Biology and Fisheries of Hilsa shad in Bay of Bengal

Mostafa A. R. Hossain[1,*], Isha Das[2], Lily Genevier[3], Sugata Hazra[2], Md. Munsur Rahman[4], Manuel Barange[3,5], Jose A. Fernandes[3,6]

1. Department of Fish Biology & Genetics, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh
2. School of Oceanographic Studies, Jadavpur University, India
3. Plymouth Marine Laboratory, Prospect Place, The Hoe, Plymouth, U.K. PL13 DH
4. Institute of Water and Flood Management, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh
5. Fisheries and Aquaculture Policy and Resources Division, Food and Agriculture Organisation of the United Nations (FAO), Rome, Italy 001536
6. AZTI, Herrera Kaia, Portualdea, z/g, Pasaia (Gipuzkoa), 20110, Spain

Running Title: Productivity, life history and catch of Hilsa

*Author to whom correspondence should be addressed. Email: marhossain@bau.edu.bd

Abstract

Hilsa (*Tenualosa ilisha*) or river shad is an anadromous fish species widely distributed in the North Indian Ocean, mainly in the Bay of Bengal (BoB). Hilsa is the national fish of Bangladesh and it contributes 10% of the total fish production of the country, with a market value of $1.74 billion. Hilsa also holds a very important place in the economics of West Bengal of India with 12.5% of the catch and also tops the marine capture in Myanmar. During the last two decades Hilsa production from inland waters has been stable, whereas marine yields in the BoB increased substantially. In order to sustainably manage the trans-boundary stock of Hilsa, the taxonomy, distribution, habitat, migration patterns, population dynamics, fisheries and socio-economics aspects of the fishery have been reviewed here. To achieve a successful trans-boundary management for the Hilsa stock, complete ban on undersize fishing, well-targeted temporal and spatial bans, creation of protected areas in strategic points, incentive for Hilsa fishers and ecological restoration of Hilsa habitats and more work on technological development of Hilsa aquaculture are recommended.

Keywords: Hilsa shad; Bay of Bengal (BoB); Trans-boundary fishery management; Sustainable fishing

1. Introduction

The Hilsa shad, *T. ilisha* (Hamilton, 1822), locally known as ilish, is a major contributor to fish consumption in Bangladesh, east of India and Myanmar. The species is also found in Iran, Iraq, Kuwait, Malaysia (Peninsular Malaysia), Oman, Pakistan, Qatar, Saudi Arabia, Sri Lanka, Thailand, United Arab Emirates and Viet Nam (Freyhof, 2014). The fish is extremely rich in amino acids, minerals and lipids, especially essential and poly-unsaturated fatty acids (Alam et al., 2012). This euryhaline anadromous shad is found in marine, coastal and freshwater environments and often shows schooling behavior in coastal waters.

Hilsa has a large market demand, with a global average annual production of more than 0.72 million tons, of which Bangladesh shares approximately 50-60%, Myanmar 20-25%, India 15-20% and other countries (e.g. Iraq, Kuwait, Malaysia, Thailand and Pakistan) contribute 5-10% (Rahman et al., 2010; Sahoo et al., 2018). The fish constitutes the largest single species fishery in Bangladesh, contributing more than 10% of the total fish production in the country. The average annual production of Hilsa in Bangladesh is more than three hundred thousand MT (inland 35% and marine 65%) (DoF, 2017). Marine Hilsa catch of Bangladesh represent nearly 40% of the total marine catch (worth USD 1.74 billion @ USD 5 kg^{-1}) of the country. It contributes to foreign exchange earnings of US$12.5 million per year (DoF, 2014). Hilsa shad is also an important contributor to catches in the Indian state of West Bengal (12.5%), yet it represents only 2.7% of total national catch (CMFRI, 2011; DAHDF, 2014). Due to its great demand and socio-cultural influences in West Bengal (Bladon et al., 2016), the state imports Hilsa from Bangladesh equivalent to 10% of its catches (CMFRI, 2011; DAHDF, 2014). Hilsa exported by

Myanmar in 2007-08 amounted to roughly 9% of the total fisheries production, and 17,952 tonnes were exported by the country with a market price of US$ 39.53 million (the second highest exported fish following the rohu, *Labeo rohita*) (FAO, 2010). The Hilsa fishery in Myanmar, however, crashed to 2,500 metric tons in 2015-16 – relative to almost 16,000 metric tons in 2006-07 (IIED, 2016).

A substantial number of fishermen in these countries are dependent on Hilsa fishery. Nearly half a million fishers in Bangladesh are directly employed in Hilsa fishing. With an indirect employment an additional 2.5 million people are engaged in the wider Hilsa sector through net and boat making, fish transport, ice production, fish processing, trading and export (BOBLME, 2010). A large number of fishers are also engaged in the exploitation of the Hilsa fishery in the marine, estuarine and freshwaters of the Hugly-Bhagirathi river system of West Bengal (Nath et al., 2016).

In Bangladesh, the total Hilsa landing ranged between 183,501 and 394,951 MT with an average of 258,012 MT during 1987-88 - 2015-16 (DoF, 2017). The average landings from inland and marine sectors were 89,110 and 168,903 MT during this period. In West Bengal, the lion shares of the total Hilsa catch come from marine fishery, since the riverine Hilsa catch has decreased substantially during the last decade (DoF, Govt. of West Bengal, Annual Report, 2008-2015). Decrease in water discharge from the upstream rivers, heavy siltation, indiscriminate exploitation of juveniles, disruption of the migration routes, loss of spawning, feeding and nursery grounds, along with increased fishing pressure have contributed to this decline (Mome, 2007; Dutta et al., 2012; Fernandes et al., 2016; Das et al., 2018).

Comprehensive action plans have been formulated by each of the major Hilsa harvesting countries *viz.* Bangladesh, India and Myanmar, to achieve sustainable Hilsa fishery. These plans are country-specific and formulated with respect to the need of regional fishing system. Since, Hilsa is a migratory fish and a single Hilsa stock is prevalent in the Bay of Bengal region (Bhaumik, 2016); a trans-boundary management plan covering all these countries is needed to sustain the stock in its natural habitat and maintain persistent production in future. Bay of Bengal Large Marine Ecosystem Project (BOBLME) project has this trans-boundary approach aiming to improve the lives of the coastal populations through improved regional management of the BoB environment and its fisheries (BOBLME, 2010).

The present review aims to summarize the existing information and identify the knowledge gaps about productivity, life history and fishery structure of Hilsa in the BoB region needed for improving its sustainable exploitation. Finally, more viable trans-boundary management options for sustainable Hilsa fishery in BoB have been provided considering existing policies from different countries.

2. Hilsa Biology

The Hilsa shad, *T. ilisha,* belongs to the sub-family Alosinae of Family Clupeidae. It is one of three species of shad that occur in BoB waters under the genus *Tenualosa* and *Hilsa*. However, the Hilsa fishery of the BoB is dominated by *T. ilisha*, which contributes more than 99% of the total Hilsa catches (Stobberup, 2011). Hilsa is a silvery fish with gold and purple shots, with a strongly compressed and highly streamlined body (Fig. 1). To protect the abdominal region of this fast-moving migratory fish, the belly is covered with 17-18 pre-pelvic and 12-14 post-pelvic scutes or keelbones. The body is covered by

1a

1b

Fig. 1. Hilsa shad, *T. ilisha*; a. Adult and b. juvenile (jatka) (Photo credit - Mostafa A R Hossain).

large cycloid scales and the number of lateral line scales ranges between 45 and 47 (nos.). The fish has very slender and soft pin bones deeply embedded in its muscle. Branched pin bones are located on the dorsal broad muscle and unbranched ones are in the tail region (Sahu et al., 2014). Generally, the body of females is broader and the girth is comparatively bigger. The urino-genital opening of gravid females is relatively flatter, but is narrower in males where papillae are comparatively prominent (Shafi et al., 1977; Quddus, 1982).

2.1. Longevity, growth and age at the catch

The majority of the Hilsa caught are less than two years old (BOBLME, 2010). However, total life span was reported to be 2-6 years (Pillay and Rao, 1962; Bhuyan and Talbot, 1968; Hossain et al., 2014a). Otolith and length frequency data of Hilsa recorded by Rahman (2001) for different age classes are listed in Table 1. Hilsa have been classified into four size groups, small (< 30 cm), medium (30-39 cm), large (40-49) cm and extra large (>50 cm) (Rahman et al., 2012a). More than 90% of the Hilsa catch falls within a range of 30-40 cm (Rahman et al., 2012a). The data from a recent survey by phone to fish vendors (2013-14) conducted under the ESPA-Deltas project in some of the largest Hilsa landing centers and markets of the Bangladesh coast show that 90% of the caught Hilsa is in the range of 25-75 cm (Fernandes et al., 2016). However, Dutta et al. (2012) found an asymptotic length of 47.7 cm and maximum length of 45.5cm using 464 Hilsa. Commercial catches in both Bangladesh and Indian waters show a general size range of about 15-52 cm (Azad et al., 1987; Gupta, 1989; Rahman, 2006).

Table 1. The minimum, maximum and mean total length (mm) of different age groups of male and female Hilsa in Bangladesh (Rahman, 2001).

Age group	From Otolith reading			From Length frequency analysis		
	Average mm	Minimum mm	Maximum mm	Average mm	Minimum mm	Maximum mm
1+	265	248	277	263	236	290
2+	314	277	377	334	294	357
3+	380	339	429	382	351	427
4+	429	381	481	424	406	455
5+	478	447	514	479	454	506
6+	519	468	553	525	512	539

2.2. Maturity, fecundity and breeding seasons

Hilsa males appear to attain maturity at a size range of 26-29 cm as compared to 31-33 cm in the case of females. Blaber and Mazid (2001), however, found sexually mature Hilsa at 20.0 cm size at 1+ years of age. During 1990-1994 the mean length of Hilsa was 356 mm (Mitra et al., 1994). It reduced markedly to 325 mm during 2003-2004 (Nath et al., 2004) and indicates deteriorating recruitment of the species (Banerjee et al., 2013). Hilsa shad is heterosexual (Bhaumik, 2013). Other species of *Tenualosa* were found to be sequential hermaphrodites (Allosp and West, 2003; Blaber et al., 2005). No Hilsa with transitional gonads were found among more than 2,000 histologically examined fish. The peak spawning season for Hilsa is September-October (Rahman et al., 2012a). Other researchers, however, pointed out a minor peak in February-April (Mathur, 1964; Moula et al., 1991). The spawning varies from a few months to year-round and this duration varies in different rivers or parts of a river where the species is distributed (Shifat et al., 2003). The spawning cycle is closely synchronized with the lunar cycle, and intense spawning is observed during three-day periods before and after the new moon and the full moon (Miah et al., 1999).

The fecundity of Hilsa is very high and ranges between 0.1 million and 2.9 million (Table 2). Larger fish tend to produce a higher number of eggs. The fecundity was found to be 0.25 to 0.40 million, 0.4 to 1.6 million and 1.3 to 2.0 million, respectively, for Hilsa with size ranges of 25 to 40 cm, 40 to 50 cm and above 50 cm (Raja, 1985). The number of ova per gram of body mass was found to be 848 (Shafi et al., 1977) and 828 (De, 1980). As Hilsa do not show any sort of parental behavior that increases the fitness of assisted offspring, the high fecundity enables the fish to compensate for any great loss of progeny which may occur due to predation and adverse hydro-ecological parameters. The diameter

of the fully ripe ovarian egg has been found to range between 0.60 and 0.90 mm (Raja, 1985). The fertilized eggs are oily and transparent, look yellow in color and are demersal in nature (Qureshi, 1968).

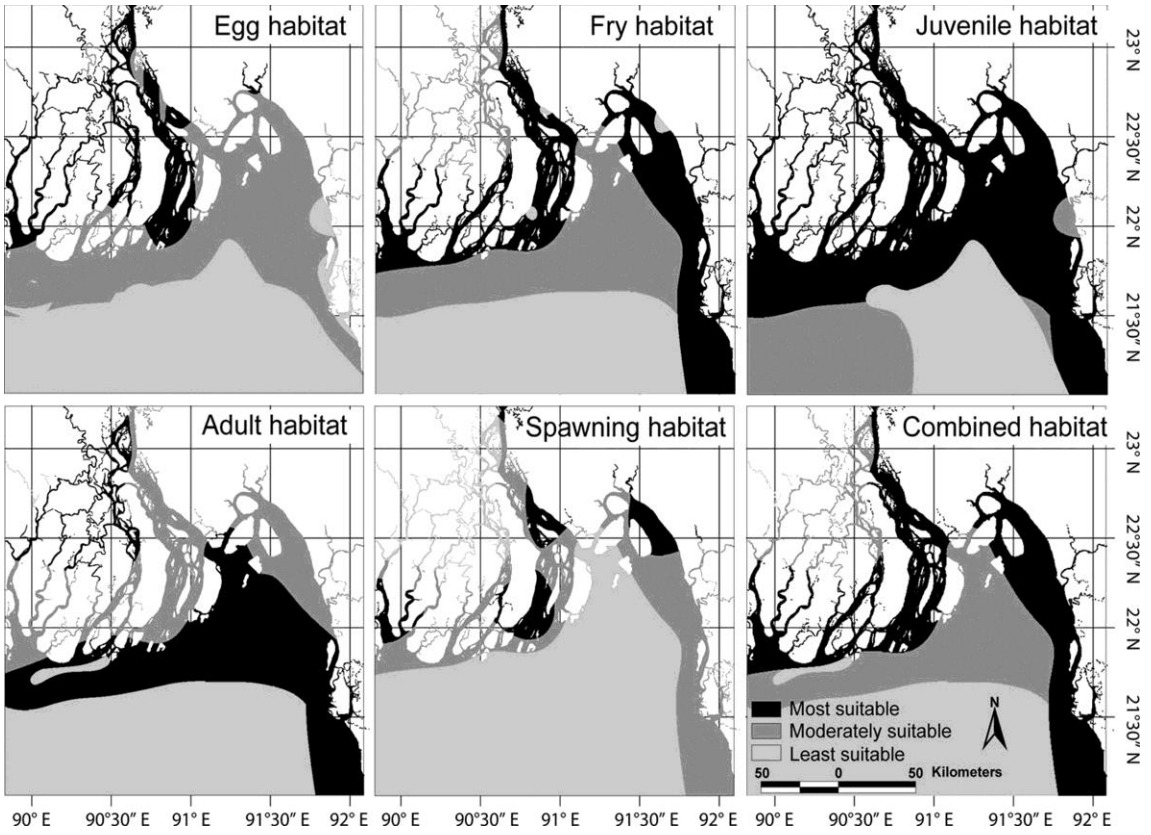
Table 2. Hilsa fecundity in different waterbodies.

Habitat/Area	Length size (cm)	Fecundity	References
Hoogly	Average	250,000-1,600,000	Pillay, 1958
Godavari	30.0-350	100,000-2,000,000	Pillay and Rao, 1962
Indus	Average	700,000-2,900,000	Pillay and Rosa, 1963
Padma – Meghna	22.5 - 48.3	900,000-2,000,000	Qureshi, 1968
Meghna	38.0 - 52.0	382,702- 1,821,420	Shafi et al., 1977
Hooghly estuary	Average	373,000-1,323,000	De, 1980
Padma – Meghna	33.0 – 51.0	600,000-1,500,000	Quddus, 1982
Padma -Goalanda	26.6 – 51.1	179,000 – 1,302,000	Moula, 1992
Meghna	28.7 – 52.3	226,000 – 1,931,000	Rahman et al., 1998a
Average Bangladesh	17.1 – 41.5	108,500 – 1,993,846	Blaber et al., 2001
Ramgoti (Luxmipur)	35.5 – 47.0	135,600 – 1,703,200	Haldar, 2004
Chandpur/Ramgoti	24.0 – 48.0	112,554 – 950,625	BFRI, 2006-07

2.3. Habitats, spawning and migration

Hilsa use different types of habitat for spawning, feeding, nursery, growth to maturity, migration and shelter (Fig. 2; Hossain et al., 2016). Therefore, a network of connected aquatic habitats is essential to maintain its life cycle and to implement successful management measures (Cooney and Kwak, 2013). Hilsa spawn in freshwater reaches of rivers (Motwani et al., 1957; Chandra, 1962; Qureshi, 1968; Mazid and Islam, 1991; Mazid, 1998). Hora (1938) suggested that the young immature specimens below one year

178 spawn towards the end of the first year of their life or in the second year. Hilsa of two and
179 more years old spawn for the second and the third time in the higher reaches, while younger
180 Hilsa making their first spawning migration are more susceptible to changes in salinity and
181 spawn in the lower reaches of the river (Rahman et al., 2012a).
182



183

184 **Fig. 2.** Suitable habitat of the developmental stages of Hilsa shad in Bangladesh (Hossain
185 et al., 2016).

186

187 The Hilsa inhabits the BoB and ascends/migrates the rivers for spawning and spent
188 fish return to marine waters together with the juveniles (BOBP, 1987; Milton and Chenery,
189 2003; Hossain et al., 2016). The environmental cues which trigger migration of Hilsa are
190 not well-known, however, factors like rainfall, current velocity, water temperature, salinity,

turbidity, primary productivity all play role in migration (Bhaumik and Sharma, 2011). It is inferred that the monsoon, monsoonal floods and sexual maturity induce the anadromous fish in the sea to undertake its upriver breeding migration (BOBP, 1987). The larvae hatch out from the developed eggs within approximately 22-26 hours (BFRI/RS, 1994). The larvae vary in size between 2.3 and 3.1 mm and is drifted by wave action and tidal currents to the nursery grounds (Rahman, 2006). As the drifting larvae become able to swim, they try to find suitable nursery grounds, normally in the downstream reaches of rivers and gradually turn to juveniles there. Juvenile Hilsa remain in the downstream riverine environment, although they have been found to occur in the upper and lower estuaries, and even further down to the coastal areas that are far from both their spawning and nursery grounds (Hossain et al., 2016). The juvenile Hilsa known as jatka remain around the nursery grounds for the next 5-6 months and attain a maximum size of 10-16 cm (Raja, 1985; BFRI/RS, 1994). Hossain et al. (2016) identified about 8,542 km^2 riverine and nearshore coastal waters in Bangladesh as most suitable habitat for the jatka. Likewise, in Indian waters, habitats of juvenile Hilsa was identified in the lower part of the Ganges – in the rivers of Hooghly, Narmada and Brahmaputra (Ghosh and Nangpal, 1970; Raja, 1985; Jafri 1988). As the jatka grow bigger with an ability to adapt to salinity, they start migrating from brackish-freshwater habitats to the offshore or seawards and at 10-16 cm total length, all the Hilsa complete their migration (BOBP, 1987; BFRI/RS, 1994). As the Hilsa become sexually mature at nearly a year of age, they start their spawning migration into freshwaters (Hossain et al., 2014b). Pillay (1964), however, observed the occurrence of three life stages of Hilsa - adult, mature and spent in a subset of sea population. Conversely, no seagoing migratory behaviour among another subset of Hilsa populations with a restricted distribution within riverine and

brackishwater environments was observed (Southwell and Prashad, 1918; Naidu, 1939). In summary, Hilsa population of the northern part of Bay of Bengal predominantly inhabits sea waters and migrates to freshwater for spawning with an additional two small subsets of the population – one that completes its life cycle within freshwater and does not migrate to sea at any stage in its life cycle, while another subset that inhabits near-shore coastal and/or sea habitats and use downstream estuarine waters as spawning ground and never migrates to fresh water (Pillay and Rosa, 1963; Quddus et al., 1984; BOBP, 1987; Milton and Chenery, 2003; BOBLME, 2010) (Fig. 3).

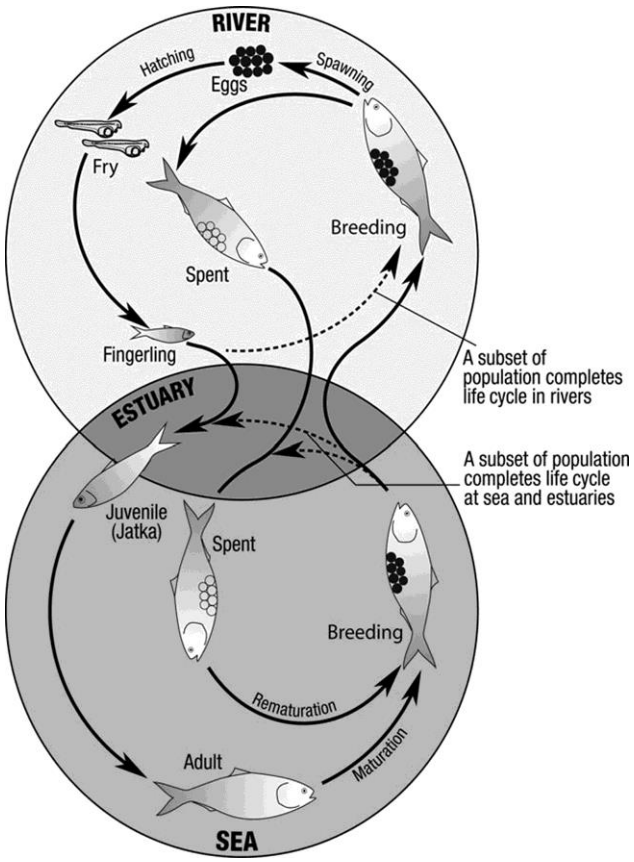


Fig. 3. Movement pattern of *T. ilisha* into different habitats (After Hossain et al., 2016).

The major five spawning grounds of Hilsa in Bangladesh, as identified by Haroon (1998) are – i. in and around the south of Moulavir Char of Hatia Island, the Hatia channel with the Bay of Bengal under the Noakhali district of Chittagong division, ii. east and southeast of Monpura Island from southwest of Hatia, extending up to the northwest of Moulavir Char under Bhola; iii. confluence of lower stretches of the river Meghna with the Bay of Bengal; iv. in and around the south of Char Fasson of Bhola; and v. confluence of the Shahbazpur River with the Bay. Hilsa also spawn along the stretch off the south of Sandwip, at the Sandwip and Hatia channel with the bay under Chittagong division. de Graaf et al. (1999) observed high density of Hilsa larva in the upper strata of the river Lohajang, near the shore in Tangail throughout the monsoon season. Two major nursery grounds, one in riverine and another in the coastal area have so far been identified. The largest riverine nursery ground is in the Meghna river covering Shatnol (Louhojang-Mawa-Gazaria, Munshiganj) under Dhaka division at the upstream end through Nilkamol of Chandpur and extending downstream to Hajimara-Char Alexander of Lakshmipur under Comilla division (BOBLME, 2010). In these nursery grounds, juvenile Hilsa (jatka) are abundant during January-May with a peak in March-April. The coastal nursery ground extends from Kuakata (Patuakhali) to Dublar Char (Khulna) – south of the Sundarbans (Haldar, 2002). The major coastal rivers that are used by Hilsa shad as nursery grounds are Ilisha, Karkhana, Pyra, Kirtonkhola, Tetulia, Bishkhali, Shabazpur channel, Arial Kha, Dharmagonj and Andarmanik under Barisal and Bhola districts. Nursery grounds of Hilsa also expand to the large rivers in and around the Sundarbans and other coastal islands (Islam and Haque, 2004; Hossain et al., 2016).

In India, presently, the Hilsa fishery largely lies within the Hooghly-Bhagirathi system - the component of Ganga river system besides other river-estuarine resources (Ahsan et al., 2014). The location of Hilsa spawning grounds in the Indian waters were in the Narbeda river (Karamchandani, 1961), Saurashtra coast and the Tapti river (Pillay, 1964) and the Ganga, Bhagirathi, Hooghly, Rupnarayan, Brahmaputra, Godavari and Narmada river of India (Ahsan et al., 2014). Stretches between Nishchintpur and Diamond Harbour at downstream, Hooghly Ghat and Kalna in freshwater tidal zone and Lalbagh to Farakka in Bhagirathi river are spawning ground for Hilsa. In the marine and estuarine part, spawning ground are located at the confluence of Hooghly river and Matla-Bidya-Raimangal (Ichamti) estuarine complex (Ahsan et al., 2014).

In Myanmar, the largest spawning ground of Hilsa is around Hinthada Township, about 230 to 310 km from the sea. These are centered on Hinthada, stretching from Zalun to Monyo, is the most important Hilsa breeding zone in the Ayeyarwady system. Ayeyarwady mainstream is the most important migratory route to upstream breeding sites of this species. However, the Toe River and Twantay Canal also play important roles as migratory routes of Hilsa. It is the convergence of these three migration routes that probably contributes most to breeding and sustainability of the Hilsa stock in Myanmar (BOBLME, 2015a).

2.4. Recruitment

With the commencement of the south-west monsoon during July-August, with heavy rains and freshwater discharge and consequent flooding of the rivers, Hilsa start their upstream migration for spawning. According to Haroon (1998), Hilsa migration is

synchronous with the increase of the average water flow and increase in average temperature of river water, though a decline in average water temperature with a stable flow does not halt migration. Rates of recruitment of Hilsa shad fluctuate greatly from year to year and this fact appears to be largely responsible for the fluctuations in the fisheries, which is common in pelagic species (Barange et al., 2009; Fernandes et al., 2013). The recruitment pattern of Hilsa is probably continuous with two major peaks (BFRI/RS, 1994; Mazid, 1998; Rahman and Cowx, 2008). This is supported by the occurrence of juvenile Hilsa throughout the year with two major pulses. For the rivers, the larger pulse was between March and May and the second pulse was between November and January. In the marine environment, the pulses were relatively shorter, having the larger pulse during March-April and the shorter pulse during January-February (Rahman and Cowx, 2008).

In Myanmar, Ayeyarwady mainstream is the most important migratory route to upstream breeding sites of this species. However, the Toe River and Twantay Canal also play important roles as migratory routes of Hilsa. It is the convergence of these three migration routes that probably contributes most to breeding and sustainability of the Hilsa stock in Myanmar (BOBLME, 2015a). Dams and embankments interfere directly with the successful completion of the breeding and feeding migrations of the Hilsa (Ahsan et al., 2014).

2.5. Hilsa prey and predator

Hilsa does not show any parental care and it is the high fecundity the source of its resilience to predation and hostile environmental conditions (Raja, 1985; de Graaf,

2003; Rahman and Cowx, 2006). There are several piscivorous species that have the potential to predate on Hilsa (Bahadur, 2010; Murugan et al., 2012) such as jellyfish, aquatic birds, minks, dolphins (*Platanista gangetica gangetica*), tooth whales, and larger predatory fishes like sharks, Indian mottled eel (*Anguilla bengalensis*), river catfishes, perches, narrow-barred Spanish mackerel (*Scomberomorus commerson*), and tunas (*Kasuwonus pelamis*, *Thunnus albacares* and *Thunnus obesus*) (Tesch, 1977; Nelson, 1998; Naser, 2014).

The absence of teeth in the mouth and masticatory apparatus in the pharynx of Hilsa is compensated by the presence of a highly developed muscular gizzard-like pyloric stomach, a well-developed gill rakers and moderately long intestine which indicates microphagous feeding (Nelson, 1967; Wahab at al., 2012). Gut analysis of different life stages of Hilsa reveals that copepods are the most important food items consumed by all sizes round the year (De and Datta, 1990; Karna et al., 2014). Adult Hilsa also feed consistently on minute organisms like diatoms, rotifers, green algae and protozoans (Moula, 1992). The availability of feed types present in the stomach indicates that that young Hilsa are surface and column feeder whereas, the presence of decayed organic matter diatoms, sand and mud along with copepods strongly suggests the bottom and column feeding habits of adult Hilsa during upstream migration. In summary, Hilsa at young stages mainly rely on zooplankton while at adult, turn to become microphagous planktivores (Hora, 1938; Hora and Nair, 1940; Swarup, 1959; De and Datta, 1990, Karna et al., 2014).

2.6. Nutritional value

Hilsa is found to be beneficial to human health because its nutritional composition (Table 3). Hilsa contains high level of high density lipoprotein and low levels of low density lipoprotein, which reduce the risk of a number of major diseases including heart disease, diabetes, cancer and obesity (Alam et al., 2012). In a study on the effect of eating Hilsa fish on hypercholesterolemic subjects, the fish was shown to reduce blood cholesterol levels, even though it is high in fat (Quazi et al., 1994). Traditionally, cooked Hilsa is known for its easy digestion and is also used as a food for people recuperating from illness.

Table 3

Nutritional value (mean ± standard deviation) of raw Hilsa – Nutrients (Alam et al., 2012) and minerals and vitamins (Mohanty et al., 2012).

Nutrients	Value (g/100 g)
Protein	24.72
Total fat	22
Total carbohydrate	3.29
Minerals	(mg/100 g)
Na	63.07±5.11
Mg	38.33±8.12
K	695.13±17.25
Ca	119.03±14.56
Mn	0.28±0.03
Fe	3.06±0.72
Cu	0.31±0.06
Zn	0.96±0.09
Vitamins	(μg/100g)
A	712.93±0.59
C	27.22*
D	133.6±0.60
E	841545.45±0.47
K	1163.85±0.62

*mg/100g

3. Environmental drivers

Reproduction in Hilsa, as one of their important life history traits, is regulated by various environmental drivers (salinity, temperature, rainfall). Changes in these parameters might affect the natural reproduction process of Hilsa and recruitment success (Miah, 2015). Salinity plays a crucial role in the lifecycle of Hilsa shad. For breeding and nursing of the juveniles, the fish prefers freshwater, for the young (pre-adult) stage it needs estuarine and coastal water and for maturation high salinity marine water is required. Since the salinity of the estuarine-river system remains low for the greater part of the year, migration and breeding activities of Hilsa are not restricted by high salinity (Rahman et al., 2012a). Temperature in the river mouth and in estuarine waters generally drops by 1.5°C from an average of 31.3°C (29.5–32.6°C) to 29.8°C (29.3-30.2°C) during the monsoon migration of the brood Hilsa. On the other hand, during the late winter (February), the ambient temperature rises by 1.8°C from an average of 27.6°C (26.8–28.4°C) to 29.4°C (27.0–31.8°C) which might influence upstream migration and breeding of Hilsa (Bhaumik et al., 2011). Rainfall, lunar periodicity, length of day, water current, freshwater flow, turbidity, sandy bottom, circular current might also influence the breeding and migration of the species (Rahman and Cowx, 2006). Water depth, particularly in the migratory route, plays an important role in the movement of migrating Hilsa and a water column of 18-20 m has been shown to be ideal for stress-free movement of the brood stocks. Nonetheless, the brood stocks can pass through a comparatively lower depth (avg. 10 m) during the winter months (Bhaumik, 2015). Evidence are available supporting early maturity of Hilsa (Almukhtar et al., 2016; Das et al., 2018) and the length at first maturity has also become lower as a probable impact of climate change and fishing (Brander, 1994; Jonsson and Jonsson, 2004; Queirós et al., 2018).

4. Global Distribution of Hilsa

Hilsa inhabits coastal zones, estuarine waters, brackish waters and freshwater rivers up to the western rim of the Indo-Pacific faunistic region (Bhaumik et al., 2013, Bhaumik, 2016). The main distribution of Hilsa (Fig. 4) extends from Iraq and Iran, where it occurs in the Tigris River basin and probably other rivers of the southern area of the country (Coad, 1995), eastwards to Myanmar, including the eastern and western coasts of India in the Arabian Sea and the Bay of Bengal (Raja, 1985; Sarkar et al., 2012).

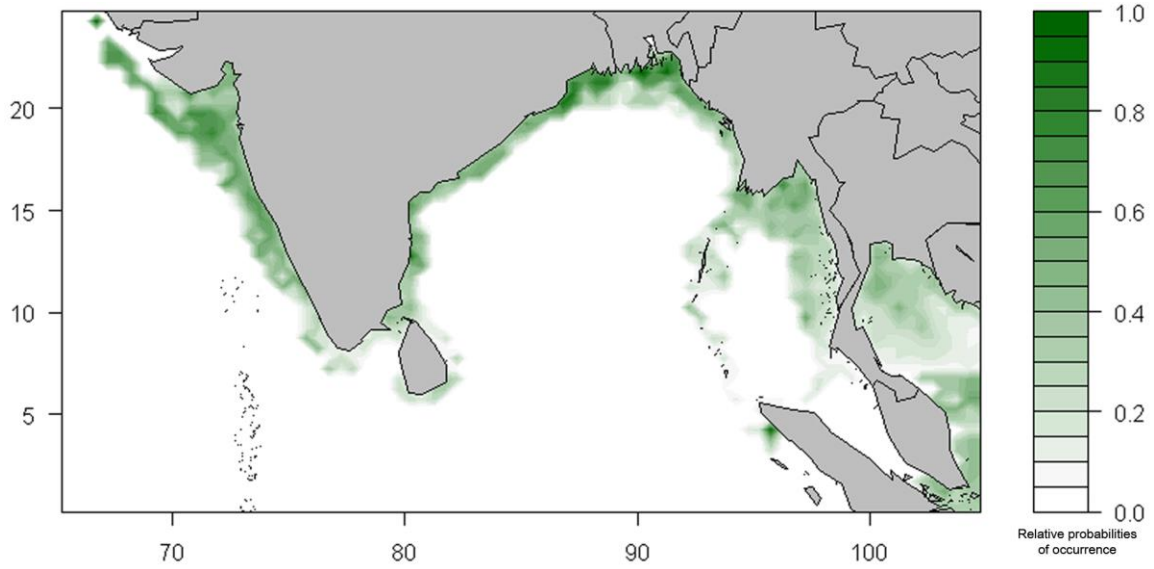


Fig. 4. The global potential distribution map of Hilsa shad, *T. ilisha*, based on projections by SS-DBEM model (Fernandes et al., 2016).

The fish has also been reported from the coastal waters of Sri Lanka and Cochin (Pillay and Rosa, 1963), from Mauritius (Fricke, 1999), from the Gulf of Tonkin, Viet Nam (Nguyen and Nguyen, 1994), Cambodian Mekong (Rainboth, 1996) and from South China

Sea (Shifat et al., 2003). The riverine and inland water transboundary distribution of Hilsa are shown in Table 4.

Table 4. Distribution of inland Hilsa shad in harvesting countries (after Bhaumik, 2016).

Country	Names of rivers/lakes
Bangladesh	**Principal rivers** The Meghna, Padma, Jamuna and Brahmaputra **Major rivers** The Sibsa, Baleswari, Pasur, Rupsa, Madhumati, Kocha, Lohalia, Tetulia, Biskhali, Buriswar, Karnaphuli, Feni, Naaf, Kharkhana, Arial Khan, Khairabad, Muhuri, Surma, Halda, Kushiyara, Matamuhuri, and Maheskhali Channel **Small rivers** The Sangu, Baral, Atai-Nabaganga, Kobadak, Chitra, Bhairab, Betna, Kumar, Chhoto Feni, Selonia, Mongla, Ilisha, Ghuaisakhali, Bhadra, Khulpetua, and Kaliganga
India (West Coast)	The Narbada, Tapti, Purna, Ulhas, Savitri, Kali and Vembanad
India (East Coast)	**Major rivers** The Hoogly-Bhagirathi, Godavari, Cauvery, Krishna, Mahanadi, Ganga and its tributaries, Padma, Brahmaputra and Barak **Small rivers** Korayar, Pamaniyar, Vellar, Palar, Pennar, Manneru and Uppeteru, and the Chilika Lake
Iraq	The Shatt-al-Arab, Tigris, Euphrates and Lake Hammar
Iran	The Shatt-al-Arab
Pakistan	The Sindh (Indus), Jhelum and Ravi
Myanmar	The Irrawaddy, Naaf and Sittang

5. Hilsa Fishery

5.1. Hilsa Catch

FAO statistics show that in recent years total catches of Hilsa from the Hilsa harvesting countries reached above than 400,000 tonnes (Fig. 5). However, FAO statistics does not reflect that Hilsa is sometimes reported together with other species (e.g. Myanmar) or directly misclassified when reported due to morphological similarity with other species

(Fernandes et al., 2016). Other assessments (Rahman et al., 2010; Sahoo et al., 2018) suggest an average annual production up to 720 000 tonnes. Of the three countries of the upper Bay of Bengal region, where the Hilsa forms a commercial fishery, Bangladesh reportedly secures the largest share of the landings with about 258,012 MT per annum (average inland and marine contribution 89,110 and 168,903 MT, respectively) during 1987-2016.

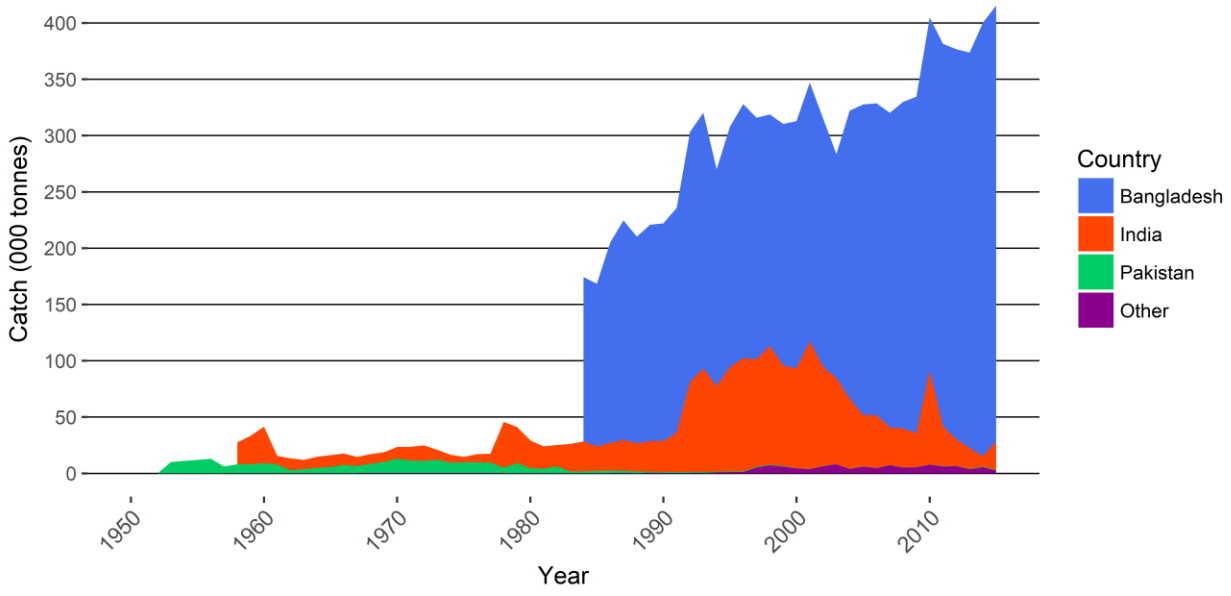
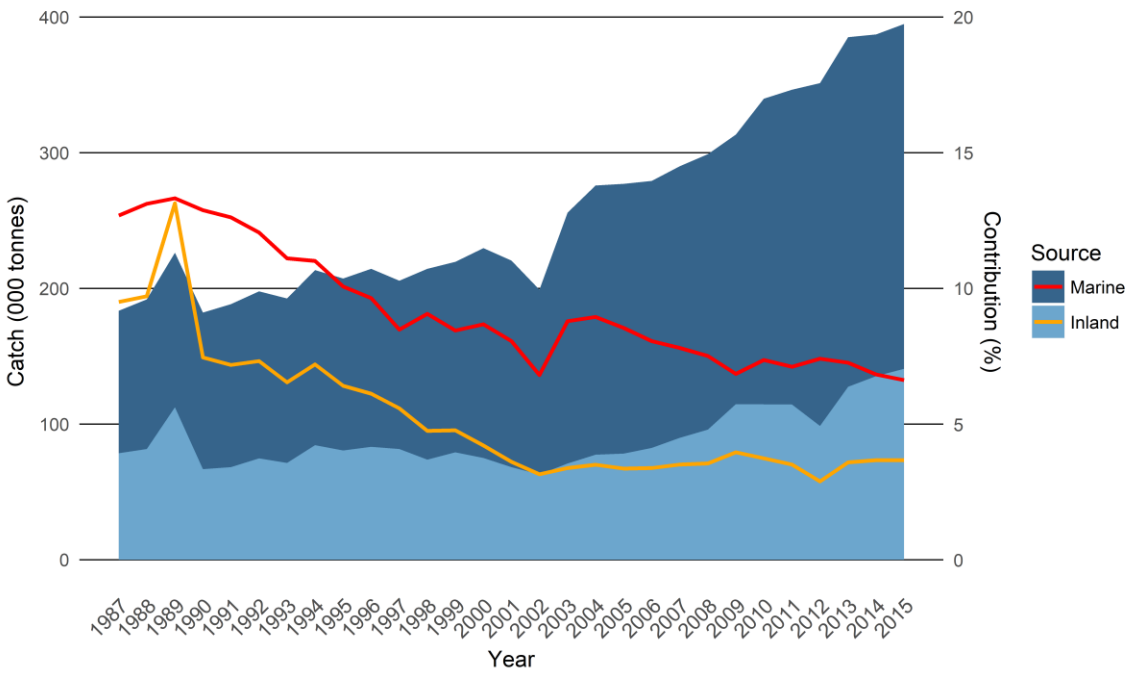


Fig. 5. Global Hilsa catch during 1950-2015 (Data source – Department of Fisheries, Bangladesh and FAO).

In Bangladesh, the monsoon months of August-October bring the peak harvest, but commercial Hilsa fishing occurs in the marine and riverine areas throughout the year (BOBP-IGO, 2008). Adults are fished during their upstream spawning migration and juveniles during their seaward migration (Haroon, 1998). The majority of the Hilsa catch (60-70%) is harvested during the peak-breeding season and about 60-70% of Hilsa caught

at this time are found to be sexually mature and ripe (Rahman et al., 2012a). The second peak of Hilsa fishing is in the riverine areas during January-February. In the sea off Cox's Bazar, though the fishery is almost year-round, marine harvest activity is much reduced during monsoon (June-August) due to the roughness of the sea (Raja, 1985). The numbers of marine fishing boats and gears have increased by nearly 4 times since 1984-85, resulting in extreme fishing pressure on the marine Hilsa population (BOBP-IGO, 2008). In addition, the intensity of marine catches has increased due to the introduction of nylon twine and mechanized fishing boats. Over the last two decades Hilsa production from inland waters increased slightly while the marine catch more than doubled. In 1987-88, about 43% of total Hilsa catch came from inland fisheries and 57% from the marine sector. Since then the share of the catch from inland waters has declined; in 2015-16, 35% of Hilsa came from inland fishery and 65% from marine fishery. During 1987-88, Hilsa contributed more than 20% in total fish production of Bangladesh and in 2015-16, the contribution was only 10.3% (Fig. 6).



412

413

414 **Fig. 6.** Catches of Hilsa (tonnes) from inland and marine sources in Bangladesh during
415 1987 – 2016 and their contribution (in %) to total fish production of Bangladesh, (DoF,
416 2006, 2008, 2010, 2014 and 2017).

417

418 Hilsa catch record of West Bengal in India shows decreasing trend of yield, though
419 the number of boats (both mechanized and non-mechanized) operating in the marine
420 fishing zone of West Bengal has increased significantly. Between 1998-99 and 2002-03,
421 the average annual catch of Hilsa in the riverine part has been estimated to be 11,483 tonnes
422 with an impressive increase of 63.3% from the corresponding five years (6,280 tonnes)
423 (Ahsan et al., 2014).

424 In Myanmar, export of Hilsa in 2012-13 was 12,324 tonnes worth US$ 33.93
425 million and Hilsa ranked second to Rohu (cultured freshwater species) in terms of export
426 volume and value (BOBLME, 2015b).

5.2. Fishing gears

The fishermen's choice of nets in different areas and seasons largely depends on the velocity of water currents, nature and size of catch and to a large extent, on their financial ability. The Hilsa fishery is mainly artisanal in nature and uses mainly drift and set gill nets from traditional non-mechanized and mechanized wooden boats (Fig. 7). Mechanized fishing with gillnets accounts for the bulk of the Hilsa landings from the Bay of Bengal. Fishers also use seine nets *Jagatber jal* (purse seine net) but catching Hilsa using this net is gradually decreasing. Fishing gears like small meshed *current jal*, *behundi jal* (set bag net), and *charghera jal* are identified as destructive and used mainly to capture juvenile Hilsa (jatka) indiscriminately in many areas. In the Cox's Bazar region, Hilsa shad is generally fished by gillnet from September to December, by comparatively larger encircling gillnet during January to March and during June-July the clap nets are used (Raja, 1985). The most important gears used to catch jatka in the river Meghna are the *jagatber jal* and *gara jal* (small meshed, very large seine net fixed with bamboo poles and extends across the river) and takes about 80% of the total jatka catch (Haroon, 1998).

In Myanmar drift nets are the dominant gear used in rivers, when water levels are high enough. Small-scale fishermen with very fine gill nets which trap very small sized fish fish in rivers. Beach seine nets are also used along river banks, in particular to catch juvenile Hilsa fish (BOBLME, 2015a). Fishers in Myanmar have long been catching Hilsa using nets with a 1″ cm mesh size trapping smaller, juvenile fish.

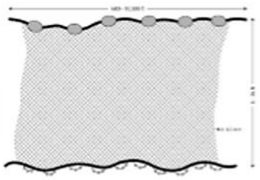
The riverine/estuarine stocks in West Bengal, India jurisdiction are exploited mostly by clap net, gill net, drift net, seine net, barrier net and fixed bag net. However, in

449 recent years the largest contribution comes from gill/drift nets and clap nets (Reuben et al.,

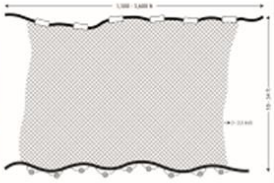
450 1992; De, 2001; Bhaumik and Sharma, 2012, Nath et al., 2016).

451

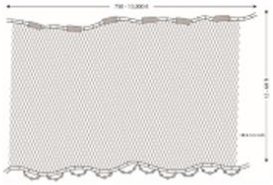
Gill Net

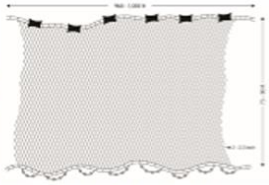
Current jal (600-10500′x6-36′, M 2-4.5″)
Other names: Rog Jal, Losa Jal

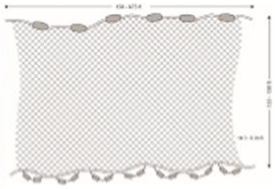
Pocket jal (1500-5600′x18-54′, M 3-3.5″)
Other name: Zero Sutar Jal

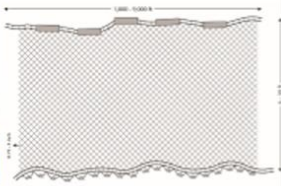
Chandi jal (750-13000′x12-60′, M 4.5-5″)
Other names: Ilish jal, Sine Jal

Kona jal (900-1000′x75-90′, M 2-2.5″)

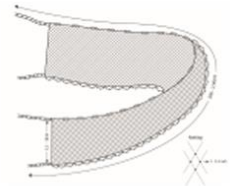



Chap jal (150-675′x135-150′, M 3-6″)
Other names: Jata Jal, Chhoi Sutar Jal

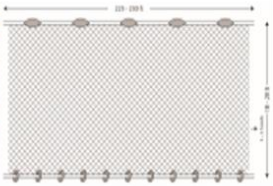



Poa jal* (1000-9000′x6-30′, M 0.75-3″)
Other names: Sada Jal, Duba Jal

Seine Net

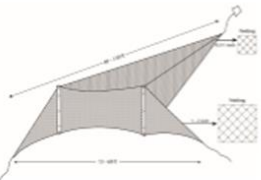



Ber jal* (500-2500′x12-18′, M 1-2.5″)
Other names: Git Jal, Pittaina Jal

Chingri jal* (225-230′x18-20′, M 1-1.5″)
Other names: Nakura jal

Fixed Purse net

Bandha jal*(40-120′x13-60′,
M 1-2″ mouth and 0.5-1 trawl end)
Other names: Bindi Jal, Behundi jal

452

Fig. 7. Common fishing gears used to catch Hilsa in Bangladesh and West Bengal, India with their local names. Length and Breadth (feet) of net given in parenthesis, M – mesh size (inches). * catches juvenile Hilsa (jatka).

5.3. Stock and exploitation of Hilsa

Various population parameters for Hilsa are summarized in Table 5. The exploitation rate (E) is defined as the quotient between fishing mortality (F) and total mortality (Z), i.e. E = F/Z (Pauly, 1984). The exploitation rate of Hilsa was higher (0.52 – 0.66) than the theoretical optimum level (0.50) during 1992-2000 (Rahman et al., 2012b). In the same period, the size at first capture (L_c) decreased gradually (35.0 cm in 1992 to 13.1 cm in 2000). This reduction in first capture size and an increasing trend in exploitation rate indicate a greater catch of under size Hilsa, which is an alarming indication of unsustainable exploitation. Haldar (2004) found that the rate of over-exploitation of Hilsa continued until 2003 with little increase in E_{max} values. However, after 2000, the size of first capture has increased significantly due to enforced protection of juvenile Hilsa.

Table 5

Estimated values of population parameters of Hilsa in Bangladesh during 1992-2000.

Parameters	BOBLME, 2010							Haldar and Amin, 2005	Amin et al., 2008	Ahmed et al., 2008
	1992	1995	1996	1997	1998	1999	2000	2002	2003	2006
Asymptotic length ($L\infty$)	61.1	58.3	59.97	61.50	66.00	60.00	62.50			52.0
Growth constant (K)	0.74	0.74	0.99	0.83	0.67	0.82	0.72			0.71
Total mortality (Z)	2.41	2.61	3.19	3.29	3.43	3.77	2.79			2.61

Natural mortality (M)	1.16	1.18	1.41	1.28	1.25	1.28	1.17			1.22
Fishing mortality (F)	1.25	1.43	1.78	2.01	2.18	2.49	1.62	2.16	1.92	1.39
Exploitation rate (E)	0.52	0.55	0.56	0.61	0.63	0.66	0.58	0.61	0.61	
Maximum yield/recruit (E_{max})	-	-	0.71	0.69	0.60	0.59	0.46			
Size at first capture (Lc)	35.0	30.0	30.34	30.25	27.06	22.80	13.12			
Growth performance (Ø)	-	3.40	3.55	3.50	3.46	3.47	3.45			

Scientists have undertaken several stock assessments of Hilsa (Miah and Shafi, 1995; Miah et al., 1997; Rahman et al., 1998b; Haldar and Amin, 2005; Amin et al., 2008; Ahmed et al., 2008; Rahman and Cowx, 2008; BOBLME, 2010). Several studies indicate that the species has been continuously over-exploited in the BoB (Amin et al., 2000, 2002, 2008; Mome, 2007; Ahmed et al., 2008; Dutta et al. 2012; Rahman et al., 2012b; Bala et al., 2014; Fernandes et al., 2016; Das et al. 2018). Recently, exploitation has reached 3 times the optimum exploitation level (f_{MSY}) of Hilsa in Bangladesh (Fernandes et al., 2016), and Myanmar (BOBLME, 2010).

The exploitation rate (E) of Hilsa shad in Bangladesh waters varied between 0.52 and 0.7 during 1992-2014 (Fig. 8). The exploitation rate (0.52) recorded in 1992 was closest to the perceived optimum levels (0.50). Since then the rate has gradually increased, until 1999 (0.66) and again decreased with a minimum of 0.53 recorded in 2006, followed by an increase in recent year during 2009-14.

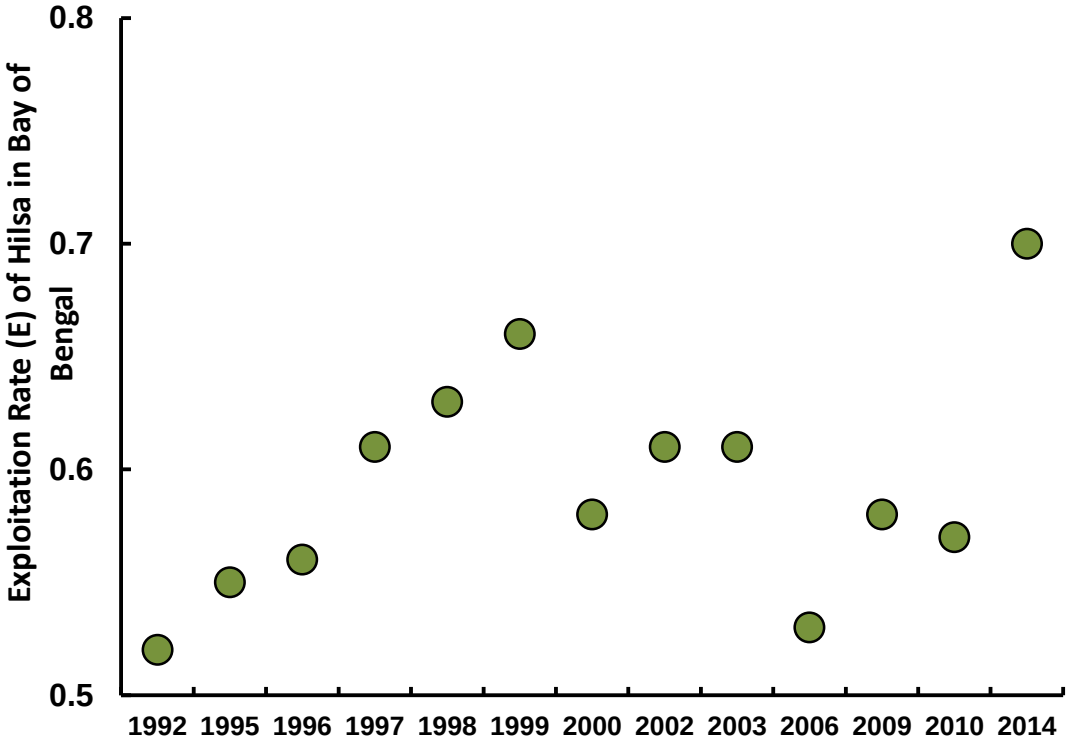


Fig. 8. Exploitation rates of Hilsa shad in Bangladesh waters (After Ahmed et al., 2008; Rahman and Cowx, 2008; Rahman et al., 2012a; Miah, 2015).

In India, total mortality has increased from 1.71 to 2.9 (Table 6). Dutta et al. (2012) studied the exploitation (E) rate of Hilsa during 2010-2011, and reported the value as 0.37 which was less than 0.50, the general exploitation rate recommended by Pauly (1980) for sustenance of a fish stock. The maximum exploitation (E_{max}) rate was reported as 0.555. Das et al. (2018) studied the rate of exploitation of the Hilsa population off West Bengal, India during the span of eight years (from 2009 to 2016). According to the study, the exploitation rate (E, 0.81) was reported to be higher than the maximum exploitation rate (E_{max}, 0.78), indicating overexploitation of the Hilsa population. Findings from the population dynamics studies also indicate unsustainable fishing of the population off West Bengal, India. The exponential value (*b*) and condition factor (K) of Hilsa has also

499 decreased by 46% and 28% respectively indicating altered growth pattern and stress due to
500 selective fishing. The fishing mortality (F, 2.34 $year^{-1}$) was significantly higher than the
501 natural mortality (M, 0.56 $year^{-1}$) and the total mortality (Z) increased by 46.5% within this
502 time period indicating increase in F. Dutta et al. (2012) reported 294.03 mm as L_{75}, i.e. the
503 294.03 mm length class in the population has 75% probability of being captured in the
504 fishery. Das et al. (2018) reported 8.3% decrease in L_{75} value (269.57 mm) since then and
505 concluded that the first spawners are being targeted by the fishery.
506
507 **Table 6**
508 Estimated values of different population parameters of *T. ilisha* in Indian waters.

Parameters	Reuben et al. (1992)	Dutta et al. (2012)	Das et al. (2018)
Asymptotic length (L∞)		47.77	54.75
Growth constant (K)		1.9	0.58
Total mortality (Z)	1.71	1.98	2.9
Natural mortality (M)	0.68	1.25	0.56
Fishing mortality (F)		0.73	2.34
Exploitation rate (E)		0.37	0.81
Maximum yield/recruit (Emax)		0.55	0.78
Growth performance (Ø)		3.637	

509
510 *5.4. Overfishing drivers*
511 Presently, fine-meshed *current jal*, *mosahri jal* (mosquito net) seine net, *behundi*
512 *jal* (set bag net) and *char ghera jal* (surrounding net) are harmful gears, being used illegally
513 in the nursery grounds to capture jatka of different sizes. During 1985-2000, the total
514 number of mechanized and non-mechanized boats was around 6,000 in Bangladesh.
515 However, in 2001-02, the number of boats and gear increased to 25,000 and 106,000,
516 respectively (Haldar, 2004). During 2011-12, the number of boats was 45,689 and the

numbers of gears reached a massive 242,450 (DoF, 2013). According to Bhaumik and Sharma (2012), more than 5,957 small mechanised and 1,533 non-mechanized boats, mostly equipped with drift gill nets containing 100 - 500 net pieces (total length 0.5 - 2 km), were actively engaged in fishing in the coastal areas of West Bengal in India. Licensed boats operated in inland and coastal waters are mainly involved in catching Hilsa. The size of the mechanised boats varies between 31-36 feet overall length (OAL) fitted with 15 HP engines and OAL 51- 58 feet fitted with 105 HP engines. In the estuarine to freshwater zones, only small non-mechanised boats are operated for Hilsa fishing (Bhaumik, 2013). Das et al. (2018) estimated the maximum sustainable yield limits (MSY) for Hilsa in the nBoB region off West Bengal. According to their study, the number of boats engaged in fishing has increased by 25% within the time span of 14 years (from 2002 to 2015) while the Hilsa catch has decreased by 13%. The MSY limit for Hilsa was estimated to be around 25,440 tonnes per year and the corresponding effort (f_{MSY}) ranged from 3571 to 3987. About 20,930 fishers are operating between Frazergunj and Raidighi in the estuary, and another 5,600 fishers do so in the freshwater zone (upper part, up to Farakka) (Bhaumik and Sharma, 2012). However, overfishing might be leading to a reduction of fleets in Bay of Bengal countries due to decreasing catches (Fernandes, 2018).

5.5. Hilsa aquaculture

Production of market size Hilsa using hatchery produced seed in aquaculture farms has the potential to substantially reduce fishing pressure on its natural stock. In the past, many Hilsa researchers (Mojumdar, 1939; Hora, 1940; Pillay, 1958) have suggested the possibility of farming of Hilsa in culture ponds. Attempts at Hilsa domestication and

culture in captivity have been made across Asia, particularly in India and Bangladesh without success to achieve a whole life cycle in captivity (Sahoo et al., 2018).

Early attempts since 1908 to develop artificial breeding of Hilsa were unsuccessful due to lack of knowledge on feeding and nutritional requirements and optimum water quality requirement for eggs, hatchling and larvae, and their adaptation mechanisms in saline water (Kulkarni, 1950; Jones and Menon, 1951; Motwani et al., 1957; Karamchandani, 1961; Dixitulu and Chacko 1962). Since 1970, success in producing larvae and rearing the fish for a few months to a few year came in captivity was achieved by a number of researchers (Malhotra et al., 1970; Mathur et al., 1974; De and Sinha, 1987; Sen et al., 1990). The first Hilsa hatchery was established in India in the of CIFRI laboratory, in Barrackpore, West Bengal in 1987 (Sahoo et al., 2018). To date notable success has been achieved in Hilsa artificial fertilization and seed production in India, however, very little success has been achieved in rearing Hilsa in confined waters, mainly due to high mortality, and lack of proper feed resulting very slow growth. In Bangladesh, since 1988, several attempts to culture the fish in ponds (Milton, 2010; Rahman et al., 2012b) resulted similar outcomes like in India. Presently, WorldFish, Bangladesh through its 'Aquaculture for Income and Nutrition (AIN)' and 'Enhanced Coastal Fisheries in Bangladesh (ECOFISH)' Project in collaboration with Bangladesh Fisheries Research Institute (BFRI) are trying to rear Hilsa juveniles in Barisal and Chandpur in freshwater and brackish water grow-out ponds.

6. Socio-economic Aspects of Hilsa Fishery

6.1. Hilsa fishery dependent livelihoods

Hilsa is an important source of employment and income in the BoB mainly in Bangladesh, India and Myanmar (Fernandes, 2018; Lauria et al., 2018). In Bangladesh, about 460,000 fishers, belonging to 183,000 families living in 148 sub-districts along the coast, are directly engaged in Hilsa fishing, with an additional indirect employment of about 2.5 million people in the wider value chain (processing, transport, trading, input supplier etc.) (BOBLME, 2010). About 2,000 mechanized boats are reported to be in operation in Cox's Bazar, and about 400 in the Chittagong district. The Hilsa fishing grounds are generally between 160 km south of Cox's Bazar (St. Martin Island) and about 50 km northwest of Cox's Bazar (Kutubdia). There are 3,700 Hilsa fishing villages under 1400 Unions, 143 Upazila and 40 districts of Bangladesh (BOBLME, 2010). Nearly 92% of the Hilsa fishers are from two divisions of Bangladesh – Barisal and Chittagong (Haldar, 2004). The major concentration is found in 6 districts of Barisal division (63%) followed by 8 districts under Chittagong division (29 %). A large number of fishers in India are engaged in the exploitation of the Hilsa fishery in the marine, estuarine and freshwaters of the Hugly-Bhagirathi river system. About 20,930 fishers are operating between Frazergunj and Raidighi, and another 5,600 fishers do so in the fresh water zone (upper part, upto Farakka) (Bhaumik and Sharma, 2012). Hilsa occurs in inland, marine, and coastal waters and is harvested throughout the year in Myanmar (Tun, 2001). Based on their study in the Ayeyarwady Delta, the most important area for the Hilsa fishery and a migratory pathway in Myanmar, BOBLME (2015c) found that a total of 1,347 stakeholders were involved in the Hilsa value chain, representing seven categories of value chain actors, - 1,020 fishers,

22 village traders, 25 township traders, 115 retailers, 10 agents, 150 wholesalers and 5 exporters.

6.2. Cultural and religious significance

Among all the fish found in the Indian sub-continent and neighboring countries, Hilsa holds a special position in the hearts as well as in the diets of people living in the region. Hilsa is the national fish of Bangladesh owing its cultural value and unique taste, especially amongst the Bengali diaspora (Bladon et al., 2016). As a fish with historical importance in the culture of Bengali and neighboring people, there is strong local and international demand for Hilsa, mainly amongst. People in Bangladesh and their closest neighbor – Indian state of West Bengal, who speak the same language – adore Hilsa as *Machher raja Ilish* (Ilish is king of all fishes) and believe the taste of Hilsa surpasses nectar (Hora, 1954a, 1954b). The author also quoted the medicinal qualities of Hilsa as - flesh demulcent (soothing), stomachic (promoting functional activity of the stomach), phlegmatic (characterized by excess of phlegm) and carminative (relieving flatulence). During the *pohela boisakh* (first day of the Bengali New Year, 14 April), it is customary to have fried ilish with *panta bhat* (fermented watery rice). In many Bengali Hindu families, a pair of ilish (*joda* ilish) is bought on special auspicious days, like *Durga puja* (the goddess of incarnation and power), *Saraswati puja* (the goddess of knowledge, music, arts, wisdom and nature) and *Lakshmi puja* (the goddess of wealth and prosperity) and without which the *puja* is thought to be incomplete (Raja, 1985). The custom, however, prevails mainly among the Bengali Hindus, many of whom now live in West Bengal, Barak Valley in Assam and Tripura in India after the partition of British ruled

India in 1947. In the Indian state of Odisha, there is a popular saying that '*Machh khaiba ilish, chakiri kariba pulis*', which literally means – 'the best fish is ilish and the best job is police' (Ghai, 2012). In Pakistan, Hilsa is a very important and famous traditional fishery of Sindh province and a demanding fish in the local markets (Panhwar and Liu, 2013). The people of Sindh are highly fond of Hilsa and there is a saying that '*Jovi palla khaega, kabhi Sindh nehi chhorega*' (whoever eats Hilsa, never leaves Sindh) (Panhwar et al., 2011). In Myanmar, Hilsa shad (ngathalauk) is a local delicacy and is used to make popular sauced fish (Pe, 2004).

6.3. Hilsa monetary value

In high demand locally, Hilsa is marketed and consumed all over Bangladesh, the Indian province of West Bengal and in Myanmar. Most of the Hilsa catch is consumed domestically as fresh fish. A salted semi-fermented product, locally known as *lona ilish*, is also popular in Bangladesh and Northeastern India. Quality is often variable and a number of different grades are available (Majumdar and Basu, 2010). Hilsa are graded according to their weight and the habitats they are caught from. Three weight grades are considered - large fish are above 1 kg, medium are 0.8 kg -1 kg and small fish less than 0.8 kg. Hilsa harvested from rivers always fetch more money than marine Hilsa (Alam et al., 2012). The market price of Hilsa, however, is determined by several additional factors including quality, seasonality, market structure, supply and demand. Prices also vary from market to market and are much higher in city/town markets than in coastal markets (Table 7).

Table 7

Mean Hilsa size (cm) and price (Taka/kg) over the year (2013-14).

Landing Centers/Markets	Type of Markets	August-October (Peak season of Hilsa fishing)		Rest of the year	
		Mean Size (cm)	Mean Price (Taka/kg)	Mean Size (cm)	Mean Price (Taka/kg)
Alipur-Mohipur	Coastal/Inland	30.5	379.5	28.2	397.1
Barisal	Coastal/Inland	31.2	383.7	31	500.8
Chittagong	Marine	29.2	266.3	29.6	418.3
Cox's Bazar	Marine	29.6	236.3	35.1	419.9

*The data are summarized from field survey conducted under the 'Assessing Health, Livelihoods, Ecosystem Services and Poverty Alleviation in Populous Deltas (EspaDeltas) project in the coastal Bangladesh during 2013-14 (Fernandes et al., 2016)
**Current exchange rate US$ 1 = Bangladesh taka (BDT) 80.0.

Price per kg of Hilsa in Myanmar varies both with season and size. In both peak and lean seasons, the initial price of the large-sized Hilsa is three times higher than that of small-size Hilsa. Along the value chain, price increases differently according to fish size - small-fish mark-up reaches 100% between first and last point of sale, while large-size fish mark-up is less, at an average 80% between first and last point of sale. Based on the size, season and location, price of per kg of Hilsa varies between as low as US$ 4.77 (5,200 Kyats) and as high as US$15.29 (16,267 kyats) (BOBLME, 2015c).

6.4. Hilsa international trade

Among the Hilsa harvesting countries – Bangladesh and Myanmar are the main exporters of Hilsa to other countries (Kleih et al. 2003; Win et al., 2008; BOBLME, 2015b). During 2011-12, Bangladesh exported 6,174 MT Hilsa and earned 36.27 million USD. According to Kleih et al. (2003), 88% of Hilsa is marketed internally for national consumption in Bangladesh and the remainder (12%) is exported. In 2010-11 the country exported 5,376 MT of Hilsa fish to India out of the total export of 8,500 MT. The rest was exported to the Bangladeshi ethnic markets in Europe and North America (Islam, 2012). Hilsa is mainly exported to the Indian state of West Bengal and other countries in the Far East and Middle East, EU, USA and Australia where there are populations of non-resident Bangladeshis and labourers (Padiyar et al., 2012). In Europe, USA, Japan and in the Middle Eastern countries, Hilsa is available at Bangladeshi, Pakistani and Indian grocery stores (pers. obs.; Mome and Arnason, 2007). The export volume dropped during 2007 due to a ban by the Government of Bangladesh. The ban, repeated in 2012 drew criticism from Hilsa exporters in Bangladesh, who claimed that on the one hand, the ban increased Hilsa smuggling to India and on the other hand, it was not effective enough to reduce the local retail price of Hilsa to within the purchasing power of retail consumers because supply in local markets remained insufficient (Daily Star, September 1st, 2012).

In 2012-13, the estimated amount of Hilsa export from Myanmar was over 12,000 tonnes and fetched nearly US$34 million from 29 countries worldwide, with 17 in Asia, six each in the Middle East and Europe (Lwin, 2013; BOBLME, 2015b). Almost 83% of total Hilsa caught in Myanmar are exported overseas and the major importing countries are India, Malaysia, China, Singapore, Dubai, UAE and Bangladesh (BOBLME, 2015c). The majority of large-size Hilsa is destined for export where smaller and lower price Hilsa is

consumed locally. India is the largest overseas buyer in high season, purchasing all sizes of Hilsa, and China is the second largest buyer, importing only large-size Hilsa.

7. Hilsa Fishery Management and Conservation Measures

Country-wise comprehensive action plans for Hilsa management have been formulated by the major Hilsa harvesting countries (Bangladesh, India and Myanmar) and is being implemented by the respective Fisheries Department. The management plans and potential conservation for each country are summarized here.

7.1. Management strategies opted by different countries

Department of Fisheries (DoF), Bangladesh Fisheries Research Institute (BFRI) and a number of other organizations formulated Hilsa fishery management plans. The plan includes the protection of the species and its habitats, with particular emphasis on juvenile Hilsa (jatka), and the spawning and nursery grounds. Implementation of these plans were initiated in 2003 with the following specific actions –

- Involvement of different agencies in the jatka protection program (Ministry of Fisheries & Livestock, DoF, Navy, Coast Guard, Upazila Administration, District and Upazila level officers of DoF).
- Identification of a special operations area for proper functioning and coordination of the Navy and Coast Guard, and enforcement of Fish Protection and Conservation Act.
- Ban on the catching, possession, transport and trading of juvenile Hilsa (jatka) (up to 23.0 cm size) during 01 November - 31 May every year.

- Establishment of Hilsa sanctuaries (five major nursery and spawning grounds) at strategic points within the Bangladesh river systems. These are, (a) from Shatnol of Chandpur district to char Alexander of Laxmipur (100 km of lower Meghna estuary); (b) Madanpur/Char Ilisha to Char Pial in Bhola district (90 km area of Shahbajpur river, a tributary of the Meghna); (c) Bheduria of Bhola district to Char Rustam of Patuakhali district (nearly 100 km area of Tetulia river); (d) 20 km stretch of Andharmanik river in Patuakhali district and (e) whole 40 km stretch of Andharmanik river in Upazila Kalapara of Patuakhali district. Fishing is prohibited during March to April in the first four sanctuaries and from November to January in the 5^{th} sanctuary - the Andharmanik river (DoF, 2006). The Department of Fisheries has also proposed four more Hilsa closure areas in the downstream part of the river Padma.
- Catching, transporting, marketing and stock-piling of Hilsa have been banned in Bangladesh each year in the major spawning grounds during the last fortnight of September for 11 days, 5 days either side of a full moon to conserve the gravid Hilsa population.
- Providing food incentives and provision of alternative livelihoods to the Hilsa fishers during the fishing ban period.

Similarly, in India, the West Bengal Fisheries Department included new amendments on April, 2013 under the West Bengal Inland Fisheries Act (West Ben. Act XXV of 1984) to protect Hilsa fishery and its breeding grounds. The following rules have been amended:

- The size of monofilament gillnets and other nets have been restricted to below 90 mm and below 40 mm respectively in the inland open water system.
- Fishing of Hilsa having a length below 23 cm is banned within the area of West Bengal Govt. jurisdiction.
- Five breeding grounds of Hilsa have been identified and marked as Hilsa sanctuary in West Bengal. Four of them are located in the Ganga-Bhagirathi-Hugli river system, these are: (a) 5 km^2 area around the Farakka barrage; (b) Farakka-Lalbagh reach; (c) Kalna-Hugli Ghat reach; and (d) Diamond Harbour-Godakhali reach. Another 5 km^2 area has been declared as Hilsa sanctuary around the sand bar located at the Thakuran-Matla-Roymongal estuarine complex in Sundarban area.
- All kinds of fishing are prohibited in the Hilsa sanctuaries during June to August and October to December of every year.
- During February to April every year, the use of bag nets, scoop nets, lift nets and small meshed gill nets (mesh size below 1 inch) is banned to protect Hilsa below 23 cm in the inland open water system (including estuarine area).
- Bottom trawling in the shallow continental shelf (12 nautical miles) is totally banned to conserve marine biodiversity and habitat in the shallow area and to facilitate Hilsa growth and breeding.
- Fishing of Hilsa of any size is completely prohibited between 5 days prior and post of the full moon for the period of 14^{th} September to 24^{th} October every year for promoting breeding and spawning.

In Myanmar's Ayeyarwady delta, the Myanmar government declared a closed season for Hilsa fishing from July to August, which corresponds to the monsoonal or flooding season (BOBLME, 2015a). The study also came up with two major recommendations:

- The convergence of the Toe River, Twantay Canal and the main channel of the river Ayeyarwady is very important for migration and breeding of the Hilsa in Myanmar, and this site should be a priority location for protection and regulation measures.
- The section of the Ayeyarwady centered on Hinthada and stretching from Zalun to Monyo is the most important Hilsa breeding zone and should also be considered a priority location for protection and regulation measures of Hilsa in Myanmar.

However, the degree to which the protected areas will actually contribute to Hilsa conservation, and the scientific basis for their locations need rigorous monitoring and critical evaluation (Bladon et al., 2016).

7.2. Alternate livelihood for Hilsa fishers

Under the Bangladesh DoF initiatives, a series of needs-based training schemes have been arranged, involving full time Hilsa-dependent fishers and their family members, to ensure effective intervention in providing alternative income generating activities (Hossain et al., 2018). During the ban period, Hilsa fishers are supported with 40 kg of food per family per month for four months. Training programs are organized for the fisher households in various income-generating activities, such as starting small businesses, poultry and livestock rearing, van/rickshaw pulling, sewing, cultivating fish in cages and financial incentives. Each of the trainees is provided with a daily meal and about BDT 500 to attend the training program (Mohammed and Wahab, 2013). The compensation scheme

currently in practice has so far proved to impact positively on Hilsa production, but there are questions surrounding sustainability, equity and efficiency of the scheme, which might be addressed through a more formalized and collective payment approach (Bladon et al., 2016).

7.3. Trans-boundary Hilsa Fishery Management

The UN Convention in 1982 suggested trans-boundary management for the fish stocks (UN, 1982, Article 63(1)) which occur within the exclusive economic zones of two or more coastal states. The BOBLME (Bay of Bengal Large Marine Ecosystem) project initiated by eight countries (Bangladesh, India, Indonesia, Malaysia, Maldives, Myanmar, Sri Lanka and Thailand) aiming at maintenance and improvement of the health of region's marine and coastal ecosystems and living resources for the betterment of the coastal populations dependent on these resources. The Regional Fisheries Management Advisory Committee (RFMAC) within BOBLME project proposed some major recommendations for Bangladesh, India and Myanmar to help to make national decisions so that sustainable Hilsa fishery can be achieved collectively. A detailed study has also been done by the IUCN funded project Ecosystems for Life: a Bangladesh-India Initiative (Ahsan et al., 2014). Several management options have been proposed for individual countries as well as for the entire BoB covering Bangladesh and India. The proposed recommendations are as follows:

- Number of fishing vessels should be reduced and the spawning and nursery grounds should be protected to increase the stock.
- The minimum legal mesh size used by the Hilsa fishers should be increased to 110 mm.

- Awareness programs involving all the stakeholders should be made more frequently so that improved implementation of the proposed regulations can be achieved.
- Establishing multi-agency committees would be more helpful to monitor the implementation of the proposed regulations.
- Restrictions should be imposed against establishing any power station or polluting industry close to the spawning grounds.

7.4. Present study recommendations for a sustainable Hilsa fishery in the BoB region

Hilsa management must move towards sustaining and maximizing the fishery. Research is needed to fill data and knowledge gaps to improve existing practices and to restore the ecosystem. To face the challenge of both anthropogenic and climate change impacts on Hilsa (Fernandes et al., 2016; Barange et al., 2018; Hossain et al., 2018; Kebede et al., 2018; Lázár et al., 2018), there is an urgent need to educate people involved in the value chain of Hilsa and associated backward and forward linkages as well as enhance socio-economic adaptation capacity (Fernandes, 2018; Hossain et al., 2018). The GO and NGO officially working on Hilsa management need a greater understanding and appreciation of the Hilsa's bio-physiology and characteristics, the locations of water bodies where the fish migrate, spawn, feed and thrive, and of the most effective and up to date management practices, in order to pave the way for a sustainable and long-lasting Hilsa fishery. After reviewing the existing regulations for all the countries as well as the recommendations made by BOBLME project and IUCN some similarities and discrepancies have been identified in the regulations. For example, schedule of seasonal

804 fishing bans differ between West Bengal in India (15th April to 15th June during monsoon
805 and another 11 days fishing ban is maintained during 14th September to 24th October) and
806 in Bangladesh, (from March to April and November to January). To achieve a successful
807 trans-boundary management for the Hilsa stock, few recommendations have been made
808 from the present study:

809 • A common regulation (e.g. mesh size and bans) should be formulated by
810 Bangladesh, India and Myanmar and other Hilsa harvesting countries to restrict
811 Hilsa fishing and trade in its estuarine and coastal waters by means of a multi-
812 country management body.
813 • A focused study in all countries should aim to declare a network of protected areas
814 protecting spawning grounds for Hilsa on the long-term.
815 • Enough food subsistence during bans and economic coverage (fair insurances and
816 loans) during the year should be provided to fishermen.
817 • Provision of education, alternative and diversified livelihoods.
818 • Real time monitoring systems should be designed to prevent illegal fishing and to
819 generate accurate data for all the countries from both the riverine and marine
820 systems, so that, in future, the "quota system" in Hilsa fishery can be applied.
821 • Collection of prawn and fish larvae as well as crabs from the estuarine rivers and
822 creeks using fine mesh or clothes should be strictly prohibited for its highly
823 unsustainable nature.
824 • More detailed research on Hilsa biology, spawning, breading and migration
825 behaviour is needed to stablish catches and protection measures based on
826 scientific knowledge.

- Hilsa culture should be developed to reduce pressure on wild stocks. It is in preliminary phase and requires technological development for broodstock management, hatchery technology, live food production for hatchling, larval rearing and farming in the grow-out systems. More collaborative works in fine-tuning the technologies through international research and development partnerships is needed.
- Detailed study of the predator-prey interactions of Hilsa with the other trophic levels of the ecosystem is needed for the entire region towards an ecosystem based management approach that would benefit also other fish stocks.

8. Conclusion

Hilsa shad is a species widely distributed across countries in the BoB and Indian Ocean of high economic and cultural value. Hilsa is known to be overexploited, but also an important income activity for coastal communities. For a long term sustainable exploitation, fishing of small sized Hilsa should be stopped through multiple socio-economic adaptation mechanisms, such as extending current food subsidies during fishing bans, extending fishermen literacy and training in alternative livelihoods. Sanctuary creation should continue, not only based on seasonal bans, but also towards creating fully protected areas. National policies can be modified to increase economic resilience with loans, minimum wages and insurances. Another set of required action are around ecological restoration, by dredging of the silted river channels, reducing discharge of pollutants and industrial effluents, provisioning fish passages or fish-friendly structures (FFS) in the dams and barrages, increasing water flow from the upstream regions (trans-boundary rivers) and

construction of large reservoirs to hold water in the dry season and maintain normal river flow. In addition, provision of suitable formation of fishers' groups and representatives and other community-based approaches is vital. More works on technological development of Hilsa aquaculture by the researchers in collaboration with governments, NGOs and the private partners are needed. Strong and effective regional collaboration among three neighboring countries, Bangladesh, India and Myanmar – should continue based on recent works such as BOBLME, ESPA and the DECCMA project.

Acknowledgements

This work is carried out under the Deltas, Vulnerability and Climate Change: Migration and Adaptation project (IDRC 107642) under the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA) programme with financial support from the UK Government's Department for International Development (DFID) and the International Development Research Centre (IDRC), Canada. The views expressed in this work are those of the creators and do not necessarily represent those of DFID and IDRC or its Boards of Governors. It builds over previous work in the project 'Assessing health, livelihoods, ecosystem services and poverty alleviation in populous deltas', project number NE-J002755-1, was funded with support from the Ecosystem Services for Poverty Alleviation (ESPA) programme. The ESPA programme is funded by the Department for International Development (DFID), the Economic and Social Research Council (ESRC) and the Natural Environment Research Council (NERC). Jose A. Fernandes received further funding through the Gipuzkoa Talent Fellowships programme, by the Gipuzkoa Provincial Council, Spain.

References

Ahmed, M.S., Sharif, A.S.M., Latifa, G.A., 2008. Age, growth and mortality of Hilsa shad, *Tenualosa ilisha* in the river Meghna, Bangladesh. Asian Journal of Biological Sciences 1, 69-76.

Ahsan, D.A., Naser, M.N., Bhaumik, U., Hazra, S., Bhattacharya, S.B., 2014. Migration, spawning patterns and conservation of Hilsa shad (*Tenualosa ilisha*) in Bangladesh and India, Academic Foundation, New Delhi.

Alam, A.K.M.N., Mohanty, B.P., Hoq, M. E., Thilsted, S.H., 2012. Nutritional values, consumption and utilization of Hilsa *Tenualosa ilisha* (Hamilton, 1822). Proc. Regional Workshop on Hilsa: Potential for Aquaculture. 16-17 September 2012. pp. 183-215, Dhaka, Bangladesh.

Allsop, D.J., West, S.A., 2003. Constant relative age and size at sex change for sequentially hermaphroditic fish. Journal of Environmental Biology 16, 921–929.

Almukhtar, M. A., Jasim, W., Mutlak, F., 2016. Reproductive Biology of Hilsa Shad *Tenualosa ilisha* (Teleostei: Clupeidae) During Spawning Migration in the Shatt Al Arab River and Southern Al Hammar Marsh, Basra, Iraq. Journal of Fisheries and Aquatic Science, 11(1), 43-55.

Amin, S. N., Rahman, M. A., Haldar, G. C., Nahar, S., Dewan, S., Mazid, M. A., 2000. Population dynamics of jatka (juvenile hilsa) in the Meghna River, Bangladesh. Asian Fisheries Science, 13(4), 383-390.

Amin, S. N., Rahman, M. A., Haldar, G. C., Mazid, M. A., Milton, D., 2002. Population dynamics and stock assessment of Hilsa shad, *Tenualosa ilisha* in Bangladesh. Asian Fisheries Science, 15(2), 123-128.

Amin, S.M.N., Rahman, M.A., Haldar, G.C., Mazid, M.A., Milton, D.A., 2008. Catch per unit effort, exploitation level and production of Hilsa shad in Bangladesh waters. Asian Fisheries Science 21, 175 – 187.

Azad, S.A., Hertel-Wulff, J., Islam, M.S., Huq, Q.M., Das, N.N., 1987. Hilsa fishery in Bangladesh in 1985-1986. Hilsa Investigations in Bangladesh. FAO-UNDP Project on Marine Fisheries Resource Management. BOBP/Rep/36, p. 46-63, Bay of Bengal, Colombo, Sri Lanka.

Bahadur, H.I., 2010. Trades of shark products in Bangladesh. In Shark Fisheries in the Bay of Bengal, Bangladesh: Status and Potentialities, pp. 43–50. ed. by M. E. Hoq, et al., 2011. Support to Sustainable Management of the BOBLME Project, Bangladesh Fisheries Research Institute, Bangladesh. 76 pp.

Bala, B. K., Arshad, F. M., Alias, E. F., Sidique, S. F., Noh, K. M., Rowshon, M. K., Islam Q. M. M., Islam, M. M., 2014. Sustainable exploitation of hilsa fish (*Tenualosa ilisha*) population in Bangladesh: Modeling and policy implications. Ecological modelling, 283, 19-30.

Banerjee, T.K., Hazra, U.S., Banerjee, R., 2013. Studies on the incidence behavior and morphometry of Hilsa Fish, *Tenualosa ilisha* in relation to environmental attributes in the selected portion of the upper stretch of Hooghly estuary. Spring 1(1), 26-47.

Barange, M., Coetzee, J.C., Takasuka, A., Hill, K., Gutierrez, M., Oozeki, Y., van der Lingern, C., Agostini, V., 2009. Habitat expansion and contraction in anchovy and sardine populations. Progress in Oceanography 83, 251-260.

Barange, M., Fernandes, J.A., Kay, S., Hossain, M. A. R., Ahmed, M., Lauria, V. 2018. Marine Ecosystems and Fisheries: Trends and Prospects. pp 469-488. In: Nicholls,

R.J., Hutton, C.W., Adger, W.N., Hanson, S.E., Rahman, M.M., Salehin, M. (Eds.). Ecosystem Services for Well-Being in Deltas: Integrated Assessment for Policy Analysis; Palgrave Macmillan, Cham: London, UK.

BFRI, 2006-07. Hilsa Fishery Management Research. Riverine Station, BFRI, Annual Progress Report, August 2007, 10 pp.

BFRI/RS, 1994. Annual Report on Hilsa Fisheries Development and Management, p. 21, Mymensingh, Bangladesh.

Bhaumik, U., 2013. Decadal Studies on Hilsa and its Fishery in India - A Review J. Interacad. 17(2), 377- 405.

Bhaumik, U., 2015. Migration of Hilsa shad in the Indo-Pacific Region–A Review. Int. J. Curr. Res. Aca. Rev. 3(11), 139-155.

Bhaumik, U., 2016. Stock Profile of Hilsa Shad Population in Bay of Bengal Region-A Review. Int. J. Curr. Res. Aca. Rev. 4(6), 22-38.

Bhaumik, U., Sharma, A.P., 2011. The fishery of Indian Shad (*Tenualosa ilisha*) in the Bhagirathi-Hooghly river system. Fishing Chimes 31(8), 21-27.

Bhaumik, U., Sharma, A.P, 2012. Present Status of Hilsa in Hooghly-Bhagirathi river, CIFRI Bulletin 179, 42 pp.

Bhaumik, U., Srivastava, N.P., Satpathy, B.B., Mukhopadhyay, M.K., Sharma, A.P., 2011. Impact of hydro-ecology on fish migration in selected east coast estuaries. Journal of Inland Fisheries Society of India 43, 1-9.

Bhaumik, U., Mukhopadhyay, M.K, Shrivastava, N.P., Mukherji, C.N., Mitra, A., Haldar, T.K., Mandi, R.C., Barui, A., Bose, S., Roshith, C.M., 2013. Distribution pattern

of Hilsa in the Tapti estuary of West coast of India, Environmental Ecology 31(3), 59- 63.

Bhuyan, N.I., Talbot, G.B., 1968. Fluvial migration, spawning and fecundity of Indus river Hilsa (*Hilsa ilisha*). Transaction of American Fisheries Society 97, 340-355.

Blaber, S.J.M., Mazid, M.A., 2001. Hilsa Fishery Research in Bangladesh. ACIAR Project 9430, Final Report, August 2001, 123+20 pp, Dhaka, Bangladesh.

Blaber, S.J.M., Milton, D.A., Brewer, D.T., Salini, J.P., 2001. The shads (genus *Tenualosa*) of tropical Asia: An overview of their biology, status and fisheries. In: Proc., International Terubok. Conf., pp. 9-17, Sarawark Development Institute (SDI), Kuching, Sarawark.

Blaber, S.J.M., Fry, G., Milton, D.A., van der Velde, T., Book-Teck, O., Pang, J., Wong, P., 2005. The life history of *Tenualosa macrura* in Sarawak, further notes on protandry in the genus and management strategies. Fisheries management and Ecology 12,201-210.

Bladon, A.J., Katherine, M.S., Essam Y.M., Milner-Gulland, E.J., 2016. Payments for ecosystem services in developing world fisheries. Fish and Fisheries 17, 839–859.

BOBLME, 2010. Status of Hilsa (*Tenualosa ilisha*) management in the Bay of Bengal – an assessment of population risk and data gaps for more effective regional management. BOBLME–2010–Ecology–01. 70 pp.

BOBLME, 2015a. Distribution, migration and breeding of Hilsa (*Tenualosa ilisha*) in the Ayeyarwady system in Myanmar, September 2015. BOBLME-2015-Ecology 39. 120 p.

964 BOBLME, 2015b. Stock assessment of Hilsa shad, *Tenualosa ilisha* in Myanmar
965 BOBLME-2015-Ecology-22.
966 BOBLME, 2015c. The value chain of Hilsa shad in the Ayeyarwady Delta, January 2015.
967 BOBLME-2015-Socioec-13.
968 BOBP, 1987. Hilsa Investigations in Bangladesh - BOBP/REP/36 .Marine Fishery
969 Resources Management (RAS/81/051) in the Bay of Bengal. Colombo, Sri Lanka,
970 June 1987. BOBP-IGO, 2008. India, Bangladesh and Myanmar Lay out Road Map
971 for a Management Plan for Hilsa Fisheries – Hilsa Management Plan. p. 18. Bay of
972 Bengal News - March - June 2008.
973 BOBP-IGO, 2008. India, Bangladesh and Myanmar Lay out Road Map for a Management
974 Plan for Hilsa Fisheries – Hilsa Management Plan. p. 18. Bay of Bengal News -
975 March - June 2008.
976 Brander, K.M., 1994. Spawning and life history information for north Atlantic cod stocks.
977 ICES Cooperative Research Report No. 205, pp 155.
978 Chandra, R., 1962. A preliminary account of the distribution and abundance of fish larvae
979 in Hooghly estuary. Indian Journal of Fisheries 9(1), 48-70.
980 CMFRI, 2011. Annual Report 2010-2011. Central Marine Fisheries Research Institute
981 Indian Council of Agricultural Research. Kerala, India.
982 Coad, B.W. 1995. Freshwater fishes of Iran- A checklist. Bulletin of the Institute of
983 Landscape Ecology of the Academy of Sciences of the Czech Republic 29, 1-64.
984 Cooney, P.B., Kwak, T.J., 2013. Spatial extent and dynamics of dam impacts on tropical
985 island freshwater fish assemblages. BioScience 63, 176–190.

DAHDF, 2014. Department of Animal Husbandry, Dairying and Fisheries, Government of India. Ministry of Agriculture. Krishi Bhavan, New Delhi.

Daily Star, 2012. Lift Hilsa export ban to avoid fish smuggling, Dhaka, Bangladesh, 1 September, 2012.

Das, I., Hazra, S., Das, S., Giri, S., Maity, S., Ghosh, S., 2018. Present Status of the Sustainable Fishing Limits for Hilsa Shad in the northern Bay of Bengal, India. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences, 1-8.

De, D.K., 1980. Maturity, fecundity and spawning of post-monsoon run of Hilsa, *Hilsa ilisha* (Hamilton) in the upper stretches of the Hooghly estuarine system. Journal of Inland Fish Society of India12, 54-63.

De, D.K., 2001. An overview of biology of hilsa, *Tenualosa ilisha* (Hamilton) and its fishery in the Ganga-Hooghly drainage system, Proceedings of the International Terubok *(Tenualosa* sp.) Conference 11-12 Sept., Sarawak, Malaysia. 25-51p.

De, D.K., Datta, N.C., 1990. Studies on certain aspects of the morpho-histology of Indian shad hilsa, *Tenualosa ilisha* (Hamilton) in relation to food and feeding habits. Indian Journal of fisheries 37(3), 189 -198.

De, D.K., Sinha, M., 1987. Artificial fecundation of *Hilsa ilisha* – a possible approach to revitalise its depleted fishery. In: Symposium on the Impact of Current Land use Pattern and Water Resources Development on Riverine Fisheries, 58 pp.

de Graaf, G. J., Born, A. F., Uddin, A. M. K., Huda, S. 1999. Larval fish movement in the River Lohajang, Tangail, Bangladesh. Fisheries Management and Ecology 6, 109-120.

de Graaf, G. J., 2003.Water management and the drift of larval fish in the floodplains of Bangladesh. Practical experiences of the Compartmentalization Pilot Project with "fish friendly" regulators. Technical report Nefisco foundation, Amsterdam, The Netherlands.

Department of Fisheries (DoF), 2006. Annual Report. (ed. Islam, M.N.). DoF & MoFL, p. 111, Dhaka, Bangladesh

Department of Fisheries (DoF), 2008. Fisheries Statistical Yearbook of Bangladesh 2006 – 2007 (July 2006 - June 2007) Twenty Fourth Edition. p. 42, Dhaka, Bangladesh.

Department of Fisheries (DoF), 2010. Fisheries Statistical Yearbook of Bangladesh 2008 – 2009 (July 2008 - June 2009), Twenty Sixth Edition, p. 41, Dhaka, Bangladesh.

Department of Fisheries (DoF), 2013. National Fish Week 2013 Compendium (in Bengali). Department of Fisheries, Ministry of Fisheries and Livestock, Bangladesh, 144 pp, Dhaka, Bangladesh.

Department of Fisheries (DoF), 2014. National Fish Week 2014 Compendium (in Bengali), Department of Fisheries, Ministry of Fisheries and Livestock, Bangladesh, p. 144, Dhaka, Bangladesh.

Department of Fisheries (DoF), 2017. National Fish Week 2017 Compendium (in Bengali), Department of Fisheries, Ministry of Fisheries and Livestock, Bangladesh, p. 160, Dhaka, Bangladesh.

Dixitulu, J.Y.H., Chacko, P., 1962. Madras Fisheries Station Report and Year Book, pp. 108–127. Madras, India.

1030 Dutta, S., Maity, S., Chanda, A., Hazra, S., 2012. Population structure, mortality rate and
1031 exploitation rate of Hilsa Shad (*Tenualosa ilisha*) in West Bengal Coast of Northern
1032 Bay of Bengal, India. World Journal of Fish and Marine Sciences 4(1), 54-59.
1033 FAO, 2010. Fishery and Aquaculture Country Profiles, The Republic of the Union of
1034 Myanmar. Fisheries and Aquaculture Department, Food and Agriculture
1035 Organization of the United Nations. 20 p.
1036 Fernandes, J.A., Lozano, J.A., Inza, I., Irigoien, X., Pérez, A., Rodríguez, J. D., 2013.
1037 Supervised pre-processing approaches in multiple class variables classification for
1038 fish recruitment forecasting. Environmental Modelling & Software 40, 245-254.
1039 Fernandes J.A., Kay S., Hossain M.A.R., Ahmed M., Cheung W.W.L., Lazar A.N.,
1040 Barange M., 2016. Projecting marine fish production and catch potential in
1041 Bangladesh in the 21st century under long-term environmental change and
1042 management scenarios. ICES J. Mar. Sci. 73(5), 1357-1369.
1043 Fernandes, J.A., 2018. Chapter 13: Southern Asian fisheries in the Arabian Sea, Bay of
1044 Bengal and East Indian Ocean. Barange, M., Bahri, T., Beveridge, M., Cochrane,
1045 K., Funge-Smith, S., Poulain, F. (Eds.). Impacts of Climate Change on fisheries and
1046 aquaculture: Synthesis of current knowledge, adaptation and mitigation options.
1047 FAO Fisheries Technical Paper 627 (in press).
1048 Freyhof, J., 2014. *Tenualosa ilisha*. The IUCN Red List of Threatened Species 2014:
1049 e.T166442A1132697. http://dx.doi.org/10.2305/IUCN.UK.2014-1.RLTS.T1
1050 66442A1132697.en.

1051 Fricke, R., 1999. Fishes of the Mascarene Islands (Réunion, Mauritius, Rodriguez): an
1052 annotated checklist, with descriptions of new species. Koeltz Scientific Books,
1053 Koenigstein, Theses Zoologicae, Vol. 31, p.759.
1054 Ghai, R., 2012. Is overfishing killing the Hilsa in Bengal? West Bengal,
1055 Environment/Wildlife, Indo Asian News Service 05.06.2012.
1056 Ghosh, A.H., Nagpal, T.D., 1968. On the winter breeding of *Hilsa ilisha* (Ham.) in the
1057 Ganga River system. Proceeding of Indo-Pacific Fisheries Council 13, 132–142.
1058 Gupta, R.A., 1989. Status and dynamics of Hilsa (*Hilsa ilisha*) in the Hooghly estuarine
1059 system, West Bengal, India. In: Venema, S.C. and van Zalinge, N.P. (eds), pp. 102-
1060 114, Contributions to tropical fish stock assessment in India. Cochin, India.
1061 Haldar, G.C., 2002. Hilsa fishery management action plan for Bangladesh. Completion
1062 report of the studies conducted under the ARDMCS, GEF component; and FFP.
1063 Report No. 38.9, Department of Fisheries, Dhaka, Bangladesh.
1064 Haldar, G.C., 2004. Present status of the Hilsa fisheries in Bangladesh: completion report
1065 of the studies conducted under the ARDNCS, GEF Component, FFP. Report no
1066 38.8, pp.i-ix + 70, December 2004, Fourth Fisheries Project, Department of
1067 Fisheries, Aquatic Resources Development, Management and Conservation
1068 Studies (Global Environment Facility/World Bank).
1069 Haldar, G.C., Amin, S.M.N., 2005. Population Dynamics of Male and Female Hilsa,
1070 *Tenualosa ilisha* of Bangladesh. Pakistan Journal of Biological Science 8, 307-313.
1071 Hamilton, F., 1822. An account of the fishes found in the river Ganges and its branches.
1072 pp.i-vii + 405, Pls. 39, Edinburgh & London.

1073 Haroon, A.K.Y., 1998. Hilsa shad: Fish for the teeming millions, new management
1074 alternatives needed for the Hilsa young. Shad Journal 3, 7-10.
1075 Hora, S.L., 1938. A preliminary note on the spawning grounds and bionomics of the so-
1076 called Indian shad, *Hilsa ilisha* (Ham.), in the river Ganges. Rec. Indian Mus. 40(2),
1077 147-1 58.
1078 Hora, S.L., 1940. Dams and the problems of migratory fishes. Current Science 9, 406–407.
1079 Hora, S.L., 1954a. Symposium on Hilsa and its fisheries - A Review. Journal of the Asiatic
1080 Society (Sci) 20, 1-5.
1081 Hora, S.L., 1954b. Proverbs and popular sayings concerning Hilsa fish current in Bengal.
1082 Journal of the Asiatic Society (Sci) 20, 19-28.
1083 Hora, S.L., Nair, K.K., 1940. Further observations on the bionomics and fishery of the
1084 Indian shad, *Hilsa ilisha* (Hamilton), in Bengal waters. Rec. Indian Mus. 42(1), 35-
1085 40.
1086 Hossain, M.S., Sarker, S., Chowdhury, S. R., Sharifuzzaman, S.M., 2014a. Discovering
1087 spawning ground of Hilsa shad (*Tenualosa ilish*a) in the coastal waters of Bangladesh.
1088 Ecological Modelling 282, 59 - 68.
1089 Hossain M.S., Sarker S., Sharifuzzaman S.M., Chowdhury S.R., 2014b. Habitat modelling of
1090 juvenile hilsa *Tenualosa ilisha* (Clupeiformes) in the coastal ecosystem of the
1091 northern Bay of Bengal, Bangladesh. Journal of Ichthyology 54, 203–213.
1092 Hossain, M.S., Sharifuzzaman, S.M., Chowdhury, S.R., 2016. Habitats across the life cycle
1093 of hilsa shad (*Tenualosa ilisha*) in aquatic ecosystem of Bangladesh. Fisheries
1094 Management and Ecology 23, 450–462.

1095 Hossain, M. A. R., Ahmed, M., Ojea, E., Fernandes, J. A., 2018. Impacts and responses to
1096 environmental change in coastal livelihoods of south-west Bangladesh. Science of the
1097 Total Environment, 637, 954-970.
1098 IIED, 2016. Scientists from Bangladesh, India and Myanmar are calling on their countries
1099 to develop a shared plan for sustainably managing the Hilsa fishery. Press Release
1100 May 5, 2016. International Institute for Environment and Development, 80-86
1101 Gray's Inn Road, London, WC1X 8NH, UK.
1102 Islam M.S., Haque, M. 2004. The mangrove-based coastal and nearshore fisheries of
1103 Bangladesh: ecology, exploitation and management. Reviews in Fish Biology and
1104 Fisheries 4, 153–180.
1105 Islam, S. 2012. BD, WorldFish Centre to work together on Hilsa aquaculture. The Financial
1106 Express, Vol 20 No 249, Dhaka, Monday June 18, 2012.
1107 Jafri, S.I.H., 1988. Biology and fishery of River Shad (Palla) – A review. Pakistan Journal
1108 of Agriculture Research 9, 252–263.
1109 Jones, S., Menon, P.M.G., 1951. Observations on the life-history of the Indian shad, *HiIsa*
1110 *ilisha* (Hamilton). Proceeding of Indian Academy of Science 31, 101-125.
1111 Jonsson, N., Jonsson, B., 2004. Size and age of maturity of Atlantic salmon correlate with
1112 the North Atlantic Oscillation Index (NAOI). J. Fish Biol., 64, 241-247.
1113 Karamchandani, S.J., 1961. On the location of spawning grounds of Indian shad, *Hilsa*
1114 *ilisha* (Ham.) in freshwater regions of the Narmada river. Current Science 30, 373–
1115 375.

Karna, S.K., Guru, B.C., Panda, S., 2014. Food and feeding habits of *Tenualosa ilisha* (Hamilton, 1822) from India's largest brackish water lagoon. International Journal of Scientific Research 3(12), 123-125.

Kebede, A. S., Nicholls, R. J., Allan, A., Arto, I., Cazcarro, I., Fernandes, J. A., ... Macadam, I. (2018). Applying the global RCP–SSP–SPA scenario framework at sub-national scale: A multi-scale and participatory scenario approach. Science of the Total Environment, 635, 659-672.

Kheih, U., Alam, K., Dastidar, R., Datta, U., Oudwater, N., Word, A., 2003. Livelihoods in coastal fishing communities and the marine fish marketing systems of Bangladesh. NRI Report No. 2712, National Resources Institute (NRI), Greenwich University, London.

Kulkarni, C.V., 1950. Breeding habits, eggs and early life history of the Indian shad, *Hilsa ilisha* (Ham.) in the Narmada River. Proceedings of the National Academy of Sciences, India 15,169–176.

Lauria, V., Das, I., Hazra, S., Cazcarro, I., Arto, I., Kay, S., Ofori-Danson, P., Ahmed, M., Hossain, M.A.R., Barange, M. & Fernandes, J. A. (2018). Importance of fisheries for food security across three climate change vulnerable deltas. Science of the Total Environment, 640, 1566-1577.

Lázár, A., Payo, A., Adams, H., AHmed, A., Allan, A., Razzaque, A., Johnson, F. A., Barbour, E.J., Biswas, S.K., Caesar, J., Chapman, A., Clarke, D., Fernandes, J.A., Haque, A., Hossain, M.A.R., Hunt. A., Hutton, C.W., Kay, S., Nichols, R., Saleh, A.F.M., Salehin, M., Szabo, S., Whitehead, P.G., 2018. Integrative Analysis Applying the Delta Dynamic Integrated Emulator Model in South-West Coastal

1139 Bangladesh. pp 525-574. In: Nicholls, R.J., Hutton, C.W., Adger, W.N., Hanson,
1140 S.E., Rahman, M.M., Salehin, M. (Eds.). Ecosystem Services for Well-Being in
1141 Deltas: Integrated Assessment for Policy Analysis; Palgrave Macmillan, Cham:
1142 London, UK.
1143 Lwin, P.T., 2013. Myanmar Ready for Hilsa Export Drive. Myanmar Business Today,
1144 1(29), August 22, 2013.
1145 Majumdar, R.K., Basu, S., 2010. Characterization of the traditional fermented fish product
1146 *lonailish* of Northeast India. Indian Journal of Traditional Knowledge 9, 453-458.
1147 Malhotra, J.C., Mathur, P.K., Kamal, M.Y., Mehrotra, S.N., 1970. Observations on the
1148 hatching of fertilized eggs of *Hilsa ilisha* (Ham.) in confined freshwater. Current
1149 Science 39,538–539.
1150 Mathur, P.K., 1964. Studies on the maturity and fecundity of the hilsa, *Hilsa ilisha* (Ham.)
1151 in the upper stretches of the Ganga. Indian Journal of Fisheries 11, 423-448.
1152 Mathur, P.K., Malhotra, J.C., Mehrotra, S.N., Shah, K.L., 1974. Experiments on the
1153 nursery rearing of spawn of *Hilsa ilisha* (Hamilton) in freshwater ponds. Journal of
1154 Inland Fisheries Society of India 6, 205–210.
1155 Mazid, M.A., 1998. An overview of Hilsa fishery research in Bangladesh. In: Mazid, M.A.
1156 and Blaber, S.J.M. (eds.) *Hilsa Fisheries Research in Bangladesh.* Proc.
1157 BFRI/ACIAR/CSIRO workshop, 3-4 March, 1998, Dhaka, Bangladesh, 86 pp.
1158 Mazid, M.A., Islam, S., 1991. Hilsa Fishery Development and Management. A report
1159 published by Fisheries Research Institute, Mymensingh, Bangladesh, 16 pp. (in
1160 Bengali).

1161 Miah, M.S., 2015. Climatic and anthropogenic factors changing spawning pattern and
1162 production zone of Hilsa fishery in the Bay of Bengal. Weather and Climate
1163 Extremes 7, 109-115.
1164 Miah, M.S, Shafi, M., 1995. Stock assessment and management of Hilsa. (In Bengali).
1165 Seminar on sustainable fish and shrimp culture in Bangladesh, pp. 101-105, BFRI,
1166 Mymensingh, Bangladesh.
1167 Miah, M.S., Haldar, G.C., Rahman, M.A., 1997. Estimation of growth and mortality
1168 parameters *Tenualosa ilisha* (Ham.) population in the Meghna river of Bangladesh.
1169 Indian Journal of Fisheries 44, 133-139.
1170 Miah, M.S., Rahman, M.A. and Haldar, G.C., 1999. Analytical approach to the
1171 spawning ground of Hilsa *Tenualosa ilisha* (Ham.) in Bangladesh water. Indian J.
1172 of Animal Science 69, 141-144.
1173 Milton, D.A., 2010. Status of Hilsa (*Tenualosa ilisha*) management in the Bay of Bengal:
1174 an assessment of population risk and data gaps for more effective regional
1175 management. Report to FAO. Bay of Bengal Large Marine Ecosystem Project 15, 70.
1176 Milton, D.A., Chenery, S.R., 2003. Movement patterns of the tropical shad, hilsa
1177 (*Tenualosa ilisha*) inferred from transects of 87Sr/86Sr isotope ratios in their
1178 otoliths Can. J. Fish. Aquat. Sci. 60(11), 1376–1385.
1179 Mitra, A., Trivedi, S., Chakravarty, K., Sanyal, T., Chaudhury, A., 1994. Trace
1180 metalpollution in the Hooghly estuary (Monographs). Indo-British Seminar on the
1181 Environmental Problems in India's Exclusive Economic Zone P.13.
1182 Mohammed, E.Y., Wahab, M.A., 2013. Direct economic incentives for sustainable
1183 fisheries management: the case of Hilsa conservation in Bangladesh. p 34.

International Institute for Environment and Development (IIED), 80–86 Gray's Inn Road, London WC1X 8NH, UK.

Mohanty, B.P., Paria, P., Mahanty, A., Behera, B.K., Mathew, S., Shankar, T.V., Sharma, A.P., 2012. Fatty acid profile of Indian Shad *Tenualosa ilisha*. The National Academy Science Letters 35, 263–269.

Mojumdar, C.H., 1939. Culture of hilsa. Modern Review 66, 293–297.

Mome, M.A., 2007. The potential of the artisanal Hilsa fishery in Bangladesh: an economically efficient fisheries policy. Final Project Report, p. 57.Fisheries Training Program. The United Nations University, Iceland.

Mome, M.A., Arnason, R., 2007. The Potential of the Artisanal Hilsa Fishery in Bangladesh: An Economically Effective Fisheries policy. Final Project, The United Nation University (UNU), Fisheries Training Programme. PO Box 1390, Skulagata 4, 120 Reykjavik, Iceland (1–52 pp).

Motwani, M.P., Jhingran, V.G., Kararnchandani, S.I., 1957. On the breeding of the Indian shad, Hilsa ilisha (Ham.) in freshwaters. Science and Culture 23, 47–48.

Moula G., Rahman, M.J., Mazid, M.A., 1991. Observations on the maturity and spawning of Indian shad, *Tenualosa ilisha* (Hamilton) of the river Meghna, Bangladesh. Journal of Zooogy 6, 109-117.

Moula, G., 1992. Studies on some biological aspects of Hilsa. Paper presented at the National Workshop on Hilsa Fishery Development and Management. Fisheries Research Institute, Riverine Station, Chandpur, 12 p.

Murugan, S., Joseph, A.P., Khan, S.A. 2012. Ecological niche of *Mugil cephalus*—an ECOPATH with ECOSIM approach in Vellar Estuary (South east coast of India). International Journal of Pharma and Bio Sciences 3, S662–S676.

Naidu, M.R., 1939. Report on a survey of the fisheries of Bengal. Calcutta. West Bengal, India.

Naser, M.N., 2014. What lesson we need to learn from Hilsa Shad (*Tenualosa ilisha*) biology! FAN-Fisheries & Aquaculture News Bangladesh 3, 5-6.

Nath, A.K. Banerjee, B., Ray, S., 2016. Socio Economic Aspects of the Fishers Engaged in Hilsa Fisheries in Hooghly Estuary of West Bengal, India. International Journal of Innovative Studies in Aquatic Biology and Fisheries 2(4), 20-26.

Nath, D., Mishra, R.N., Karmakar, H.C., 2004. The Hooghly estuarine System: Ecological flux, Fishery resources and Production potential. CIFRI, Bull No. 130, 10-15.

Nelson, G., 1998. Clupeidae: Wikis. In Encyclopedia of Fishes, pp. 91– 92. Ed. by J. R. Paxton, and W. N. Eschmeyer. Academic Press, San Diego, CA, USA.

Nelson, G.J., 1967. Gill arches of teleostean fishes of the family Clupidae. Copeia 2, 389 – 399.

Nguyen, H.P., Nguyen, N.T., 1994. Checklist of marine fishes in Vietnam. Vol. 2. Osteichthyes, from Elopiformes to Mugiliformes. Science and Technics Publishing House, Vietnam.

Padiyar, A., Belton, B., Swain, T., Mome, M.A., 2012. Hilsa Market Trends in Bangladesh and India. Regional Workshop on Hilsa: Potential for Aquaculture, pp. 173-182, 16-17 September 2012, Dhaka, Bangladesh.

1227 Panhwar, S.K., Liu, Q., 2013. Population statistics of the migratory Hilsa shad, *Tenualosa*
1228 *ilisha*, in Sindh, Pakistan. Journal of Applied Ichthyology 29, 1091–1096.
1229 Panhwar, S.K., Siddiqui, G., Ayub, Z., 2011. Reproductive pattern and some biological
1230 features of anadromous fish *Tenualosa ilisha* (Family: Clupeidae) from Pakistan.
1231 Indian Journal of Geo-Marine Sciences 40, 687-696.
1232 Pauly, D., 1980. On the inter-relationships between natural mortality, growth performance
1233 and mean environmental temperature in 175 fish stock. ICES Journal of Marine
1234 Science 39(2), 175–192.
1235 Pauly, D., 1984. Fish population dynamics in tropical waters: a manual for use with
1236 programmable calculators. ICLARM Studies & Reviews8, p. 325.
1237 Pe, M., 2004. National report of Myanmar on sustainable management of the Bay of Bengal
1238 large marine ecosystem. Prepared under the BOBLME Programme of the UN FAO,
1239 p. 61.
1240 Pillay, T.V.R., 1958. Biology of the Hilsa, *Hilsa ilisha* (Ham.) of the river Hooghly. Indian
1241 J. of Fish. 5, 201-257.
1242 Pillay, T.V.R., 1964. Maturation and spawning of the hilsa, *Hilsa ilisha* (Ham.) of the
1243 Saurashtra coast. Proc. Nat. Inst. Sci. India 30, 8-14.
1244 Pillay, T.V.R., Rao, K.V., 1962. Observation on the biology and fishery of *Hilsa ilisha*
1245 (Ham.) of river Godavary. Proceeding of the Indo-Pacific Fisheries Council 10, 37-
1246 61.
1247 Pillay, T.V.R., Rosa, H., 1963. Synopsis of biological data on Hilsa, *Hilsa ilisha*
1248 (Hamilton). FAO Fisheries Biology Synopsis, pp.24-64.

1249 Quazi, S.M., Mohiduzzaman, M., Rahman, M., Ali, S.M.K., 1994. Effect of Hilsa
1250 (*Tenualosa ilisha*) fish in hypercholesterolemic subjects. Bangladesh Medical
1251 Research Council *Bulletin*20, 1-7.
1252 Quddus, M.M.A., 1982. Two types of *Hilsa ilisha* and their population biology from
1253 Bangladesh waters. Doctoral Thesis, p.180, the University of Tokyo, Japan.
1254 Quddus, M.M.A., Shimizu, M., Nose, Y., 1984. Spawning and fecundity of two types of
1255 *Hilsa ilisha* in Bangladesh waters. Bulletin of the Japanese Society of Science,
1256 Fisheries 50, 177-181.
1257 Queirós, A. M., Fernandes, J., Genevier, L., & Lynam, C. P. (2018). Climate change alters
1258 fish community size-structure, requiring adaptive policy targets. Fish and Fisheries.
1259 DOI: 10.1111/faf.12278.
1260 Qureshi, M.R., 1968. Hilsa Fishery in East Pakistan. Pakistan Journal of Scientific
1261 and Industrial Research 11, 95-103.
1262 Rahman, M.A., Islam, M.S. Mazid, M.A. Moula, G. Rahman, M.J., 1998a. On the
1263 spawning biology of Hilsa, *Tenualosa ilisha* (Hamilton) of the river Meghna near
1264 Chandpur. Bangladesh Journal of Fisheries 21, 77-81.
1265 Rahman, M.A., Emran, M., Islam, M.S., 2010. Hilsa Fisheries Management in
1266 Bangladesh. Regional Consultation on Preparation of Management Plan for Hilsa
1267 Fisheries. Chittagong, Bangladesh, 7 - 8 February 2010. Report to the Bay of
1268 Bengal Programme Inter-Governmental Organisation (BOBP-IGO). BOBP-
1269 IGO/RC-HF2/5. pp. 16
1270 Rahman, M.A., Alam, M.A., Hasan, S.J., Jaher, M., 2012b. Hilsa fishery management in
1271 Bangladesh. In: Anon. (ed.) Hilsa: Status of Fishery and Potential for Aquaculture,

pp. 40–60. Proc. of the Regional Workshop Held in Dhaka, 16–17 September, 2012, The WorldFish, Bangladesh and Asia, 238 pp.

Rahman, M.J., 2001. Population biology and management of the Hilsa shad (*Tenualosa ilisha*) in Bangladesh. Ph.D. Thesis, p. 253. The University of Hull, England.

Rahman, M.J., 2006. Recent advances in the biology and management of Indian shad (*Tenualosa ilisha* Ham.). SAARC Journal of Agriculture 4, 67-90.

Rahman, M.J., Cowx, I.G., 2006. Lunar periodicity in growth increment formation in otoliths of Hilsa shad (*Tenualosa ilisha,* Clupeidae) in Bangladesh waters. Fisheries Research 81, 342-344.

Rahman, M.J., Cowx, I.G., 2008. Population dynamics of Hilsa shad in Bangladesh waters. Asian Fisheries Science 1, 85-100.

Rahman, M.J., Mustafa, M.G., Rahman, M.A., 1998b. Population dynamics and recruitment pattern of Hilsa, *Tenualosa ilisha*. *Proceedings of FRI/ACIAR/CSIRO* 6, 28-36.

Rahman, M.J., Rahman, M.A., Bhaumik, U., 2012a. Biology and Ecology of Hilsa Shad, *Tenualosa ilisha* (Ham.). Regional Workshop on Hilsa: Potential for Aquaculture, pp. 1-39, 16-17 September 2012. Dhaka, Bangladesh.

Rainboth, W.J., 1996. Fishes of the Cambodian Mekong. FAO Species Identification Field Guide for Fishery Purposes. FAO, Rome, p.265.

Raja, B.T.A., 1985. A review of the biology and fisheries of *Hilsa ilisha* in the Upper Bay of Bengal. Bay of Bengal Program. BOBP/WP/37. Marine Fishery Resource Management in the Bay of Bengal. p. 66.

Reuben, S., Dann, S.S., Somaraju, M.V., Phillipose, V., Sathianandan, T.V., 1992. The resources of Hilsa Shad, *Hilsa ilisha* (Ham) along the Northeast coast of India. Indian Journal of Fisheries 39,169-181.

Sahoo, A.K., Wahab, M.W., Phillips, M., Rahman, A., Padiyar, A., Puvanendran, V., Bangera, R., Belton, B., De, D.K., Meena, D.K., Behera, B.K., Sharma, A.P., Bhaumik, U., Mohanty, B.P., Choudhury S.R., Mohan C.V., 2018. Breeding and culture status of Hilsa (*Tenualosa ilisha*, Ham. 1822) in South Asia: a review. Reviews in Aquaculture 10, 96–110.

Sahu, B.B., Pati, M.K., Barik, N.K., Routray, P., Ferosekhan, S., Senapati, D.K., Jayasankar, P., 2014. Record of Skeletal System and Pin Bones in Size Hilsa *Tenualosa ilisha* (Hamilton, 1822). World Journal of Fish and Marine Sciences 6, 241-244.

Sarkar, U. K., Pathak, A.K., Sinha, R.K., Sivakumar, K., Pandian, A.K., Pandey, A., Dubey, V.K., Lakra, W.S., 2012. Freshwater fish biodiversity in the River Ganga (India): changing pattern, threats and conservation perspectives. Reviews in Fish Biology and Fisheries 22, 251–272.

Sen, P.R., De, D.K., Nath, D., 1990. Experiments on artificial propagation of hilsa, *Tenualosa ilisha* (Hamilton). Indian Journal of Fisheries 37, 159–162.

Shafi, M., Quddus, M.M.A., Islam, N., 1977. Studies of gonad weight, sex-ratio and fecundity of *Hilsa ilisha* (Hamilton-Buchanan) from the river Meghna. Journal of the Asiatic Society of Bangladesh (Sci.) 2, 51-58.

1315 Shifat, R., Begum, A., Khan, H., 2003. Use of RAPD Fingerprinting for Discriminating
1316 Two Populations of Hilsa shad (*Tenualosa ilisha* Ham.) from Inland Rivers of
1317 Bangladesh. Journal of Biochemistry and Molecular Biology36, 462-467.
1318 Southwell, T., Prashad, B., 1918. On Hilsa investigations in Bengal, Bihar and Orissa. Ibid.
1319 11, 1-12.
1320 Stobberup, K., 2011. Review of data collection systems in BOBLME countries. Bay of
1321 Bengal Large Marine Ecosystem Project, p 88.
1322 Tesch, F.W., 1977. The eel biology and management of anguillid eels. John Wiley & Sons,
1323 New York, 434 p.
1324 Tun, M.T., 2001. Marine fishes of Myanmar (Pelagic and Demarsal). Marine Fisheries
1325 Resources Survey Unit. Department of Fisheries. Yangon, 276 pp.
1326 Wahab, M.A., De, D.K., Ahmed, Z.F., Phillips M.J., 2012. Food, Feeding and Nutritional
1327 Requirement of Hilsa, *Tenualosa ilisha* (Ham.). Regional Workshop on Hilsa:
1328 Potential for Aquaculture. 16-17 September 2012. Dhaka, Bangladesh.
1329 Win, H., Twin, S., Pe, M., Myint, M., 2008. Commercial fishes of Myanmar. Myanmar
1330 Fishery Processors and Exporters Association. 249 pp.