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Bio-economic trends of the Hilsa Shad (*Tenualosa ilisha*) fishery: Perspectives of transboundary management

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Abstract:-Hilsa Shad (*Tenualosa ilisha*), the choicest table fish of the Indian Sub-continent,provides livelihood for2.5 million fishers in Bangladesh (Islam et al. 2016)and 0.46 million inWest Bengal, India. The contribution of Hilsa to GDP is around 1 % (Mohammed 2014) in Bangladesh .Hilsa is an anatropous fish spread over Ganga-Brahmaputra-Meghna basin which sprawled across the International boarders of India and Bangladesh. This paper suggest that such steps towards the long term sustainability of the Hilsa fishery are not to be taken unilaterally but through a trans-boundary management approach by neighbouring India and Bangladesh.

Keywords: Hilsa fishery, Economic efficiency; Discount rate, Effort dynamics, Trans-boundary management

I. INTRODUCTION

Marine fisheries are in a global crisis, mainly due to open access policies and subsidy driven over-capitalization (Garcia and Newton, 1997; Pauly et al., 1998).Exploitation in open-access fisheries is so pervasive that many marine species are either extinct or threatened to extinction (Jackson et al., 2001; Dulvy et al., 2003). Such problems are tantamount in the developing world where open access fisheries reign.Butthese fisheries often fall shortin servingthe social-economic developmental targets that are expected from them (Andrew et al., 2007). Blaming it on the 'failure of fisheries management' is a widespread practise.However, open-access fisheries suffer adversely from the sectorial political and economic interests of national and/or international institutionsand from the indifference and or neglect of government(s)(Andrew et al., 2007). In this respect deterministic bio-economic modelling tools have long been advocated as solutionsfor deploying effective and sustainable fisheries management policies,but are rarely implemented for most fisheries of South-East Asia (SEA) (Garcia and Le Reste 1981; Habib et al. 2013).

Compared to other parts of the world, people of SEA rely heavily on fish as a primary source of their dietary protein and for their income generation (ICLARM, 1999; FAO, 2001; Pomeroy, 2012). Most fishers of South Asia (SA)are poor; their capital investment and technology for fishing are very limited,and fishers generally do not catch fish beyond continental shelf (FAO, 2005; Pomeroy, 2012). Fishing is concentrated almost exclusively in the coastal watersof SEA and that has left the most commercially exploited coastal fish populations in an overfished state (Stobutzki et al. 2006; Pomeroy, 2012). China,as the world's largest fish producing country, is a classic example of open-access fisheries of Asia (FAO, 2016). India, Myanmar and Bangladesh are among the most important open access fish producing countries of SEA (Martosubroto, 2002).

The Hilsa Shad (*Tenualosa ilisha*, Hamilton 1822) fishery is one of the most valued open access fishery of SEA (Hossain et al., 2018). In the marine waters of Indian sub-continentHilsa Shad (*Tenualosa ilisha* Hamilton) is the highest priced species.In Bangladesh ~2% of the entire population is directly or indirectly engaged with Hilsa fishing (BOBLME, 2010). Population density of Hilsa increases in the Ganga-Brahmaputra-Meghna (GBM) basins which spread across the International boundaries of India and Bangladesh (Froese and Pauly, 2016)(Fig. 1). Hilsa is ananadromous Clupeidae.During the monsoon Hilsainvades river courses of countries that surround Northern Bay of Bengal (NBoB)for breeding (Mackinson et al., 1997; BOBLME, 2010; Froese and Pauly, 2016)(Fig. 2).Hilsa stocks are commercially exploited by Bangladesh, India and Myanmar (BOBLME, 2010). Hilsa fetches highmarket values in India and Bangladesh, butits production is higher in Bangladesh (Rahman et al., 2009; Alam et al., 2010) than in India (BOBLME, 2010).Thus, India receives considerable Hilsa product by way ofexport from her neighbour (Alam et al., 2012).At present 50-60 % of the global Hilsa catch is reported from Bangladesh waters, 15-20 % from India and the rests from other countries (e.g., Myanmar, Iraq, Kuwait, Malaysia, Thailand, and Pakistan) (BOBLME, 2010).

Hilsa is severely overfished in Bangladesh as well as in India (Nurul Amin et al. 2004, 2008; Bhaumik and Sharma, 2012; Hossain et al., 2018; Hossain et al., 2019). Overfishing takes place both at the spawning season ('recruitment overfishing') when Hilsa migrates from the sea to rivers; and also during the grazing, feeding and development season, when juveniles are less than 23 to 25 centimetres long (‘growth overfishing’) (Islam, 2014).India(through the Ministry of Agriculture & Farmers Welfare), has taken some unilateral measures in order to revive the Hilsa fishery; such as a National Plan of Action for Hilsa. However, this has failed to achieve the desired objectives to save Hilsa fishery. A Hilsa conservation plan has been instigatedby the government of West Bengal (WB) - a state of India.The plan includes mesh size restriction, restriction on juvenile capture, and sporadic fishing bans (The Kolkata Gazette, 2013).But enforcement is weak, illegal juvenile capture and uses of small mesh size are still in practise. Bangladesh has also taken steps to revive the Hilsa fishery, such as restrictions on fishing gears, exclusive closing of some areas for Hilsa fishing, restrictions on the fishing season and regulations for fishing vessels. (Islam et al. 2016). Bangladesh has also introduced a ‘payment for ecosystem services (PES) scheme’ to conserve and sustainably manage Hilsa shad fish (*Tenualosa ilisha*) populations.

The prospect of transboundary management of the Hilsa fishery was discussed through the Bay of Bengal Large Marine Ecosystem Project (BOBLME, 2012), which suggested that a cooperative transnational Payments for Ecosystem Services (PES) (Bladon et al. 2016) system is desirable. However, in order to consider such trans-boundary management strategies an evaluation and comparison of the state at which the Hilsa population and fisheries should be undertaken. Unfortunately, there are data deficienciesin India and Bangladesh for these fisheries, especially data needed forbio-economic modelling of the Hilsa fishery of the Indian sub-continent (Mome, 2007; Hossain and Arnason, 2016).Despite this, the authors used the available date to compare the catch and effort (CPUE), fishing costs and market prices, maximum sustainable yield (MSY), MSY of catch effort (E_{MSY}), MSY of harvest (H_{MSY}), Biomass of MSY (X_{MSY}), Open access equilibrium (OAE), effort of OAE (E_{OAE}) and harvest of OAE (H_{OAE}), Maximum Economic Yield (MEY), Effort of MEY (E_{MEY}) and harvest of MEY (H_{MEY}), Biomass of MEY (X_{MEY}), Optimum Sustainable Yield (OSY), Optimal stock, Optimal effort and Optimal profit, issues of effort tax and landing taxes for these Hilsa fisheries. The authors aimed to describe the fate of Hilsa stock of India and Bangladesh from 2002 to 2012. This assessment can guide policy makers to devise improved trans-boundary management strategies for the Hilsa fishery of Indian sub-continent.

II. MATERIALS AND METHODS

Source of catch effort, fishing cost and market price data

Catch effort data of 2002 to 2012 of the Hilsa fishery were collected from the Department of Fisheries of India and the Department of Fisheries Bangladesh(Table 1). The numbers of boatswas used to assess catch per unit effort(CPUE),expressed as tonnes/boat. Fishing cost and market price data of the Hilsa fisheries of Bangladesh were collected from Mome (2007) and Department of Fisheries Govt. of Bangladesh Report (2012). Fishing cost and market price data for the Indian fishery were collected through a primary survey conducted (during 2011-12)in fish markets, fisherman associations and from boat owners who are involved in the Hilsa fishery (Table 2).

Calculating the economic efficiency of the Hilsa fishery

The Gordon-Schafer surplus production model was used to derive a deterministic bio-economic model for the Hilsa fishery considering Indian and Bangladesh scenarios.

Logistic growth equation

A general biological growth model of a fish stock can be expressed as

$$\frac{dx}{dt} = rx(1 - \frac{x}{K})$$

Eq. 1

where r is the intrinsic growth rate, K is the environmental carrying capacity and x is the biomass. The equation implies a parabolic growth curve, where the logistic function is strictly concave from below and exhibits positive growth for all positive values of $0<x < K$.

Harvest function

Harvest function $H(t)$ is derived based on the assumption (Clark, 1990) catch per unit effort is directly proportional to the density of fish. The following commonly used production function was assumed

$$\frac{dH}{dt} = qEx$$

Eq. 2

where q is the catchability coefficient, E is the fishing effort. Similarly, the biomass variable x is the density of the fish at time t.

If the population described by the logistic Eq. (1) is subject to harvesting at a rate $H(t)$, then Eq. (1) becomes

$$\frac{dx}{dt} = rx(1 - \frac{x}{K}) - qEx$$

Eq. 3

At equilibrium the harvest is

$$H = qEK(1 - \frac{qE}{r}) = qEK - \frac{q^2E^2K^2}{r}$$

Eq. 4

From the catch per unit effort hypothesis we know that,

$$CPUE = \frac{H}{E} = qK - \frac{q^2K}{r}E$$

Eq. 5a

$$CPUE = a + bE$$

Eq. 5b

$$a = qK = \frac{a}{q}$$

Where, and

$$b = -\frac{q^2K}{r}, b = -\frac{aq}{r}, r = -\frac{aq}{b}$$

Bio-economic model

The maximum sustainable yield (MSY) of effort, harvest and biomass have been estimated by differentiating yield with respect to effort and putting the result to zero.

$$E_{MSY} = \frac{r}{2q}, H_{MSY} = \frac{rk}{4}, X_{MSY} = \frac{K}{2}$$

The total cost of fishing effort is defined as

$$TC(E) = cE$$

where, *c* is the cost of fishing effort, assuming a constant unit price of harvest, total revenue of the fishery is found by:

$$TR(E) = pH(E)$$

where, *p* is the unit price of the Hilsa.

The economic rent is the difference between total revenue and total cost, so the sustainable economic rent is

$$\pi(E) = TR(E) - TC(E)$$

In the case of an open access or an unregulated fishery, it is clear that the individual fishers attempt to maximize their income using maximum level of fishing effort. They will attempt this as long as their average revenue of effort *AR*(*E*), i.e., the revenue per unit of effort, is greater than their marginal cost of effort *MC*(*E*). Thus, the open access equilibrium (OAE) could be achieved when no economic rent is obtained from the fishery or profit is zero, i.e., *T C*(*E*) = *T R*(*E*) or *AR*(*E*) = *MC*(*R*) which gives *P H*(*E*) = *cE* implying

$$E_{OAE} = \frac{r}{q}(1 - \frac{c}{pqK})$$

Now to get the yield level at open access, we substitute the effort of open access in the Eq. (4), which gives

$$H_{OAE} = \frac{rc}{pq}(1 - \frac{c}{pqK}).$$

Maximum Economic Yield (MEY) is defined as the level of landings that would maximize profits to the harvesting sector (Lopez and Pascoe, 2011). The long-term economic optimum could be found where the marginal sustainable yield is equal to the value ofthe cost of an additional unit of effort. Let us assume *MR*(*E*) be the marginal revenue of effort, which is a change in the total revenue when effort changes by an additional unit.*MC*(*E*) representsthe marginal cost of effort which is the change in the total cost when the level of fishing effort changes by an additional unit. Thus, the maximum Economic Yield (MEY) can be obtained from the fishery when the difference between total revenue and total cost is at a maximum. Therefore, at a point where *MR*(*E*) = *MC*(*E*) we get maximum economic yield which implies

$$\frac{dTR(E)}{dE} = \frac{dTC(E)}{dE}.$$

Thus,

$$\frac{d}{dE}[p(qEK - \frac{q^2K}{r}E^2)] = \frac{d}{dE}(cE)$$

gives us

$$p(qK - \frac{2q^2K}{r}E) = c$$

Hence,

$$E_{MEY} = \frac{r}{2q}(1 - \frac{c}{pqK}).$$

MEY can be obtained by substituting E_{MEY} in Eq. (4) which gives,

$$H_{MEY} = \frac{r}{4}(K - \frac{c^2}{p^2q^2K})$$

$$X_{MEY} = \frac{K}{2} + \frac{c}{2pq}$$

From an economic point of view MSY doesn't imply efficient harvesting, relating efficiency to maximizing the net benefit from the use of economic resources, i.e., maximizing the resource rent. Resource rent is maximized at lower level of effort, the MEY level. The MEY point yet depends on prices and costs, and therefore is not constant overtime, rather it varies as price of fish and input change. When we consider time as a variable, it is possible to establish dynamic reference points in addition to the static reference points MSY, MEY and OAY. Present valuation of capital flow over time depends on thediscount rate. The discount rate would therefore determine the stock level maximizing the present value of theflow of resource rent over time. This reference point is referred to as the Optimal Economic Yield biomass.

Optimal Sustainable Yield (OSY)

The equation that maximizes the present value (PV) of the fishery can be expressed as,

$$\max PV = \int_0^\infty e^{-\delta t}(pH(t) - \frac{c}{qx(t)}H(t)),$$

The Hamiltonian must be maximized for $H_e[0, H_{\max}]$. Let us assume that the control constraints are not binding (i.e. the optimal solution does not occur at 0 or $H_{\max}$) and it is called the switching function.

The optimal control $H(t)$ that maximizes *L* must satisfy the following condition,

$$H = H_{\max}, when \mu(t) < 0, i.e. \lambda < p - \frac{c}{qx}$$

$$H = 0, when\mu(t) < 0, i.e.\lambda > p - \frac{c}{qx}$$

The optimal stock is

$$x^* = \frac{K}{4}(1-\frac{\delta}{r}) + \frac{c}{4pq} + \sqrt{(\frac{K}{4rp})^2(p(\delta-r)-\frac{cr}{qK})^2 + (\frac{K}{4rp})^2\frac{8rp\delta c}{Kq}}.$$

By using the basic bio-economic input parameters we also calculate the optimal harvest andoptimal effort.

$$H^* = rx^*(1-\frac{x^*}{K})$$ and $$E^* \frac{H^*}{qx^*}$$

Thus, the optimal profit is

$$\pi(p,q,K,r,c,x^*) = pH^* - \frac{c}{qx^*}H^*.$$

And the present value of the profit is reduced to

$$PV = \int_0^\infty (\pi)e\_\delta t = \frac{1}{\delta}\pi$$

Tax policies

Let us now assume that the Hilsa fisheries of India and Bangladesh are in an open access situation and the controlling agencies of these two countries levies a tax (T >0) in order to achieve H_{MSY}, H_{OSY} or H_{MEY} by incorporating the fishing effort equally E_{MSY}, E_{OSY} or E_{MEY}. Here we derived the equations to calculate the different types of tax policies using H_{MSY} and E_{MSY}.We evaluated the following types of taxes to achieve *MSY*, *OSY* and *MEY* for the Hilsa fisheries of India and Bangladesh.

Landing tax

If ($T > 0$) the landing tax are to be includedfor achievingH_{MSY} or H_{MEY} by incorporating the fishing effort equally E_{MSY} or E_{MEY}, then we get the following equation:

$(p - T)H_{MSY} = cE_{MSY}$, which gives $T = p - c\frac{E_{MSY}}{H_{MSY}}$.

The intercept between $TR_1 = (p - T)H$ and $TC = cE$ will give us $(E_{MSY}, (p - T)H_{MSY})$.

Effort tax

If (T >0) the effort tax are to be included to achieve H_{MSY} or H_{MEY} by incorporating the fishing effort equally E_{MSY} or E_{MEY}, then we get the following equation:

$pH_{MSY} = (c + T)E_{MSY}$, which gives

$$T = \left[p\frac{H_{MSY}}{E_{MSY}}\right] - c.$$

The intercept between $TR = pH$ and $TC_1 = (c + T)E$ will give us E_{MSY}, pH_{MSY}.

Stock analysis of Hilsa fisheries of India and Bangladesh

Stock Reduction Analysis (SRA) is a biomass-based method of stock assessment that uses the exponential form of the catch equations and annual catch recorded in weight (Kimura et al., 1984). The Kobe I+II software (New version 3, 2014**)** consists of Kobe I (stock status trajectory plot) and Kobe II (risk assessment diagram). Kobe Plot I was used to derive the historical stock status trajectory plots for Standing Biomass (SB)/SB_{MSY} and Fishing mortality (F)/F_{MSY} using the results of the stock assessments. Kobe II was used to draw the colour diagrams for the results of the risk assessments for the SB/SB_{MSY} and the F/F_{MSY}(i.e., probabilities of violating their MSY levels in the future by different catch level scenarios). The Hilsa stock status between 2002 and 2012 of India and Bangladesh was figured out by using the Stock Reduction Approach (SRA) ofthe Kobe I+II software (New version 3, 2014**)**.

III. RESULTS AND DISCUSSION

Hilsa population status

Hilsa is a transboundary and migratory fish which is often caught near-shore inboth countries and exhibit lots of commonalities in biology and life histories (Jahan et al. 2017). Some differences in the biology havebeen reported owing to local habitat and oceanographic condition. For example, body size of Hilsa is larger in Bangladesh waters than those from Indian waters (Bhaumik and Sharma, 2012). Our results indicate thatthe Bangladesh Hilsa population has the growth rate (r) of 0.211,whilein India this is 0.202(Table 3). We found that the carrying capacity (K) of Hilsa in the Bangladesh waters (1,810,603 tons) is almost 9 times more than of Indian waters (200,432.5 tons) (Table 4). This is plausible because the majority of the Hilsa population) of the NBoB migrates towards Bangladesh waters for spawning and hence, dominated by large individuals (Mome, 2007). This largely explains why Bangladesh leads India by far in Hilsa catch (Miah, 2015)despite the catch ability coefficient (q) of Hilsa being9 times lower in the Bangladesh (0.00000586) compared to India (0.0000529) (Table 3).A decrease in catch ability generally leads to an increase in the fishing effort which may result in an increase in the total catch (Agmour et al., 2018).

Bio-economics

The static biological equilibrium i.e. Maximum Sustainable Yield (MSY), economic optimum i.e. Maximum Economic Yield (MEY), optimal equilibrium for open-access fisheries i.e. Optimal Sustainable Yield (OSY), corresponding effort levels, and economic rent were calculated in response to the changes in the biological growth rate (r). The values of fishing efforts at MSY, MEY and OSY were calculated using equations 6, 10 and 12. The results (in terms of the number of boats) are E_{MSY} = 1905.41, E_{MEY} = 1790.32, and E_{OSY} = 3580.63 for the Hilsa fishery of the India; and for the Banga1adesh they were E_{MSY} = 7960.92, E_{MEY} = 16749.21, and E_{OAE} = 33498.41 respectively (Table 4). The harvests at MSY, MEY, and OSY were calculated using the fishery's harvest equation (14) and the results were10,098.39 tonnes, 10,061.54 tonnes and2,292.58 tonnes for H_{MSY}, H_{MEY} and H_{OAE} for India; and 95,269.86 tonnes,94,836.25 tonnes and23,974.65 tonnes for H_{MSY}, H_{MEY} and H_{OAE} for Bangladesh, respectively (Table 5). The biomass at biological equilibrium (X_{MSY}), economic optimum (X_{MEY}) and optimal equilibrium (X_{OAE}) of both countries are shown in the Table 4. Thus, these results indicate that the fishing efforts, harvest and population (biomass) of the Hilsa fishery of Bangladesh are higher than the Indian Hilsa fishery. If we incorporate the effort tax in the Indian Hilsa fishery, then around 1,790 boats have to operate in the Indian waters to reach the MEY, and 1,905 boats to reach the MSY (Fig.5). But the current number of boasts operatingaveraged3,928.55±1,491.26 from 2002 to 2012. Whereas in the Bangladesh around 16,749 boats have to operate to reach the MEY, and 17,960 boats to reach the MSY, whereas the present number of boats in the Bangladesh aremean 25,499±275.77 from 2002 to 2012 (Fig. 5).

Discount rate

Figure 3 show the optimal biomass, harvest, effort, and profit of the Hilsa fishery of the India and the Bangladesh,respectively,considering the discounting rate from 0 to 1. In order to achieve MEYthrough incorporation of the tax values optimal fishing effort has to be 1,873.63 fishing boats for the Indian Hilsa fishery and 17,490.37 fishing boats for the Bangladesh Hilsa fishery at a 10% discount rate (Fig. 3). The optimal profit of the Hilsa fishery is much higher in the Bangladesh than in India given any discount rate, but with the increasing discount rate optimal profit of the Bangladesh Hilsa fishery declines (Fig. 4). At a higher discount rate optimal biomass and the harvest would decline (Fig.3). If the discount rate is in between 10-25 % then the optimal effort would increase (Fig. 3) before stabilizing at a higher discount rate (>25 %).

If we increased the discount rate the population will decline along with harvest and profit, but the effort will be increased. In this present study, the optimal number of boats operatingin India and Bangladesh waters to harvest the Hilsa, are 2,561.56 and 23,603.96 simultaneously at 10 % discount rate (Fig. 3). Whereas the Hilsa population woulddecrease from 106,269.78 tonnes to 65,705.45 tonnes at a 0% discount to 10 % discount in India (Fig. 3) and in Bangladesh, the Hilsa biomass would be966,376.63 tonnes at a 0% discount rate and 620,869.66 tonnes at 10 % discount rate (Fig. 3).

Taxation on Hilsa Fishery

The numerical values of the landing tax andthe effort tax to achieve MSY, MEY and OSY are estimated for the logistic and the Gordon Shepherd growth models (see Tables 5). The landing tax, is found to be more than ~5 times lower than the effort tax for MSY and MEY, and more than~3 times lower than the effort tax for OSYforIndia and Bangladesh (Table 5). But the landing and effort taxes arealmost double in India in comparison to Bangladesh (see Table 5). Figure 5 and 6, respectively, show the incorporation of the tax (i.e. effort taxand landing tax)to reach the MEY, MSY, and OSY in India and Bangladesh respectively.

The introduction of suitable tax policies to overcome property rights related problems is of concern. Fishing effort could be increased to reach the optimal yield (more than MSY, see Fig. 5 and Fig. 6) by incorporating effort and landing taxes in the Hilsa fisheries of India and Bangladesh. Therefore, the introduction of tax will be one of the better approaches for the management of Hilsa resources.

Stock Status of Hilsa

Stock Reduction Analysis (SRA) (Fig.7) shows Hilsa stock status between 2002 and 2012for the India and the Bangladesh. Results demonstrate that in 2002 the Hilsa stock in India was in the safe zone but later it spilled over to the overfishing zone (from 2003-2006 and 2010) and then to the overfished zone.In contrast to the Indian scenario, Hilsa stock of Bangladesh in 2003 was nearing the overfishedzone butthe stock improved from 2004 to 2012and remained within the boundary of the overfishing zone.In open accessfisheries, fish stocks are often biologically over-fished (Bjørndal and Conrad, 1987; Pauly et al, 2002; Worm et al, 2009). These types of fisheries are generally characterized by high unit prices relative to the harvesting costs so are open to long-term biological exploitations (Kar and Chakraborty, 2011). Table 2 shows that the unit price of Hilsa is considerably higher in India compared to the unit price of Hilsa in the Bangladesh, which possibly indicates higher demand of Hilsa in India despite the low stock. SRA found that the Hilsa stock of India in 2010 temporarily recovered from the overfished zone into the overfishing zone. The cause of such a temporary recovery is unknown and could be of future interest to the policy makers.

Current Status of Hilsa conservation In India and Bangladesh

In fisheries the most common two types of management practise are controlling fishing effort and controlling catch (Crutchfield, 1979; Hilborn, 1979). These are usually managed through ‘close seasons’, ‘gear restrictions’, ‘allocation of quotas’, and ‘limited entry’ with some country-specific adjustments (Conrad, 1982).Earlier India followed a single policy of ‘Close season’ and that was the only approach for the sustainable management of any fish stock, including Hilsa. For Bangladesh, both ‘close season’ and ‘limited entry ‘were the two main management strategies. Thus, there are some similarities in the fisheries management practices of these two neighbouring countries. In addition to the strategies mentioned above there are unilateral measures to conserve Hilsa stocks.

Measures taken by Bangladesh side

From the 1970s to 1990s there was no clear objectives for the development of the fisheries sector in Bangladesh. Bangladesh developed the “National Fisheries Policy” in 1998. There are five major areas of this policy,including a “policy for exploitation, conservation and management of marine fisheries resource”. The government also developed the “National Fisheries Strategy” (NFS) in order to support the ‘National Fisheries Policy’. Bangladesh have a better understanding of the life cycle of Hilsa than India (BOBLME, 2010). The Bangladesh Department of Fisheries (DoF) have made several practical management interventions in the last decade which seem to have had a positive effect on the total production of Hilsa reported in the Bangladesh (BOBLME, 2010). Some of these measures includedeclaration of i. Hilsa sanctuaries where all types of fish catch have been banned during certain periods of time every year (15 to 24 October);ii. mesh size regulation (not exclusive for Hilsa fishery); iii.Hilsa fishing ban periods (e.g. March to April and November to January - specific to certain restricted areas only); iv. allocation of alternative livelihoods to Hilsa fishers during the ban period of the Hilsa fishery; and v.a Hilsa conservation campaign (e.g. Hilsa Fisheries Management Action Plan running since 2003)with emphasis on protecting the Hilsa females and 'Jatka' (i.e. juvenile Hilsa).In a drastic move towards improving its Hilsa resources,Bangladesh imposed afishing ban for an indefinite period in 2012. This action impactedthe relationship with Indiaover the management of Hilsa. These measures contribute to a more stable exploitation of Hilsa resources in the Bangladesh,and this is reflected in the Stock Reduction Analysis that we have conducted.

Measures taken by Indian side

In India, the Hilsa fishery is managed by the solo state of West Bengal not by the central government, which results in less capacity and resources for the implementation of any comprehensive management measure (BOBLME, 2010). Department of Fisheries, Govt. of West Bengal followsmanagement practises that include mesh sizeregulation (90 to 110 mm gill net)(not exclusive for Hilsa fishery), Hilsa fishing ban period (10 days in October depending on lunar cycles), and a massive awareness campaigning of Hilsa conservation from 2010 onwards. Apart from the Hilsa fishing ban,there remains a blanket ban on any fishing activity between 15 April and 15 June of every year. Despite these measures many fishers illegally use small mesh net and theso capture of juvenile fish remains high. Furthermore, there is no control on fishing effort. Issues such as theseare likely to be contributing to the overfished condition of Hilsa stock of India.

Recently 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 the Hilsa fishery and its breeding grounds. Five breeding grounds of Hilsa have been identified and designated as Hilsa sanctuariesin West Bengal. All kinds of fishing are prohibited in these Hilsa sanctuaries during June to August and October to December of every year. The capture and retention of Hilsa with a length below 23 cm is also banned in West Bengal. Bottom trawling in the shallow continental shelf (12 nautical miles) is totally banned 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 14th September to 24th October every year for promoting breeding and spawning.

Proposal of transboundary management of Hilsa fishery

Transboundary fishing has a long history (e.g. Butcher 2004) but it recently gained attention because of the over overexploitation of migratory stocks like Salmon, Billfish, Shark and Tuna (White and Costello 2014). Transboundary fisheries, on the high seas in particular, "pose perhaps the greatest global challenge to sustainable fisheries management" (White and Costello 2014). This challenge includes the need to account for diverse national interests while adopting compromises necessary to develop and implement robust conservation and management measures (Hanich et al. 2015). Thecollective effort of Mexico, USA and Canada towards the conservation and management of Pacific sardine could achieve sustainable Pacific Sardine fisheries instead of a unilateral effort to maximize conservation and management benefits (Ishimura et al. 2013).

Hilsa of the Sundarban region of the Indian sub-continent is a mixed population that occur across the waters of Bangladesh and India,so these countries are most likely sharing some of the same Hilsa stocks (Milton & Chenery, 2001). Therefore, these neighbouring countries should actively cooperate with each other and develop joint a Hilsa management strategy. At present both the nations are unilaterally striving to protect Hilsa populations during the breeding seasons by imposing a seasonal ban (October month). Joint declaration (by partnering/neighbouring nations) of marine protected areas in the Northern Bay of Bengal which hold the common stock may also be helpful in Hilsa conservation. Further, creation of the regional Hilsa Fisheries Institution for joint monitoring and facilitating data availability is also advised. Thus, India and Bangladesh should increase their capacity in terms of number and quality of researchers and better research facilities for promoting research of Hilsa fisheries. Hossain et al. (2018) recommend that real time monitoring systems should be designed to prevent illegal fishing and to generate accurate data for all the countries from both the riverine and marine systems, so that a"quota system" can be appliedin the Hilsa fishery. In this present study we recommended a 10-20% quota for the both countries. Bi-lateral agreements are suggested forregulating mesh size, ban periods andreduction in the number of fishing boats currently operating.Furthermore, the introduction of effort and landing taxes on Hilsa fisheriesis needed. In this context, establishment of multi-agency committees would be required to monitor the implementation of the proposed regulations. Finally, along with the regulation, bi-lateral awareness campaigns on Hilsa conservation among the fishers and Hilsa consumers of India and Bangladesh may see the long-term benefits of Hilsa fishery.

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Table 1. Total catch (2002 – 2012) (in tonnes), effort (in a number of boats)and CPUEfrom theHilsa fisheriesofIndia and Bangladesh.

	India			Bangladesh		
Year	Hilsa catch (tonnes)	Effort (no of boats)	CPUE (tonnes/boats)	Hilsa catch (tonnes)	Effort (no of boats)	CPUE (tonnes/boats)
2002	29,345	1,431	20.51	152,343	25,369	6.01
2003	26,985	2,607	10.35	136,088	25,369	5.36
2004	27,256	3,285	8.30	184,838	25,369	7.29
2005	19,061	2,520	7.56	198,363	25,369	7.82
2006	16,072	2,585	6.22	198,850	25,369	7.84
2007	9,430	4,318	2.18	196,744	25,369	7.76
2008	11,744	4,202	2.80	200,100	25,369	7.89
2009	10,560	4,821	2.19	202,951	25,369	8.00
2010	60,460	6,194	9.76	198,574	25,369	7.83
2011	18,126	6050	2.99	225,325	26,084	8.64
2012	8,510	5201	1.64	232,037	26,084	8.90

Table 2. Estimated costs of trips per boatand the average price of Hilsa from 2000 to 2012inIndia and Bangladesh.

	Cost		**Price**	
	India (INR)	Bangladesh (Taka)	India (INR)	Bangladesh (Taka)
Year	Cost/boat/year	Cost/boat/year	AVG Price/kg	AVG Price/kg
2002	240,000	85,000	143	94

2003	280,000	89,000	143	98
2004	310,000	93,000	175	104
2005	340,000	102,500	175	130
2006	390,000	111,000	203	148
2007	420,000	117,000	203	153
2008	460,000	129,000	350	161
2009	520,000	136,000	350	167
2010	570,000	144,000	500	178
2011	590,000	158,000	500	185
2012	640,000	164,000	666	193

Note: 1$=71.57 INR; 1$= 83.92Taka

Table 3. Biological growth model parameters of Hilsa from India and Bangladesh.

	India	Bangladesh
K	200,432.5	1,810,603
q	0.0000529	0.00000586
r	0.202	0.211
MSY	10,098.39	95,270

Table 4. The effort, harvest and biomass for sustainable yield, economic yield and optimal yield forthe Hilsa fisheriesofIndia (*I*) and Bangladesh (*B*).

India			**Bangladesh**		
E_{MSY}	H_{MSY}	X_{MSY}	E_{MSY}	H_{MSY}	X_{MSY}
1,905.41	10,098.39	100,216.25	17,960.92	95,269.86	905,301.50
E_{MEY}	H_{MEY}	X_{MEY}	E_{MEY}	H_{MEY}	X_{MEY}
1,790.32	10,061.54	1,696,183.90	16,749.21	94,836.25	966,376.63
E_{OSY}	H_{OSY}	X_{OSY}	E_{OSY}	H_{OSY}	X_{OSY}
3,580.63	2,292.58	731.32	33,498.41	23,974.65	8,240.73

Table 5. The landing tax and effort tax for sustainable yield, economic yield and optimal yield of the Hilsa fisheriesof India and Bangladesh.

INDIA

	MSY	MEY	OSY
Landing Tax	269,938.94	272,051.85	250,456.78
Effort Tax	1,430,634.57	1,528,926.20	870,280.35

BANGLADESH

	MSY	MEY	OSY
Landing Tax	123,535.46	124,753.22	114,708.36
Effort Tax	655,267.49	706,369.42	417,281.61

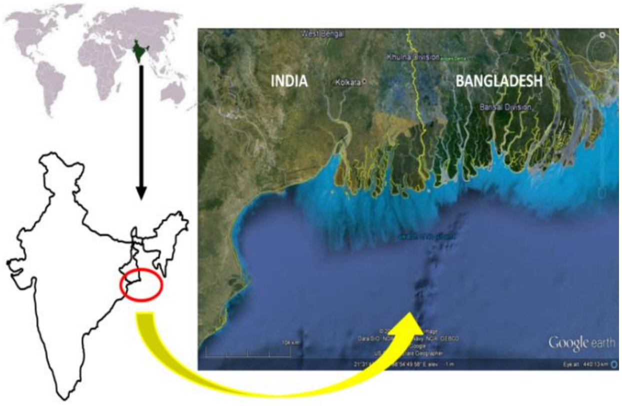


Figure 1. Map showingthe part of the northern Bay of Bengal with India and Bangladesh.The yellow line signifies the political boundary betweenthese two countries.

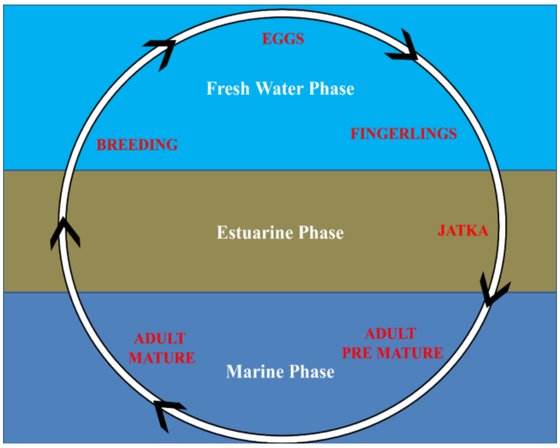


Figure 2. The life cycle of Hilsa with the migration pattern and different phasesfrom marine to fresh water.

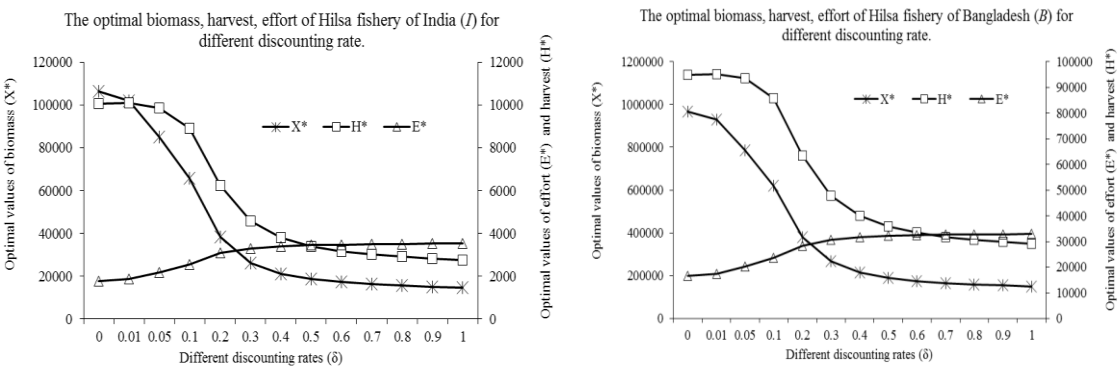


Figure 3. The optimal biomass, harvest and effort for theHilsa fisheriesof India andBangladesh for the different discounting rates.

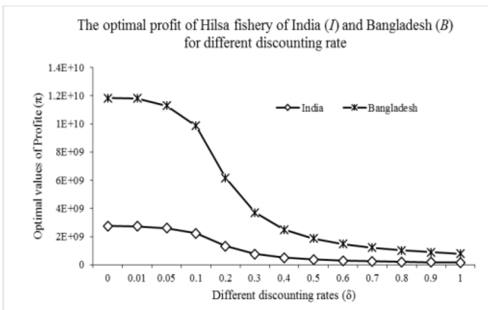
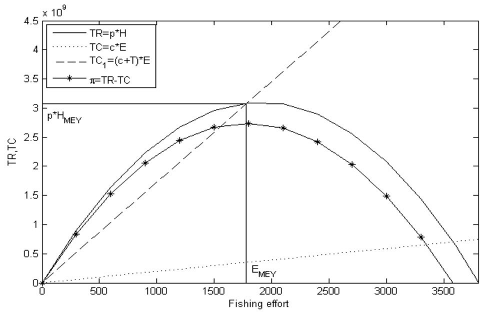
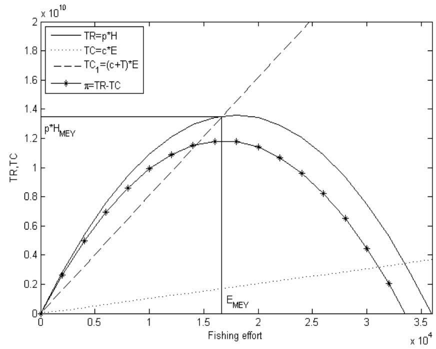


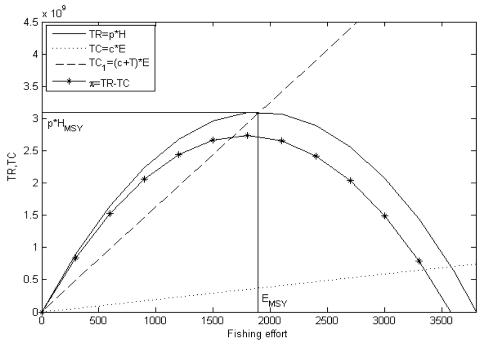
Figure 4. The optimal profit for theHilsa fisheriesof India and Bangladesh for different discounting rates.



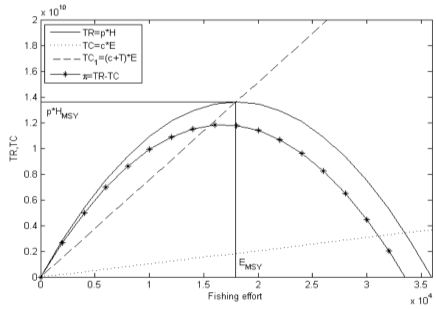
India Effort MEY



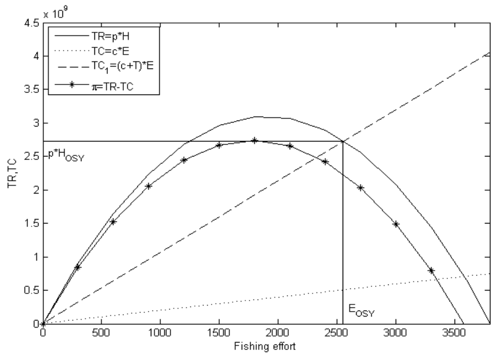
Bangladesh Effort MEY



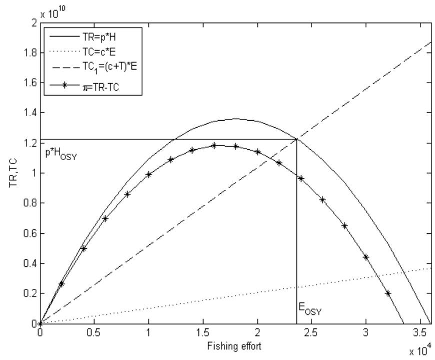
India Effort MSY



Bangladesh Effort MSY

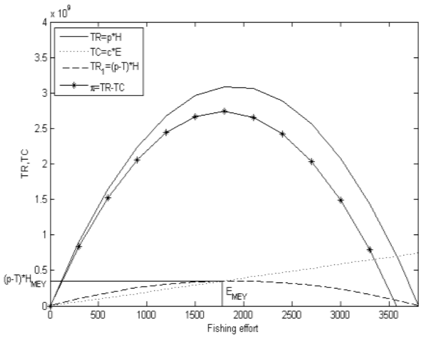


India Effort OSY

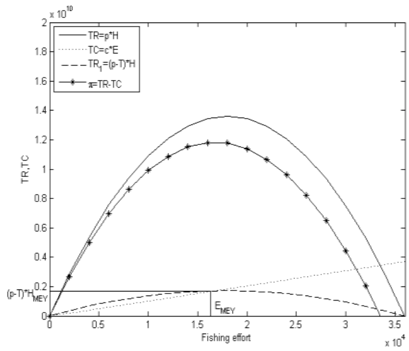


Bangladesh Effort OSY

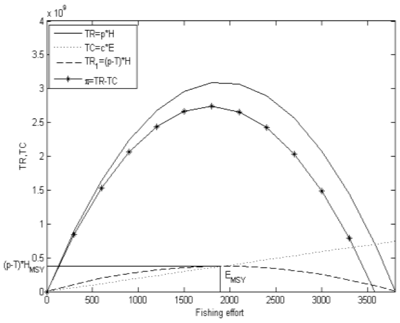
Figure 5. Effort tax to reach the maximum economic yield, maximum sustainable yield and optimal sustainable yield for theHilsa fisheriesof India and Bangladesh.



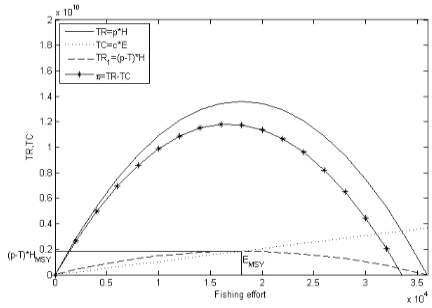
India Landing MEY



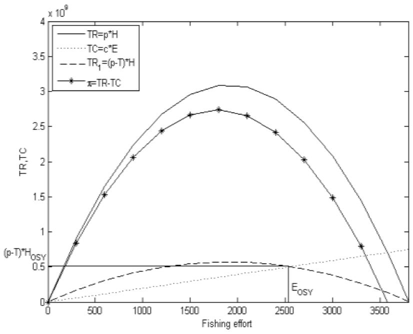
Bangladesh Landing MEY



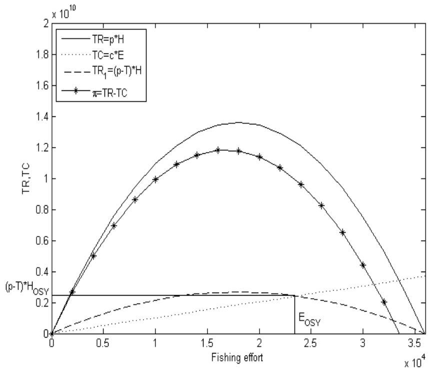
India Landing MSY



Bangladesh Landing MSY

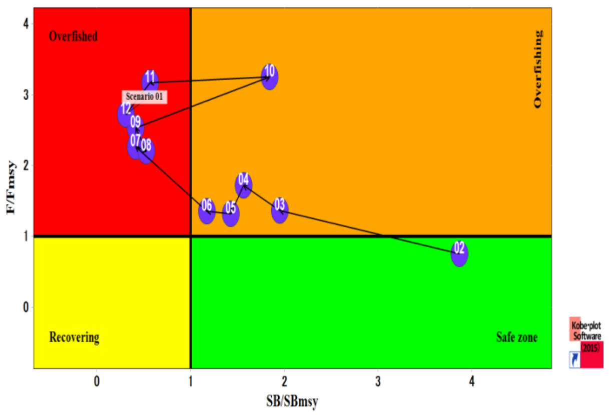


India Landing OSY

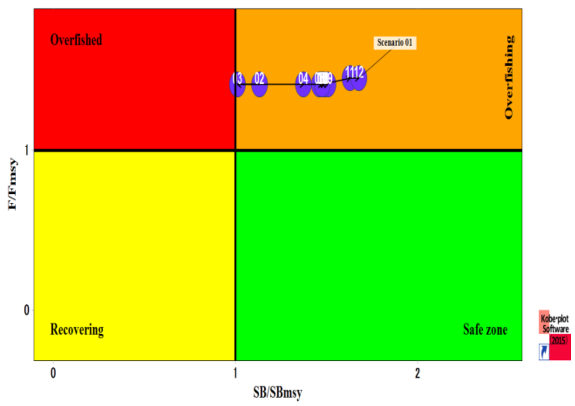


Bangladesh Landing OSY

Figure 6. Landing tax to reach the maximum economic yield, maximum sustainable yield and optimal sustainable yield for theHilsa fisheriesof India and Bangladesh.



India



Bangladesh

Figure 7: Phase plot for SB/SB_{MSY} and F/F_{MSY} for India and Bangladesh Hilsa using stock reduction based approaches for last 11 years (2002 to 2012). The Hilsa population is overfished in recent years from West Bengal part of India, whereas, the Hilsa population in Bangladesh is approaching recovery from overfishing in recent years .

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Dr.Shatrajit Goswami, worked as associate professor in Department of Economics and& Research coordinator in SRM university of Sikkim in 19th July 2018. He was former fellow of IIEST and Economist. Hedid Graduation in Science With Economics (H) and Master degree of science in Economics with specialization econometrics and statistics in2000& 2002 respectively from The university of Burdwan. Did PhD in Economics (registered in 2012) from BESU (reg-R/PHD-661/1)and again awarded (Doctorate in ENGINEERING) in 2017from Indian institute of engineering science and technology. He is expert in handling Some statistical packages **as SPSS, EVIEWS, STATA, GRTL, and R** also and also expert in analysing any Economic model. His interest areas are advanced and Basic Econometrics, Environmental Economics, Development Economics, and Crime Economics. His teaching experience is more than 16 years.