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Socio-economic and ecological challenges of small-scale fishing and strategies for its sustainable management: a case study of the Old Brahmaputra River, Bangladesh

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Socio-economic and ecological challenges faced by the small-scale fishers dependent on the Old Brahmaputra River, Bangladesh are assessed using a combination of questionnaire survey, co-monitoring of fish catch, focus group discussions and key informant interviews. Results reveal that the fishers are involved in professional, seasonal or subsistence fishing. Fish catches from the river have declined significantly because of overfishing, destructive use of fishing gear, water pollution, siltation, rapid urbanization and human encroachment, thereby threatening the health of the river ecosystem as well as the future of small-scale fishing. We evaluate various social, economic and ecological challenges faced by the fisher communities. We propose a conceptual framework that recognizes linkages among social, economic and ecological aspects in devising a sustainable river fisheries management system. We recommend effective legal enforcement of policies and regulations, strong institutional collaboration and active fisher community participation in management to ensure sustainable use of the resource base.

Keywords: small-scale fishing, socio-economic, ecological, sustainable fisheries management, Old Brahmaputra River, Bangladesh

Introduction

By virtue of its location between the Great Himalayan Ranges in the north and Bay of Bengal in the south, Bangladesh has the unique advantage of possessing many rivers with vast fisheries potential (Hoggarth *et al.*, 1999a; 1999b; Valbo-Jørgensen & Thompson, 2007). Bangladesh is one of the world's largest deltas through which flow two of the world's largest rivers, the Ganges and Brahmaputra (Brichieri-Colombi & Bradnock, 2003). Bangladesh is called a 'land of rivers' as the country is crisscrossed with networks of around 700 rivers and tributaries totalling 24 140 km (Islam, 2011). These rivers carry huge amounts of nutrient-rich runoff from their catchments, and are the ideal natural breeding, feeding and nursery grounds for many commercially and ecologically important fish species.

The rivers of Bangladesh are the principal source of subsistence for poor fishing communities.[1] Subsistence fishing is carried out by almost all households in rural areas with access to a water body (Rab, 2009). Some 1.4 million full-time fishers and 12 million part-time fishers operate in Bangladesh (Hossain *et al.*, 2006). Total fish production in Bangladesh was estimated at ~~2.7~~ million tonnes in ~~2008–09~~, of which ~~1.06~~ million tonnes (~~39~~ per cent) were obtained from inland aquaculture, ~~1.12~~ million tonnes (~~42~~ per cent) from inland capture fisheries and ~~0.51~~ million tonnes (~~19~~ per cent) from marine fisheries (Department of Fisheries, ~~2010~~). However, the declining trend of

fish production from capture fisheries over the last three decades has negatively affected fishers' livelihoods (Aghazadeh, 1994; Craig *et al.*, 2004; Sultana & Thompson, 2007; Ahmed *et al.*, 2010). There has been a gradual decline in the catch of fish from open-water resources because of overfishing and environmental degradation. Population growth, rapid urbanization and industrialization have reduced productivity and biodiversity of aquatic resources (Alam & Thomson, 2001; Hossain *et al.*, 2006). Climate change is likely to further increase pressure on aquatic resources (Allison *et al.*, 2009).

One of the principal objectives of the national fisheries policy of the government of Bangladesh is to increase fish production through maintaining capture fisheries, while enhancing the ecological balance and conserving biodiversity (Valbo-Jørgensen & Thompson, 2007). However, there has been a low level of compliance with fisheries management rules and legislation, compounding issues of over-exploitation and resource degradation (Nielsen *et al.*, 2004; Rab, 2009). This is because such management strategies have often ignored the socio-economic aspects of small-scale fisheries[2] which provide an important source of food, income and livelihoods for fishing communities (Dugan *et al.*, 2006). The absence of robust and trustworthy information on fish catches inhibits efficient management, thereby reducing the sustainability of fishers' livelihoods. Traditional knowledge within fishing communities has potential to fill this gap and improve conservation of fisheries resources and their management (Berkes *et al.*, 2000).

Given this backdrop, we assess the nature of small-scale fishing activities on the Old Brahmaputra River while examining the socio-economic conditions of the fishers as well as the ecological features of the river that have a direct bearing on their livelihoods. Promising management strategies in support of sustainable fisheries are proposed.

Methodology

Study area: Old Brahmaputra River

The study was conducted on the Old Brahmaputra River, Mymensingh District in north-central Bangladesh (Figure 1). The Brahmaputra River is one of three major rivers in Bangladesh and has a total length of 2900 km (Islam, 2011). It is a trans-boundary river, originating in Tibet and flowing across southern Tibet to break through the Himalayas in the Great Gorges and into Arunachal Pradesh, India. Subsequently it flows southwest through the Assam Valley as the Brahmaputra River and continues south through Bangladesh. The Brahmaputra in Bangladesh splits into two main channels known as the Jamuna and Old Brahmaputra which starts near Bahadurabad and runs south through Mymensingh until reaching Bhairab Bazaar where it joins the Meghna River. The Jamuna flows into the Lower Ganges near Goalanda assuming the name of Padma. Both rivers, the Padma and Meghna eventually re-converge near Chandpur and flow to the Bay of Bengal.

A considerable number of people were known to be associated with fishing in the study area of the Old Brahmaputra River (Rahman *et al.*, 2002), located east of Bangladesh Agricultural University (BAU) campus and Mymensingh town. The selected study site starts from the China-Bangladesh friendship bridge and extends 5 km south along the river, adjacent to BAU. Most of the fishers live in the fishing village of Char[3] Nilakshmia on the east bank. These fishing communities are subject to seasonal cycles of stress experiencing tropical climatic conditions, dominated by dry (January–March), pre-monsoon (April–June), monsoon (July–September) and post-monsoon (October–December) seasons. During the monsoon, much of the area is inundated with floodwater hence flooding the nearest fishing villages. The floodwater starts to recede during

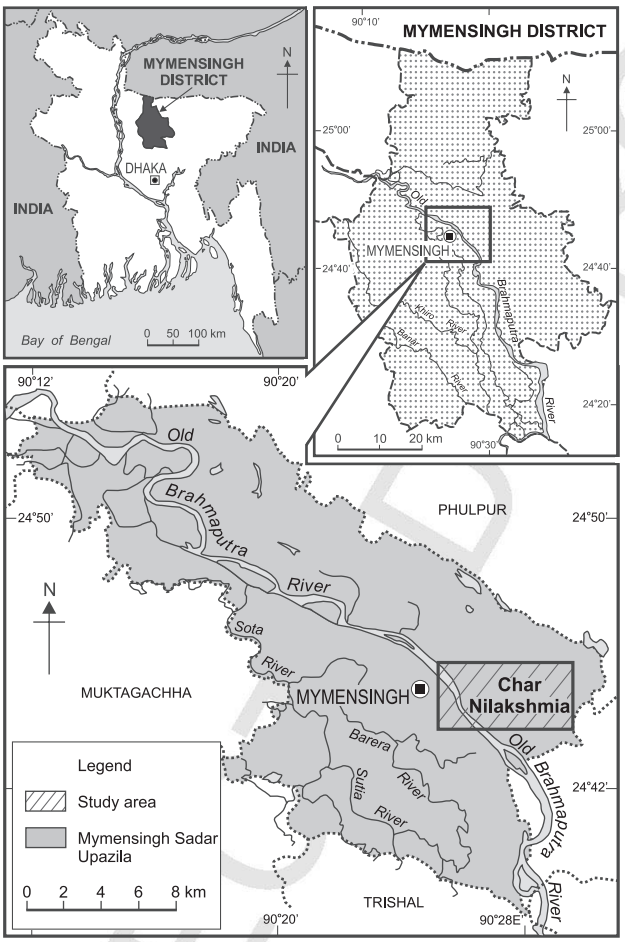

Figure 1. *Study area of the Old Brahmaputra River including a fishing village.*

the post-monsoon and by the end of December the entire area becomes dry, except the main course of the river. The average depth of the river in the monsoon and dry season is about 15 m and 3.5 m respectively. Most fishers appeared to be active in the monsoon. As soon as the monsoon rains arrive, the water level rises and the number of fishers increases simultaneously. When the water level starts to recede during the post-monsoon period, the number of fishers again increases because of the increased concentration of fish. However, fishing activity is very limited during the dry and pre-monsoon seasons.

Data collection methods

Primary data were collected for a period of 12 months from January to December 2009 using a combination of participatory, qualitative and quantitative methods. A total of 72 fishers were interviewed at fishing sites or on the river banks. For questionnaire interviews, fishers were selected through stratified random sampling based on categories of fisher (i.e. professional, seasonal and subsistence). Fishers were classified into three groups/strata on the basis of their scale of involvement in fishing (i.e. full-time, seasonal and part-time). Fishers of each group were viewed as the population of each stratum.

The samples were proportionately selected from each stratum following random sampling technique. A boat was hired for data collection and observation of fishing practices. Interviews with fishers, lasting on average one hour, focused on fishing practices, gear use, fishing duration, daily catch, income, fishing constraints and socio-economic conditions.

Community-based monitoring or co-monitoring was conducted to examine fish catch, species composition, gear use and fishing times. Co-monitoring is a method that can be used by fishers to monitor and assess trends in their local fisheries (Conrad & Daoust, 2008). Four volunteers from the fishing community who could read and write were selected to carry out co-monitoring. Two enumerators were trained in fisheries science (fisheries graduates) and helped the volunteers with co-monitoring. Data were collected from all types of gears (nine in total) and one gear in each category was randomly selected for sampling in each month from January to December 2009.

Focus Group Discussions (FGDs) were conducted with fishers and other community members including women, boatmen and day labourers. A total of 15 FGD sessions were conducted where each group consisted of 8–12 people, thereby covering 152 people in total. The duration of each FGD session was approximately two hours and they were held on the river banks, at fishers' houses and catch landing sites, wherever there were spontaneous gatherings and where participants could sit, feel comfortable and were easily observed. Discussions focused on existing fishing practices, overall constraints faced by fishers and the ecological condition of fishing sites.

Rapid Appraisal of Fisheries Management Systems (RAFMS) was adopted to identify appropriate management strategies for sustainable fisheries management (Chowdhury & Yakupitiyage, 2000). For RAFMS, a total of 25 knowledgeable community members and key informants were contacted who were able to provide information on sustainable fisheries management strategies, based on their knowledge, skills and experience. Discussions were conducted with government fisheries officers, non-governmental organization (NGO) workers, policy makers, researchers and relevant project staff as a means to validate collected information and identify potential management strategies.

Data analysis

Data from the questionnaire interviews and co-monitoring were coded and entered into a spreadsheet using Microsoft Excel software. Descriptive statistics were derived using SPSS (Statistical Package for Social Science). Comparisons among different types of fishers were made by applying the non-parametric Kruskal-Wallis test (H-statistic) which is an alternative for analysis of variance when data are not normal distributed; the Kruskal-Wallis test uses median values to compute the test statistic. Results from data analysis, in combination with qualitative information collected through various methods, were used to describe small-scale fishing practices, socio-economic conditions of fishers and ecological features of the river.

Small-scale fishing practices

The majority of fishers in the study area could be referred to as 'fishing-dependent', although the degree of dependency varies with the type of fisher. Three categories of fisher were identified: professional, seasonal and subsistence, although there is substantial overlap. According to the survey, about half of the fishers (54 per cent) were cent seasonal and 17 per cent subsistence fishers. Professional shing throughout virtually all the year for their livelihood and

don't think it's necessary to number the categories, especially when it's already mentioned at the start of the sentence that there are three categories, and the categories are not long phrases. but it's up to you.
RESPONSE: OK, DO NOT NEED NUMBERS.

'throughout the year' or 'all through the year'?
RESPONSE: Your choice is the correct one)

Table 1. Fishing information by category of fisher based on 72 survey questionnaires.

Fishing information	Professional (n = 39) Mean ± SD (Median)	Seasonal (n = 21) Mean ± SD (Median)	Subsistence (n = 12) Mean ± SD (Median)
No. of fishers (percentage of total sample)	54	29	17
Education (percentage literate)	10	14	17
Age of fishers (years)	43 ± 7.58 (44)	35 ± 6.24 (34)	38 ± 6.30 (38)
Fishing experience (years)	14 ± 3.10 (14)	9 ± 3.66 (8)	8 ± 3.02 (8)
Fishing duration (hr/day/fisher)	6.73 ± 0.86 (6.5)	5.18 ± 1.06 (5)	4.96 ± 0.78 (5)
Commonly used fishing gears	Current net, drag net, hook and line, lift net, seine net	Cast net, drag net, stick hook, push net, trap	Cast net, stick hook, push net, trap

n: sample size of fishers.
SD: standard deviation.
Figures in parentheses indicate median values.

income. Seasonal fishers undertake fishing during part of the year, mainly in the monsoon and post-monsoon seasons, supplementing their fishing income by working as day labourers, rickshaw pullers and boatmen. Subsistence fishers are opportunistic and fish mainly for household consumption. They rely primarily on petty business, livestock rearing and agriculture on alluvial char land for their livelihoods.

According to fish catch assessment, fishers caught on average 1.15 kg of fish per day, varying from 1.31 kg for professional fishers to 1.11 kg for seasonal and 1.02 kg for subsistence fishers ~~(Table 1)~~. Variations in fishing rate between categories of fisher were associated with differences in fishing experience, duration of fishing and gear used. During the field survey, nine types of fishing gear, mostly traditional, recorded in operation, including cast net, current net, drag net, lift net, push net, seine net, trap, stick hook, and hook and line. Professional fishers commonly use small boats with higher value and more efficient gear (e.g. current net, drag net, seine net), and requiring greater skill to operate. They work alone or in small groups of up to five people. Seasonal fishers commonly use gear that permits targeting of small fish (e.g. cast net, push net, stick hook, trap), while subsistence fishers operate relatively inexpensive and simple gear. The largest catch for different gears was obtained whilst monsoon flood-waters were receding and the smallest in the pre-monsoon when the river level was lowest.

A total of 42 fish species were recorded in catches obtained with different gears. Small indigenous species (SIS) of fish were the dominant group, accounting for 41.13 per cent of the total catch, while minor carp were least abundant (0.27 per cent). Other notable groups of fish represented were catfish (15.35 per cent), ~~climbing~~ perch (11.82 per cent), prawns (10.63 per cent), snakeheads (8.25 per cent), spiny eel (8.10 per cent), Indian major carps (3.54 per cent) and exotic carps (0.91 per cent). There are 260 freshwater fish species in Bangladesh of which 143 species (55 per cent) are classified as SIS (Mazid & Kohinoor, 2003), attaining a maximum length of 25 cm. Nevertheless, only 16 species representing the SIS group were recorded in catches.

Again, don't thi it's necessary t number the categories, but it's up to you. RESPONSE: OK. Leave the numbers.

According to the survey, all fishers were concerned about the decline in availability of fish species and diminishing catches. About 28 per cent of respondents identified overfishing as the single most important reason for declining fish catches. The proportion of respondents identifying use of destructive gears (e.g. monofilament nylon nets, small-mesh size nets) and river pollution was 25 per cent and 22 per cent respectively. About 14 per cent of fishers reported that siltation and river erosion were key reasons for declining fish catches. Only 11 per cent of fishers identified human encroachment, including urbanization and infrastructure development (i.e. bridge construction, sand extraction, tourism, housing) to be the most important reason. Collectively this array of factors has exerted extreme pressure on the aquatic environment and associated biodiversity.

According to the survey, the highest number of fish species (39) caught was recorded during the post-monsoon season and the lowest (12) in the pre-monsoon season. The number of species caught was 23 and 35 in the dry and monsoon season respectively. The highest number of fish species (22) was caught by current net (officially banned), followed by seine net (20), push net (17), cast net (16), lift net (15) and drag net (13), while the lowest number was by trap (6). Nets were found to be quite effective in catching various sizes of fish species. Considering the variety of species caught in nets, these are regarded as multi-species gear. Traps are considered a selective gear with which to target SIS. Stick hook was found to catch a modest number of small sized fish species (11), while hook and line was used to catch a slightly larger number of species (14) of various sizes, including catfish.

Socio-economic conditions of fishers

Income of fishers

Fishers tend to sell their catches on reaching landing centres. Around 25 per cent of catches were sold directly to local consumers including residents on the west bank, while the remainder (75 per cent) were sold in fish markets located in Mymensingh town. Fishers that sold their catch on the west bank reported that selling fresh fish to local residents fetched a higher price and avoided marketing costs. The average price of fish sold by fishers was estimated at USD 1.17[4] per kg, ranging from USD 0.86 to 1.48 per kg. Fish prices depend on species, quality, size and weight, seasonality, supply and demand, and volume of fish.

According to the survey, the average daily net income from fishing (including sales and consumption) was calculated at USD 1.24, varying from USD 1.40 for professional fishers to USD 1.19 for seasonal and USD 1.11 for subsistence fishers in 2009 (Table 2). There was a significant difference ($p<0.01$) in annual income from fishing among categories of fisher. Based on fishing, the average annual net income was calculated at USD 276, varying from USD 407 for professional fishers to USD 213 for seasonal and USD 208 for subsistence fishers. According to the survey, on average 90 per cent of the total annual income for professional fishers originated from small-scale fishing, while it was 55 per cent and 40 per cent for seasonal and subsistence fishers respectively.

All surveyed fishers claimed that their income had decreased because of declining catches. Fish catches are perceived to have declined by an estimated 34 per cent over the last decade (Figure 2) while increased market prices for fish have not compensated for this decline. According to the fishers, fish prices had increased by an average of 31 per cent over the preceding decade.

Table 2. Income from small-scale fishing by category of fisher.

Income from fishing	Professional (n = 39) Mean ± SD (Median)	Seasonal (n = 21) Mean ± SD (Median)	Subsistence (n = 12) Mean ± SD (Median)	Kruskal-Wallis test H statistic
Fish catch (kg/day/fisher): F	1.31 ± 0.53 (1.10)	1.11 ± 0.44 (1.00)	1.02 ± 0.29 (0.95)	3.32
Market price (USD/kg): P	1.17 ± 0.14 (1.10)	1.16 ± 0.13 (1.20)	1.18 ± 0.15 (1.20)	0.20
Gross income (USD/day/fisher): G = F × P	1.53 ± 0.67 (1.29)	1.29 ± 0.58 (1.20)	1.20 ± 0.41 (1.14)	2.91
Fishing and marketing costs (USD /day/fisher): C	0.13 ± 0.07 (0.13)	0.10 ± 0.06 (0.10)	0.09 ± 0.05 (0.10)	10.07***
Net income (USD/day/fisher): N = G − C	1.40 ± 0.33 (1.16)	1.19 ± 0.27 (1.10)	1.11 ± 0.24 (1.04)	2.28
Annual fishing days/fisher: D	291 ± 34 (295)	179 ± 27 (187)	187 ± 31 (193)	53.02***
Annual net fishing income (USD/fisher): N × D	407.40 ± 46.71 (354)	213.01 ± 23.57 (203)	207.57 ± 35.42 (205)	22.37***

n: sample size of fishers.
SD: standard deviation.
Figures in parentheses indicate median values.
*** = Significant at 1% level (p<0.01).

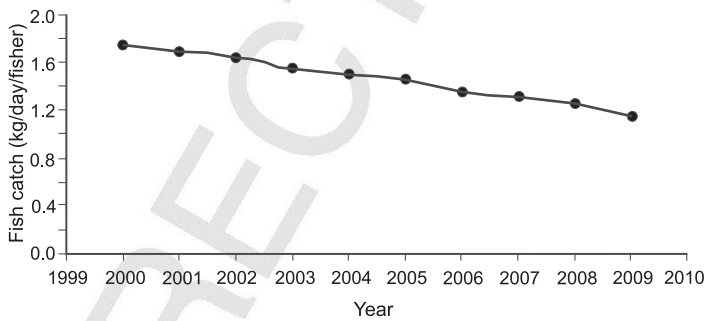

Figure 2. *Perceived trend in fish catches in the Old Brahmaputra River study area.*

All fishers surveyed reported that small-scale fishing may contribute to poverty reduction at higher catch levels, especially as fish prices have increased considerably (i.e. at 3 per cent per annum) owing to population growth and a growing gap between supply and demand. Small-scale fishing has not generated desired levels of economic return for all groups but has arguably assisted those classified here as professional fishers in sustaining their livelihood. For seasonal fishers, fishing activities have prevented them from falling deeper into poverty as their fishing incomes often supplement wages received from labouring (on average USD 1.62 per day). Small-scale fishing provides a safety net for subsistence fishers when faced with a decline in income from non-fishing activities. According to ~~Bene~~ and Friend (2009), small-scale fishing can be a critical component of the livelihood strategies and source of income for local communities.

Social status and vulnerability context

Fishers are socially, economically and educationally disadvantaged. They lack access to financial resources and their households face various constraints (Table 3), most serious being their meager income. Regardless of classification, the average annual net income of a fisher was calculated at USD 276 from fishing (Table 2). Major fishing times occur during the monsoon and post-monsoon seasons, thereby limiting associated cash income to a relatively short period. Professional fishers engaged in the highest average annual number of fishing days (291), followed by subsistence (187 days) and seasonal (179 days) fishers (Table 1). Fishers reported that their incomes were spent on meeting basic needs such as food, clothes and household maintenance. However, the vulnerability[5] context has a major impact on household security and consequently on the ability to benefit from small-scale fishing. Fishers often require loans during crisis periods, such as illness and dowry payment when a daughter gets married. Credit facilities are very limited in the fishing community and only 17 per cent of fishers were able to access microcredit (USD 15–45 annually) from local NGOs with interest rates of annually.

Food insecurity is an important issue which most fishers attributed to meager incomes and rising food prices in recent years. According to key informants, food prices over the course of 2009 had increased by 10–15 per cent, resulting in many fishers living from hand-to-mouth, with limited capacity to recover from food crises. According to Lein (2009), fishing communities have been identified as the most food insecure, marginalized, vulnerable and poorest people in Bangladesh. 86 per cent of the fishers reported that their families could not have three full meals a day (usually two). Reducing the number of meals and switching to less desirable but cheaper food to conserve scarce resources are common coping strategies. Nevertheless, an important contribution of small-scale fishing to food supply is through consumption of their catch, although the percentage of catch consumed by households varies greatly. Households of professional fishers consume a lower proportion (10 per cent) of their catch, choosing to sell most of their catch and purchase cheaper foodstuffs. However, subsistence fishers eat most of their catch (80 per cent) and sell the surplus, especially large fish which fetch a higher price. Seasonal fishers tend to eat half their catch mainly small fish.

Most fishers surveyed (81 per cent) lived in very basic housing made of bamboo, mud and tree leaves. These houses are susceptible to storm damage and vulnerable to

with annual interest rates? or with interest rates of XX annually? RESPONSE: With interest rates of 10-15% annually.

Table 3. Major constraints faced by fishing households (multiple responses).

Constraint	Professional (n = 39)	Seasonal (n = 21)	Subsistence (n = 12)
Poor income	39 (100%)	20 (95%)	11 (92%)
Shortage of food	35 (90%)	18 (86%)	10 (83%)
Climate change (flood, cyclone)	30 (77%)	15 (71%)	8 (67%)
Illness of fisher	20 (51%)	10 (48%)	6 (50%)
Procure drinking water	12 (31%)	7 (33%)	4 (33%)
Children education	9 (23%)	5 (24%)	3 (25%)
Scarcity of cooking fuel	7 (18%)	4 (19%)	2 (17%)
Lack of infrastructure	5 (13%)	3 (14%)	2 (17%)
Social conflict	4 (10%)	2 (10%)	1 (8%)

n: sample size of fishers.
Figures in parentheses indicate percentage of responses.

flooding. Likely impacts of climate change, including the increased incidence of floods and cyclones pose a serious threat to fishing communities. Almost every year in recent decades, the Brahmaputra River has flooded adjacent areas for periods ranging from a few weeks to several months. According to key informants, flooding has many causes including heavy rainfall, limited river flow capacity and geographical position. Because of its location just south of the Himalayan foothills, Mymensingh receives the second highest average annual rainfall (2174 mm) in Bangladesh after Sylhet (4180 mm) (Islam, 2011). Surveyed fishers reported that heavy rain and cyclones often restrict fishing days. Floods periodically destroy crops grown on char lands and every year the Brahmaputra floods leave many char dwellers homeless.

Members of fishing households face severe health and sanitary problems with no medical support. Members of fishing families often suffer from diarrhoea, cholera, dysentery, malnutrition, skin diseases and mosquito-borne diseases including dengue fever and malaria. 63 per cent of fishing households rely on polluted river water for bathing and washing clothes and dishes, and household members experience rashes and itching. Disease outbreaks are quite common among fishing communities owing to overcrowded and contiguous living conditions and a general lack of sanitation. Fishing families often cannot access fresh drinking water (reported by 32 per cent of fishers) because of poor tube well facilities and consequently women have to walk long distances to procure drinking water. A few fishers (10 per cent) reported that arsenic is a common problem in drinking water. During field visits, arsenic-related skin disease was reported by fishing families, including women and children.

Fishing families struggle to provide an adequate education for their children. Most fishers (76 per cent) reported that they did not see any value in educating their children. Rather, they send them to fish or engage in other supplementary activities to obtain additional income. Children of fishers were, however, interested in going to school and noted there are primary schools on the other side of the river. Some fishing families (18 per cent) face severe problems owing to a scarcity of cooking fuel and most households are forced to use cow dung, paddy straw, tree branches and dry leaves which are inefficient and pose health risks. Livestock rearing is difficult on char lands for fishing families because of the shortage of fodder (i.e. paddy straw). All surveyed fishers reported that cattle raising by the households had declined by 25 per cent over the last decade, resulting in decreased availability of cow dung, milk and meat. Some fishing families (15 per cent) reported a lack of infrastructure as a major constraint and they cited lack of access to electricity, roads, communication and recreational facilities. Only a small number of fishers (10 per cent) have radios, which are used for recreational purposes (e.g. listening to folk songs and news). Owing to widespread illiteracy, newspapers are not read by many fishers, but gathering at village tea stalls is a common recreational activity for fishers and a source of news and information.

Social conflicts including access to fishing grounds, possession of char lands, theft and dowry payments have been noted by 9 per cent of fishers as major constraints. Conflict can occur between professional and subsistence or seasonal fishers over access to fishing grounds. Conflict often intensifies when professional fishers are prevented from fishing in areas where people have fished for subsistence for generations. Disputed ownership of, and control over char lands have been dominant themes in the study area, at times leading to violent conflict. According to Lein (2009), riverine communities have long been portrayed as frontier societies characterized by violent conflicts over control of fisheries resources.

Ecological river features

The Old Brahmaputra River was an ecologically healthy river, robust and rich in biodiversity (Smith *et al.*, 1998; Rahman *et al.*, 2002). There is overwhelming evidence, however, that past and present human activities have affected the ecosystems of the Old Brahmaputra River. According to key informants, activities such as urbanization, human encroachment, tourism, bridge construction, pollution and siltation have caused significant ecological concern.

Fishing can have profound effects on river ecosystems (Coll *et al.*, 2006; Smith *et al.*, 2011). According to questionnaire interviews, however, the majority (72 per cent) of fishers believed that small-scale fishing was not harmful to the river ecosystem; their argument was that they had been fishing for decades. Nevertheless, the remaining respondents (28 per cent) acknowledged that small-scale fishing could impact negatively on the river ecosystem when destructive gears are used or overfishing occurs. Over-exploitation has been reported by respondents as a major reason for the decreasing availability of fish over the years resulting in severe consequences for artisanal and commercial fisheries. Excessive fishing has negative impacts on the river ecology, thereby affecting feeding and breeding grounds for many commercially and ecologically important species, potentially undermining the basis for capture fisheries (Ahmed & Troell, 2010).

Intensive fishing constitutes a threat to the aquatic biodiversity and conserving fish species in the river is a constant struggle. For example, intensive fishing has resulted in physical destruction of nursery grounds (Ahmed & Troell, 2010). The Old Brahmaputra River was once famous for Indian major carp seed collection (Rahman *et al.*, 2002) but this is now threatened. Larger fish have declined or even disappeared because of prolonged fishing with destructive gears. Fishers also reported a lower abundance of broodstock in the river and this has probably compounded declines in capture fisheries and biodiversity. The present study reveals that only 42 species were recorded. Almost all fishers surveyed reported that the abundance of commercially and ecologically important species had declined by 35–40 per cent over the past decade. Excessive removal of ecologically important species may lead to serious problems for long-term fisheries development. Biodiversity loss has negative implications with regard to the resilience of riverine environments as species-rich communities are understood to support more stable ecosystems (Schindler *et al.*, 2010).

A further ecological problem identified by the fishers was pollution. The activities of over 550 000 people in Mymensingh town have affected the Old Brahmaputra River ecosystem, leading to problems with water quality and significant reductions (around 20 per cent) in aquatic biodiversity. The main pollution problem is associated with excessive nutrient loads entering the river, mainly from municipal sewage, household waste and street drainage which are not adequately treated. According to key informants, solid waste, organic matter, metals, acidifying compounds and nutrients leach into the river as a consequence of land use practices and point source loading within a drainage basin. These substances can cause significant changes in the aquatic environment and oxygen balance of the river (Kallenborn, 2006), and in turn impact on the composition of aquatic species, including planktons, benthos, plants and animals. Primary production of rivers differs significantly with oxygen level, surface temperature and wind, and has profound effects on the food web (Pauly *et al.*, 1998; Coll *et al.*, 2006).

Study findings suggest that rapid urbanization, river erosion, siltation and human encroachment have affected the river ecosystem. Urbanization has affected the physical

process of river growth, modified river structure and further influenced the functions of river ecosystems. According to key informants, the Old Brahmaputra River has dried up and lost navigability at many points because of river erosion and siltation. Dredging has been undertaken but only on a limited scale. Dramatic effects of human encroachment have been observed in the river ecosystems. Riparian systems are under increasing pressure as a result of community water use. According to community members, construction of the Bangladesh-China Friendship Bridge in 1991 fragmented adjacent aquatic ecosystems, reduced the water area and promoted char land formation. This resulted in adverse consequences for biodiversity, with migratory fish species reportedly being severely affected.

The Ganges river dolphin (*Platanista gangetica*), locally known as *shushuk*, was once widely distributed throughout the Old Brahmaputra River (Smith *et al.*, 1998), but has severely declined in recent years. Dolphins have been lost because of environmental degradation and human encroachment. According to the fishers and community members, construction of bridges and engineering works to protect river banks and housing development to the west have had a devastating effect on the river dolphin population. Many key informants reported that large-scale sand extraction was also responsible for their decline. Overfishing was also blamed for the decline in dolphins as fishers often block the river with gill nets, hindering their migration.

Noise pollution from mechanized boats used for transport and tourism is a growing problem of river ecosystems, causing distress to fish and wildlife. The study area of the Old Brahmaputra River has always been at the heart of the Mymensingh town and surrounding places are of interest to tourists. However, impacts on river ecosystems caused by tourist activities are far-reaching. Visitors, who are not concerned about the environment or fragile nature of the river ecosystem, unwittingly cause negative impacts. Tourism activities can disrupt fish breeding and nurturing behaviour, hampering recruitment and potentially affecting biodiversity. According to Pickering (2010), noise from visitors can have a detrimental effect on animal behaviour. Wildlife can be displaced or disturbed during critical breeding times. The study area of the Old Brahmaputra River was an important habitat for many species of wildlife, including birds, crabs, frogs, molluscs, oysters, snails and turtles. Fishers and community members reported that the abundance of wildlife had declined by 40 per cent over the past decade.

Sustainable fisheries management

Despite having access to the significant water resources of the Old Brahmaputra River, fishers have not improved their status owing to declining catches and the fragile state of the river ecosystem. Because of low incomes the socio-economic status and living conditions of fishing households remain poor, and many have become further impoverished and food insecure. A key characteristic of their vulnerability is that the situation is not under their control and it is therefore important to identify means by which the level of vulnerability can be minimized and resilience enhanced (Clay & Olson, 2008).

To improve the living conditions of fishing families and reduce pressure on the river ecosystem, strategies are needed for developing a sustainable fisheries management system. Such strategies must address the diverse socio-economic and ecological challenges faced by the fishing communities and problems affecting the riverine environment upon which their livelihoods depend.

The co~~-~~ncept of sustainable fisheries management links social, economic and ecological aspects of fishery systems (Cowx & Anrooy, 2010). We propose a conceptual

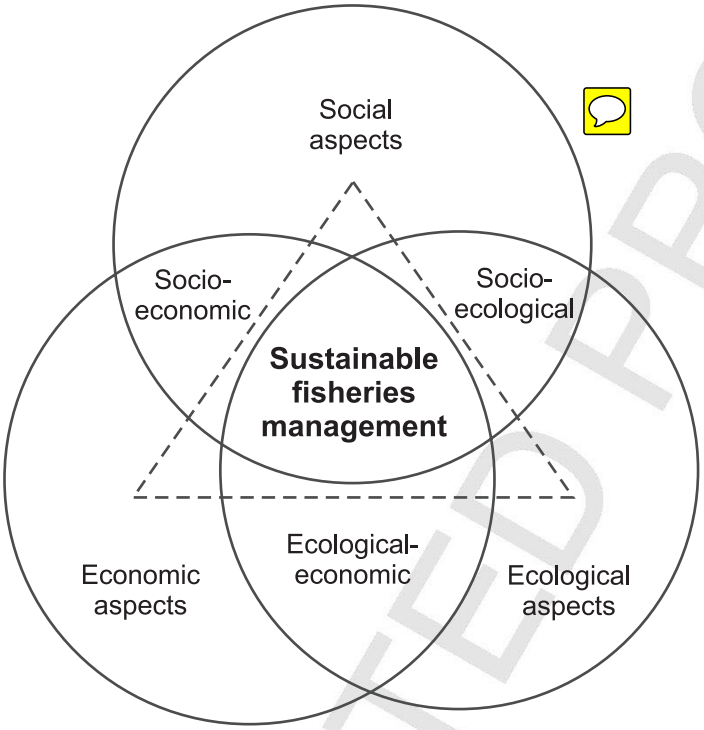

Figure 3. *A conceptual framework for sustainable fisheries management highlighting the need to assess and account for socio-economic, ecological-economic and socio-ecological interaction in sustainable fisheries management systems.*

framework for such a sustainable fisheries management system for the Old Brahmaputra (Figure 3). The ecological aspects here refer to the long-term condition of the river, including pollution, siltation and conservation of aquatic biodiversity. Economic aspects cover employment, income, fishing costs and fish marketing. Social aspects include livelihoods of fishers, social benefits and cultural factors. To implement a sustainable fisheries management system, interactions between these social, economic and ecological aspects must be understood and accounted for (Holling, 2001; Buchholz *et al.*, 2007).

Connections between the social, economic and ecological aspects are highlighted in Figure 3 and visualizing them in this manner appears to hold promise in terms of promoting understanding of the influence and importance of socio-ecological, ecological-economic and socio-economic interactions. Knowledge concerning these interactions will be critical in better managing fisheries, enhancing the conservation of ecological processes supporting fisheries, refining and reinforcing social mechanisms governing access to fisheries and equitably distributing economic benefits at multiple scales (Berkes *et al.*, 2000; Folke *et al.*, 2005). Mutually supportive linkages among these systems can bring benefits in terms of resource management, including community participation, social relations, institutional responsibility, governance and development planning (Jentoft, 2000; Garcia & Charles, 2008).

To manage river ecosystems sustainably, it is essential to have an understanding of social-ecological systems that is deeply interconnected across temporal and spatial scales (Folke, 2007). Robust socio-ecological systems can buffer against negative shocks and

trends, and consequently reduce vulnerability experienced by the fishing communities (Folke *et al.*, 2005). Socio-ecological thinking constitutes an integrated concept which emphasizes human-environment interactions for resource management (Berkes *et al.*, 2003), and social and natural linkages for small-scale fisheries management (McClanahan *et al.*, 2009). According to Garcia and Charles (2008), fishery systems are founded on human and natural linkages from which benefits such as food, income, employment and livelihoods are derived. Social-ecological resilience in the fishing context is determined by the livelihood security of fishers (Sneddon, 2000; Berkes *et al.*, 2003). In a social-ecological system of small-scale fishing, subsystems such as a resource system (fishing), resource units (river, fish), users (fishers) and governance systems (government, NGOs and community-based organizations) can interact to produce positive outcomes (Ostrom, 2009).

Conceptually, ecological-economics considers the full range of services and benefits that society derives from nature and aims to reconcile the interdependence of human economies and natural ecosystems (Armsworth & Roughgarden, 2001). In fisheries, ecological-economics encompasses payments for ecosystem services and the practice of offering incentives to fishers in exchange for managing their catchment area to maintain and enhance ecological services (Farley & Costanza, 2010). Thus, ecological-economics offers a practical approach to sustainable fisheries management, including income, food and livelihoods for fishers (Sneddon, 2000; BenDor *et al.*, 2009).

Socio-economic driving forces and pressures are important in fisheries management. Socio-economic issues are critical in decision-making and their potential contribution to better understanding of fisheries processes is significant (Garcia & Charles, 2008). In establishing a sustainable fisheries management system, it is essential to maintain a balance between social, economic and environmental benefits and costs to ensure attainment and continued satisfaction of human needs for the present and future generations. Such sustainable management conserves natural resources and improves people's quality of life within the context of environmental carrying capacity (Ostrom, 2009).

Three key components that can facilitate sustainable river fisheries management have been identified in this study: (1) policies and laws; (2) institutional collaboration; and (3) community participation (Table 4). Appropriate policies, legal instruments and enforcement can remove most of the aforementioned constraints to fisheries management. Although several policies have been devised by the Department of Fisheries,

Table 4. Strategies to promote sustainable fisheries management.

Component	Example
Policies and laws	• Pertinent government policies and implementation of regulations (control overfishing, ban item of current net) • Environmental protection (control pollution, siltation) • Conservation of fish biodiversity through establishing sanctuaries
Institutions	• Support services by government agencies, NGOs and private sector • Roles of Bangladesh Agricultural University and Bangladesh Fisheries Research Institute (research and monitoring for river management) • Training for fishers to enhance ability and willingness to participate in fisheries management
Community participation	• Community participation through formation of fishers' cooperatives • Active community participation for resource utilization and management • Community awareness for environmental protection (pollution, siltation) and maintaining river ecosystems

management of the riverine fisheries is still fraught with dilemmas regarding sustainable maximization of benefits, a situation that has been made worse by predominantly top-down policymaking (Valbo-Jørgensen & Thompson, 2007). According to key informants, fisheries regulations could be implemented to reduce fishing pressure. Moreover, restrictions on the use of destructive fishing gears (e.g. current net, small-mesh size nets) would help broodstock to survive and breed successfully, thus conserving fish biodiversity. Most key informants suggested that the establishment of fish sanctuaries can be an effective conservation measure for fish biodiversity. Restrictions on fishing in sanctuaries would help conserve resident species (Baird, 2006) and may result in spillover benefits for fishing communities.

A major constraint in managing open-water fisheries resources is the lack of environmental awareness and ecological knowledge among local communities (Craig *et al.*, 2004). We propose that government agencies, NGOs and the private sector working jointly would help to protect the river ecosystem. We suggest that strong collaboration between BAU and Bangladesh Fisheries Research Institute (both located near the Old Brahmaputra River) could make a significant contribution to promoting better management of river ecosystems in Bangladesh through collaborative projects and monitoring activities such as research, water pollution control, biodiversity conservation and sanctuary management. Providing training and technical support to fishers would enhance knowledge and improve management of the fisheries resources (Valbo-Jørgensen & Thompson, 2007).

The lack of community participation in fisheries management is a key factor that increases vulnerability and impoverishment for the fishers and their families. Active community participation is one of the best strategies for achieving sustainable fisheries management (Jentoft, 2000; Valbo-Jørgensen & Thompson, 2007). Therefore, we also consider that a community-based fisheries management system could be an important innovation to overcome the aforementioned socio-economic and ecological challenges constraining sustainable fisheries management in the Old Brahmaputra River. There are various ways in which community participation can be strengthened, including formation of fishers' cooperatives and involvement in various social and community-based organisations (Sultana & Thompson, 2007). Community participation is crucial in decision making processes for resource management as many regulations have not been well received or respected by poor fishers with limited livelihood options (Rab, 2009). Enforcement of fisheries regulations in relation to fishing with banned gear as suggested above could be implemented more effectively based on community participation. Community-based awareness programmes can contribute towards environmental protection (Colvin, 2002) and wider community participation would empower local communities to report and take action against river pollution.This is needed to conserve fisheries biodiversity. Furthermore interactive community participation is necessary to successfully establish and manage fish sanctuaries (Baird, 2006).

Conclusions

Fishers in the study area of the Old Brahmaputra River depend on small-scale fishing as a source of income and food, which varies according to their capacity to fish. However, some small-scale fishing activities are destructive leading to biodiversity loss and the decline of capture fisheries. Mechanisms are required to ensure benefits of enhanced management are distributed equitably among fishing communities to safeguard the long-term sustainability of their resource-base. A number of significant challenges,

spanning social, economic and ecological domains must be overcome before the anticipated benefits to fishing community and aquatic biodiversity are realized.

Livelihoods of fishers are vulnerable owing to declining catches resulting from overfishing, use of destructive fishing gears, environmental degradation, human encroachment, rapid urbanization, water pollution and siltation. Moreover, growing populations within fishing communities have increased fishing pressure which is threatening current income levels. Fishers are vulnerable to over-exploitation of the resource resulting in the loss of social, economic and ecological benefits that can be obtained from responsible fisheries exploiting common-pool resources.

It is important to acknowledge that open-access to fishing grounds has been critical in permitting fishers to engage in professional, seasonal and subsistence level fishing. The challenge remains, however, concerning how to increase the contribution of small-scale fisheries to poverty reduction and increased food security for fishing communities.

To implement a sustainable fisheries management system, the interacting social, economic and ecological aspects must be taken into consideration. Therefore, any effective management strategies must jointly control over-exploitation of the resource, protect the river ecosystem and conserve fisheries biodiversity. Hence, a combination of socio-ecological, ecological-economic and socio-economic approaches to fisheries assessment and governance must be included in management strategies as highlighted in this study. In addition to effective implementation and enforcement of legal instruments and strong institutional collaboration, active community participation in the management of the resource base will be crucial in ensuring the long-term sustainable use of fisheries resources.

Endnotes

1 River fisheries in Bangladesh are characterized as 'open-access' and 'common-pool resources'.
2 Terms such as small-scale fisheries, subsistence, traditional and artisanal are often used interchangeably (Sowman, 2004). According to Food and Agriculture Organization (2005), small-scale fisheries are similar to artisanal fisheries, referring to households who catch fish for a living, as opposed to large commercial activities.
3 Chars are new land formed through the continual process of erosion and deposition in the rivers.
4 USD 1 was equivalent to the Bangladesh unit of currency Tk 68 in December 2009.
5 Vulnerability is the degree to which fishing communities, supporting aquatic resources, fishing systems and social, cultural, economic and environmental activities are susceptible to shocks and negative trends (Clay & Olson, 2008).

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