fishing. Many coastal fishers are leaving their hereditary profession and moving around every day as ‘environmental refugees’ from a state of unemployed and poverty to underemployment and grim poverty in large cities. Many shrimp farmers left shrimp farming because of ever increasing price of inputs and mounting value of lease. The food incentive is available in the hilsa districts but as the supply is limited, Government of Bangladesh can provide incentive to selective and very few hilsa fishers. The incentive in the form of 40 kg rice a month for 4 months (total 160 kg) does not meet the demand of a family of hilsa fisher, let alone most of the fisher families who are not included in the incentive list. Therefore, both groups who receive and who don't, often continue fishing defying fishing regulations and occasionally caught by the police, pay fine/go to jail for a few months and their nets are burned.

4. Discussion

4.1 Cyclones

Bangladesh, due to its geographical location, receives about 40% of the total impacts of global storm surges (Dasgupta et al., 2010). The country is turning more prone to severe cyclones[5], particularly during November and May (Krishna, 2009) since cyclones are strongly influenced by sea surface temperature (Ahmed et al., 2013). In 2009 Cyclone Aila[6], a 1.2 year return period cyclone with an average wind speed of 95 km per hour caused 190 deaths, 7,103 injuries and affected 3.9 million people (Dasgupta et al., 2011). An estimate of 20 million people became vulnerable and at risk of post-disaster peril due to Aila in Bangladesh. A recent report by FAO shows highlights the broad range of impacts these periodic cyclones have in the country (Hussain and Hasan, 2017). Damages to water embankments throughout the coast was estimated at taka

[5]On average 5.48 storms per year or once every 9.49 weeks and if the increasing trend continues the cyclonic frequency may reach 7.94 storms per year or once every 6.54 weeks by 2050 (Chowdhury et al., 2012).

[6]Formed 23 May 2009 and dissipated 26 May, 2009.

one billion (US$14.4 million) and total damage to assets from Aila was US$270 million (CRED, 2011). About 200,000 people, including children, became homeless (Sarmin and Naznin, 2012).

The magnitude of this event has been largely reflected in the stakeholder consultations of the current analysis, showing the consequences of Aila for the biodiversity, productivity and livelihoods of the aquatic systems. Aila was described as the main reason behind the least abundance and disappearance of fish, due to salinity intrusion (DRCSC, 2009). As a consequence, the exotic tilapia, totally absent in *gher* and ponds in the past, has now become the top species for livelihoods, with increasing abundance. We discuss in the next section what the adaptation responses to these major impacts are.

4.2 Adaptive responses

The results obtained in this study can also help us understand the available adaptive responses for achieving ecosystem and livelihoods sustainability in aquatic systems. Recent studies assess the adaptive capacity of fisheries management to confront climate change (Allison et al., 2009; Melnychuk et al., 2014; Leith et al., 2014), and identify economic resilience attributes for a given fishery (van Putten et al., 2013), including fisheries sustainable management (Ojea et al., 2017), livelihood diversification options (Leith et al., 2014), the role of cooperation, and addressing equity concerns (Pascual et al., 2014). In this context, the main adaptive responses that have been identified in the case study and in the context of South Asian countries (SA), based on the results and the existing literature, are: decreasing livelihood vulnerability, sustainable fisheries management, livelihood diversification, fisher mobility, planned adaptation, access to markets, spatial management, economic stability, and scientific knowledge.

4.2.1 Decreasing livelihood vulnerability

Most vulnerable livelihoods in coastal Bangladesh are poor people and women. In the coast, gender imbalance, salinization of cropland, decreased access to cooking fuels and drinking water are the major livelihood problems contributing to vulnerability. These issues were raised in the focus groups and suppose important barriers to sustainable livelihoods and adaptation in the area. In addition to almost all the household works – washing, cleaning, cooking, looking after the kids and elderly and colleting cooking fuel and drinking water, women in coastal villages also work as hired labour, like cutting earth, deweeding in the crop fields and working in the shrimp *gher*. However, when it comes to the wages, men receive almost 50% more. According to CCC (2009), if a woman wants to sell labour to earn money, she is given a lower wage than any man in the neighbourhood. Nonetheless, scholars have found that women in the coast are often degraded, deprived and discriminated by contemporary values and attitudes, norms and traditions, rules and regulations that together characterize a state of patriarchy despite recent development success (White, 2016). Finding no alternate and with the lack of support from men, women have no voice to break through the long run discrimination.

The decline of rice production and livestock resources directly contribute to the shortage of cooking fuel as the rice straw and dried dung of livestock used to be the two most common fuels in rural households in Bangladesh and severely harm the poor families in the shrimp farming areas of coastal Bangladesh (Paul and Vogl, 2013). The extent and range of salinity in groundwater has long been increasing, in part because of continued expansion of shrimp cultivation in to fresh agricultural land (Rahman et al., 2013; Hossain et al., 2013b). People rely on pond water or rainwater in the monsoon season for drinking (Hagler et al., 2009). Broadly, there is therefore an overall difficulty in gaining sufficient drinking water, what makes households very vulnerable to impacts in aquatic systems and exacerbates poverty. As the analysis conducted in the present study reveals, it is crucial to bridge the gender and poverty gaps in order to adapt vulnerable livelihoods to the more severe impacts seen in aquatic systems.

4.2.2 Sustainable fisheries management

Fisheries sustainable management has been estimated to have the potential to increase global fisheries production by 10% (Cheung et al., 2017), however, the expected benefits at the local scale are less known and can be in the form of bigger and higher value fish increase (Coll et al., 2013; Bundy et al., 2017). Despite suggestions that adaptation is limited to altering catch size and effort (Easterling et al., 2007) there are in fact many options available, many of which benefit or provide an advantage to small-scale fishers and fish-farmers. These include direct adaptations to specific changes as well as actions that increase the resilience and adaptive capacity of communities and ecosystems, particularly by reducing other stresses such as social (poverty, inequality) and environmental (over-fishing, habitat destruction, pollution), which can significantly increase vulnerability of communities and ecosystems to the impacts of climate change (Cheung et al., 2009). Many fishing communities are dependent on stocks that exhibit regular fluctuations and so have already developed considerable coping capacity (Easterling et al., 2007). Development agencies should direct efforts to documenting and understanding existing adaptation mechanisms and, where these prove successful, supporting and strengthening them and applying them elsewhere. However, although traditional management systems may support sustainable livelihoods, they may also reinforce the social positions of those who oversee them, at the expense of less privileged members of the community (Neiland et al., 2005) and thus may not meet the requirements of equitable development.

As we have seen in the case study region, barriers to sustainable fisheries management in southwest Bangladesh include the decrease in productivity due to climate change and the livelihood needs for accessible food supply and markets. In rivers, villagers distinctively reported that the fish catch had been reduced in more than half, despite increased effort (e.g. time at sea). The Hilsa shad, *Tenualosa ilisha* (Hamilton, 1822) stocks are susceptible due to prevailing jatka (Juvenile hilsa) catching. The Government of Bangladesh imposed ban in 2000 for shrimp/prawn PL collection, however, it has never been implemented firmly because of the lack of alternative livelihoods for coastal livelihoods (about 500,000 people are involved in shrimp/prawn PL collection). The government also imposes nation-wide ban on the catching, possession, transport and trading of juvenile Hilsa (up to 23.0 cm size) between 01 November and 31 May. In addition, catching, transporting, marketing and stock-piling of Hilsa of all sizes are banned in the major spawning grounds (an estimated area of 6,882 km^2) during last fortnight of September for 11 days, 5 days either side of a full moon. Overall coastal fishery dwindles due to the use of illegal and destructive gear, defying the ban period by the fishers and catching of undersized fishes. The incentive provided by the government during ban period is not sufficient. In terms of fisheries, intensification of shrimp farming has brought collapses due to diseases dispersal (Hossain et al., 2013b. Marine fish catch has also been reduced due to overfishing, in particular in species of high commercial value. Protection of coastal biodiversity has been detrimentally affected by myopic government focus on economic development ignoring ecosystem and species biodiversity of the coast (Siddiquee et al., 2009, Sovacool, 2018). The CPUE (catch per unit effort) has been reduced to more than half comparatively of a few decades ago (Barua, 2013). In addition, several socio-economic and climate scenarios developed in ESPA Deltas project forecast a decrease of Hilsa biomass due to environmental changes (Fernandes et al., 2016). However, these projections from a fisheries model shows that sustainable fishing would mitigate those effects. What we are seeing is that following a very drastic fish biodiversity decrease in wild rivers and mangroves, livelihoods are only left with the choice of shifting to another aquatic livelihood based on farmed species (crab point), or even completely shifting livelihoods by exiting the fisheries and migrating to cities. Biodiversity conservation should be prioritized in order to reverse this trend and make the aquatic systems more sustainable and resilient in the longer term.

4.2.3 Livelihood diversification

Livelihood diversification, for example increasing the number of fishing gears has been seen as a way to empower communities (ILO, 2015; Shaffril et al., 2017). However, it must be considered that fishers are strongly attached to their work and diversifying has associated costs (Shaffril et al., 2017). Nevertheless, the promotion of non-fishing, non-environment-related income-producing activities should be intensified among small-scale fishers, which in turn should reduce their dependency on the sea and diversify their income (Shaffril et al., 2017).Examples of such mechanisms include diversification of livelihood systems, such as switching between farming and fishing in response to seasonal and inter-annual variation in fish availability, providing opportunities with training and alternative income generating activities. In Myanmar, training efforts lead to 40 fishery training courses in aquaculture, fisheries management, English, computer literacy, and market access requirements during 2013-2014 (ILO, 2015). In India, cultivating aquatic algae is an alternative livelihood which has positive response to climate change for food and pharmaceutical purposes and for production of biodiesel (Vivekanandan, 2011). On most industrialized continents such as Europe, North America, and Australia, recreational fisheries represent the primary fisheries sector in inland waters (Christensen et al., 2007). Recreational fisheries provide substantial additional value because they can also boost other tourism industries (Cooke et al., 2016; Paukert et al., 2017). Even in emerging economies, inland recreational fisheries are expanding due to angling tourism and increasing domestic participation (e.g., India: Gupta et al., 2015). However, the lack of scientific knowledge on the basic biology of sport fish species, together with the absence of region- or species-specific angling regulations for recreational fisheries can lead to target threatened species. Moreover, governance structures are disorganized, with multiple agencies assuming some responsibility for recreational fishing but none tasked explicitly with its sustainable development and management (Gupta et al., 2015).

As families' financial dependence on small-scale fishers is very high (Shaffril et al., 2013), it would be advantageous to offer such alternative skills not only to small-scale fishers, but also to their families. Many women are unable to diversify livelihoods because of lack of credit support from government organization with is a common problem in south east countries (Shaffril et al., 2013; ILO, 2015; Jahan et al., 2017). Homestead gardening, petty businesses, poultry farming, livestock rearing and fish farming in cages by the women with the low interest institutional credit support could supplement the family income and increase security for coping with impacts such as the ones identified in this case study area. One example of a raising activity in the study area is crab fattening. As observed in the focus groups, is potentially profitable and a feasible fishery venture in and around the Satkhira coast. The mud crab, *Scylla serrata* is widely distributed in the Pacific and Indian oceans including Bangladesh coast. There is an unmet demand for mud crabs in overseas markets (Begum et al., 2009). Production from crab fattening is quite healthy (nearly half of the total harvest) and scaling up rapidly in the coastal areas. A number of factors hinder the sustainable development of the crab sector and the key one is the sustainable supply of crab seed. Wild seed collection is becoming risky for environment and the natural stock has already been suffering overexploitation. Although there are long established crab hatcheries in the neighbouring countries like Thailand, Malaysia and Vietnam to date no initiative either from government or from private sector is taken to establish crab hatchery in Bangladesh. If crab seed production systems are not established in near future, the whole fattening industry as well as the natural crab population will be in jeopardy. Provision of hatchery produced crab seed, proper training in fattening and farming, transport, facilities of formal credit, good and stable markets and increased demand in domestic market can assist the sector.

4.2.4 Fisher mobility

Deltas and low-elevation coastal zones are known for significant urbanisation trends and land use change (Meyer et al., 2016) and associated high movement of people, mainly due to economic reasons (Foresight, 2011) but also climate change. A 1 m sea level rise could make an additional 15 million people landless who will act as 'climate refugees' in Bangladesh (Hossain, 2008). Migration is a socially embedded process, which is mostly perceived for bringing low adaptive capacity to the individuals or the communities coping with stressful changes in the environment (Adger, 1999; Brooks et al., 2005). Exiting the fisheries can have negative impacts in the fishing communities, and remaining in the fisheries under heavy impacts can also set a poverty trap (Cinner et al., 2009). However, considering the broader perspective of migration, sometimes they can enhance the adaptive capacity of a community to cope with climate change (Barnett and

Webber, 2009). For example, seasonal migration to locations where fish are available are common between fishers in the case study area and has an important role in sustaining livelihoods in the face of external impacts.

4.2.5. Spatial management

The establishment of marine protected areas is an effective tool for conserving fish stocks, protecting biodiversity and increasing fish production (Lubchenco et al., 2003). Protected areas have been defended as a solution to fisheries collapse, due to their potential positive spill over effects for adjacent fisheries (White et al., 2008; Costello and Polasky, 2008; Lester et al., 2009). Series of marine reserves or reserve networks have been proposed as a logical response to shifting species ranges due to climate change (Hannah, 2008; Jones et al., 2013). Bangladesh has established more than 500 fish sanctuaries throughout the country (FRSS, 2017) including the Saint Martin Island, the Sundarbans (mangrove forest) and a marine reserve (covering 698 km^2) in the Bay of Bengal to protect and preserve the breeding grounds of marine flora and fauna. However, good practices and enforcement are needed in order to make these reserves successful. As observed from the present analysis, illegal fishing practices are still common in protected areas.

Ecological restoration is widely practiced as a means of rehabilitating ecosystems and habitats that have been degraded or impaired through human use or other causes such as climate change (Timpane-Padgham et al., 2017). Evidence of increased biodiversity and improved ecosystem function following restoration demonstrates that restoration can be successful in rehabilitating the condition of ecosystems due to certain ecological attributes, such as diversity and connectivity, are more commonly considered to confer resilience because they apply to a wide variety of species and ecosystems (Timpane-Padgham et al., 2017). Marine Spatial Planning is a public process of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic and social objectives (Ehler and Douvere, 2009). Novel approaches can use ecosystem models to consider socio-economic activities as well as climate scenarios in areas with sparse biological data using methodologies that have been tested in rich data areas (Queirós et al., 2016). These tools are needed to promote ecosystem based management and revert, as much as possible, the biodiversity decreasing trends observed in the present analysis.

4.2.6 Planned Adaptation

An adaptation plan must be in line with the community's needs, abilities and interests by including the community, which will empower them by enabling them to posit their own ideas and take action (Grafton, 2010; Shaffril et al., 2017). Fisher’s sense of belonging to their place of residence has been identified as leading to strong cooperative behaviour and social reciprocity in Malaysia and Pakistan, therefore, strengthening social relationships can be an important adaptation measure (Salik et al, 2015; Shaffril et al., 2017). All the SA countries are making efforts to develop community-based fisheries management. An important element is the fishers associations such as Fish Farmers Development Agencies in India (DAHDF, 2014) or Myanmar Fisheries Federation (ILO, 2015). In Bangladesh, understanding threats and livelihood dependence in time is crucial for the design of adaptation planning and the present study contributes in that respect.

5. Conclusions

Ecosystems in Bangladesh are home to more than a thousand marine organisms including finfish, shellfish and other organisms which support the livelihoods of coastal people. The country, however, is experiencing serious biodiversity losses in recent years, which threatens the services provided by these ecosystems. We investigated the perceptions on the recent trends of aquatic-based animal diversity using focus group discussions covering the period 2002-2012 in four villages of Shyamnagar Upazila (Sub-district) under Satkhira District at the west coast of Bangladesh. Furthermore, we analyse the main impacts in these communities, including cyclone Aila in 2009, and how the livelihoods have adjusted to them.

We find that livelihoods strongly depend on ecosystem production services that at the same time are tight with uncertainty and variability. Their livelihoods are adapted to this by diversifying the sources of goods and income through the four main aquatic systems (shrimp *ghers*, fish ponds, the river and crab points). However, these livelihoods are threatened by anthropogenic activities and unsustainable practices such us destructive gears, faulty shrimp post-larval collection with high seed mortality and water pollution by industry and agrochemicals. In addition, cyclones such as Aila have devastating effects on all the main livelihoods. Aila in 2009 destroyed wild and cultured freshwater fish stocks and reduced diversity of coastal and freshwater fish and shellfish species in rivers and farming systems of fish, shrimp and crab due to increased salinity. To cope with the changed scenario, people brought modification in farm design and farming practice, the inputs used and trading off between selling fish for cash and household consumption. One of these adaptations was the use of invasive and low value tilapia to feed crabs in ponds as well as for household food supply. Hydrological changes in coastal ecosystems also impacted other livelihood needs like availability and accessibility of potable water, and cooking fuel. The effects of destructive fishing and pollution also pose threat.

We conclude that changes in diversity are impacting mostly the fish species of high economic value and increasing the availability of the low value invasive species tilapia. Overfishing, destructive fishing and shrimp post larvae collection are creating hardship for the coastal community. These problems have greatly accelerated due to the impact of the cyclone Aila, that disturbed many of the production systems. Nonetheless, despite the decrease of productivity of fish ponds and rivers, there has been an increase of productivity of *gher* and crab points. However, it is unlikely that the systems can sustain over time due to dependence of the people on natural resources that seem to be highly overexploited. A multidisciplinary approach is needed for improving the adaptability of coastal communities depending on aquatic ecosystem services such as alternative livelihoods that don't depend only on the production, but that community-based approaches, training and education, and economic measures to guarantee minimum wages to men and women, access to credit and insurance. We observed how potential adaptation measures such as livelihood diversification are in practice not feasible due to the cultural and economic attachment to the activities undergone. Finally, we conclude that sustainable aquatic livelihoods are only possible to reach if different players agree on the need for investing in alternative livelihoods, reducing poverty and gender gaps, and fostering biodiversity conservation.

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Appendix 1

The Questionnaire

1. Name: ………………………………………………………………………………..

2. Address: Village/ Mauza………………………. Union…………………………

Upazila…………………………….. , District……………………

3. Sex: Male= 1, Female=2

4. Age (Year): ……………………………

5. Educational Qualification:
Illiterate=0, Can Sign=1, Read &Write=2, Primary level=3, Secondary level=4, Higher Secondary Level=5, Graduation & above=6, Others =7(specify)………. .

6. Occupation: Main……………………..Secondary/Substitute-……………………

7. Marital Status:
Unmarried=1, Married=2, Separated/Divorced=3, Widow/Widower

8. Fisheries Assets:

Type	Quantity(nos.)
Nets	
Traps	
Hook and line	
Fishing weapons	
Boats	
Others	

9. Household Assets:

Type	Quantity(nos.)
Rickshaw/van	
Mechanized three wheeler	
Bicycle	
Motorcycle	
Radio	
Fridge	
Sewing Machine	
Others	

10. Household Food security and Consumption status: Can ensure food supply for total …months/year

Items	Number of lean months - Duration

Rice	
Fish	
Meat	
Eggs	
Vegetables	

11. Annual Household Income from fish:

Source of Income	Income(Taka/Year)
Fishing	
Fish/shellfish farming	
Fish/shellfish trading	
Others	

12. Did the productivity of aquatic animals (kg/dec, acre or ha) increased/ decreased compared to 10 years back.

Farming system	**Increased (%)**	**Decreased (%)**	**Same**
Gher			
Fish pond			
Crab point			
Other			

13. What are the changes in farm design over last 10 years?

Farming system	**Area Increased/ Decreased (%)**	**Depth Increased/ Decreased (%)**	**Height and width of dyke**
Gher			
Fish pond			
Crab point			
Other			

13a. What are other changes (like - intermediate nursing, water supply, mechanization etc.):

14. What are the changes in species composition?

Farming system	**Added**	**Dropped**	**Reason**
Gher			
Fish pond			
Crab point			
Other			

15. What are the changes in inputs use?

Farming system	**Seed**	**Feed**	**Fertilizer/chemical**
Gher			

Fish pond			
Crab point			
Other			

16. What are the changes in profitability?

Farming system	**Increased**	**Decreased**	**Same**
Gher			
Fish pond			
Crab point			
Other			

17. Who/what are the driving forces behind the changes?

Actors	**Score (1-10)**
PL Collector	
Gher farmer	
Pond farmer	
Crab fattener	
Input supplier	
Input manufacturer	
Depot holder	
Middlemen	
Processor	
Large wholesaler	
Exporter	
Consumer	
Labour	
Climate	
Global market	
Govt. policy	
Technical expertise	
Finance	`
Transport & Communication	
Others	

18a. Make a list of fish/shellfishes/molluscs available in different production systems in your area.

18b. Name 10 fishes/shellfishes/molluscs with increased abundance (%) and name 10 fishes/shellfishes/molluscs with decreased abundance (%) in river, gher, pond and canals over last 10 years.

Increased (%)	Decreased (%)	Same

19. Name of fish/shellfish/mollusk not found in river over time

Local name	Approx. how long they have not been found

20. Make a list of all the gears (traps, nets, wounding gears, hooks and lines etc) used to catch fish/shellfish/molluscs in this area.

21. Name three major threats/risks/barriers towards the following systems in your area.

System	Threats/risks/barriers
River	
Canal	
Pond	
Gher	
Crab point	

22. What are your three suggestions to mitigate /avert the threats/risks?

System	Suggestions to mitigate /avert
River	
Canal	
Pond	
Gher	
Crab point	

23. What are the livelihood opportunities available here that you think you would like to be involved other than fishing and fish culture?

Name & Signature of the Interviewer: **Date:**

Questionnaire Code:

Appendix 2

Table A1. The aquatic animals and plants available in and around the four study villages as enlisted by the FGD participants.

Group	Local names	Common English Name	Scientific name	Habitat/ ecosystem
Wild Fish (50)	Amadi	Pointed Tail Anchovy	*Colia dussumieri*	River
	Baila	Tank goby	*Glossogobius giuris*	River, Shrimp *gher*
	Bamosh	Yellow Pike Conger	*Congresox talabon*	River
	Bashpata	Doublelined Tonguesole	*Paraplagusia bilineata*	River
	Bhangon	Flathead mullet	*Mugil cephalus*	River, Shrimp *gher*
	Bhetki	Giant Perch	*Lates calcarifer*	River
	Bhola	Cuja Bola	*Macrospinosa cuja*	River
	Bishtara, Paira	Spotted Scat	*Scatophagus argus*	River
	Chandona	Toli Shad	*Tenualosa toli*	River
	ChataBaila	Bartail Flathead	*Platycephalus indicus*	River
	Chiring	Mudskipper	*Apocryptes bato*	River
	Datina	Silver grunt	*Pomadasys argyreus*	River
	Ekthuita	Gangetic Halfbeak	*Dermogenys brachynotopterus*	River
	Gangoina	Grunting Toadfish	*Allenbatrachus grunniens*	River
	Ghagla	Engraved Catfish	*Arius gagora*	River
	Gule	Goggle-eyed Goby	*Boleophthalmus boddarti*	River
	Hangor	Spadenose shark	*Scoliodon laticaudus*	River
	Ilish	Indian River Shad	*Tenualosa ilisha*	River
	Jaba	Spindle Croaker	*Johnius elongates*	River
	Kain	Gray Eel Catfish	*Plotosus canius*	River
	Kakila	Asian Needlefish	*Xenentodon cancila*	River, Shrimp *gher*
	KaloBaila	Black-spotted Gudgeon	*Butis melanostigma*	River
	Kankshol	Crocodile Needlefish	*Tylosurus crocodiles*	River
	Katapata	Gagora Catfish	*Nemapteryx nenga*	River
	Kawtak	Congaturi Halfbeak	*Hyporhamphus limbatus*	River
	Khoira	Indian Ilisha	*Ilisha melastoma*	River
	Khorol	Corsula Mullet	*Rhinomugil corsula*	River, Shrimp *gher*
	Koipunti	Chacunda Gizzard Shad	*Anodontostoma chacunda*	River
	Kuicha	Mud Eel	*Monopterus cuchia*	River, Shrimp *gher*
	Lakhua	Indian Tasselfish	*Leptomelanosoma indicum*	River
	Loita	Bombay Duck	*Harpadon nehereus*	River
	Luicha	Largescale Archerfish	*Toxotes chatareus*	River
	Mad	Beardless Sea Catfish	*Batrachocephalus mino*	River
	Maita	Eastern Little Tuna	*Euthynnus affinis*	River
	NunaTengra	Long Whiskers Catfish	*Mystus gulio*	River
	Pangas	Yellowtail Catfish	*Pangasius pangasius*	River
	Pankhaki	Saddlegrunt	*Pomadasys maculates*	River
	Parse	Goldspot mullet	*Liza persia*	River
	Phaisa	Oblique-jaw thryssa	*Thryssa purava*	River
	Poa	Sharpnose Croaker	*Johnius borneensis*	River

	Ram Phasa	Hamilton’s Thryssa	*Thryssa hamiltonii*	River
	Ramkarati	Ramcarat Anchovy	*Colia ramcarati*	River
	Rekha	Fourband triple tail	*Datnioides polota*	River
	ShaplaPata	Bleeker'swhipray	*Himantura bleekeri*	River
	Taila	Four Finger Threadfin	*Eleutheronema tetradactylum*	River
	TakChnada	Greater Ponyfish	*Leiognathus equulus*	River
	Tapa	Milkspotted Puffer	*Chelonodon patoca*	River
	Thuita	longjawed garfish	*Rhynchorhamphus georgii*	River
	Topshe	Paradise Threadfin	*Polynemus paradiseus*	River
	TulBaila	Northern whiting	*Sillago sihama*	River
Farmed Fish (10)	African Magur	African catfish	*Clarias gariepinus*	Fish pond
	Catla	Catla	*Catla catla*	Fish pond
	Carpii	Common Carp	*Cyprinus carpio*	Fish pond
	Mrigal	Mrigal	*Cirrhinus mrigala*	Fish pond
	Rui	Rohu	*Labeo rohita*	Fish pond
	Silver Carp	Silver Carp	*Hypophthalmichthys molitrix*	Fish pond
	Thai Pangas	Iridescent Shark	*Pangasianodon hypophthalmus*	Fish pond
	Thai Sarpunti	Silver barb	*Barbonymus gonionotus*	Fish pond
	Tilapia/Monosex	Nile tilapia	*Oreochromis niloticus*	Shrimp *gher*, Fish pond
	PonaMachh	-	Carp fingerlings	Fish pond
Wild Crustaceans (6)	Chaka Chingri	Indian white shrimp	*Penaeus indicus*	River, Shrimp *gher*
	ChaliChingri	Yellow shrimp	*Metapenaeus brevicornis*	River, Shrimp *gher*
	ChhitKankra	Crucifix crab	*Charybdis feriata*	River, Shrimp *gher*
	HarinaChingri	Speckled shrimp	*Metapenaeus monoceros*	River, Shrimp *gher*
	PatiKankra	Ridged Swimming Crab	*Charybdis natator*	River, Shrimp *gher*
	RashmiChingri	Kuruma prawn	*Penaeus japonicas*	River, Shrimp *gher*
Farmed Crustaceans (3)	Kara	Mud Crab	*Scylla serrata*	Crab point, Shrimp *gher*
	GoldaChingri	Freshwater giant prawn	*Macrobrachium rosenbergii*	Shrimp *gher*, River
	BagdaChingri	Tiger shrimp	*Penaeus monodon*	Shrimp *gher*, River
Mollusc (3)	Jomra	Coastal Snail	Different types	River, Shrimp *gher*
	Jhinuk	Green Mussel	*Perna* sp.	River, Shrimp *gher*
	Koshtura	Oyster	*Crassostrea* sp.	River, Shrimp *gher*
Mammal (1)	Shush	Irrawaddy dolphin	*Orcaella brevirostris*	River
Amphibians (3)	Kuno Bang	Asian Toad	*Duttaphrynus melanostictus*	Shrimp *gher*, Fish pond
	Sobje bang	Green Frog	*Euphlyctis hexadactylus*	Shrimp *gher*, Fish pond
	Katkati Bang	Indian bull frog	*Hoplobatrachus tigerinus*	Shrimp *gher*, Fish pond
Reptile (3)	Bhora Sap	Striped Keelback snake	*Amphiesma stolata*	Shrimp *gher*, Fish pond
	Kumir	Saltwater crocodile	*Crocodylus porosus*	River
	Guia Sap	Bengal Monitor lizard	*Varanus bengalensis*	Shrimp *gher*, Fish pond
Plants (5)	Kalmi	Water spinach	*Ipomea aquatica*	Fish pond
	Helencha	Harkuch	*Enhydra fluctuans*	Fish pond
	Kachuri Pana	Water Hyacinth	*Eichhornia crassipes*	Fish pond
	Samudra Sheola	Sea weeds	Different types	Shrimp *gher*
	Idurkani Pana	Watermeal, duckweed	*Wolffia* sp., *Lemna* sp.	Fish pond