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Research Article

Bioeconomics of Commercial Marine Fisheries of Bay of Bengal: Status and Direction

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The fishery of the Bay of Bengal (BOB) is assumed to be suffering from the overexploitation. This paper aims to assess the sustainability of current level of fishing effort as well as possible changes driven by anthropogenic and climate driven factors. Therefore, the commercial marine fishery of BOB for the period of 1985/86 to 2007/08 is analyzed by applying Gordon-Schaefer Surplus Production Model on time series of total catch and standardized effort. Static reference points such as open-access equilibrium, maximum economic yield, and maximum sustainable yield are established. Assumptions about potential climatic and anthropogenic effects on r (intrinsic growth rate) and K (carrying capacity) of BOB fishery have been made under three different reference equilibriums. The results showed that the fishery is not biologically overexploited; however, it is predicted to be passing a critical situation, in terms of achieving reference points in the near future. But, on the other hand, economic overfishing started several years before. Higher fishing effort, and inadequate institutional and legal framework have been the major bottlenecks for the proper management of BOB fisheries and these may leads fishery more vulnerable against changing marine realm. Thus, the present study calls for policy intervention to rescue the stock from the existing high fishing pressure that would lead to depletion.

1. Introduction

Marine wild capture fisheries are crucial to the food and livelihood security for millions of people, supplying approximately 53% of fish food among the 110 million tonnes of wild capture fisheries and aquaculture [1]. Globally, nearly 170 million people are employed in the primary fish production, secondary processing, and marketing sectors [1] and thus the importance of fish to human food security and the burgeoning human population had placed marine fish populations under considerable stress [2]. At the same time, the relative economic efficiency of the fishing industry has significantly declined in many countries due to overexploitation and the consequent reduced yield from fish stocks [3]. Therefore, there is an increasing call to conserve and manage commercial fishery resources by developing proper management measures, using time series data, to ensure sustainability and economic efficiency for certain fishery. However overfishing, pollution, and other anthropogenic causes were thought to be major causes behind underperforming of global marine fisheries [4]. Recent climate change is supposed to make the situation more complicated for global fisheries, as it has begun to alter ocean conditions, particularly water temperature and biogeochemistry [5–7]. Climate change will likely affect the economics of fishing through changes in the price and value of catches, fishing costs, fishers' incomes, earnings of fishing companies, discount rates, and economic rent, as well as throughout the global economy [5, 8].

In Bangladesh, the fisheries are the second largest employing sector involving 13 million people or about 8% of the total labor force of the country as well as the second largest export sector [9]. The country's marine fisheries have two subsections, artisanal and industrial fisheries [10] contributing to approximately 92% and 7.26% of the total marine production, respectively [9]. However, after the independence of Bangladesh in 1971, industrial trawl fisheries suffered from poor investment because of the lack of knowledge and information on the availability of the size of different fish stocks. Though some reports are available for describing biological, economical, and resource management issues of the fisheries of the Bay of Bengal (BOB) [10–12], a proper bioeconomic analysis of the commercial trawl fisheries is scarce, except few [3, 10], mostly dealing with shrimp fishery resources. However, a proper understanding of bioeconomic resources and its utilization is an urgent need to promote sustainable development of marine fisheries resources of BOB. To control the stock, catching and fishing effort of the fishery and to get protection from overexploitation required strong scientific research in the field of fisheries biology and economics that can be easily examined with the help of a suitable model using the empirical data of the resource. Bioeconomic modelling has long been advocated as an important tool in managing single as well as multispecies fisheries for sustainable fisheries management.

Hence the present study is undertaken in the BOB commercial trawl fishery to assess the sustainability of marine fish production and to suggest appropriate policy recommendations for improving the capture fisheries scenario of the country. This study also puts a little effort to analyze the potential impacts of climate change and anthropogenic disturbances (e.g., pollution, habitat degradation, errors of estimation due to lack of accurate information, and other unpredictable events) on the fish stock resources. To do so, this paper has made some assumptions about climate change and anthropogenic effects on r (intrinsic growth rate) and K (carrying capacity) in a surplus production model.

2. Theoretical Model

Bioeconomic theory in fisheries combines the biological and economic aspects of a fishery to explain stock, catch, and effort dynamics under different regimes and provides insights into the optimal management of the stock [13]. The bioeconomic model provides an integrated approach for evaluation of effective fishery management strategies [14–16].

3. Reference Equilibriums and Management Regimes

The overall goal of fisheries management is to provide sustainable biological, social, and economic benefits from renewable aquatic resources. For the long-term sustainability and for enhancing the revenue of the fishery, static as well as the dynamic behavior of the system should be investigated by achieving the targeted reference points. Maximum economic yield (MEY) and maximum sustainable yield (MSY) represent different fisheries objectives which are the basis of identifying suitable management measures. The other reference point, namely equilibriums open access (OA), is more likely a regime rather than a performance objective (such as MSY and MEY). Open access represents a lack of property rights to restrict harvesters from common pool resources. However, OA is not socially efficient (suboptimal) because of its higher effort [17]. Moreover, this practice can

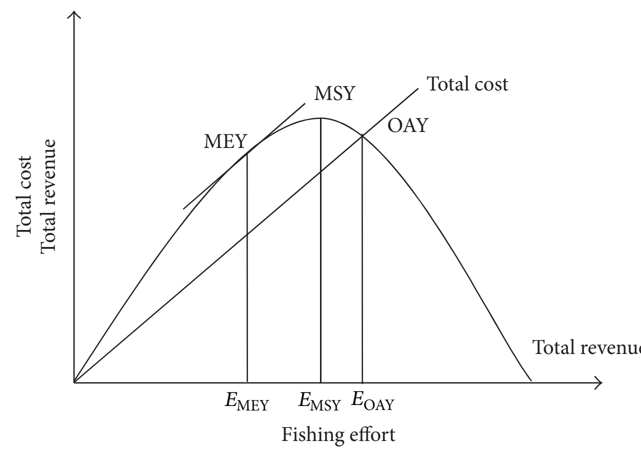

Figure 1: The Gordon-Schaefer model.

also produce a lower level of catch as compared to the MSY at comparably higher cost. Therefore, MEY is considered as the optimal solution since it equates the marginal revenue of an additional unit of effort. However, the "optimal" allocation of fishery resources can be determined by bioeconomic modelling comparing OA, MSY, and MEY solutions and often depends on the objective of particular fisheries management.

4. Model's Choice and Description

In bioeconomic modelling, surplus production model which is an equilibrium model has the capability to determine the sustainable yield from a given fishing effort (Figure 1) and regarded as valuable tool for its first approximation even in time or data limiting condition [18]. These models are generally used to examine economic performance or rent dissipation in a fishery [19] and well known in the fisheries economics literature [20–22]. Moreover, it is simple and easy to incorporate environmental attributes in the model and its parameters can be estimated using catch and effort data. The Gordon-Schaefer (GS) model, with extension (such as habitat, environmental variables), can potentially identify the underlying relationship between incorporated variables, stock, effort, and harvest under open access and maximum economic yield managed fisheries [23, 24].

The GS model originated from Gordon [17] and Schaefer [25]. Therefore, the GS surplus production model has been selected for this study. The model has a big advantage of requiring limited data and could produce rough guidance on fleet size in the case of single-species as well as multispecies fishery.

Fisheries based on highly productive biological resources with large r (intrinsic growth rate) and K (carrying capacity) may sustain a large fishing effort under OA [26]. In all populations, natural surplus growth is small for both high and low stock level and the largest for some intermediate level. However, the GS model is based on the logistic growth equation:

$$F(X) = rX\left(1 - \frac{X}{K}\right), \qquad (1)$$

where $F(X)$ is surplus biomass growth per unit of time; X is stock biomass. The equation describes a parabolic curve as a function of X.

The harvest rate (H) is assumed by the simple relation of Schaefer catch function,

$$H(E, X) = qEX, \tag{2}$$

where E is fishing effort and q is a constant catchability coefficient. Sustainable yield occurs when harvest equals the surplus growth; that is, when rate of change of biomass,

$$\frac{dx}{dt} = F(X) - H(E, X) = 0. \tag{3}$$

This implies $qEX = rX(1 - x/K)$ based on (1) and (2). Therefore, biomass at equilibrium, X, is solved to be

$$X = K\left(1 - \frac{qE}{r}\right). \tag{4}$$

Inserting (4) into (2) gives the long-term catch equation

$$H(E) = qKE\left(1 - \frac{qE}{r}\right) = qKE - \frac{q^2KE^2}{r}. \tag{5}$$

Dividing both sides of (5) by effort (E) gives the linear relationship between catch per unit of effort (CPUE) and fishing effort:

$$\text{CPUE} = \frac{H}{E} = qK - \frac{q^2KE}{r}. \tag{6}$$

Assuming constant price, equation (5) can be used to define total revenue (TR) in equilibrium as a function of standardized effort:

$$\text{TR}(E) = p \cdot H(E), \tag{7}$$

where p denotes a constant price per unit of harvest. Total cost of fishing effort (TC) is given by

$$\text{TC}(E) = c \cdot E, \tag{8}$$

where c denotes unit cost of effort including opportunity cost of labor and capital.

From equations (7) and (8), the equilibrium resource rent ($\prod$) can be derived as a function of fishing effort (E)

$$\prod(E) = \text{TR}(E) - \text{TC}(E). \tag{9}$$

5. Environmental Scenarios

In most surplus production models, environmental factors are found to be ignored over time. However, this is evident that climatic variables as well as anthropogenic factors driven environmental variablity have a notable impact on fisheries stock and its growth. The increasing human activities have become a major factor in progressive environmental degradation on the global scale, particularly biological structures and ecological processes that mean a reduction in the ecosystem's carrying capacity [27]. Therefore, in the present model, nine environmental scenarios have been considered, including the present situation (Scenario 0). The scenarios were based on the current model where each scenario represents possible climate change and anthropogenic consequences. The authors in [28] described environmental scnerio and possible growth rates. As Bangladesh is more vulnerable to climate change impact, therefore, we assume that the following nine scenarios are included:

(0) current situation (i.e., r and K as now),

(1) growth rate change by 10% (i.e., r-10% and K as now),

(2) growth rate and carrying capacity both change by 10% (i.e., r-10% and K-10%),

(3) carrying capacity change by 10% (i.e., r as now and K-10%),

(4) growth rate change by 25% (i.e., r-25% and K as now),

(5) carrying capacity by 10% and growth rate by 25% (i.e., K-10% and r-25%),

(6) carrying capacity change by 25% (i.e., r as now and K-25%),

(7) growth rate change by 10% and carrying capacity by 25% (i.e., r-10% and K-25%),

(8) growth rate and carrying capacity both change by 25% (i.e., r-25% and K-25%).

6. Data and Parameter Estimates

6.1. Fish Catch and Fishing Effort Data. Time-series data (1985/86 to 2007/08) on catch and effort of the BOB commercial fishery have been gathered and compiled for the present study (Table 1). Data have been collected from the statistics of Marine Fisheries Department, Chittagong (MFDCTG), Bangladesh. The catch has been expressed in weight of biomass in tonnes and effort has been expressed in terms of fishing days. The commercial catch data usually been collected as fiscal (i.e., 1985-1986) year by Marine Fisheries Department. In this study, data were presented by both fiscal economic year (Table 1) and as the single economic year (text).

The unit price of the harvest and unit cost of fishing effort of the Bay is considered as 50000 BDT and 75000 BDT (1 USD = 81.75 BDT), respectively, in 2007 [29]. This fish price is the price paid in the wholesale market.

6.2. Economic and Statistical Parameters. Parameters are estimated by regression of the catch per unit effort data on the corresponding effort data (Table 1) for the BOB Fishery. In this study, in OA equilibrium, we have considered that average revenue AR = TR/E is equal to marginal cost (MC = TC$'(E)$). Therefore, from (7) and (8), we get

$$\begin{aligned} \frac{pH}{E} &= c, \\ \frac{H}{E} &= \frac{c}{p}. \end{aligned} \tag{10}$$

Table 1: Total catch and effort data of the Bay of Bengal, Bangladesh, from Fish trawlers. (Source: Statistics of Marine Fisheries Department, Chittagong, Bangladesh).

Year	Number of trawlers	Catch (tonnes)	Effort (days)	CPUE
1985-1986	14	5500	1783	3.085
1986-1987	18	4769	2351	2.028
1987-1988	19	4393	2331	1.885
1988-1989	8	931	617	1.509
1989-1990	8	2105	990	2.126
1990-1991	12	1532	721	2.125
1991-1992	14	1974	1421	1.389
1992-1993	12	2545	1545	1.647
1993-1994	11	3305	1228	2.691
1994-1995	14	4404	1354	3.253
1995-1996	12	4568	1432	3.19
1996-1997	14	5793	1656	3.498
1997-1998	13	7515	1856	4.049
1998-1999	18	6680	2136	3.127
1999-2000	21	8017	2517	3.185
2000-2001	31	16027	3871	4.14
2001-2002	36	16586	4841	3.426
2002-2003	42	19428	5414	3.588
2003-2004	49	23207	6284	3.693
2004-2005	68	25895	8535	3.034
2005-2006	78	27096	11469	2.363
2006-2007	88	29446	11462	2.569
2007-2008	95	29176	13368	2.183

By using the unit cost of harvest and the resource rent per unit harvest, we can find the open-access equilibrium level of the fish stock. The unit cost of harvest follows by use of (2) and (8).

$$C(X) = \frac{\mathrm{TC}(E)}{H} = \frac{cE}{qEX} = \frac{c}{qX}. \tag{11}$$

This demonstrates that the unit cost of harvest decreases with an increase in the stock size.

With the constant price of fish, the resource rent per unit harvest is

$$b(X) = p - \frac{c}{qX}. \tag{12}$$

At the open-access equilibrium, the stock level X_∞ follows from b $(X_\infty = 0)$, and open access stock biomass,

$$X_\infty = \frac{c}{pq}. \tag{13}$$

The long-term harvest function can be expressed by

$$H(E) = aE + bE^2. \tag{14}$$

So, CPUE could be expressed by

$$\mathrm{CPUE} = a + bE, \tag{15}$$

where $\mathrm{CPUE} = H/E$, $a = qK$, and $b = (-aq/r)$.

Since data on catch and effort are available for the BOB fishery, this allow us to estimate the parameters a and b by linear regression of the catch per unit of effort on effort.

Effort at maximum sustainable yield can be obtained from (12) by taking the partial derivative of H with respect to E and setting it equal to zero as

$$E_{\mathrm{MSY}} = \left(\frac{-a}{2b}\right). \tag{16}$$

Hence, the output at MSY is

$$\mathrm{MSY} = \left(\frac{-a^2}{4b}\right). \tag{17}$$

Further on the OA point, total fishing costs equal the total revenue from the fishery ($\mathrm{TR}(E) = \mathrm{TC}(E)$).Therefore, using the Gordon-Schaefer model, the effort at OA yield can be obtained by equating

$$\mathrm{MC} = \mathrm{AR} \tag{18}$$

or

$$\begin{gathered} c = \frac{pH(E)}{E}, \\ cE = pH(E) \equiv E_{\mathrm{OAY}} = \left(\frac{c/p - a}{b}\right). \end{gathered} \tag{19}$$

The maximum economic return is realized at a lower total fishing effort for positive economic rent that is only obtained at efforts lower than E_{OA}. Maximum economic yield (MEY) is attained at the profit maximizing level of effort which is obtained using (9) $\prod'(E) = 0$ or $d\mathrm{TR}(E)/dE = d\mathrm{TC}(E)/dE$. Therefore, the effort at MEY is

$$E_{\mathrm{MEY}} = \left(\frac{c/p - a}{2b}\right). \tag{20}$$

Different parameter values and statistical tests of a linear regression on the basis catch and effort data (Table 1), considering (13), have also been analyzed (Table 2). The regression analysis reveals that about 60% of the CPUE variation is explained by the linear model.

The results of regression analysis (Table 2) were obtained from time series catch and effort data of the BOB fishery for the years of 1996 to 2007. It is noteworthy that data collected since 1996 is being considered more reliable compared with earlier years, which included a more homogenous fleet as well as a more homogenous catch composition. The four major concerns, motivated to use the shorter time series are as follows; (1) change in accuracy of statistics; catch composition has been changed (i.e., more predators early years), (2) corresponding increase in catch while including more prey species; (3) changes in size composition (i.e., decreasing mesh

Table 2: Regression analysis of catch on the corresponding effort data (1996–2007) including intercept.

Parameters	Coefficients	Standard error	t Stat	P value
a	3.974	0.208	19.107	0.000
b	−0.0001203	0.0000285	−4.22	0.0018

Adjusted R square 0.604.

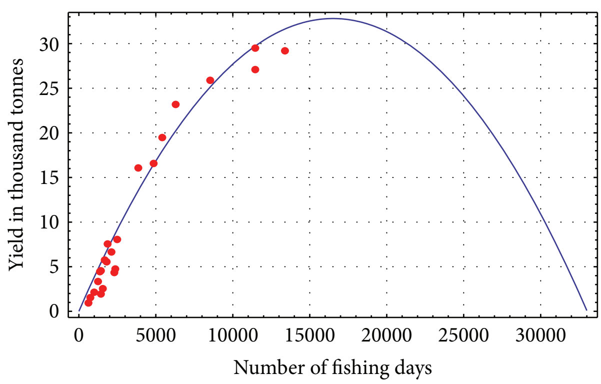

Figure 2: Gordon-Schaefer harvest curve for the fishery of 1996 to 2007 based on (14) and catch data from Table 1.

size or similar); and (4) change in operational pattern (i.e., approaching other areas, longer days). All of these factors are regarded to take a significant shift around 1996, though no such changes have been observed over long periods of time.

From the estimated coefficients for a and b, we can get values of K and r, respectively, as follows:

$$K = \frac{a}{q}, \tag{21}$$

$$r = \frac{-aq}{b}. \tag{22}$$

7. Results

Intrinsic growth rate and the carrying capacity were calculated based on the estimated coefficients, which were derived from (Table 2) the model. The GS model has predicted that the values of K and r had been 40660 tonnes and 3.228 by (21) and (22), respectively, and catchability coefficient ($q = 9.77332 * 10^{-5}$ in 2003) has been taken from [10]. The harvest function for the BOB fishery is based on (14) and values of parameters estimated from Table 2. Thus, a yield-effort curve (Figure 2) was found to be

$$H(E) = 3.974E + \left(-0.0001203E^2\right). \tag{23}$$

Calculation of reference points is the key step towards approaching the bioeconomic analysis; hence, MSY, MEY, OA, corresponding effort levels, and economic rent were calculated in response to changes in the biological parameters. The values of effort at MSY and MEY were calculated using (16) and (20) while harvests at MSY, MEY, and OA were calculated using this fishery's harvest equation (14). Economic rent is the difference between total revenue and total cost. Therefore, total cost and total revenue were calculated using (7) and (8). In order to come up with estimation in changes at various levels of r and K, variationwas assumed to range between 10% and 25%. A change in K and r mayalso imply changes in harvest, corresponding effort and economic levels (Table 3). As indicated in Table 3, MSY was at 32,895 tonnes valued at BDT 406 million and produced at effort value of 16,517 standard units. When these estimated values were compared with the recorded catch and effort values (Table 1), it has been found that the current catch level nearly approaches to MSY value that is obtained from this empirical model. In contrast, the MEY was at 28,143 tonnes valued at BDT 636 million and obtained as effort value of 10,282 standard units. Comparing these with the actual catch and effort figures, MEY was attained very recently between 2006 and 2007. The OAY was at 30,854 tonnes and produced at an effort level of 20,558 standard units which is very close to the catch data of 2007-2008 considered for the current study. In addition to the present situation, eight possible scenarios were presented in response to potential climate change and anthropogenic induced variability in the biological parameters of K and are (Table 3).

The parameter value has been changed under each regime with individual climatic and anthropogenic consequences. All scenarios have been compared with changing conditions to quantify the possible impact on the fisheries resources. In addition, confidence interval (95% level) has showed (Table 3) climate change impacts on stock and effort level at OA, MEY, and MSY. Lower and upper vlue has presented. Only current scnerio has shown for this change.

7.1. Scenario 0 (Present Situation). This present situation based on the estimated K and r valued from available historical catch data reveals that the multispecies fisheries of BOB are in a transition period. Since both MSY and MEY were found to occur within very short and recent times, a more integrative approach is needed for intense observation on the yields of the upcoming years. However, the profit level was found to be BDT 636 million at MEY level and BDT 406 million at MSY level.

7.2. Scenario 1. In the case of this scenario, the average change or difference was about 10% of harvest levels and nearly 11% in profit level, compared to the present situation (Scenario 0).

Consequences. This may result in a change of BDT 63 and BDT 44 million at MEY and MSY level, respectively, compared to the present scenario.

Table 3: Harvest, corresponding effort, and profit at OA, MEY, and MSY level in response to changes in the biological parameters K and r with potential changing climatic and anthropogenic scenarios with confident intervals for current scenario.

$K = 40660$—25%	$r = 3.228$—25%	$r = 3.228$—10%	$r = 3.228$
	Scenario 8	Scenario 7	Scenario 6
	$E_{OA} = 12304$	$E_{OA} = 14765$	$E_{OA} = 16404$
	$E_{MEY} = 6152$	$E_{MEY} = 7382$	$E_{MEY} = 8202$
	$E_{MSY} = 12385$	$E_{MSY} = 14862$	$E_{MSY} = 16511$
	$H_{OA} = 18454$	$H_{OA} = 22145$	$H_{OA} = 24606$
	$H_{MEY} = 13781$	$H_{MEY} = 16537$	$H_{MEY} = 18375$
	$H_{MSY} = 18568.42$	$H_{MSY} = 22150$	$H_{MSY} = 24607$
	$\prod_{MEY} = 227 * 10^6$	$\prod_{MEY} = 273 * 10^6$	$\prod_{MEY} = 304 * 10^6$
	$\prod_{MSY} = -6 * 10^6$	$\prod_{MSY} = -7 * 10^6$	$\prod_{MSY} = -8 * 10^6$
$K = 40660$—10%	Scenario 5	Scenario 2	Scenario 3
	$E_{OA} = 14382$	$E_{OA} = 17258$	$E_{OA} = 19173$
	$E_{MEY} = 7191$	$E_{MEY} = 8629$	$E_{MEY} = 9587$
	$E_{MSY} = 12385$	$E_{MSY} = 14863$	$E_{MSY} = 16511$
	$H_{OA} = 21570$	$H_{OA} = 25884$	$H_{OA} = 28760$
	$H_{MEY} = 18251$	$H_{MEY} = 21901$	$H_{MEY} = 24335$
	$H_{MSY} = 22146$	$H_{MSY} = 26575$	$H_{MSY} = 29528$
	$\prod_{MEY} = 373 * 10^6$	$\prod_{MEY} = 448 * 10^6$	$\prod_{MEY} = 498 * 10^6$
	$\prod_{MSY} = 178 * 10^6$	$\prod_{MSY} = 214 * 10^6$	$\prod_{MSY} = 238 * 10^6$
$K = 40660$	Scenario 4	Scenario 1	Scenario[a] 0
	$E_{OA} = 15421$	$E_{OA} = 18505$	$E_{OA} = 20558$, [11350, 29779]
	$E_{MEY} = 7710$	$E_{MEY} = 9252$	$E_{MEY} = 10282$, [5675, 14889]
	$E_{MSY} = 12385$	$E_{MSY} = 14862$	$E_{MSY} = 16517$, [9374, 23659]
	$H_{OA} = 23128$	$H_{OA} = 27754$	$H_{OA} = 30854$, [8053, 53642]
	$H_{MEY} = 21101$	$H_{MEY} = 25321$	$H_{MEY} = 28143$, [21558, 34728]
	$H_{MSY} = 24607$	$H_{MSY} = 29528$	$H_{MSY} = 32895$, [17670, 47968]
	$\prod_{MEY} = 476 * 10^6$	$\prod_{MEY} = 572 * 10^6$	$\prod_{MEY} = 636 * 10^6$
	$\prod_{MSY} = 301 * 10^6$	$\prod_{MSY} = 361 * 10^6$	$\prod_{MSY} = 406 * 10^6$

[a]Confident intervals are shown in square brackets.

7.3. Scenario 2. The differences of harvest level were 4970, 6242, and 6320 tonnes at OA, MEY, and MSY level, respectively, compared to the current situation. The average change in harvest level was 20% compared to the current situation.

Consequences. Since both carrying capacity and growth rate change negatively, the MEY and corresponding profit are found to be lower which is expected. The profit level is decreased by about 30% as MEY level compared to the present situation.

7.4. Scenario 3. Compared to Scenario 0, the differences of economic level were found to be BDT 138 million and BDT 168 million at MEY and MSY level, respectively. Furthermore, harvest level was changed approximately 10% compared to present conditions.

Consequences. Under this scenario, about 41 % of change has been shown at the MSY level which will not certainly be a good sign of the country's economy.

7.5. Scenario 4. The results of the model based on this scenario differ about 20% of effort level (at OA) and average 25% of the harvest level of OA, MEY, and MSY level from scenario 0.

Consequences. The profit impact is roughly 25% on MSY level compared to the reference situation.

7.6. Scenario 5. About 35% lower harvest was accounted for MEY under this scenario compared to present situation whereas nearly 30% and roughly 32% change of OA and MSY level have been found to be occurring, respectively.

Consequences. The profit level was approximately 56% lower from the present situation.

7.7. Scenario 6. The difference of harvest level has been found to be 6248, 9768, and 8288 tonnes at OA, MEY, and MSY level, respectively, compared to the present scenario. In contrast, effort level has been changed only 10% from the same situation.

Consequences. However, profit level has been impacted at 10% on MEY level compared to the current situation.

7.8. Scenario 7. The comparative higher difference of harvest and profit level has been shown in this scenario from the reference scenario.

Consequences. The difference of profit level has been BDT 363 million at MEY level compared to the current situation.

7.9. Scenario 8. This is the last scenario and the highest change or difference has been observed among all the scenarios which are very much expected due to the significant changes in carrying capacity and growth rate of the fishery. The difference of harvest level has been found to be 12,400, 14,362, and 14,440 tonnes at OA, MEY, and MSY level, respectively, compared to the current situation.

Consequences. This sort of dramatic change in growth and carrying capacity has an impact on profit by 64% at MEY level compared to the present situation.

8. Discussion

Managing multispecies fisheries are a challenging task; therefore, continuous effort has been made over the years to develop new models to manage complex fisheries system. To examine biological and economic over fishing of fish stocks, detailed scientific data on stock levels, regeneration, and catch are prerequisite. However, less costly methods such as observing certain indicators like catch per unit of effort, changes of price, changes in market supplies, and a percentage composition change of species or size over time can also be good references to address overfishing in data poor system [30]. Thus, traditionally CPUE had been used as an index of stock abundance assessments [31]. CPUE for fish showed an increasing trend immediately after the 1990s and started to decline from the late 2000s which is believed to be continued. The initial CPUE increase is most probably due to the increase of modernized fishing fleets in the coastal and marine water of BOB. The BOB fishery is assumed to be characterized by smaller pelagic and smaller demersal fishery in the recent decades [11]. This could be an indication of "fishing down the food web" and a corresponding low CPUE. Therefore, effort pressure that is exerted on small fish, which does not contribute a lot in terms of total weight in yield, consequently takes part in lower CPUE.

The regression results showed that the GS model aims to explain most of the variation found in the empirical data. The results also indicated that fisheries of the BOB are characterized by increasing fishing effort and decreasing CPUE. Several studies also predicted that BOB fishery could be unsustainable with continuous increasing of fishing effort in the absence of proper regulation and lack of implementation of current initiatives [11]. This is also clearly supported by the yield-effort curve obtained from the current model results. Present condition of high effort, less harvest, and less biomass stock also indicated that the danger of depletion of the resource cannot be ruled out [10]. Fish prices have been rising with the declining market supplies relative to the increase in population number, and this may suggest that the stock is becoming scarce. Based on the analysis of catch and effort level of the last few years, the sustainable harvest curve and catch level are expected to be coming down.

To establish the ecological sustainability of current fish harvesting practices, the estimated MSY and the corresponding effort levels were compared with the actual catch and effort figures. MSY for the GS model of the BOB fishery was found to be occurring very recently. It is noteworthy that during the same time, effort almost became doubled from 2003 to 2007. It has been assumed that there is little difference between the situation in the later years and that of OA. However, from an economic point of view, MSY does not imply efficient harvesting, relating efficiency to maximizing the net benefit from the use of economic resources, that is maximizing the resource rent [32]. Therefore, for the BOB fisheries management, MEY is considered as a proper reference point. Furthermore, by-catches of BOB fishery have never been reported to be discarded by fishers. Based on the aforementioned indicators, it is evident that there was biological overfishing but not severe for the fishery resources.

A fishery cannot be sustainable if total catch exceeds the MSY level. However, the fact is that the MEY solution is best characterized as one that considers the economic efficiency associated with the sustainable yield curve, and there are a number of salient benefits of pursuing such a goal—or at least evaluating it for any given fishery. Given this context, present model result showed that BOB fishery is passing a very critical time, as both MSY and MEY have been achieved recently and within very short time (2003–2008). Most importantly, among the reference points, consideration of MEY as a key reference point is very important due to the four major facts which are as follows: this approach is responsive to changes in economic conditions, its implication is efficient, it minimizes harvesting costs, and lastly MEY might be considered to be preferable to the MSY as a management goal is that the MSY solution compromises the ability of a commercial fishery to remain viable [13]. The analysis on actual catch and effort figures reveals that the BOB fishery sustained economic overfishing from 2005 onwards. As a result, even higher levels of effort in the later years did not get adequate quantities of catch. This is obviously alarming and demands immediate attention of policy makers and administrations. Therefore, further increase in fishing effort will certainly pose a negative impact on the fish stock and none of the reference points (MSY and MEY) will be in equilibrium condition. In this study, [11] also commented that twice increase of current fishing effort will severely impact the fisheries of BOB, declining major targeted commercial pelagic and demersal fish groups. Furthermore, a recent study showed that most of the commercial fish groups of BOB had a trophic efficiency (EE) $>$ 0.90 indicating that the consumers are heavily exploited by the system [11]. That is why immediate attention needs to be taken to reevaluate the current management measures for the sustainable management of BOB fishery.

Sensitivity of fisheries against possible climatic change and anthropogenic disturbances has been considered in respect to carrying capacity, growth rate, and economic performance fewer than nine different regimes. A notable percentage of change in harvest level (OA, MEY, and MSY), corresponding effort, and profit level had been shown in

Scenarios 4, 5, 7, and 8. These four scenarios showed a difference between profit levels of BDT 159 million (25%), BDT 262 million (41%), BDT 363 (57%) million, and BDT 408 (64%) million at MEY level compared to the current situation. These situations are not expected to occur in case of BOB fishery. However, current anthropogenic disturbances, changing climatic pattern, and existing management measures of BOB fishery can easily lead to a situation which is predicted under Scenarios 1, 2, 3, and 4. However, in that possible climate change consequence, the fishery manager should put enough effort to keep maintain existing MEY which in turn will help to sustain BOB fishery.

Climate change may directly affect fishery production through changes in reproduction, growth, recruitment, and migration patterns which are all affected by temperature, rainfall, and hydrology [28, 33]. According to [34] growth, mortality and recruitment parameters are extremely dependent on environmental conditions, even between small distances. Therefore, an assessment and projections about the future fishery cannot be made without due consideration of the climatic influences. In addition, the output of the surplus production models reveals that climate driven changes in the productivity of the fishery can significantly influence the economy of fisheries. An assessment report of the World Fish Centre identified four tropical Asian countries such as Bangladesh, Cambodia, Pakistan, and Yemen as the most vulnerable depending on the vulnerability of national economics to the impacts of climate change on fisheries [35]. The database on climatic variables of tropical BOB is very poor. However, average tropical sea surface temperature is predicted to increase by 50–80% of the average atmospheric change over the same period [36]. This may change the average ocean pH and consequently can cause significant damage to the juvenile and adults [37] and leads a shift in fish-stock distribution [2]. The situation might be the same or even worse for tropical BOB as the bay more often suffered from the multiple anthropogenic disturbances and natural disaster. Finally, the confidence intervals have showed how changes in the effort levels and yields were impacted by climate change. In current scenario, 44% of effort level could increase during confidence interval changes at OA, MEY, and MSY levels. The confidence intervals have demonstrated that harvest might increase by 73%, 23%, and 45% at OA, MEY, and MSY levels, respectively.

Moreover, fishing zones and fish production in the coastal area of Bangladesh are declining gradually over the years and those attributed to the sea level rise, pollution, increase of salinity in the coastal belt, frequent cyclone, and changes in pH and oceanic current pattern [38]. Freshwater discharge has found to be a significant factor in the recruitment of juveniles and distribution of marine and estuarine species in the Bakkhali river estuary of Bangladesh [39]. Since a number of rivers have found their final way to BOB, it is assumed that these river estuaries could play significant role in recruitment of valuable commercial marine species. Consequently, under changing environmental conditions, the natural recruitment process may face severe problems.

9. Conclusion and Recommendation

The commercial fishery of the BOB may easily lead to over-exploitation, mainly attributed to the higher corresponding effort, in the absence of proper conservation, management, and policy measures. This study also indicated that effort level may increase in the near future. It is obvious that, for MSY, resource rent cannot be maximized without significant effort reduction. Since, in the recent years, the fishery of BOB has achieved both MSY and MEY, a closer inspection is needed to ensure the sustainability of this resource exploitation. Any inexpedient changes in fisheries sector, that is, the effort (e.g., trawler, fishing events, and new technology) and management regulation, might lead the fishery into such a critical condition that could be very difficult to deal with, especially given the poor management systems and resources of Bangladesh. The continuous increase of effort level can occur due to the increasing population level at the coast, high unemployment rate, demand of fish, and fishery products for the country. It is assumed that a reduction in fishing effort to attain MSY, OA, or MEY will raise the productivity of the marine fisheries. However, it will also result in the unemployment of fishermen who will ease out fisheries. This could be a major problem in countries like Bangladesh, where coastal fishing community relies heavily on marine fisheries, or when there are no alternative employment opportunities outside the fishing sector. However, withdrawing fishing would mean reduction in cost as well as increase in the resource rent, which could be used to compensate the unemployed fishing people. Additionally, individual transferable quotas (ITQs) that have the potential to reduce excess competition and investment common in limited entry and open-access fisheries [40] and individual quotas of habitat impact units (HIU) to mitigate possible habitat damage arising from some forms of harvesting, such as bottom trawling [23], could be two good alternatives for BOB fishery management. Besides this, a campaign, an awareness program, and education related to sustainable fishing could be arranged for commercial trawler owners. A reduction of cost, effort, introduction and expansion of mariculture, sufficient and alternative employment opportunity, technical and logistic support, and well-monitored market may help compensating the climate and anthropogenic driven economic loss in the fishery. Finally, proper implementation of rules and regulation on different technical issues of fishing should be strongly implemented and monitored.

Abbreviations

BOB:	Bay of Bengal
r:	Intrinsic growth rate
K:	Carrying capacity
OA:	Equilibriums open access
MEY:	Maximum economic yield
MSY:	Maximum sustainable yield
CPUE:	Catch per unit effort
MFDCTG:	Marine Fisheries Department, Chittagong
BDT:	Bangladeshi Taka.

Conflict of Interests

Authors declare that they have no competing interests.

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