Mud crab fishery in climate vulnerable coastal Bangladesh: an analysis towards sustainable development

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ABSTRACT

Developing countries are far more vulnerable to climate change impacts than industrialized countries. Most of the world's poor live in South Asia where they have limited livelihood options that have become even narrower in recent years, indicating a need for alternative income-generating options. Mud crabs (*Scylla* spp.) are considered to have promising prospects in different parts of the world including Bangladesh, a well-known region for its vulnerability to climate change. At present this fishery has become a growing venture in coastal Bangladesh, primarily due to the potential of the export market and availability of

seed locally. This study included a calculation of the Human Development Index linked to mud crab fishery (HDIMCF) and a SWOT (strengths, weaknesses, opportunities, and threats) analysis to clarify the present status of and strategic directions for the mud crab fishery, for the first time. Results revealed an intermediate level of development of mud crab aquaculture, indicating potential alternative livelihood opportunities for vulnerable coastal communities. The SWOT analysis revealed that positive factors, both internal (strengths) and external (opportunities), predominate over negative factors (weaknesses and threats) and that the fishery can be an alternative livelihood option for vulnerable coastal communities. Despite noticeable diversification of the mud crab fishery, dependence on wild seedstock and possible over-exploitation in the wild appear to constrain sustainable development of the fishery. This study's findings suggest undertaking immediate wild crab stock assessment for determining current status of wild populations. Moreover, modification of the Government of Bangladesh's existing mud crab policy is needed to better meet growing demand and sustainability of the fishery. Recommendations of this study may be of help in guiding responsible integrated coastal fisheries management and policy.

Keywords: Mud crab aquaculture, *Scylla* spp., climate change, HDI, HDIMCF, SWOT, conservation, coastal Bangladesh, coastal management policy

1. INTRODUCTION

Coastal communities are particularly vulnerable to climate change impacts, especially those in developing countries (Hoegh-Guldberg and Bruno 2010; Chinowsky et al. 2011; Barbier 2015). About 38% of the world's population lives in coastal areas (UNEP, 2014) of which over three quarters (1.9 billion) are in developing countries (Barbier 2015) with relatively poorer capacity of mitigating climate change impacts (Chinowsky et al. 2011). South Asia, particularly known for its vulnerability to climate change, supports the largest poor rural populations of the world with the highest rate of infant mortality (40 million in South Asia) and malnourished children (35 million); Bangladesh ranked within top two countries on these lists (Barbier 2015). Livelihood options are limited and primarily depend on fishing, aquaculture, agriculture and manual work as daily labourers (Tobey and Torell 2006; Paul and Routray 2011). In recent times, livelihood options have become even narrower due to climate change impacts. For example, salt water intrusion has adversely affected the agricultural cropping and livestock in 105.6 million ha areas of coastal Bangladesh, reducing up to 92% of cropping areas in some locations (Chowdhury et al. 2011; Mahmuduzzaman et al. 2014; Alam et al. 2017; Hoque et al. 2018). Salinity intrusion in coastal areas has increased about 26% between 1973 and 2009 (Mahmuduzzaman et al. 2014; Alam et al. 2017). This impact exemplifies the need for alternate livelihood options for vulnerable communities, toward improved resilience and maintenance of socio-economic status.

The utilisation of mud crab has been commercially practiced for many years in different parts of the world including South and Southeast Asian countries (Overton and Macintosh, 1997). In recent times the global demand for commercial exploitation of mud crab fisheries and aquaculture has rapidly increased and is expected to continue to increase (Azra and Ikhwanuddin 2016; Hungria et al. 2017). In 2015, the world production of mud crabs was roughly 226,390 metric tons with a farm-gate value of US$1.06 billion (FAO 2015). Currently four species of mud crabs, *Scylla serrata*, *S. olivacea*, *S. tranquebarica,* and *S. paramamosain* are considered economically valuable and common in aquaculture in different parts of the world (Keenan and Blackshaw 1999; Allan and Fielder 2003). The commercial market for crabs is driven by different forms of the product including live, chilled, frozen, and processed (Hungria et al. 2017).

In nature mud crabs are widely distributed in the Western Indo-Pacific (Keenan et al. 1998; Macintosh et al. 2002) and abundantly found in Bangladesh's southwest coastal waters including the Sundarbans mangrove forests and adjacent areas (Chandra et al. 2012). The coastal environment of Bangladesh can potentially be utilised for capture, culture, and trade of mud crabs (Islam et al. 2015; Hussain et al. 2018) especially *S. serrata* (Saha et al. 2000).

Crabs have been harvested from the Sundarbans and its surroundings for several decades for export and, as juveniles, to be reared in brackish water ponds with the aim of exporting them when they reach a suitable size. In Bangladesh, the export of crabs to international markets first started in 1977–1978. Since 1982 crab export has been solely based on harvest from the wild (Rahman et al. 2017). Farming mud crabs, primarily entailing fattening, has gained popularity since the mid-1990s (Azam et al. 1998), while other forms of crab culture (e.g., cage culture, pen culture and polyculture) started in 2000s (Khatun et al. 2009). Currently crabs are being produced in 27,010 ha of coastal ponds in Bangladesh (FRSS 2017).

The mud crab fishery can potentially offer a wide range of economic options to stakeholders, as a source of income, nutrition, and livelihoods for vulnerable people of coastal Bangladesh, a well-known region for its vulnerability to climate change (Molla et al. 2009; Rahman et al. 2017). Although crab farming is an economically promising activity, industry development is constrained by inadequate research focused both on the mud crab fishery and biology of species. Therefore, this fishery remains relatively undeveloped in coastal Bangladesh, and is in need of comprehensive planning and strategic decision-making toward its sustainable growth and development. Despite an earlier socio-economic study of the mud crab fishery to determine its contribution to coastal communities (Istiak 2018), no such studies, to the best of our knowledge, have yet been carried out.

The SWOT analysis is a simple, flexible, and effective tool to inform the preliminary stages of decision making and as a precursor to long-term strategic planning in various disciplines (Johnson et al*.* 1989; Bartol and Martin 1998; Chermack and Kasshanna 2007) including marine and freshwater sciences (Stead 2005; Panigrahi and Mohanty 2012). The SWOT analysis can be broadly utilised in evaluating internal (strengths and weaknesses) and external (opportunities and threats) factors by gathering opinions from relevant key stakeholders of a particular sector (Coman and Ronen 2009; Helms and Nixon 2010). Such an examination of internal and external factors can assist in shaping the future of a sector of interest (Çelik et al. 2012) including aquaculture (Garza-Gil et al. 2009; Rimmer et al. 2013). In this study, the SWOT analysis can help identify the embedded and anticipated issues of the mud crab fishery of coastal Bangladesh, for the first time, that are likely to influence its sustainable development.

2. METHODS

2.1 Study sites

The study was carried out in three coastal districts: Satkhira, Khulna, and Bagerhat (21°43′ to 22°57′ N and 88°56′ to 89°55′ E) of southwest Bangladesh where the mud crab fishery is primarily based (Figure 1) and are also well-known areas for vulnerability to climate change impacts. Various activities of the mud crab fishery --including wild crab collection, crab fattening, grow-out culture, soft-shell crab production, processing, transportation and marketing—contribute to a harvest of more than 70% of the total mud crabs in the country (Istiak 2018).

2.2 Identification of stakeholders and socio-economic survey

The mud crab fishery stakeholders are those individuals or groups who depend on the fishery to fulfil their livelihoods or vice versa, on whom the fishery depends (Johnson and Scholes 1997). Different heterogeneous groups of fishery stakeholders (wild crab collectors, crab fatteners, *farias* [mid-level participants in the marketing channel who buy crabs from collectors/farmers], depot holders, suppliers, transporters, input suppliers, exporters, service providers etc.; Figure 2) in the study areas were identified by visiting in person.

Members of the two major groups of stakeholders – crab collectors (fishermen engaged in catching wild crabs; N = 75, 25 from each of the three districts) and crab farmers (who rear wild crab in coastal ponds for the purpose of crab fattening, grow-out, and soft-shell production; N = 150, 50 from each district) – were interviewed with a semi-structured survey to obtain information of their socio-economic profile and interaction with the mud crab fishery. In addition, 15 focus group discussions (FGDs), five in each sampling district, were also organised with mud crab stakeholders. We conducted outcross-check interviews with several key informants (KI) including three Fisheries Officers, five NGO personnel, and five fisheries researchers with relevant expertise. Socio-economic data were subjected to simple descriptive analysis.

2.3 Human Development Index linked to mud crab fishery (HDIMCF)

The Human Development Index (HDI) was developed to prioritise people and their capabilities for assessing the development of a country, and was not based on economic growth alone. In this study, we linked HDI to the mud crab fishery of the study area. To calculate HDIMCF, we used a slightly modified formula of Germain et al. (2015) to better suit our study due to the similarities in business venture and community concerned between studies. However, the HDI formula adopted by Germain et al. (2015), where three sub-indices (Economic Index, Schooling Index, and Health System Index) were considered, was originally a modification of the initial HDI formula proposed by the UNDP (2010). In our study, we replaced the Health System Index by the Life Expectancy Index of the original HDI

155 formula in order to obtain the HDIMCF value. This is because Germain et al. (2015) used
156 'health insurance' data for calculating the Health System Index, but none of our respondents
157 had health insurance.

158 HDIMCF = 0.5 (EI) + 0.1 (SI) + 0.4 (LEI)

159 Where EI = Economic Index, SI = Schooling Index, and LEI = Life Expectancy Index.

160 The EI carries more weight than the educational and health indices because quality
161 education and health supports are not possible without sufficient financial resources (after
162 Germain et al. 2015). The equations for calculating EI, based on the average, maximum, and
163 minimum monthly income, and SI, based on average, maximum, and minimum schooling
164 year, are available elsewhere (see Germain et al. 2015 for details). However, instead of
165 incorporating estimated income data, as used by Germain et al. (2015), we used wild mud
166 crab collectors' and crab farmers' actual monthly income generated from the crab fishery,
167 obtained during socio-economic surveys. For LEI, the following equation was used: (72 – 20)
168 / (85 – 20) as the HDI measures life expectancy from 20 to 85 years and the mean life
169 expectancy at birth in Bangladesh is 72 years. The HDIMCF was expressed within a range
170 from 0 to 1 and classified as low (0.000 – 0.499), medium (0.500 – 0.799), and high (0.800 –
171 1.000) human development for the HDIMCF (Germain et al. 2015).

172 **2.4 SWOT analysis**

173 A comprehensive participatory workshop was organised in September 2017 for screening
174 potential, prospects, status, and sustainability of the mud crab fishery (Chambers et al.,
175 1989) with 34 participants belonging to various stakeholder groups. Informative
176 presentations provided an overview of the mud crab fishery sector including primary data
177 generated from field, followed by detailed discussion of nuances of the fishery.
178 Subsequently, the participatory SWOT analysis was facilitated around clustered issues by
179 group work, followed by classifying and consensus-building for the identification of specific
180 strengths and weaknesses, as well as the identification of specific opportunities and threats
181 of the sector (Nouri et al. 2008; Helms and Nixon 2010). During the SWOT analysis,
182 representatives of all stakeholder groups were organized to maximize their chances of
183 contribution toward a list of relevant economical, ecological, and societal issues of the mud
184 crab fishery. The list will form a basis for further implementation of the study results (after
185 Mollenhorst and de Boer 2004).

186 After the identification of internal and external factors, a prioritization process was done by
187 evaluating their positive and negative contributions to the fishery. Internal factors include

strengths and weaknesses and were weighted on a scale ranging from 0.01 to 1.0 (least important to most important) such that the sum of these weights are equal to one (after Nouri et al. 2008; Ommani 2011). An individual rating, ranging between 1 and 4, was allocated to each of the factors where rate 1 represents severe weakness, 2 denotes common weakness, 3 shows common strength, and 4 represents vital strength. The score for each of the factors, determined by multiplying the weight by the rate, represents the importance of the corresponding factor. However, a total score of less than 2.5 for all the effective factors represents that weaknesses are more prevalent than strengths and a total score of more than 2.5 indicates that strengths dominate over weaknesses (Nouri et al. 2008). External factors, consisting of opportunities and threats, were also evaluated as mentioned earlier. The fishery is able to rely on its most important strengths towards well-being for the sector (Jurevicius 2013).

3. RESULTS AND DISCUSSION

3.1 Socio-economic conditions of mud crab collectors and farmers: Human Development Index linked to the mud crab fishery (HDIMCF) in southwest Bangladesh

The mean (± SD) age of crab collectors and farmers were 34.6 ± 9.1 (range: 16 – 59) years and 36.7 ± 9.7 (range: 24 – 56) years, respectively. Although a majority of crab collectors and farmers (~70 – 75%) were men, a considerable portion of the total respondents of both communities (~25% crab collectors and ~30% crab farmers) were women. This represents greater involvement of women in crab farming than in fisheries and aquaculture worldwide (~14%; FAO 2018) and in other forms of agriculture production in Bangladesh (3.85% in crop cultivation; Mamun-ur-Rashid et al. 2017). Most respondents were married (77–80%) with a small proportion that were single, widowed, or divorced (Table 1).

A majority of the crab collectors (78.7%) and crab farmers (64%) were Hindus followed by Muslims and Christians (Table 1) which is a common trend among fishing communities in Bangladesh (Islam et al., 2013). Crab collection or farming was not the only income generating activities of the respondents in the study area, as 65% of crab collectors and 58.7% of crab farmers had secondary occupations (Table 1). The land holding status of crab farmers was slightly greater than that of crab collectors, with about 80% of wild crab collectors owning 0–4000 m^2 of land and about 80% crab farmers owning 2000–6000 m^2 (Table 1). Similar findings were also noted when income was considered, in that crab farmers earned more than crab collectors. Several sources of finance were identified in the study areas but interest rates for loans were high, except for government banks, as reported by respondents.

The Economic Index (EI) of crab collectors was comparatively higher (0.58) than crab farmers (0.49) (Table 2) reflecting, for both collectors and farmers, a moderate income-level that affects HDIMCF and is scored as 'medium' by HDI standards (Germain et al. 2015). This state was also reflected by their income, land holding status, and standard of living (Table 1). The monthly income varied between low to moderate (8700–32000 BDT; ~85 BDT = 1 US$ in 2020) levels for both crab collectors and farmers. Participants reported that about 70–100% of their income was generated from the mud crab fishery.

For Schooling Index (SI), scores for both crab collectors and farmers were classified as 'low' by the Human Development Index (Germain et al. 2015). Education level was higher among crab farmers as compared to crab collectors; 17% of crab collectors had no schooling background (Table 1). Poor education of the crab collectors was also reported earlier in Bangladesh (Molla et al. 2009) and reflects a similar situation all over the country. This is primarily the result of early engagement in an economic activity to assist the household economically. Despite having a desire to go to school or pursue higher education, as mentioned by all the respondents, it was not possible due to lack of financial support. However, respondents expressed their desire to send their children to school and to encourage them towards literacy. Eventual improvements in the literacy of farmers' and collectors' children can play a significant role in increasing the HDIMCF in the near future.

Life Expectancy Index values were found to be the same for both stakeholder groups because life expectancy at birth in Bangladesh was the same for both groups, at 72 years. The HDIMCF was similar for both crab collectors and crab farmers (Table 2). Respondents reported few serious health issues, as crab collectors (16%) and crab farmers (14%) did not suffer from any common diseases over the year whereas a majority of them (74.7% and 26% for crab collectors and farmers, respectively) suffered from gastritis (Table 1). Respiratory problems were more common among crab collectors (41.3%) than crab farmers (15.3%) and this could be attributed to the frequent fishing trips by the crab collectors to mangrove areas, often for several days, which exposed them to cold. Irregular meals during these fishing trips also make them susceptible to gastritis. However, treatments for their ailments were not optimal, as almost two-thirds of collectors and more than one-third of farmers reported that they received care from village doctors who had no formal medical training. Although a considerable number of respondents went to the Upazila Health Complex, these facilities are not especially well-equipped and proper health care is seldom received by the patients (Aldana et al. 2011; Toufique and Yunus 2013; M.M. Rahman, per. obs.).

3.2 Internal factors of the mud crab fishery

Evaluation of internal factors, focusing on both strengths and weaknesses of the mud crab fishery in southern Bangladesh, revealed that a range of factors can affect this fishery (Table 3). However, strengths dominated over weakness as the sum of score of all the factors was more than 2.5.

3.3.1 Strengths

Among strengths, high demand and price of mud crab scored the highest (0.36) followed by local availability (0.32), high tolerance to environment and diseases (0.28), and other factors (Table 3).

3.2.1.1 High export potential and price

In Bangladesh, the mud crab fishery is primarily an export-oriented venture (Chandra et al. 2012; Ferdoushi and Xiang-Guo 2013). High demand from international markets (Azam et al., 1998) continues to play a key role in developing the mud crab fishery in southern Bangladesh (Marichamy and Rajapackiam 1999; Rahman et al. 2017). The mud crabs are among the most popular and costly seafood in Southeast Asia (Pripanapong and Tongdee 1998) and elsewhere. Although all exportable forms (crab meats as a value-added product and frozen soft-shelled mud crab) are in high demand, live and soft-shell crabs command premium prices in export markets (Wickins and Lee 2002; Hungria et al., 2017). This helps people involved in the mud-crab value chain to obtain a high price, as recognised by all participants of this study.

3.2.1.2 Mud crabs are available locally in the wild

Though not yet extensively investigated, 28 crab species have been reported in coastal Bangladesh (Ahmed 2008) of which several species belonging to genera *Scylla, Portunus, Charybdis, Matuta, Varuna* and *Sartorina* are reported to be used for human consumption (Shafi and Quddus 1982). However, *Scylla serrata*, commonly available in the Sundarbans mangrove forests and associated coastal water bodies, is considered the most important in the country because of consistently high demand for this species in export markets. If properly managed, maximum sustainable yield could continuously be harvested from the wild to support the mud crab fishery in Bangladesh.

3.2.1.3 High tolerance

Because of high tolerance to environmental parameters and diseases, mud crab emerges among the fittest candidates for coastal aquaculture in Bangladesh. They are considered to be remarkably climate adapted and highly tolerant of salinity and temperature variation,

capable of surviving in salinities from 2–50 ppt and living in temperatures from 12–35^{o}C (Bhuyian and Islam 1981; Le Vay et al. 2001). Bangladesh is one of the most climatically vulnerable countries in the world (IPCC 2007) and its low lying coastal regions are extremely vulnerable to and affected by climate change impacts, e.g., hot summers, with increased salinity in soil and water; destructive storms and flooding (Rachel 2002). Regarding disease susceptibility, mud crabs have distinct advantages over widely cultured shrimp and prawn species (primarily *Penaeus monodon* and *Macrobrachium rosenbergii*) because shrimps are susceptible to infectious diseases including viruses in these environmental conditions, and if affected, complete mortality is common (Karim and Stellwagen 1998; Ali et al. 2016; M.M. Rahman and T. Pervez, per. obs.). Various conditions including contamination of shrimp, fraudulent inclusion of materials to increase weight, and presence of chemicals often result in export bans and complete loss of investment (Rahman et al. 2017). Eventually, many shrimp farmers are likely to shift to mud crab farming as crabs are currently less susceptible to disease and comparatively more resistant and adaptive to adverse aquatic conditions (Zafar et al. 2004; Islam et al. 2015).

3.2.1.4 Short cropping cycle

Mud crab culture, primarily crab fattening, has been practiced in coastal Bangladesh for about 25 years (Rahman et al. 2017). Year-round short cropping cycles of crab-fattening are common in all the study areas, adding flexibility and profit for farmers as compared with other aquaculture practices (e.g. finfish or shrimp culture) with longer cropping cycles (Ferdoushi and Xiang-Guo 2010). However, in crab fattening, 8 (in crab juvenile fattening, both sexes) to 18 (in fattening of unripe female crabs) crops can be harvested a year which is 5–15 times higher than other aquaculture species in Bangladesh. Growth rates of mud crab are relatively strong; crabs can reach a size of 300–400 g in 3 to 5 months (Johnston and Keenan 1999). It is also possible to culture mud crab with little or no capital, and without supplemental feed (Johnston and Keenan 1999; Rahman et al. 2017).

3.2.1.5 Diversified culture systems

Different culture technologies of mud crab are available, offering potential farmers flexibility in choosing among a variety of approaches. Culture strategies include fattening of mud crabs, as traditionally practiced in the study areas, along with grow-out farming (Azam et al. 1998; Rahman et al. 2017). In recent times, soft-shell crab production has been introduced and is gaining popularity in coastal Bangladesh; soft shell mud crabs command high prices and are believed to have strong potential for mass culture and business development

(Rahman et al. 2018). Apart from monoculture, polyculture is also possible together with tilapia and other finfish species in coastal ponds.

3.2.1.6 Alternative livelihood option

The marginalised coastal communities of Bangladesh are more vulnerable to climate change impacts due to their dependency on natural resources and lack of alternative livelihoods (Bauman 2002; Ellis and Allison 2004; ESPASA 2008). The mud crab fishery offers a potential source of financial security for maintaining livelihoods by providing a new source of income (Mirera and Mtile 2009; Rahman et al. 2017; Hussain et al. 2018), especially when other options (mostly shrimp farming) experience reduced production and when there are environmental and other challenges in coastal areas (Johnston and Keenan 1999; Chowdhury and Muniruzzaman 2003; Karthik et al. 2005; Islam and Bhuiyan 2016). Viral disease outbreaks in shrimp farms in 1995–96 led to reduced interest in coastal shrimp farming in Bangladesh (Karim and Stellwagen 1998) but fattening of wild-sourced mud crabs by some shrimp farmers showed hope as an alternate option for income. This fishery has recently emerged as an important component of coastal livelihoods offering employment and income opportunities (Salam et al. 2005; Rahman et al. 2017; Hussain et al. 2018) supporting more than 300,000 fishers, traders, exporters, and transporters (Islam et al. 2015). This range of positive economic prospects, in combination with inherent biological characteristics and favorable potential for human nutrition, suggest that improved coastal livelihoods are likely to result from the development of the mud crab fishery in Bangladesh. This integration of the commercial mud crab fishery into coastal ecosystem-based management (EBM) can potentially improve the resilience and adaptive capacity of poor and vulnerable fisher folks as they adapt to the impacts of climate change (Haq et al. 2015).

3.2.1.7 Simple culture technique

Mud crab culture technology is straightforward and requires a minimum of technical knowledge, skills, and investment when compared to other established aquaculture species (e.g. finfishes and tiger shrimp) in the study areas. Feeding is one of the major costs of any aquaculture operation including crab culture (Cholik 1999) though mud crabs can be fed with low-valued locally available freshwater and marine fishes, snails, poultry entrails, eels, and shrimp byproducts (e.g., heads) produced locally in culture systems. While at this time, respondents did not indicate that feeds were a significant negative, crustacean culture requires high protein feeds, which will be costly no matter the source. Presently the cost of crab feed is low because of the undervaluing of wild caught fish and other seafood byproducts. However, if crab culture becomes more intensified, problems with relying on wild

caught feed sources will magnify, and the biological requirements for high protein diets will drive feed costs to become a major portion of the farm operating budget. Locally available materials (mangrove twigs, straw-sheafs, coconut leaves, or shells of dead animals) can be supplied to the culture ponds for use by crabs as shelters, resulting in reduced cannibalism and increased survival and yield (Fielder et al. 1988; Chen 1990).

3.2.1.8 Exportable product ranking

Bangladesh exports a limited number of fishery products, of which frozen shrimp is the principal item. At present mud crab is ranked second among annual exports of fish and fish products after shrimp (FRSS 2017). Mud crab is therefore considered a very important exportable item with strong future potential because of its soaring demand and price in international markets (Rahman et al. 2017).

3.2.1.9 Increasing popularity

Popular interest in mud crab farming has been increasing rapidly in the study areas, primarily because of practical and perceived benefits over traditional aquaculture, especially shrimp culture (Johnston and Keenan 1999). Mud crab culture involves relatively lower environmental and economic risks because of the adaptability and high tolerance capabilities of crab (Zafor et al. 2004), coupled with high demand and price (Mahmud and Mamun 2012; Rahman et al. 2017). However, strong demand in international markets for Bangladeshi crabs has led to increased aquaculture and fisheries activities in coastal areas (Overton and Macintosh 1997; Rahman et al. 2017). This trend is reflected in the steadily increasing engagement of coastal people into the mud crab fishery. A six-fold increase has occurred within a half-decade period, from 50,000 people in 2009 to 300,000 people in 2015 (Molla et al. 2009; Islam et al. 2015).

3.2.2 Weaknesses

SWOT analysis revealed numerous limitations to the sustainable development of the crab fishery in Bangladesh. Participants acknowledged numerous issues working against the dynamic functioning of the growing mud crab fishery.

3.2.2.1 Dependency on wild stocks

The overwhelmingly most critical constraint on the mud crab fishery, wherever it is practiced, is the unavailability of hatchery raised crab seeds, typically leaving farmers dependent on wild-caught juveniles (Sathiadhas and Najmudeen 2004; Begum et al. 2009; Ferdoushi and Xiang-Guo 2013; Noorbaiduri and Ikhwanuddin 2015). Seedstock limitations restrict the

expansion of mud crab aquaculture and industry development globally (Shelley and Lovatelli 2011; Ikhwanuddin et al. 2012) as timely supply of seeds is practically impossible throughout the year. The fishery, as long as it remains dependent on wild crabs, is viewed as unsustainable for medium- or long- term development (Shelley 2008; Ikhwanuddin et al. 2012). The impact of such dependency is obvious in the mud crab export figures of Bangladesh, which was, despite high demand, not consistent over the period (Figure 3).

3.2.2.2 Unknown status of wild stock

Unfortunately, there are no population data of wild crabs in Bangladesh and thus, it is not possible to accurately determine the status of existing natural stocks. It has been speculated that the existing crab stock in the wild, primarily in the Sundarbans mangrove areas, is already at risk and possibly over-exploited (Chantarasri 1994; Azam et al. 1998; Kosuge 2001) and this may be influenced by collectors' poor educational status and lack of awareness of conservation concerns (Molla et al. 2009). Indiscriminate harvesting, harvesting freely during the breeding season, and destruction of natural habitats including breeding, feeding, and nursery grounds of crab have been reported more recently (Rahman et al. 2017). Unregulated and unmonitored harvests could potentially pose serious problems in the development of a sustainable crab fishery in the country.

3.2.2.3 Extensive culture system

Although different forms of crab cultures, *viz.* crab fattening, grow-out, soft-shell production, and polyculture were available in the study areas, small-scale traditional fattening of juvenile and unripe female crabs predominated. No standard crab culture manual or relevant literature is available in the country and existing culture methods do not ensure maximum production. Several problems including improper salinity, poor survival due to cannibalism, and water quality deterioration have been reported in crab farming (Ballio et al. 1981; Ferdousi and Xiang-Guo 2013), and as well by respondents of this study. No report of using improved technologies (e.g. use of suitable shelters to minimise cannibalism, cage and pen culture) was reported by respondents.

3.2.2.4 Poor post-harvest handling

Mud crabs have to go through a dozen hands and such post-harvest activities in Bangladesh have resulted in high mortality of live crabs during post-harvest handling. Lack of storage facilities was also common in the study areas, confirmed by the workshop participants, especially during transportation of live crabs from coastal areas to Dhaka (capital city of the country from which crabs are exported by air). For wild-captured crabs, survival rate is

affected by erratic handling, delayed landings, and poor transportation systems which negatively affect aquaculture output and national production (Zafor and Ahsan 2006). This loss during transportation is unusually high in Bangladesh, with reports of 14–20% mortality (Chandra et al. 2012) as compared to other crab producing countries (e.g. Philippines, with only 1% mortality; Gaillard 2010). This is due to heavy stress during the long transportation time in Bangladesh where crabs are transported using vertically elongated baskets resulting in increased weight on those crabs on the bottom of the basket, which contributes to mortality.

3.2.2.5 Lack of technical expertise

Training, and technical support and services are scarce and best management practices (BMPs) have not been standardized in the study areas. Moreover, there is no professional organization among crab farmers in the study areas, also reported earlier by Shelley (2013), making it difficult for the farmers to develop or share the knowledge and skills required to be an advanced farmer. Poor knowledge of crab farming of the respondents (e.g. stocking of heterogenic sizes of crabs, mixed-sex culture, escapement from ponds, avoidance of cannibalism) sometimes resulted in overall production loss (Baliao et al. 1981; Sulaeman and Hanafi 1993; Shelley 2008). The lack of technical training is thought to present a major obstacle to the development of crab aquaculture in Bangladesh (Ferdousi and Xiang-Guo 2013).

3.2.2.6 Lack of credit facilities

In the recent past, credit facilities were scarce in the study areas and it has been reported that the extremely poor coastal residents of Bangladesh including many actual and potential crab stakeholders (~20% of the total population) have no access to formal or informal credit (NRI Report 2003; Huq et al. 2015). However, at present, crab stakeholders, primarily crab collectors and farmers, have limited access to various financial instruments at high interest rates that can make them vulnerable to financial exploitation under difficult circumstances (e.g. sickness or death of an earning person in the family, and natural calamities) (Zafor and Ahsan 2006; Ferdousi and Xiang-Guo 2013).

3.2.2.7 Lack of standard marketing facilities

There is a prevailing sense of mistrust and misunderstanding at different levels within the mud crab marketing channel. An extensive and unstructured value chain, with virtually no government involvement disrupts the flow and fairness of mud crab trading in Bangladesh (Zafar and Ahsan 2006; Rahman et al. 2017). We found that crab grading criteria and price

varied from place to place and among depots in the study areas. Some farmers recognized unfair pricing as an issue, in part because farmers are excluded from the pricing process. Price fluctuation by unfair means by the actors in the middle and insufficient market information (e.g. up-to-date supply and demand data regarding both domestic and international markets) were reported by the respondents. These problems have also been recognised in other studies (e.g. Zafor and Ahsan 2006; Ferdousi and Xiang-Guo 2013; Rahman et al. 2017).

3.2.2.8 Limited domestic consumption

Traders who participated in this study mentioned that the mud crab business is solely export-oriented, with practically no domestic market, leaving them at the mercy of prices set by importers. The near absence of domestic demand allows little outlet for inferior crabs in local markets (Pollnac and Weeks 1992). In Bangladesh, social and religious restrictions on crab consumption, primarily among Muslims, have added to the undeveloped status of domestic markets (Ferdoushi et al. 2010), which is similar to the low local demand for shrimp.

3.2.2.9 Inadequate development commitment

There is negligible involvement of government and non-government organizations in the mud crab fishery in Bangladesh, which has hindered the development of this sector (Zafar and Ahsan 2006; Ferdoushi et al. 2010; Shelley 2013). The absence of appropriate policies and coordination measures among government agencies and other institutions is also perceived as a barrier to the development of the mud crab fishery. Conversely, involvement of a range of authorities (several ministries and government departments) has made the crab business a complex one (Istiak 2018) influencing some stakeholders to follow illegal practices.

3.2.2.10 Lack of information

Adequate data on mud crab culture, capture, production, and export are not available in the country. Although estimates of total export amount and value have been published for the past few years by the Department of Fisheries (FRSS 2017), it is believed that the actual figures are higher (Rahman et al. 2017). A reliable, detailed inventory of the mud crab fishery is essential in order to develop a proper strategic plan for this fishery. However, insufficient baseline data regarding any issue is quite common in Bangladesh (e.g. Chaki et al. 2014), and is sometimes extrapolated from data from neighbouring countries (e.g. India; Panigrahi and Mohanty 2012).

3.3 External factors of mud crab fishery

Similar to internal factors, external factors also involved a wide range of items including 11 opportunities and four threats (Table 4). Again, like internal factors, SWOT analysis showed that the opportunities dominated over the threats involved in the mud crab fishery in southern Bangladesh.

3.3.1 Opportunities

3.3.1.1 Availability of suitable water bodies for crab culture

Almost all the coastal ponds, locally known as *gher*, of Bangladesh are suitable for crab farming, reflecting the high potential for extension of this technology. There are 272,717 ha of coastal ponds currently being used for shrimp culture (FRSS 2017), which also have potential for mud crab culture. However, Salam et al. (2003) identified, based on GIS models, a total of 228,111 ha of suitable land; 552,897 ha of moderately suitable land; 30,072 ha of marginally suitable land, and 195 ha of unsuitable land for crab aquaculture in the coastal areas of Bangladesh. In addition, selected zones in the Sundarbans mangrove and inshore areas could also be considered for cage and pen culture of mud crabs, which are common practices in other countries involved in mud crab culture (e.g. David 2009).

3.3.1.2 Successful hatchery technology will substantially boost the fishery

Limitation in seed supply is a common problem in crab farming, leaving the supply of juveniles entirely dependent on wild sources (e.g. Fortes 1999; Noorbaiduri et al. 2014; Hungria et al. 2017). Success in hatchery seed production could result in a boon~~m~~ in the mud crab fishery in Bangladesh as has happened for the mitten crab industry in China (Rosenberry 2012). Despite inconsistent production of mud crab seed due to unpredictability in reproductive performance (Ghazali et al. 2017), efforts have been undertaken to produce seeds in captivity in several countries including Indonesia (Cholik 1999) and Malaysia (Noorbaiduri et al. 2014) with considerable success in some cases (e.g. in India; Anand and Soundarapandian 2011). Unfortunately, despite good potential for hatchery establishment (Salam and Ross 2000) the few initiatives undertaken in Bangladesh have met with limited or no success so far. However, hatchery improvements could help to protect natural stocks from being over-exploited (Ferdoushi and Xiang-Guo 2013; Quinitio 2015), and could offset some demand on wild seeds (Marichamy and Rajapackiam 2001).

3.3.1.3 Access to modern post-harvest facilities will reduce mortality and production loss

Rough handling and stress during the long transportation of mud crabs to market contribute to increased mortality (Liong 1991). Moreover, the absence of storage facilities results in a loss of overall production as crabs transported and stored under suboptimal circumstances

(e.g. political unrest or transportation delays) was commonly reported by the participants of this study. Thus, by promoting post-harvest facilities, especially storage and an effective cold chain, such losses can be reduced to a great extent.

3.3.1.4 Enterprise and industrial development

The mud crab fishery is an important feature of coastal fisheries in tropical and subtropical Asia (Le Vay 2001), including Bangladesh (Ferdoushi and Xiang-Guo 2010). Like shrimp, the most common aquaculture species in the southern Bangladesh, a separate industry could be developed if it receives proper attention from the appropriate bodies (e.g. government organisations) because mud crab offers a higher profit margin than other coastal aquaculture species including shrimp (Johnston and Keenan 1999; Sathiadhas and Najmudeen 2004). However, at present few crab depots have been established in recent times in different areas of southern Bangladesh. Substantially more depots are needed with more facilities.

3.3.1.5 Appropriate policies and initiatives can help the fishery become more economically functional

Currently there is no proper policy to guide the mud crab fishery in the country (Istiak 2018). As the crab fishery is primarily an export-oriented business in Bangladesh, a policy, the 'Bangladesh Mud Crab Export Policy 1998', was introduced by the Bangladesh government to regulate export of crabs which is often blamed as a 'barrier' by the stakeholders for restricting the development of the crab fishery (Mahmud 2017). Per the same policy, wild crabs are only allowed to be collected using 'line hooks', but this practice is not recommended because it can injure crabs and damage burrows (Kasprzyk and Rajaonson 2013) resulting in high mortality and destruction of habitats. However, by formulating an appropriate policy, it is possible to make this sector more functional in order to support a wide range of stakeholders more efficiently and contribute more to national trade.

3.3.1.6 Potential coastal farmers

Fish farmers in the study areas have shown a positive response toward mud crab farming. This technology can be particularly important for the landless poor or those who have no private water access because they can rear crabs in cages in open waters, although this involves risk of poaching. Moreover, many shrimp farmers were also interested in shifting to crab farming due to adverse socio-economic and environmental issues associated with shrimp farming (Paul and Vogl 2011; Akber et al. 2018).

3.3.1.7 Improved technology and best management practices

Apart from traditional crab farming practices (e.g. fattening and grow-out) possibilities for increasing income through intensification include ripe female production and practicing crab fattening in cages (Overton and Macintosh 1997). Crab farming can also be integrated with forestry, rice culture, horticulture, and polyculture with fish, which are ineffective with shrimp farming (Chandrasekaran and Perumal 1993).

3.3.1.8 Potential for value addition and product promotion

The international market for value-added crab products (e.g., crab meat and frozen soft-shelled mud crab) has been growing over last two decades (Wickins and Lee 2002; Hungria et al. 2017). This is recognized for having good future potential for expansion.

3.3.1.9 Awareness building and law enforcement can support fishery sustainability

Proper implementation of fishery laws and regulations and mass awareness building programmes could be of particular help to save wild crab stock from the fishermen involved in indiscriminate catching. The level of awareness of the crab collectors, farmers, and traders was found to be poor with no knowledge of existing fisheries rules and regulations, both for crabs and other aquatic organisms. Although it is not permissible to export wild crabs, this practice was reportedly common in the study areas in which wild crabs were mislabelled and sold to local depots as farm-reared crabs. Moreover, fishing for crabs over restricted periods (breeding season, from January to February) in the Sundarbans mangrove is also regularly ignored by collectors.

3.3.1.10 Potential export markets

Currently the export markets for crabs from Bangladesh are limited. Of these, China is the main importing country, importing about 90% of the total from Bangladesh; other importing countries include Hong Kong, Taiwan, Singapore, Malaysia, Thailand, and Japan (Ali et al. 2004; Chandra et al. 2012; Rahman et al. 2017). However, there is a largely unexploited demand for value-added crab products worldwide including in Europe and North American countries (Fortes 1999; Hungria et al. 2017) and these are recognized as potential export markets for Bangladesh's mud crab fishery.

3.3.1.11 Promulgation of domestic consumption

Despite being an almost entirely export-oriented business, mud crab has little demand in local markets for the purpose of consumption by vulnerable and poor people including non-Muslims of the study areas. Some people buy crabs unsuitable for export (e.g. damaged, undersized, moribund etc.) at a low price. However, crabs are an excellent source of protein

and its meat contains essential amino acids, unsaturated fatty acids, minerals, and other micronutrients (Chen 1990; Gokoolu and Yerlikaya 2003). The perceived protein quality of crab meat is considered more favourable than other animal source foods (Derosier 1963; Zaitsev et al. 1969) and could be a source of protein for the poor rural population, with the caveat that crabs may still be too expensive as a reliable protein source, given tradeoffs when selling crabs and the availability of less expensive proteins such as legumes or fish. A small portion of the harvested crabs are being sold and served to customers at the restaurants of Cox's Bazar and St. Martin's Island. It is expected that this practice will expand to other areas, especially different tourist attractions in the future.

3.3.2 Threats

Few critical issues were identified during SWOT analysis that could hinder or threaten the promising mud crab fishery in Bangladesh.

3.3.2.1 Exports solely based on harvesting of wild stocks

Sustained efforts have reportedly improved crab seed production in some cases (Kumar 2015) and this would be the key to growing a sustainable mud crab industry globally (Salam and Ross 2000). Unfortunately, no success has been reported in Bangladesh so far and this fishery, to date, is totally dependent on wild-caught crabs. A continuous and sustainable supply of mud crab cannot be reliable in this way, which will impose limits on the expansion of the fishery in Bangladesh like many other countries of the world (Marichamy and Rajapackiam 2001; Shelley and Lovatelli 2011; Ikhwanuddin et al. 2012).

3.3.2.2 Excessive and indiscriminate harvesting of wild population

In Bangladesh, mud crabs were primarily caught from the Sundarbans mangrove areas. It has been reported that the fisheries resources, including crab populations, have already been over-fished in these areas (Chantarasri 1994), like other countries of Southeast Asia (Shelley 2008, Johnston et al. 2011) resulting in severe impacts on the genetic diversity of the crab population (Ahmed 1992; Acharya and Kamal 1994). Moreover, depletion of wild mud crab stock may lead to ecosystem imbalances resulting in ecological deterioration of water and soil, along with loss of biodiversity in the Sundarbans mangrove forests and other areas experiencing high fishing pressure.

3.3.2.3 Uncertain market in some cases

Although the demand for mud crabs is high, market price fluctuates commonly in Bangladesh, which sometimes can lead to dissatisfaction of the crab farmers. In addition, a

long marketing chain of mud crabs, with a high number of people in the middle, results in a higher product price that can lead to a collapse of this fishery because other exporting countries may offer the same product at competitively lower prices. Unexpected political events are also common in Bangladesh, and this can hamper any business especially marketing of perishable seafood products including crabs.

3.3.2.4 Disease outbreak

The history of the shrimp industry has shown that intensively cultured crustaceans can be vulnerable to disease outbreaks, as experienced in Bangladesh and elsewhere (Genodepa 1999; Johnston and Keenan 1999; Paul and Vogl, 2011). Potential impacts of infectious pathogens on intensive mud crab farming are not well established, although this could be particularly challenging during larval rearing in hatcheries (Cholik 1999).

4. CONCLUSIONS AND RECOMMENDATIONS

Outcomes of this SWOT analysis can contribute to the sustainable development of the mud crab fishery in Bangladesh. Both the positive internal and external factors (strengths and opportunities) showed dominance over negatives (weaknesses and threats), suggesting good potential for the rapid growth of this fishery in the country. The sector has clearly identifiable risks and limitations that can be minimised through proper monitoring and critical planning.

Studies are needed to determine the status of existing wild mud crab populations, especially in the Sundarbans mangrove areas, in order to formulate an appropriate management strategy to support the growing crab fishery while maintaining sustainable wild stock. This could be done by simple techniques (e.g. using baited traps; Kosuge 2001). Breeding and nursery grounds and possibly protected areas also need to be identified. Unfortunately, no comprehensive effort has been taken in Bangladesh so far except for few older localized studies (e.g. Chantarasri 1994; Hoq 2007) speculating possible over-exploitation of the wild crab population. However, reliable data on population dynamics need to be obtained and without this an effective strategy for the crab fishery, currently dependant on wild-sources, cannot be formulated. If data reveal that the wild crab population is at risk, efforts like habitat restoration and stock enhancement can be considered to mitigate the impacts of overfishing (Le Vay 2001; Walton et al. 2006).

Indiscriminate harvesting of wild crabs is common and this may be due to the limitations of existing management policy, which is inadequate to ensure effective conservation of mud

crab in nature. Even though the Bangladesh crab export policy forbids wild crabs to be exported, violation of this rule is often reported (e.g. Istiak 2018). Crab collectors are known to sell wild crabs directly to depot owners, from which they find their way to the export markets. The government should institute updated policies to regulate every step of the mud crab export chain effectively, as well as regulating capture from the wild. Despite having a fishing ban over the breeding season, illegal crab harvesting during this season was also reportedly common in the study areas. Strict monitoring by regulatory bodies and awareness programmes for crab collectors and local residences should be instituted. Modification of the existing mud crab export policy is also needed to meet crab fishery and conservation needs, rather than solely for export.

The mud crab fishery should be supported by government and non-government organisations through the development of a sustainable management strategy, offering extension services, training, and financial support for stakeholders. To address the scarcity of crab seed and to ensure its timely supply to the farmers, larviculture of crabs, as a supplementary method, could be considered (Chong 1995). Initiatives should also be taken to produce hatchery raised crab seeds commercially through induced breeding and larval rearing. This can reduce the dependency on wild crab seeds and be helpful for maintaining biodiversity in the wild. Currently there is a lack of expertise within the country and thus, foreign consultants of appropriate background could be hired to assemble a team involving national participants to address this issue. Loans at low interest rates need to be ensured for stakeholder groups, especially for the crab collectors and farmers.

The existing crab marketing systems require improvement. Initiatives could include introduction of processing and storage facilities at depots and elsewhere, standard grading systems and prices, and improved transportation facilities (e.g. mechanised vehicles, cold chain infrastructure, and appropriate carrying baskets) to improve the quality of products and also to shorten the marketing channel thereby promoting vertically integrated value chains. In addition, improved post-harvest systems and infrastructure can minimize deterioration under unexpected circumstances (e.g. political unrest) when transportation is not possible or difficult. Simple upgrades from baskets to crates could be an effective improvement during the transportation of live crabs, perhaps reducing losses by more than 60% (Kasprzyk and Rajaonson 2013).

Currently only one species of crab, *S. serrata*, is considered to have strong potential for aquaculture in Bangladesh. However, the merits of other crab species should also be evaluated. Crab farmers need to be trained about best management practices so that they can maintain a healthy culture environment, minimise loss of production through cannibalism

and disease outbreak, and optimize their culture systems. The mud crab fishery can generate substantial employment in different farming systems, including marketing, transportation, and other associated businesses directly and indirectly; however, sustainable practices should be strongly encouraged (Roy et al. 2013).

The poverty and poor education of crab collectors and farmers, along with religious and other relevant social concerns should be addressed in order to promote this sector. Promotional and educational activities (e.g. advertisement on mass media) could be considered with a view to expanding crab markets locally.

In summary, support of promising opportunities in mud crab must be coupled with the mitigation of threats through careful planning and regulation. The unusually strong potential of the mud crab sector as elaborated in the SWOT analysis suggests that the resolution of hatchery constraints united with a carefully conceived plan of development may contribute to the realisation of substantial trade and livelihood benefits from the mud crab fishery. A carefully conceived approach of this sort can enhance alternative livelihood options for climate-change vulnerable coastal communities. However, any strategic plan for the crab fishery, now based on wild crabs, must take into consideration the conservation of natural crab populations.

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Conflict of Interest:

The authors declare that they have no conflict of interest.

Ethical statement

This article does not contain primary research involving animals or human subjects.

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1074

1075 **Table 1:** Personal and housing data of mud crab collectors and farmers obtained through
1076 socio-economic surveys

Household attributes		***Percentage (%)***	
		Crab ***collectors (N = 75)***	***Crab farmers (N = 150)***
Sex	Men	74.7	69.3
	Women	25.3	30.7
Civil status	Married	77.3	80.0
	Single	14.7	11.3
	Widowed	5.3	4.7
	Divorced/abandoned	2.7	4.0
Religion	Hindus	78.7	64.0
	Muslim	20.0	34.0
	Christian	1.3	2.0
Age	< 20 years	6.7	0.0
	20 – 30 years	26.7	19.3
	30 – 40 years	44.0	56.7
	40 – 50 years	17.3	18.0
	> 50 years	5.3	6.0
Schooling	No schooling	17.3	4.0
	Primary school	52.0	33.3
	Secondary school	24.0	41.3
	Higher secondary and above	6.7	21.3
Other economic activities	Yes	65	58.7
	No	35	41.3
Father involved in crab collection/culture	Yes	57	18
	No	33	82
Land holding[a]	1–50 decimal	36.0	16.7
	50–100 decimal	45.3	47.3
	100–150 decimal	16.0	32.0
	>150 decimal	2.7	4.0
Annual income[b]	<50000 BDT	0.0	0.0
	50000 – 100000 BDT	24.0	14.7
	100000 – 150000 BDT	45.3	41.3
	150000 – 200000 BDT	18.7	30.7
	>200000 BDT	12.0	13.3
Access to credit facilities	Relatives	6.7	9.3
	Money lender	8.0	3.3
	NGOs	36.0	40.0
	Banks	0.0	7.3
	Crab depots holders, *Farias*	49.3	40.0
Health	**Diseases**		
	Gastritis (Stomach)	74.7	26.0
	Respiratory	41.3	15.3

	High blood pressure	17.3	23.3
	Diabetics	8.0	12.7
	Backache	36.0	27.3
	None	16.0	14.0
	Treatment		
	Village doctor	63	37
	Upazila Health Complex	33	51
	Private clinic	4	12
Experience with crab activities	Ave. experience (years)	16.4	5.1
	Highest experience	34.7	14.0
	Lowest experience	6.7	1.3
Housing conditions[c]	Kacha	16	08
	Tin shaded	39	16
	Semi-pucca	32	54
	Pucca	13	22
Household facilities	**Use of electronics**		
	Cell phone	72	86
	Television	21	50
	Refrigerator	00	2.67
	Type of sanitary facilities[d]		
	Pucca	13	22
	Semi-pucca	52	62
	Kacha	35	16
	Power sources		
	Electricity	29	58
	Solar	47	26
	Wood / fuel	24	16
	Transport		
	None	81	58
	Motor cycle	4	22
	Rickshaw	15	20

[a], 1 ha = 247 decimal;

[b], 1 US$ = ~80 BDT;

[c], Housing conditions: kacha, wall made of mud/bamboo splits with golpata [leaves of *Nypa* spp., collected from the Sundarbans] shed or thatched; tin shaded, wall made of bamboo splits with tin shed; semi-pucca, concrete-based wall made of tin with tin shed; and pucca, concrete wall with tin shaded roof/concrete roof.

[d], Sanitary facilities: pucca, concrete wall with tin shaded roof/concrete roof; semi-pucca, crushed bamboo mat (locally called *chatai*) or tin walled with ring slave; and kacha, wall covered with sackcloth or polythene (locally called *chat/sala*) and having no shed.

1087 **Table 2:** Different HDI indices of the wild mud crab collectors and farmers of southwest Bangladesh.

Indices	*Crab collectors*	*Crab farmers*
Economic index	0.58	0.49
Schooling index	0.32	0.44
Life expectancy index	0.8	0.8
HDIMCF	**0.64**	**0.61**

1088

1089 **Table 3.** Evaluation of internal factors (EIF) of mud crab fishery in Bangladesh

Sl.	Internal Factors	Weight	Rate	Score
Strengths				
S_1	Availability of commercially important mud crabs species locally	0.08	4	0.32
S_2	High demand and price in local and export markets	0.09	4	0.36
S_3	Ranked very high among exportable aquatic species	0.03	3	0.09
S_4	High tolerance to environmental factors and diseases	0.07	4	0.28
S_5	Gaining popularity among coastal communities	0.03	3	0.09
S_6	Simple dietary requirements (e.g. easily fed with low valued fish)	0.04	3	0.12
S_7	Year-round production in all types of ponds	0.05	4	0.2
S_8	Diversified culture systems (e.g. fattening, grow-out, soft-shell farming, polyculture)	0.05	4	0.2
S_9	Alternative income and livelihood options to vulnerable coastal communities	0.05	4	0.2
Weaknesses				
W_1	Complete dependency on wild stocks	0.09	1	0.09
W_2	Traditional or extensive farming systems	0.02	2	0.04
W_3	Lack of technical expertise, trainings, and extension services	0.06	1	0.06
W_4	Lack of capital of farmers and limited access to financial supports	0.03	2	0.06
W_5	Limited domestic consumption	0.03	2	0.06
W_6	Lack of standard marketing facilities	0.04	2	0.08
W_7	Poor population data of existing stock in the wild (population status, breeding season, breeding and nursery grounds and so on)	0.08	2	0.16
W_8	Poor post-catch handling with poor storage facilities and transportation system causes high mortality	0.04	2	0.08
W_9	Inadequate data on production, marketing and export	0.04	2	0.08
W_{10}	Lack of appropriate and sustainable policies, and coordination among relevant government agencies, and stakeholders	0.08	1	0.08
	Sum	**1**		**2.65**

1090

1091 S: strength; W: weakness

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1094 **Table 4.** Evaluation of external factors (EEF) of mud crab fishery in Bangladesh

	External factors	***Weight***	***Rate***	***Score***
Opportunities				
O_1	Suitable water bodies for crab aquaculture	0.1	4	0.4
O_2	Potential coastal farmers	0.05	3	0.15
O_3	Potential export markets	0.04	3	0.12
O_4	Improved technology and best management practices	0.05	3	0.15
O_5	Access to modern post-harvest facilities will reduce mortality and production loss	0.09	3	0.27
O_6	Successful hatchery technology will certainly boost the fishery	0.1	4	0.4
O_7	Potential for value additions and product promotion	0.05	3	0.15
O_8	Enterprise and industrial development	0.08	3	0.24
O_9	Promulgation of domestic consumption	0.02	3	0.06
O_{10}	Appropriate policies and initiatives can help the fishery become more economically functional	0.06	4	0.24
O_{11}	Awareness building and law enforcement can support to exploit the fishery sustainably	0.05	3	0.15
T_1	Exports solely based on harvesting of wild stocks	0.1	1	0.1
T_2	Excessive and indiscriminate harvesting of wild population	0.1	1	0.1
T_3	Uncertain market in some cases	0.06	2	0.12
T_4	Disease outbreak	0.05	1	0.05
	Sum	**1**		**2.7**

1095 O: opportunity; T: threat

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1097

Figure captions

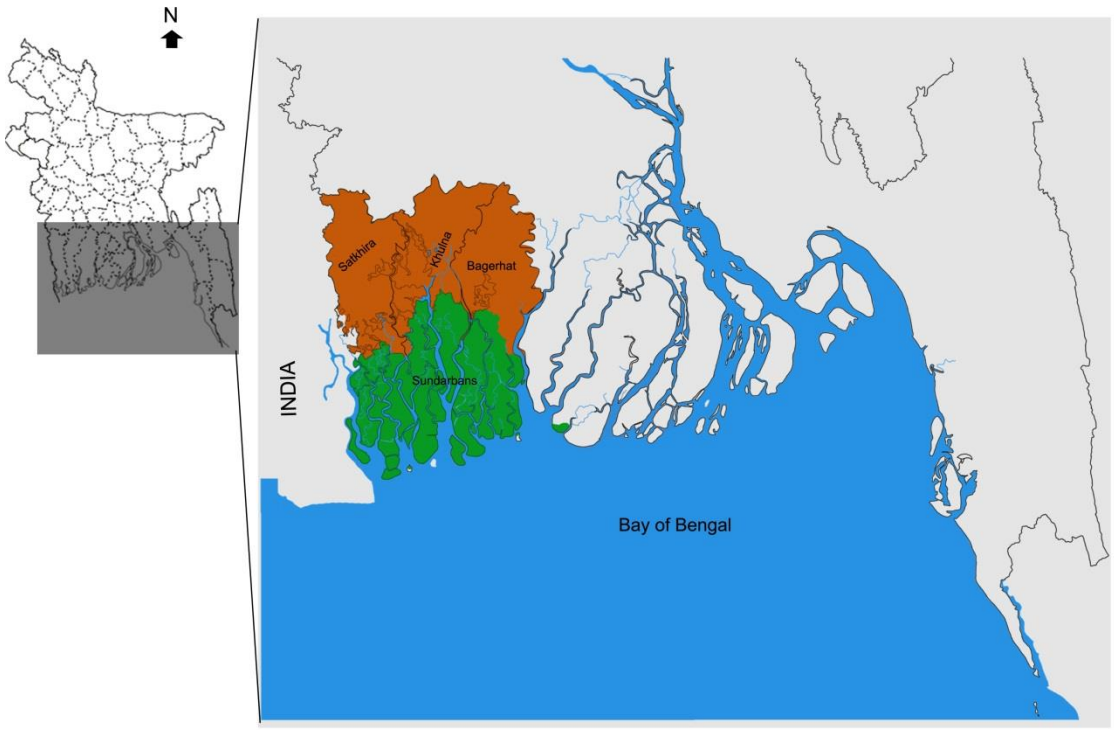

Fig. 1. Coastal regions of Bangladesh showing the study areas (Satkhira, Khulna and Bagerhat districts) featuring the Sundarbans mangrove forest.

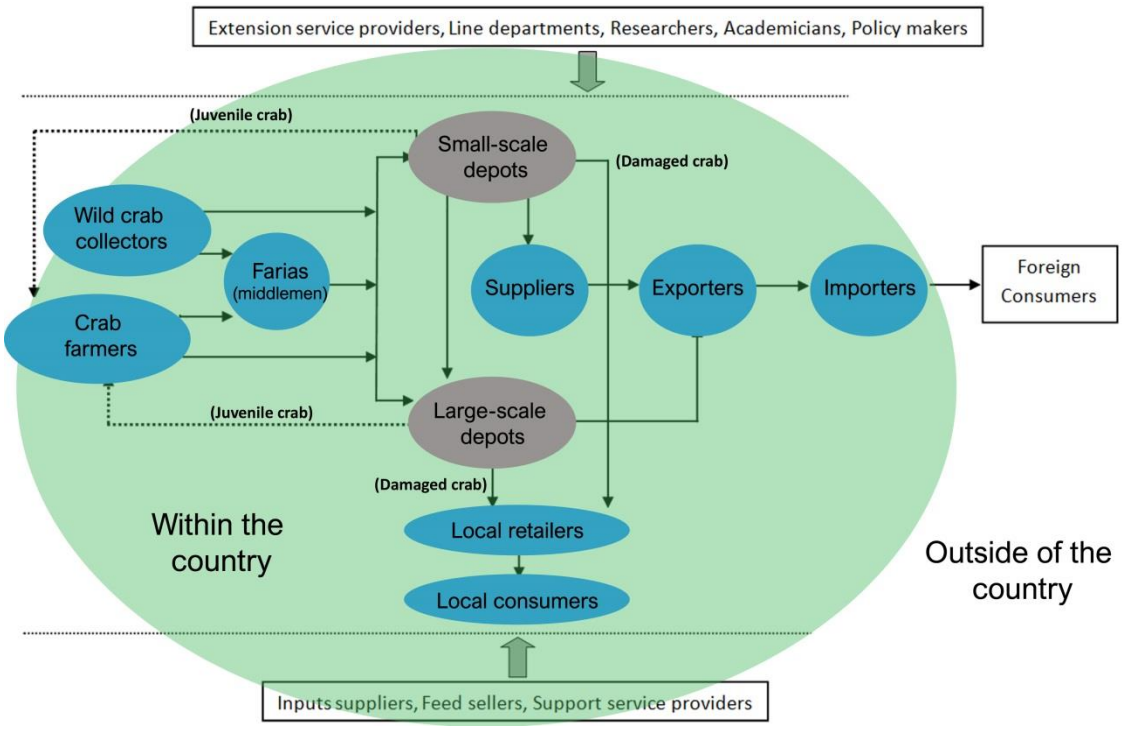

Fig. 2. Stakeholders of a typical mud crab value chain in southwest coastal Bangladesh

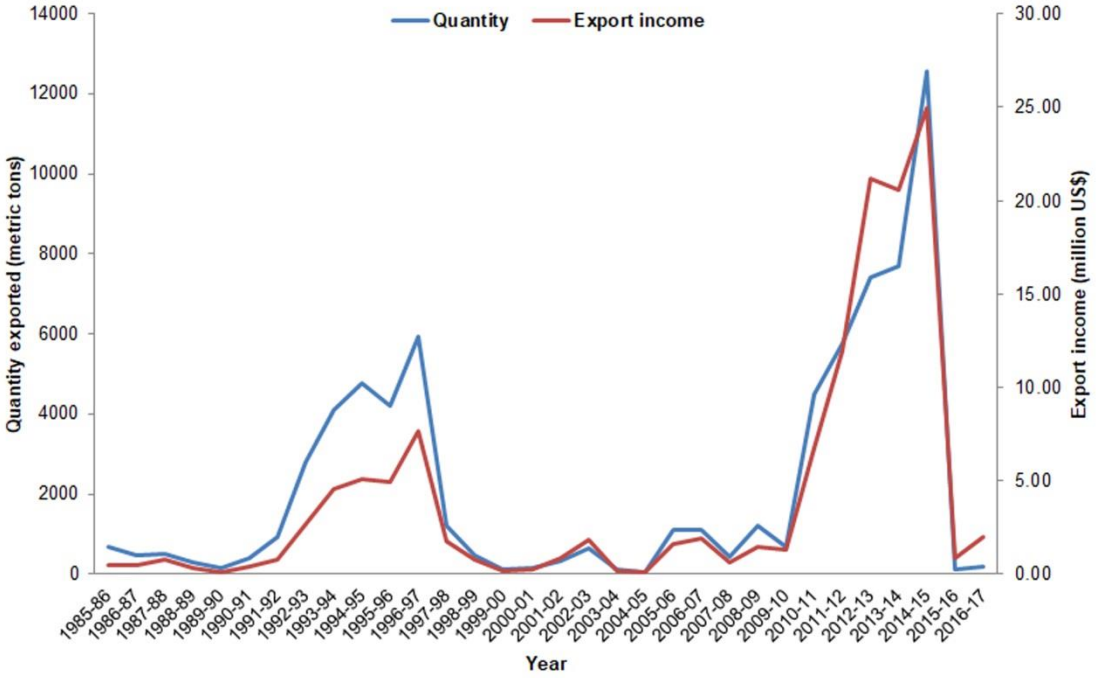

Fig. 3: Status of mud crab export from Bangladesh (source: FRSS 2017)