




On the potential and constraints of mariculture development in Bangladesh

Sheikh AftabUddin¹ · M. Gulam Hussain² · Mamun Abdullah Al¹ · Pierre Failler³ · Benjamin M. Drakeford³ 

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Abstract

Development of a blue economy is firmly embedded in the development plans of Bangladesh. Advances in freshwater aquaculture have promoted Bangladesh to the fifth largest fish producer in the world. However, the marine resource base of Bangladesh, which is now even greater following the recent settling of disputes regarding maritime boundaries with neighbouring countries, lends itself to the development of marine aquaculture—known as mariculture. Several potential areas and opportunities for mariculture development have been identified for implementation under the concept of blue economy development in Bangladesh. We identify the most promising fish species as the hilsa shad (*Tenualosa ilisha*), seabass (*Lates calcarifer*) and the grey mullet (*Mugil cephalus*), and the shrimp species as black tiger shrimp (*Penaeus monodon*), brown shrimp (*Metapenaeus monoceros*), Indian white shrimp (*Penaeus indicus*) and the mud crab (*Scylla serata*). Further, some non-traditional marine species like seaweed, microalgae, shellfish (mussel, oyster) and the sea cucumber offer considerable potential. However, there remain major challenges and constraints that need to be addressed in order for mariculture to further develop and contribute to a growing blue economy in Bangladesh. Most notably, ministries, departments and research institutions, along with interested private entrepreneurs, must collaborate to formulate strategies for effective development and implementation, so that mariculture can contribute to food security and economic development through export opportunities.

Keywords Mariculture · Blue economy development · Constraints · Collaboration · Potential

✉ Benjamin M. Drakeford
ben.drakeford@port.ac.uk

¹ Institute of Marine Sciences, University of Chittagong, Chittagong 4331, Bangladesh

² Feed the Future Innovation Lab for Fish Project, Global Center for Aquatic Food Security, Mississippi State University, Mississippi, MS, USA

³ Centre for Blue Governance, Faculty of Business and Law, University of Portsmouth, Portsmouth PO1 3AE, UK

Introduction

Aquaculture has grown rapidly in Bangladesh from a production of almost nothing in 1980 to over 2 million tonnes in 2018 (World Bank 2019), with an almost doubling of output in the last decade. By 2016, Bangladesh was ranked the 5th largest aquaculture producer—a position maintained since 2003 (FAO 2018). Previously, fish production was dominated by tilapia species and current output ranks third, behind only China and Indonesia (FAO 2016). Production increased from 2140 t in 1999 to 370,017 t in 2017 (Hussain et al. 2017a; DoF 2017). Besides tilapia, inland aquaculture production of indigenous species, i.e. Pangas (*Pangasius pangasius*), Rui (*Labeo rohita*), Catla (*Labeo catla*), other carp species and climbing perch (*Anabas testudineus*), has expanded significantly. Among the top ten world aquaculture producing countries, seven belong to the Asia-Pacific region, where Bangladesh ranks three out of five (FAO 2018). Aquaculture production accounts for around 2.8% of GDP in Bangladesh, only aquaculture in Vietnam accounts for a higher share of GDP in the Asia-Pacific Region (FAO 2017).

Mariculture covers a wide range of activities, practiced using a variety of techniques from extensive to intensive in habitats ranging from coastal lagoons to the open ocean. A variety of species in the food chain, from single cell algae to pelagic predators such as seabass (*Lates calcarifer*) and groupers are now farmed on a commercial scale. Integrated multitrophic aquaculture (IMTA), i.e. where the diversification of aquaculture results in greater benefit (e.g. economic) over single species farming due to lower environmental impacts and better social acceptance, is the main theme of mariculture (Hughes et al. 2016) and the focus of blue economy development plans in Bangladesh. IMTA increases production by farming species from different trophic levels in the same production system, i.e. fish, molluscs and crustaceans while minimising the use of supplementary inputs, e.g. artificial feed (Guerrero and Cremades 2012; Hughes et al. 2016). “With these processes (IMTA), all the cultivation components have an economic value, as well as a key role in environmental and societal services and benefits” (Guerrero and Cremades 2012). However, while having limited impact on the environment, this cultivation technique has become more complex and intensive, requiring development in infrastructure and greater human capacity. Nevertheless, since the extension of Bangladesh’s Exclusive Economic Zone (EEZ) in 2012 and 2014, a result of the maritime boundary disputes with Myanmar and India being settled—there has been broad interest in developing the blue economy (Hussain et al. 2017a, 2017b), and mariculture is a potential prospect which features in Bangladesh’s seventh five-year national plan (Fig. 1).

Although Bangladesh has focused greatly on high value shrimp species for export, disease outbreaks have led to the conversion of brackish water shrimp farms to either fish or mud crab culture. Traditional shrimp farming—a practice of trapping tidal waters in coastal enclosures known as “Gher” (earthen ponds)—an extensive farming technique with no feeding, fertilising etc. has been replaced by highly intensive farming techniques. This has taken place in response to strong export markets for shrimp (*Penaeus* species), which have developed since the early 1970s. The Government of Bangladesh supported the development of the sector by launching infrastructure development programmes (IDP), together with improved technology dissemination and fiscal incentives for producers and processors with the help of international development partners (WB, ADB, FAO, ODA). However, they had limited impact in achieving their goals (Sarkar et al. 2019). As a result, shrimp farming developments took place solely in the private sector, without any extension, demonstration or new infrastructural support from the Government of Bangladesh. During fiscal year 2016–17, Bangladesh recorded earnings of US\$ 446 million by exporting 39,705 t of shrimp. The main export market is the EU (accounting for over 80% of exports), especially Belgium, Germany and the Netherlands.

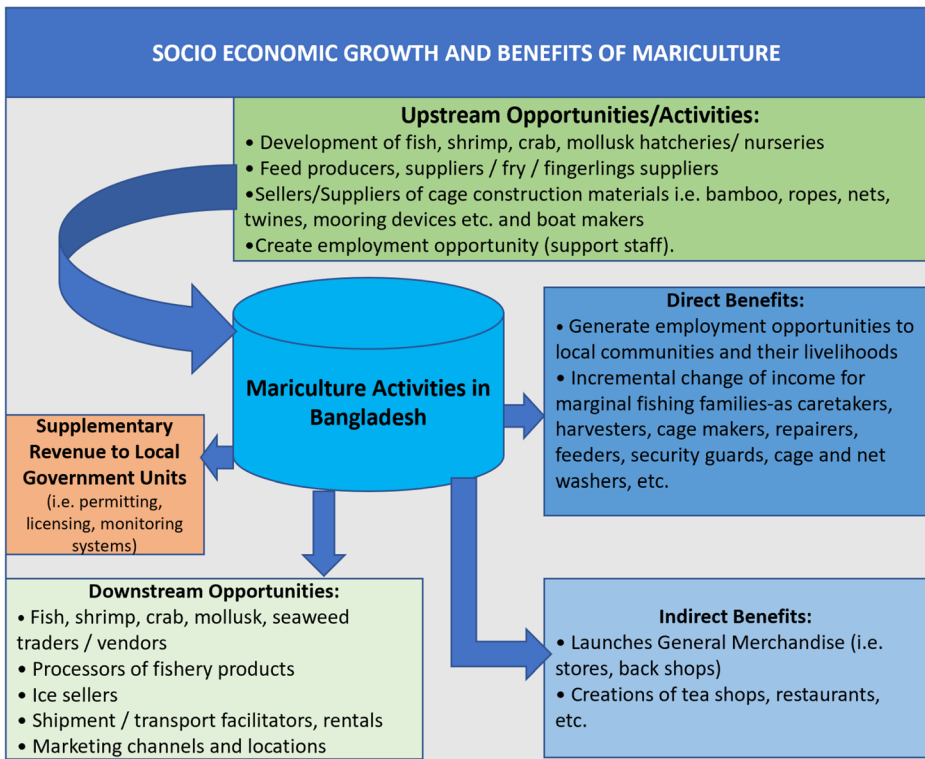


Fig. 1 The socioeconomic benefits of mariculture activities in terms of space and resources in densely populated coastal regions in Bangladesh

However, to date, the productive coastal waters of the northern Bay of Bengal, especially in Bangladesh’s territory, are devoid of mariculture activity. On the one hand, the expansion of the mariculture along the coast would play an important role in food security, social and economic welfare in Bangladesh. On the other hand, mariculture would compete with other human activities in densely populated coastal areas in terms of space and resources, such as fishing, tourism, port operations, shipping, nature conservation and industry.

In this paper, we present the potential and constraints for mariculture development in Bangladesh. The next section assesses the potential for mariculture development in the coastal waters of Bangladesh, considering resource availability and species suited for cultivation. This is followed by a discussion of the major constraints and challenges regarding the development of mariculture in Bangladesh. Finally, we conclude on the future prospects of mariculture under the concept of blue economy development and the seventh five-year plan of the Government of Bangladesh.

Potential for mariculture in the coastal waters of Bangladesh

Interest in developing mariculture in Bangladesh results largely from overfishing and overexploitation of wild stocks (DoF 2017). The current resource availability—after the settling of conflicts regarding maritime boundaries—lends itself to the cultivation of a range of species

(considered later in this section), leading to both economic benefits (e.g. growth and employment) and improving food security. This section details the indicators, such as species and cultivation systems, which will dictate the promotion and acceptance of mariculture as part of Bangladesh's blue economy development.

Indicators for assessing and monitoring mariculture development

We developed the set of indicators based on studies performed in the “EU-BGD joint collaboration on Blue Economy” technical assistance programme (August 2016–July 2018) that engaged a wide range of stakeholders including Bangladeshi academicians, researchers, public agencies, commercial farms, technicians and aquaculture and fisheries exporters and importers.. The development of indicators followed the dimensions-principles-criteria-indicators framework (Rey-Valette et al. 2008; Valenti et al. 2018), and we considered all actors and stakeholders involved in the production chain. Indicators are both quantitative and qualitative metrics, demonstrating relative positions in each dimension such as economic, social and environmental (Fezzardi et al. 2013). The application and use of indicators for sustainable aquaculture is regarded as the most appropriate tool for creating conditions for sustainable growth—and for evaluating and monitoring the progress of aquaculture activities (GFCM 2011).

Indicators are useful only when measurement targets are clear. Descriptive indicators would respond to questions such as, “What is happening in the mariculture industry?” Indicators of performance, on the other hand, would clarify whether objectives are being met, while efficiency indicators would show whether improvements have been made. For sustainable mariculture development in Bangladesh, the dimensions used are environmental, economic, social, including governance and management, which provide the basis for the selection of indicators (Table 1). The selection of criteria, and the related indicators and targets, usually involves considering some conceptual view or model of how the system works and how its elements interact. In this study, the criteria used for listing the matrices in terms of economic, social, environmental and governance dimensions are not exhaustive, rather they are intended to provide a useful checklist for the potential development of sustainable mariculture. Radar charts have been used based on these indicators within the same sustainability dimension or among several dimensions of potential species for mariculture in Bangladesh's coastal water bodies in the northern Bay of Bengal.

We followed Fezzardi et al. (2013), who described different criterion to select indicators, which are summarised in Table 1. In brief, we transformed four vulnerability indicators into arbitrary values as 0 (low consideration) to 5 (high consideration), then we considered three levels in between (arbitrary value > 4), medium (> 2–4) and low (< 2) (Fig. 2).

Potential species for mariculture in Bangladesh's coastal water bodies

In Bangladesh's coastal and marine water bodies, there are about 490 species of fish, 28 species of shrimp, 16 species of crab, 30 species of shark and 39 species of ray. The farming of marine species (i.e. seabass, hilsa, mullet, pomfret) in coastal ponds/enclosures and coastal cages could be a potential prospect for social-economic ventures in the country. However, success in this sector depends on cooperation between investors, private entrepreneurs and government organisations—mainly financial during crisis or accidental damage. In addition, success is also reliant on highly effective commercial (or semi-commercial) production systems based on hatchery-produced seed of these finfish and shellfish species.

Table 1 The principles-criteria-indicators (PCI) framework and its assessment to identify potential species of fish and shellfish for sustainable mariculture in Bangladesh coastal areas

| Dimension | Principle | Criteria | Indicator |
|-------------|--|--|---|
| Economic | Strengthen risk assessment and crisis management capabilities | Level of diversification | Number of products (i.e. species, size categories, value-added) |
| | | Level of inputs self-sufficiency | Number of national hatcheries (also % of fry imported/wild catch) |
| | Strengthen financial management of enterprises | Level of market maturity | Supply and sales by contract or by market |
| | | Level of input efficiency | Feed cost/kg fish produced (and % of total cost/kg) Fry cost/kg (and % of total cost/kg) Labour cost/kg fish produced (and % of total cost/kg) Unit production cost (total variable and fixed costs/kg fish produced/operating costs) (exchange) FCR, food conversion ratio (kg food/kg fish) |
| Environment | Minimising the global impact of aquaculture | Needs of natural resource (pelagic fish and vegetable inputs in feed) | Turbidity/transparency (Secchi disk) |
| | | Water quality | Microbiological indicators (total coliform) |
| | Respect the ecological service of the ecosystem | Oceanographic conditions | Depth (m) Hydrodynamic (cm/s) Interchange with open sea (offshore) (distance in m) Percentage of used space (%) Oxygen saturation (%) Annual production |
| | | Trophic conditions | Quantity of fish produced for domestic markets (self-consumption) and apparent consumption |
| Social | Contribution to food security and healthy nutritional needs | Importance of fish availability | Minimum wage of employees compared to national minimum wage |
| | | Accessibility for local consumers | Number of professional associations |
| | Strengthen the role of Producer Organisations and NGO's to improve image of aquaculture, social awareness and responsibilities | Average salary levels | Number of workers (direct and indirect) |
| | | Importance of fish farmer organisations | Number of areas allocated for aquaculture Number of fish-farmers taking part in consultative bodies |
| Governance | Strengthen integration of aquaculture in local development | Level of contribution to local employment - and to poverty alleviation | |
| | Promote participation in decision making process | Importance of development initiatives and level of participation | |
| | | Level of management and regional planning | |

Table 1 (continued)

| Dimension | Principle | Criteria | Indicator |
|-----------|---|--|---|
| | | | Existence of ICZM plan for coastal areas, including aquaculture under head state authority, considering the future evolution of industry. |
| | Strengthen research, information systems and extension services | Importance of research and training in aquaculture | Number of new sites created. |
| | | | Existence of bodies in support of aquaculture training |
| | | | Existence of research funds |

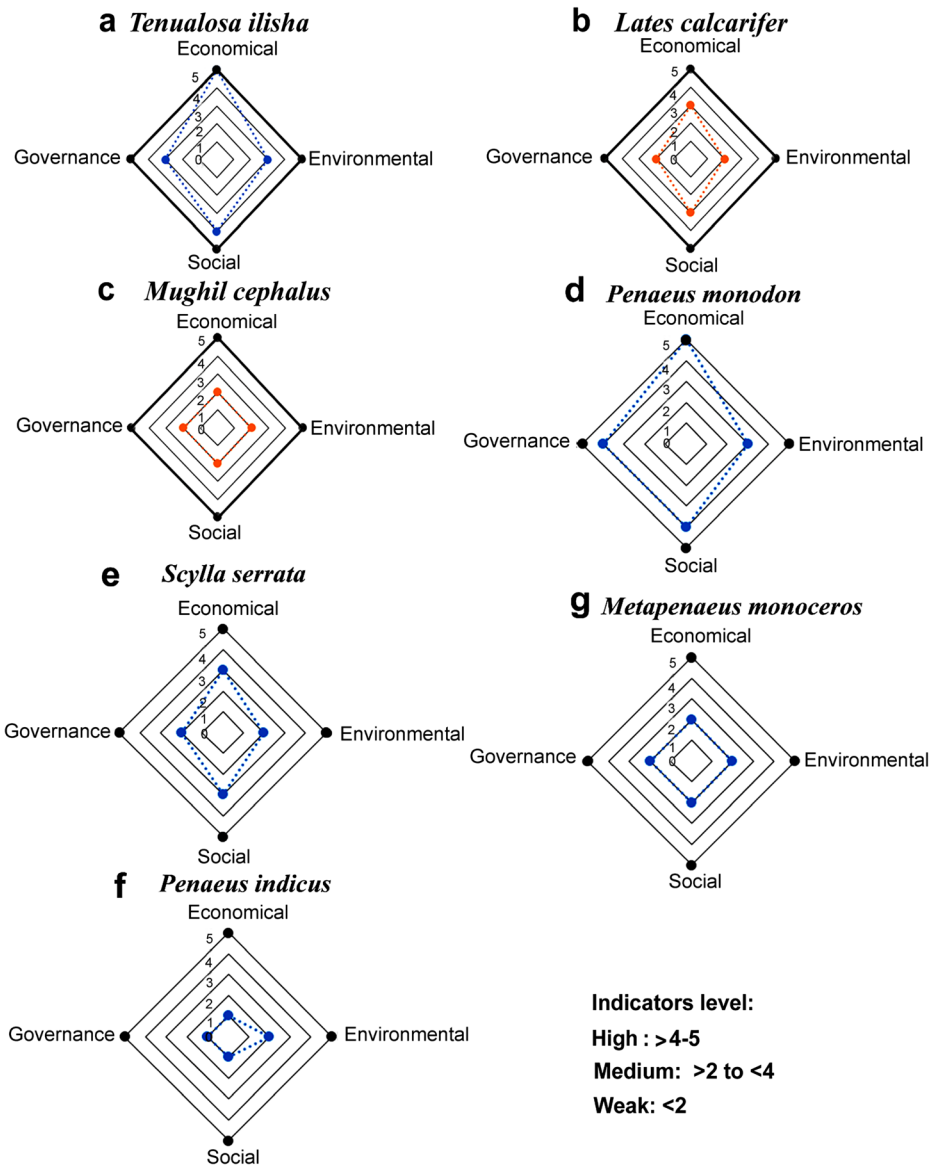


Fig. 2 Potential fish and shellfish species for mariculture in Bangladesh’s coastal water bodies

Potential fish and shellfish for mariculture

The potential candidate species for mariculture were determined by following the consideration of a number of factors specific to Bangladesh, such as local environmental conditions, local market drivers, available knowledge and capacity and the Ecosystem Approach to Aquaculture (EAA). In particular, the species chosen were native to the environment where it is to be cultured, with broodstock sourced from local populations and produced in local

hatcheries. Furthermore, we considered the species life history traits, such as trophic level, feeding biology, growth rates and suitability for cultivation in net cages (Fig. 2).

Hilsa shad (*Tenualosa ilisha*) The hilsa shad, known locally as illish, is a pelagic fish, which represents the largest single-species fishery (in both commercial and subsistence activities) in the Bay of Bengal region, primarily in Bangladesh. It is seen as the national fish of Bangladesh, with around 12% of the country's total fish production coming from hilsa fishing. Since the 1960s, the majority of hilsa production comes from marine fisheries (around 70%). Hilsa spawns in the riverine and estuarine ecosystems, here larval development takes place and thus fry and juveniles are dispersed in the river and inshore waters for feeding. Hilsa is typically fished by deploying drift gill, fixed gill or seine nets. Gear characteristics depend on water current, depth, tidal phase, as well as seasonality and weather conditions. The fishing hotspots include Meghna estuary, south-west of Hatia Island, Shahbajpur Channel, Sandwip Channel, south-west of Sonadia Island and south of the Sunderbans. In 2016, the hilsa catch in Bangladesh was nearly 496,000 metric tonnes, contributing \$2 billion to the economy, providing livelihoods to 0.5 million fishermen and 2.5 million people throughout the value chain (DoF 2017).

In view of the importance of social, cultural, food, nutrition and conservation perspectives, there is growing interest in hilsa production. Thus, domestication of hilsa for artificial propagation and mariculture in cages represents a potential option to contribute to blue economy development in the country (Hossain et al. 2019).

Seabass (*Lates calcarifer*) The seabass, known locally as Koral, is found in coastal, brackish and freshwater environments, being able to tolerate a wide range of salinity. The species has a biphasic life cycle, with juvenile stages occurring in freshwater followed by migration to sea for sexual maturation and spawning (i.e. catadromous). The timing of spawning occurs from June to September and the larvae enter into the rivers, estuaries, tributaries, mangroves and swamps from October to February. Recently, there has been increased interest in seabass for induced breeding (partial), polyculture with tilapia in ponds and experimental cage culture in the coastal waters of Cox's Bazar. Currently, extensive methods of seabass farming are undertaken in tide-fed brackish water ponds on a limited scale being completely dependent on the supply of natural seed. Therefore, artificial breeding and mass seed production in hatcheries are prerequisites for expanding mariculture in land-based shore ponds and lagoons, as well as offshore cages in suitable coastal areas. The domestication, captive breeding and export orientated production hold great promise for helping develop a blue economy in Bangladesh.

Grey mullet (*Mugil cephalus*) The fish is locally known as "Khorul bata", a catadromous euryhaline species, found in estuary and freshwater ecosystems, being able to tolerate salinity up to 30 ppt. Adults migrate offshore to spawn from January to March, and larvae/juveniles move inshore to shallow waters, rivers, estuaries and mangrove areas for feeding and avoiding predation. The species can be caught by gill net, beach seine and cast net throughout the year along the coast, with peak fishing from September to December.

The artificial breeding and seed production techniques of green back mullet, *Chelon subviridis*, has successfully been developed at the Bangladesh Fisheries Research Institute, Brackish Water Station, Paikgacha, Khulna (Saha and Kabir 2014). However, successful captive breeding of grey mullet is still far from reality. Commercial aquaculture production

of grey mullet worldwide is largely based on the stocking of wild caught fry, although seed produced through artificial propagation is used on a limited scale in Egypt, Italy and Hawaii. Fry or fingerlings are usually grown in monoculture or polyculture in semi-intensive ponds and pens in shallow coastal waters. In polyculture system, species such as carp and tilapia are reared together with mullet in fresh, brackish or marine waters.

Black tiger shrimp (*Penaeus monodon*) This species of shrimp is known locally as Bagda chingri. Shrimp is the major species farmed in Bangladesh with the Bagda chingri comprising 49% of farmed shrimp production, followed by the giant freshwater prawn (*Macrobrachium rosenbergii*) (31%), brown shrimp (*Metapenaeus monoceros*) (6%), Indian white prawn (*Penaeus indicus*) (2%) and others (12%). The others include (*Penaeus merguensis*, *P. semisulcatus*, *P. japonicus*, *P. latisulcatus*, *P. canaliculatus*, *P. penicillatus*, *Metapenaeus monoceros*, *M. affinis*, *M. brevicornis*). These species are all native to the Bay of Bengal region. Accompanied by production, the country's exports have also been gradually increasing over the past two decades and farm reared black tiger shrimp alone contributed to 60% of total shrimp exports in 2017 (Hussain et al. 2017a).

At present coastal aquaculture, mainly tiger shrimp (*P. monodon*) and six other species are practiced in low-lying tidal flood plains of several upazilas of Bagerhat, Chittagong, Cox's Bazar, Khulna and Satkhira districts. Shrimp farming expanded rapidly from 20,000 ha in 1980 (Paul and Vogl 2011) to approximately 276,000 ha in 2013, dominated by marine shrimp farming which accounts for 195,000 ha, while freshwater shrimp accounts for 86,000 ha (Kabir 2013; Kabir and Eva 2014; Rahman et al. 2017a). This expansion of shrimp aquaculture is credited to the country's suitable climatic conditions and the availability of resources such as shrimp post larvae, feed, water conditions and low-priced labour (Islam 2003). Ecologically, shrimp farming areas are interconnected by numerous rivers, where river water with salinity of 5 to 26 ppt for 8 to 10 months of the year and tidal fluctuations between 2.25 and 0.75 m. The tidal fluctuation, along with salinity, are the key influences for the utilisation by shrimp producers.

Mud crab (*Scylla serrata*) The mud crab is widely distributed in the Indo-West-Pacific region as mangrove associated fauna (Macintosh et al. 2002), and in Bangladesh, it is well suited for production (Zafar 2004a). Availability of marine and coastal water with optimal salinity and temperature conditions are well suited to mud crab farming in the mangrove forests of Sundarban area and coastal districts in Satkhira, Khulna, Bagerhat and Cox's Bazar regions. Mud crab farming is playing a significant role in the livelihoods of coastal communities in Bangladesh (Basu and Roy 2018). Crab is less susceptible to disease and more resistant to adverse environmental conditions and the effects of climate change. As a result, many of the shrimp farmers of Bangladesh are now converting existing systems to mud crab farming (Huq et al. 2015; Rahman et al. 2017b). Soft-shell crab farming (mostly *Scylla serrata*) has recently attracted attention of entrepreneurs in Shyamnagar, Shatkhira, Moheshkhali and Cox's Bazar regions. Crab farming provides jobs for around 300,000 farmers, collectors, traders, brokers, transporters and exporters in Bangladesh (Islam et al. 2015). Crab fattening and culture in earthen ponds, pens or in floating cages has a long history in the Asia-Pacific region (Cholik and Hanafi 1992; Liong 1993; Thach 2004) but is a new practice in Bangladesh (Zafar 2004b; Mia et al. 2007; Khatun et al. 2009).

Crab farming is promising for the growing export markets, as they can be easily packed and transported in live condition (Wilfredo et al. 2006) and Bangladesh has a bright prospect to

increase exchange earnings by exporting crab species. According to the Export Promotion Bureau (EPB 2018), Bangladesh exported crab worth US\$ 17.38 million in the 2017–2018 fiscal year. China is the major destination of Bangladeshi crab (80%), with other destinations including Malaysia, Singapore, the United Arab Emirates, Thailand, Vietnam and South Korea.

Other potential species for mariculture development

Molluscs There is potential for green mussel (*Perna viridis*), clam (*Meretrix meretrix*) and oyster (*Crassostrea madrasensis*) production, especially in Moheshkhali, Kutubdia and Sonadia islands of Cox's Bazar and Teknaf regions (Shahabuddin et al. 2010). Suitable habitats and environments like rocky and sandy areas, mangrove and coral reefs with high tidal breadth, adequate tidal current, absence of pollutants and available phytoplankton and zooplankton provides opportunities for mollusc mariculture. As well as export opportunities, there is strong domestic demand for mollusc meat (Shahabuddin et al. 2010) and demand from poultry industries for molluscs shell, providing an excellent opportunity for mollusc mariculture to contribute to blue economy development. Further, mussel and clam culture can create potential for resource and employment generation among coastal communities, especially women living below the poverty line. Moreover, the culture technologies such as raft, long-lines and cages, as practiced elsewhere in the Southeast Asian countries (Tendencia 2007; Bulmer et al. 2012; Piyathilaka et al. 2012), can easily be adopted in Bangladesh. Furthermore, better post-harvest technologies can develop attractive value-added products.

World mollusc production in 2015 was 15.26 million tonnes. Currently, Bangladesh contributes very little towards total production. This culture, however, is a low-investment activity with very good returns. Bangladesh earned US\$5.51 million in the 2017–2018 fiscal year by exporting oysters, mussels and scallops (EPB 2018). Besides, pearl farming has generated high export earnings in China and other countries. Pearl oyster spat collection can also make an important contribution to livelihoods in some coastal areas, though suitable sites are probably fewer and husbandry more demanding. However, this may represent a good opportunity for private companies and other non-government organisations in generating high-quality pearl products for local tourists, craft and supermarket chains.

Sea cucumber and marine coral Sea cucumber (*Parastichopus californicus*) collection and culture can also be initiated in Bangladesh. Sea cucumber has significant importance for Asia-Pacific countries (e.g. China, Japan, Korea Singapore and Malaysia) as a high nutrient food item, and for developing pharmaceutical products for foreign exchange earnings. Further, other non-traditional marine species, such as coral farming in St. Martin's Island may have more potential, and is more suited to small-scale artisanal production, possibly affiliated to—or supported by—commercial aquarium product exporters.

Marine macroalgae (i.e. seaweeds) Utilisation of seaweed (macroalgae) as food has a long history in Japan, China, Republic of Korea, the Philippines, Taiwan, Indonesia, Malaysia and Thailand, but nowadays, it is consumed around the world (Armisen 1995; McHugh 2001; Sajid and Satam 2003; Kılınc et al. 2013). Unfortunately, seaweed is almost unknown to Bangladeshi people as a source of food and has only been utilised by Mog or Rakhine ethnic communities. In Bangladesh, naturally growing seaweeds are seen in the littoral and sub-

littoral zones of St. Martin's Island to the Sundarbans Mangrove forest and are available from October to April throughout the whole southern coast (Islam and Aziz 1987; Islam 1998). Water quality parameters and rocky substratum makes St. Martin's Island an excellent place for naturally occurring seaweeds (Khan 1990; Tomascik 1997; Zafar 2004a). In total 244 seaweed species (AftabUddin 2019), including 19 commercially important species are found in Bangladesh and about 5000 metric tonnes of seaweed biomass are available (Sarkar et al. 2016). As a diversification activity in mariculture, the cultivation of seaweed has huge potential all along the Bangladesh coast. Seaweeds such as *Gracilaria* sp., *Hypnea* sp., *Enteromorpha* sp. and *Kappaphycus* sp. can be effectively cultivated by vegetative propagation methods in long-line ropes and nets.

Besides production for human consumption, seaweed is being utilised in phyccolloid or hydrocolloid, cosmetic, biofuel, biotechnology, pharmaceutical, waste water treatment and bioplastic industry (Vera et al. 2011; Jiao et al. 2011; Wargacki et al. 2012; Gade et al. 2013; Singh et al. 2013; Cardoso et al. 2014; Fernandes et al. 2014; Plouguerne et al. 2014; Suleria et al. 2015). Moreover, seaweed has anticoagulant (Wijesinghe et al. 2011), antiviral (Damonte et al. 2004), antioxidant (Cox et al. 2010), anticancer (Namvar et al. 2013), and anti-inflammatory (Kazlowska et al. 2010) active compounds, which might be used for other essential medicine development. The growing markets for seaweed around the world, and the availability of resources for production of seaweed in Bangladesh, offers significant potential for blue economy growth.

Marine microalgae Microalgae (i.e. single-celled algae or phytoplankton) fulfil a significant nutritional role for marine animals in the open sea and consequently in aquaculture (Muller-Feuga et al. 2003). Microalgae are utilised as live feed for larval/early juvenile stages of crustaceans (e.g. shrimps, crabs, etc.) and some fish species, for all growth stages of bivalve molluscs (e.g. oysters, scallops, clams and mussels) and for zooplankton used in aquaculture food webs overall (Guedes and Malcata 2012; Abdullah Al et al. 2018). While microalgae signify a sustainable energy source, through their high biomass productivity and ability to remove airborne and water-borne pollutants (Wu et al. 2012), they can also provide several distinct types of renewable biofuels. For example, methane produced by anaerobic digestion of the algal biomass (Spolaore et al. 2006), biodiesel derived from microalgal oil (Ramos et al. 2009) and photobiologically produced biohydrogen (Akkerman et al. 2002; Fedorov et al. 2005).

In Bangladesh, diversity, distribution and density of microalgae in estuarine and coastal waters is limited and inadequate, although several studies have already demonstrated its potential (Islam and Aziz 1975, 1977, 1980). Presently, 135 phytoplankton species have been identified from offshore waters of the Bay of Bengal (Boonyapiwat et al. 2008). Among them *Skeletonema costatum*, *Thalassiosira* sp., *Chaetoceros gracilis*, *Tetraselmis* sp. and *Nanochloropsis oculata* are important microalgae for larval rearing of marine penaeid shrimp and other fish species (Humayun and Karim 2016). Moreover, microalgae oil sources for making biofuels in Bangladesh as noted by Tania et al. (2016) and Hasan et al. (2016).

Major constraints and challenges

Marine organisms are highly sensitive to water quality (i.e. salinity, temperature, pH, dissolved oxygen, nitrate and ammonia) and are vulnerable to disease and predation. However, natural

and anthropogenic activities such as cyclones, e.g. pollution due to the metal frame with netting material forming the cage are also responsible factors for uncertainty in mariculture operations. Many species require significant investment and working capital and require a long time to grow to marketable size. In terms of promotion, assistance and support of mariculture development in Bangladesh, the fundamental constraints and challenges are (i) site suitability, (ii) availability of seed and broodstock, (iii) cost and availability of feed, (iv) skills, (v) markets, (vi) finance, (vii) logistics, (viii) environmental issues and (ix) biosecurity.

Site suitability

The geographical position and climatic conditions of Bangladesh have made coastal areas suitable for various species and forms of mariculture, specifically shrimp, mussel and crab culture (Fig. 3). It should be noted that commercial farms have achieved a balance regarding environmental requirements, product quality, infrastructure and market access. However, several commercial shrimp farms in Bangladesh have no effluent treatment. Many sites are simply not available for reasons related to inter-ministerial conflict, ownership, tenure and tradition. Based on waterway uses in the northern Bay of Bengal, several key factors need to be taken into consideration before establishing floating cage farms in the continental shelf of the Bay. Moreover, not all sites are economically feasible for potential species (as discussed earlier in the paper), because sustainability is a prime objective of mariculture.

Availability of seed and brood stock

Seed is a necessity for the farming of any species and where wild seed is not available hatcheries are required. For some hatcheries, wild broodstock is required at least in the initial stages (e.g. mud crab and tiger shrimp). Bangladesh has significant wild seed resources, although not sustainable, yet much depends on location relative to suitable growing sites, abundance, behaviour, labour costs associated with collection and the quality of seed collected.

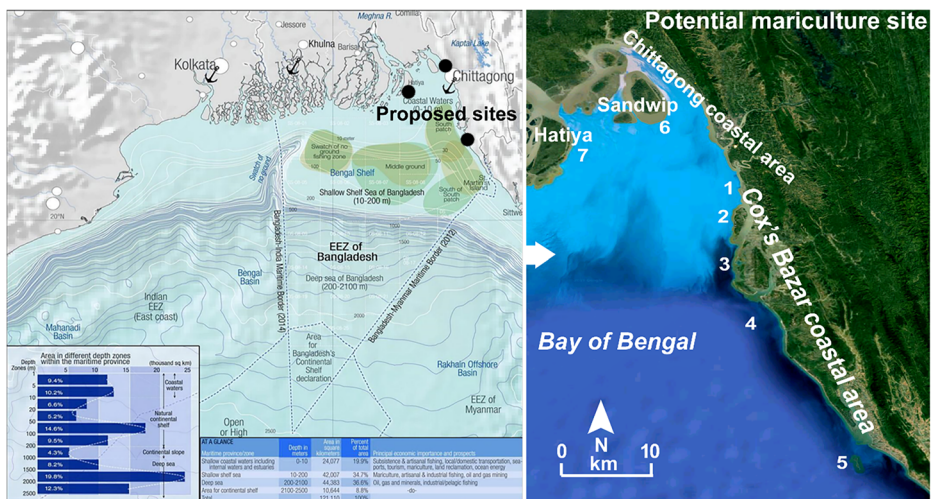


Fig. 3 The geographical position of Bangladesh and potentially suitable sites for mariculture development in coastal areas. Source: Chowdhury (2014)

In Bangladesh, mussel, clam, oyster, mud crab and seaweed wild seeds are available and wild broodstock of *P. monodon*, *S. serrata* are collected from the Bay of Bengal and mangrove areas. However, due to the rapid expansion of mud crab farming, a significant quantity of juvenile mud crab is being captured, exerting pressure on wild populations. Unfortunately, there are no marine finfish or crab hatcheries in the country, which is more crucial for mariculture development. Although, *P. monodon* is a native species to Bangladesh and this species reinforced the dynamic growth of shrimp industry in Bangladesh over 20 years, further resources and effort in identifying and sourcing wild broodstock is not efficient. Rather, the domestication of *P. monodon* broodstock and production of specific pathogen free seed in the country is needed.

Cost of feed and feeding

There are many forms of mariculture that do not require costly feed inputs (including some forms of finfish culture, e.g. tilapia), and this represents an advantage where mariculture is being promoted for food security reasons. However, intensive feeding with high quality food (both live and supplementary) is required for some species (e.g. tiger shrimp and species of carnivorous finfish) and may be desirable in the case of tilapia species to increase yield, reduce grow out times, pay off investment in ponds or cages more rapidly and improve profitability. This may increase production costs, financial risks and the danger of disease and may not be appropriate for food security purposes. These are all vital issues to be considered when developing production models, e.g. for mullet and seabass, which have not been thoroughly addressed in most development initiatives to date.

Feed costs, whether local or imported, are the major constraint, and substantial resources are being used for research into the production of low-cost feeds. However, high-quality fish feed is an international commodity and when traded in large volumes does not vary significantly in price between the major trading centres in the world. The trend in Bangladesh has been toward dry pelleted formulated feed. Modern prepared fish feeds are easy to store and manage and greatly reduce employment costs over on farm-produced feeds.

However, the food conversion ratio is as significant as feed price. Unfortunately, feed conversion ratios and feed management practices for marine fish/shrimp are not well established in Bangladesh and need to be initiated at the same time as expanding mariculture in the country. Other elements of feed management practices are also important, e.g. development and implementation of supplemental feeding strategies (that could decrease pellet feed dependence), appropriate selective breeding programmes (enhance growth performance traits), selection of potential marine finfish, and the adoption of integrated multi trophic aquaculture.

Skilled labour

At present, the Department of Fisheries (DoF) of the Bangladesh Government—and in some cases local government—appear to be relatively well resourced and are capable of offering a range of extension and training services. There are still many opportunities for training abroad and/or on aid funded marine aquaculture development projects. However, private sector capacity is not as well established, and for both public and private sectors, practical skills and technical knowledge are not well developed in Bangladesh. China and Indonesia have skilled manpower in seaweed culture, whose services could be made available to Bangladeshi farmers and researchers through training programmes and demonstrations. Furthermore, for most mariculture species, there is considerable

expertise available in China, Thailand and Vietnam, and more use can be made of this expertise either by sending key staff (public sector hatcheries and farms, private entrepreneurs, research institutions and public universities) to work with commercial mariculture businesses abroad or by sourcing foreign technicians to work for a period in the country.

Market preference

Markets are both the vital opportunity and constraint related with any commercial venture. Even when the species are produced for subsistence food, the market cannot be ignored, as it may be more cost-effective to import from abroad rather than to produce for domestic consumption. Markets for mariculture products, e.g. shrimp, crab and others, vary significantly between Bangladesh and some Asian countries (China, Japan, Korea and Thailand), but in most cases, there are some significant market limitations that must be addressed.

Financial support

Moral business opportunities should be able to attract finance and most countries have aid funded, government funded, or bank funded schemes targeted at small-scale development. Government and aid organisations can, however, facilitate bank lending by undertaking thorough and realistic sectoral and exemplary enterprise analysis on viability, offering generic guidance to funders about risks, opportunities, likely returns and favourable/unfavourable conditions for diverse types of mariculture development. This may of course reduce the chances of funding (if significant risks are identified) but that is common to all industries. Unfortunately, in the past, the availability subsidies and enthusiastic promotion by technical specialists have distracted from the thorough economic development analysis required.

Logistics support

Transport costs are often cited as a major constraint to many forms of economic activity in Bangladesh, particularly the transport of fresh, chilled or live products, or any product with a relatively low value/weight ratio. The problem in most cases lies with the lack of access to the farms, i.e. Cox's Bazar, Teknaf, Satkhira and Sundarban area, and the inadequate and costly internal delivery systems. This means that logistics represents a major issue for successful positioning of mariculture enterprises in Bangladesh.

Environmental issues

Intensive forms of finfish (e.g. tilapia) and shrimp mariculture, which depend on fertiliser and/or feed, are by their nature polluting and are subject to increasingly strict controls on location and discharge. The impacts of nutrient pollution from semi-intensive shrimp farms in Satkhira-Khulna region are also significant. The requirement for a high-quality feed for some mariculture systems, typically incorporating a sizable proportion of fishmeal, also raises complex issues about the efficiency and use of the world's high-quality fish protein and oil resources. Even the cultivation of filter feeders such as oysters and mussels will generate significant pollution if kept at high stocking densities. Although no artificial feeding is required, they effectively concentrate plankton, convert a small proportion of this into body mass and release the rest either as ammonia to the water column or as faeces and pseudo-faeces (rejected food) to the sea floor.

Biosecurity degradation

Biosecurity (protection from and resistance to disease), which should reduce the risks associated with disease offers opportunities to produce certified disease free stock. Domesticated *P. monodon* broodstock is absent in Bangladesh and wild broodstock are often exposed to (or infected by) pathogenic microbes, i.e. viruses and bacteria (Debnath et al. 2014; Uddin and Rahman 2015). The white spot syndrome virus has caused huge economic losses in shrimp production in the country (Paul and Vogl 2011). Further, the Bangladeshi shrimp industry has already been affected with various viral and bacterial diseases, i.e. white spot syndrome virus, Hepatopancreatic virus, Monodon baculovirus and Vibriosis (AftabUddin et al. 2017). Biosecurity concerns and the need to fulfil appropriate protocols may also represent a bottleneck in terms of starting new ventures.

Conclusions

Bangladesh is one of the leading countries for aquaculture production in the Asia Pacific region. Over the last 15 years, the major advances have been in freshwater aquaculture rather than marine aquaculture. Unlike some other tropical and sub-tropical countries in the Southeast Asia region, the invent of hatchery-based seed production techniques, the innovation and implementation of advanced aquaculture farming technologies, along with the development of feed mills have been responsible for the growth experienced in freshwater aquaculture in Bangladesh. Although marine fish farming is a promising area, it has only really developed in the case of shrimp. This has resulted from a number of issues, e.g. availability of hatchery produced seed, low levels of farming technology development and transfer to farmers, lack of affordable formulated feeds, lack of government assistance and lack of serious initiatives by public and private sector organisations and entrepreneurs.

In the Asia Pacific region, countries like China, Indonesia, Malaysia, Taiwan Province of China, Thailand, Singapore and Vietnam are making headway in finfish mariculture using hatchery-produced seeds and formulated feeds. Lessons can be learnt from these countries and under the concept of blue economy development, the Bangladesh government can develop mariculture. Subsequently, ministries, departments and research institutions—along with interested private entrepreneurs—should collaborate to formulate a strategy for the effective development and implementation of marine aquaculture farming in the coast, inshore and offshore areas of the country.

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