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Trophic structure and energy flow of the resettled maritime area of the Bay of Bengal, Bangladesh through ECOPATH

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Abstract
The existing study was taken to represent the current information in order to develop a mass-balanced ecosystem model within the resettled maritime boundary area of the Bay of Bengal (BoB), Bangladesh from July 2016 to June 2017 through ECOPATH approach covering over 90 000 km^2. A total of 19 functional groups were considered representing all trophic levels in the foodweb where estimated trophic interactions between the groups were varied from 1 (primary producers and detritus) to 3.45 (sharks). The ecotrophic efficiency (EE) of most of the consumers was greater than 0.80; symbolizing a largely exploited ecosystem and high energy transfer from lower to higher trophic levels. Moreover, the gross efficiency (0.001 8) and transfer efficiency (11.12%) of the whole system symbolizes the "Developing Systems" with somewhat maturity currently. Ecosystem's overhead (64.6) and ascendancy (35.4) also designate the ecosystem's stability. Thus, this study determines that the resettled maritime area of BoB reserves significant backup strength to face stress situations having capacity to rapid restoration to the original states.

Key words: Ecopath with Ecosim, Bay of Bengal, ecological groups, maritime ecosystem, mass balance

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1 Introduction

Ecosystems are superbly balanced although they are reasonably complex, non-linear and its structures are composed by the interconnection of living and non-living bodies with their habitat, but every portion of an ecosystem, has a significant role to play and alteration of any portion of a particular ecosystem, the whole ecosystem of that area can be altered. This is not only dynamic but also hierarchically ascended. Ecosystem structures and processes are associated across the spatial and temporal balances. Due to their complication and the array of negative and positive response across balances, the predictability of these structures is inadequate (Gunderson, 1999). Sustainable usage of ecosystem components is unlikely deprived of a better understanding of balancing ecosystem dynamics that foster ecosystem capability (Bengtsson et al., 2003). Coastal and marine ecosystems are among the largest aquatic ecosystems of the world, covering 71% of the earth and fish populations are one of the most vital parts of these systems (BOBLME, 2011). Therefore, management approach that is based on ecosystem to fisheries has reaped consideration for maintaining long-term sustainability to fisheries and balanced ecosystems (ICES, 2000). In recent, the ability of marine ecosystems to produce fish for supporting human interest is extremely degraded by overfishing, excessive trawling, and loss of spawning and nursing grounds (McGlade et al., 2002). Noticeable limitation exists between single and multispecies fisheries management, which does not consider a comprehensive assessment of changes in ecosystem arrangement, and functions linked with the interactions of individuals (Mace, 2001; Pikitch et al., 2004). The concept of ecosystem-based fishery management needs the improvement of tools to gain perceptions in ecosystem functioning and the effect of fishing on ecosystem structure. Some of the critical issues like interspecies interactions within an ecosystem, effects of the enormous environmental and climatic alterations along with the fishing impacts should be incorporated to formulate an ecosystem based management strategy in any habitat (Browman et al., 2004; Pikitch et al., 2004).

Recent improvements in constructing multispecific ecosystem based modeling approach of aquatic ecosystems named "Ecopath with Ecosim (EwE)" are successfully used to evaluate the structure and ecosystem effects of fishing (Polovina, 1984; Christensen and Pauly, 1992). This approach provides a base for feasible and applied simulation model having actual predictive power that can be performed more rapidly and rigorously than ever before (Christensen and Pauly, 1993; Walters et al., 1997; Christensen and Walters, 2004). The construction of such mass-balance models of ecosystems are based mainly on food consumption, diet composition, biomass and mortality estimates. The ECOPATH packages of software have now been improved (Walters et al., 1997, 1999) through including ECOSIM (simulation module) and ECOSPACE (spatial module). These new modules have not only upgraded the quantitative command of the approach but also permitted qualitatively new inquiries.

Recently, Bangladesh has been settled maritime boundary with neighboring states Myanmar and India up to 200 nmile from the coastline comprising about 121 110 km^2 (MoFA, 2014), whereas coastal and shallow shelf waters constitute about 20%

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and 35%, respectively, the rest covers deeper waters (Khan et al., 1997). The entire shelf area of Bangladesh (up to 200 m depth contour) covers about 66 440 km^2 and from the coastline to 10 m (0–10 m) depth zone comprises 24 000 km^2 (Table 1). Nevertheless, in the context of fisheries resources, from the coastline to 200 m depth zone plays a significant role as it almost covers four major fishing grounds of Bangladeshi waters and also produces most of the marine catch (Khan et al., 1997; Lamboeuf, 1987). The declared areas of four major fishing grounds (Fig. 1) are "South Patches" and "South of South Patches" covering an area about 6 200 km^2. In addition, "Middle Ground" contains 4 600 km^2 area (Table 1) and "Swatch of No Ground" covers 3 800 km^2 (Khan et al., 1997, 1998). Among them "Middle Ground" and "South Patches" have been declared as "Fish Sanctuaries" in the Bay of Bengal (BoB), Bangladeshi martime waters. Still, the detailed ecological and oceanographic data of these areas are limited to determine the suitability of these areas as fish sanctuary.

Table 1. The geographic location and covered areas of the major fishing grounds of the EEZ (Exclusive Economic Zone) of the Bay of Bengal, Bangladesh (Khan et al., 1997)

Depth zone/m	Area/km^2	Fishing grounds	Location	Depth/m
⩽10	2 400	South Patches (3 400 km^2)	20°57′–21°25′N; 91°25′– 91°33′E	10–40
10–24	8 400			
25–49	4 800	South of South Patches (2 800 km^2)	19°58′–20°56′N; 91°32′–92°24′E	10–100
50–74	5 580			
75–99	13 410	Middle Ground (4 600 km^2)	20°50′–21°20′N; 90°00′–91°00′E	10–100
100–199	10 250			
All shelf	66 440	Swatch of No Ground (3 800 km^2)	21°00′–21°25′N; 89°00′–90°00′E	10–100

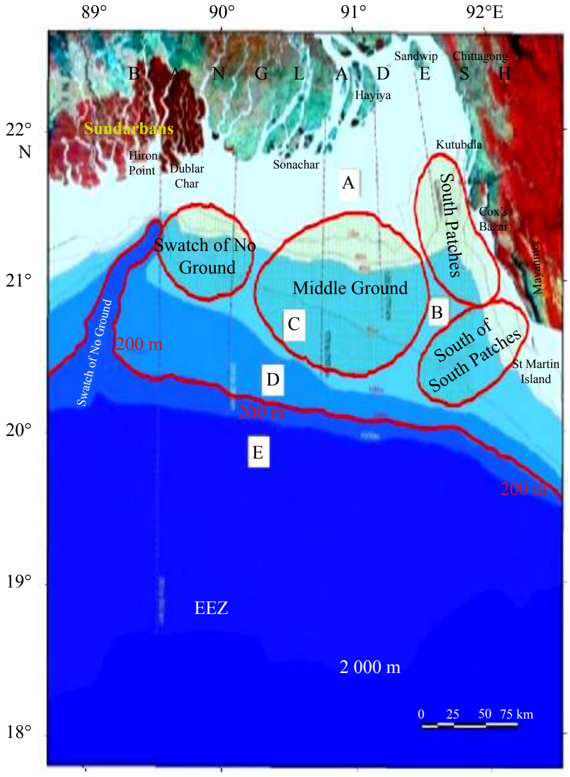

Fig. 1. Existing maritime capture fisheries zones of Bangladeshi waters focused on the four major fishing grounds.

In the context of the recent settlement of the maritime boundary, "blue economy" recently turned into a buzzword for sustainable development, particularly in highlighting the vision of SDG (Sustainable Development Goals) for Bangladesh. The Government of Bangladesh emphasized those marine and coastal fisheries resources based blue economy might act as a driver for sustainable development, designating development not only for today but also for the upcoming years (Shamsuddoha and Islam, 2016). Moreover, this new relocated vast area could not be accomplished to fishing due to the lack of vessel capability and suitable fishing technology (Hossain et al., 2014). The Bay of Bengal defined as a temperately productive ecosystem among the world' s 64 Large Marine Ecosystems (Hussain and Hoq, 2010) has great potential for fisheries because of the enormous nutrient input from the rivers flow of the Ganges and Brahmaputra (ESCAP, 1987). A total of 475 species of finfish, 36 of shrimps, 15 types of crabs, 5 varieties of lobster, and over 300 species of mollusks were recorded (FRSS, DoF). The fishes which are presently exploited consist mainly of the shallow water estuarine species and some mid-water species. The average total marine catch over the last decade (Table 2) was 540 592 t (DoF, 2016). Functionally, marine fisheries are sub-divided into industrial and artisanal fisheries. The average production of the last ten years shows that the industrial fishery based on trawl fishery (shrimp and fish trawl) contributes only 5% of the total marine captures and the artisanal fisheries (mainly based on Set bag net and Gillnet fisheries) contributes 95%.

Several surveys and studies have been piloted to assess and estimate the potentialities of marine fisheries resources of Bangladesh since 1970 to 1980 (Mustafa and Khan, 1993) by the collaboration of national and international agencies, but no fresh assessment is available. Limited reports are found focusing on biological, environmental and resource management concerns of the BoB (Hossain, 2004; Huntington et al., 2007; Hussain and Hoq, 2010), but such evidences are insufficient to consider and manage of our marine resources systematically. Conversely, in near future, there is a possibility of drop down of the fisheries role on people's livelihoods as the stocks of various fish and shrimps are showing diminishing trends due to effects of climatic change, water pollution and fishing pressure (BOBLME, 2011). Previously, Mustafa (2003) made an attempt to describe the ecosystem features of BoB based on trawl catch data but overlooked the most vital artisanal fishing areas, e.g., coastal areas. Similarly, Ullah et al. (2012) described the eco-structures of the shallow coastal areas that not exceeded more than 10 m in depth. Therefore, the maritime waters of the BoB, Bangladesh leftovers to be the most unfocused areas in the world, thus limiting the exploitation, exploration, conservation and management of its marine, though this zone is recognized as one of the world's ample and diversified ecosystems considered by greater productivity (Islam, 2003). All of these studies considered only short-term available

Table 2. Gear wise landed total marine catches (t) from 2005–2006 to 2014–2015 (10 years) of Bangladesh

Year	Fishing types (fleets/gears)						Total marine catch
	Industrial trawl catch	Gillnet	Set bag net (SBN)	Longline	Trammel net	Others (purse seine)	
2005–2006	34 084	264 627	153 687	16 224	7 399	3 789	479 810
2006–2007	35 391	265 668	154 736	15 325	12 883	3 435	487 438
2007–2008	34 159	274 526	159 043	13 856	12 466	3 523	497 573
2008–2009	35 429	296 634	154 164	16 724	9 680	2 013	514 644
2009–2010	34 182	297 332	149 142	18 373	12 608	5 645	517 282
2010–2011	41 665	321 114	148 718	14 928	10 956	5 214	546 333
2011–2012	73 386	327 222	142 383	14 967	10 858	9 808	578 620
2012–2013	73 030	350 910	136 385	13 038	9 725	5 900	588 988
2013–2014	76 885	357 006	133 520	16 054	5 357	6 563	595 385
2014–2015	84 846	334 420	154 245	13 985	4 350	6 000	599 846
Average	52 306	308 946	148 602.3	15 347	9 628	5 189	540 592

data that not properly elucidate long-term outputs. Hence, attempts are made by authors to drive a new study concerning management of the maritime resources of the BoB, Bangladesh using the ecosystem scheme. The EwE (ECOPATH with ECOSIM; Version 6.5) routine package was used in the current study to develop the mass-balance ecosystem model. The aim of this study is to illustrate the interaction between the diverse ecological groups and to define the flow of energy in the maritime area of the Bay of Bengal, Bangladesh. In addition, another aim of this study is to measure the existing capability of the maritime ecosystem of BoB, Bangladesh to cope with the emerging “blue economy” pressure.

2 Materials and methods

2.1 *Study areas*

The Bangladesh part of the BoB is located between 20°N and 22°30′N, and 89°E and 92°30′E (Fig. 2). The current study mainly focuses on the ecosystem structures of the major fishing grounds of the BoB which lies from the baseline to 200 m depth zone (Table 1) occupying about 90 000 km^2 that covers not only 24 000 km^2 of inshore area but also 66 440 km^2 of all shelf areas. The demarcation line (Figs 1 and 2) are used to illustrate the depth zone and fishing grounds in the current study. Nevertheless, this area of both offshore and inshore water covers more than 90% of fishing activities in the country (DoF, 2015a, b) and thus, this model can be designated as “Resettled Maritime Ecosystem of the Bay of Bengal, Bangladesh”.

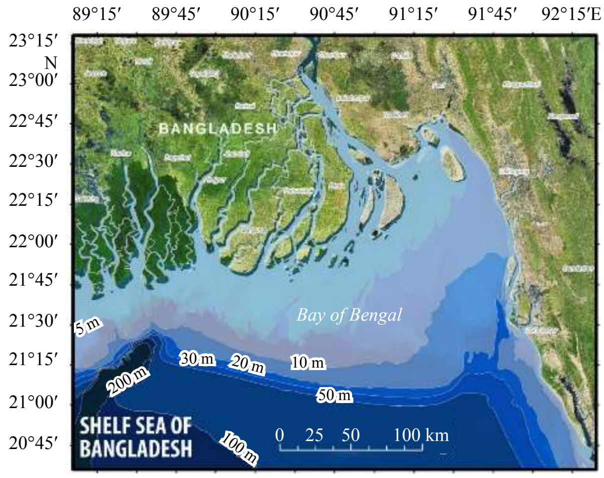

Fig. 2. Total shelf area of the Bay of Bengal, Bangladesh emphasizing the depth zones.

The bottom topography of the shelf sea is usually coarse sandy and muddy with some rocky blotches, but the shallow inshore areas are dominated by muddy bottom. Moreover, the shelf zone down to about 150 m seems to be quite smooth with very limited obstacles to bottom trawling whereas due to existence of precipitous slope trawling is not possible into the waters deeper than 180 m (Khan et al., 1997). The oceanographic features in the BoB mainly depend on three key factors: (1) precipitation, (2) wind direction, and (3) mass siltation from the river discharges (Lamboeuf, 1987) that have a strong influence on the abundance and distribution of fishes too. The annual average temperature is about 27°C and the yearly average rainfall of the BoB, Bangladesh is approximately 3 800 mm where over 80% precipitation is received from June to September (DoE, 2015). Hence, these areas are treated as a sole homogenous area as it covers a wide range of marine habitats. However, this zone has been carefully chosen for the present study because of the availability of fisheries landing data from the period of July 2016 to June 2017.

2.2 *Overview of Ecopath model (Version 6.5)*

The software “Ecopath” was designed for analyzing trophic dynamic interactions within the fisheries resources systems (Christensen and Pauly, 1992, 1995). This scheme is based on the previous work, which was first demonstrated by Polovina (1984), and it has been widely applied to aquatic systems after successive improvements (Christensen and Pauly, 1993; Pauly et al., 2000). Ecopath is basically a large spreadsheet that is instantaneously keeping track of all the individuals or species and entire feeding interactions occurring within the ecosystem (Christensen and Pauly, 1993). This approach designates an ecosystem at steady-state for a certain period and assumes mass balance in production of any specified prey that is equivalent to the biomass consumed by predators in combination with the estimated captured biomass (e.g., in fisheries) and any other exports from the system, i.e.,

$$B_i(P/B)_iEE_i = Y_i + \sum (B_j)\,(Q/B)_jDC_{ij} + EX_i, \qquad (1)$$

where B_i represents the biomass of prey i group, $(P/B)_i$ is the production/biomass ratio of that group, and EE_i is the ecotrophic efficiency. Y_i symbolizes the yield (or catch rate of fisheries) of i

groups, B_j is the biomass of predator j group, $(Q/B)_j$ is the food export or consumption per unit biomass of j, DC_{ji} is the fraction of prey i in the diet of j, and EX_i is the export of i. When the input values of the parameters of the model are delivered, ECOPATH assesses the missing parameters for each group within the model, e.g., the annual biomass production, the annual biomass consumption or ecotrophic efficiency for each functional groups of the ecosystem.

2.3 *Model construction*

2.3.1 *Fisheries landing data*

Existing marine capture fisheries of BoB are categorized into two major sub-divisions, i.e., industrial trawl captures and artisanal captures which contribute about 95% of the total marine landings. The term "industrial captures" indicate "large-scale" which mainly focus on demersal fish and penaeid shrimps in the offshore waters. Artisanal consist of a number of diverse categories of traditional fishing gears and crafts, i.e., gillnets, set bag nets (SBN), longline, trammel net, purse seine, etc. (Table 2).

Annual catch data of the last 10 years (from 2005–2006 to 2014–2015) from the Fisheries Resource Survey System (FRSS) of Department of Fisheries (DoF), Bangladesh were considered in this study (Table 2). Due to the scarcity of an efficient data collecting and recording system, it is not possible to find the total species-wise annual landing data but group-wise data in FRSS. In addition, some of the reference reports (Nabi, 2007; Mustafa, 1999) and reports from the NGO organizations (e.g., FAO country data) were also considered for this study. To acquire necessary percentage of yield data, it was combined all of the source data under various species or groups and a weighted average technique was used. Weighted average is a techniques in where each quantity to be averaged is assigned a weight and these weightings determine the relative significance of each amount on the average. The formula for calculating weighted average is (Gupta, 2000):

$$\dot{X}_{\rm w} = \sum WX / \sum W, \tag{2}$$

where $\dot{X}_{\rm w}$ symbolizes the weighted average, X symbolizes the variable values, i.e., $x_1, x_2, \ldots, x_n$, respectively while W symbolizes the weights variable values, i.e., $w_1, w_2, \ldots, w_n$, respectively.

2.3.2 *Ecological or functional groups*

Functional groups were characterized based on similarities in feeding habits, bulk body mass, life history parameters, physiological behavior and spatial distributions to keep homogeneous characteristics throughout the species within a group (Yodzis and Winemiller, 1999). More than 82 fish species and 20 types of shrimps and crustacean's are regularly collected by FRSS, thus, over 77 taxonomic families of fish, shrimps, crustaceans, mollusks were included in this study. Representative species were selected based on their significance to fisheries and available information in the statistics (Table A1 in Appendix).

Greater preference was given to collect data from those literatures having local and regional data for every group when life history parameters, diet composition, food consumption, habitat and other information were considered for the modelling (Table 3). If diet data was not available, information from similar ecosystems were considered. Fishbase (www.fishbase.org; Fröese and Pauly, 2006) has also been applied to linkup the gaps whenever possible. Data sources of non-fish groups are given in Table 4.

2.3.3 *Basic parameters of fish*

2.3.3.1 *Estimation of biomss (B)*

The biomass (t/km^2) of each ecological group per unit area in the habitat area was estimated in average by using Gulland (1971) formula of $B=Y/F$, where Y represents the annual yield of each group and F symbolizes the coefficient of fishing mortality. Biomass of sharks and other unexploited groups, i.e., benthos, aquatic invertebrates, zooplankton, phytoplankton, and detritus were obtained from various reference data (Table 4). In addition, biomass of other crustaceans, gastropods and cephalopod group were obtained from Arreguín-Sánchez et al. (1993) and Christensen and Pauly (1993).

2.3.3.2 *Estimation of production/biomass (P/B)*

Estimation of this ratio is equivalent to the total mortality (Z) (Pauly et al., 2000) as it was really hard to assess directly. Consequently, this parameter was calculated by obtaining the sum of the fishing (F) and natural (M) mortalities while the entry of P/B ratios is optional. The estimated P/B values and other population parameters are given in Table 3.

2.3.3.3 *Estimation of relative food consumption (Q/B)*

Consumption/biomass (Q/B) ratio of each group was calculated through the following empirical relationship suggested by Palomares and Pauly (1998).

$$\begin{aligned} \lg Q/B = & 7.964 - 0.204 \lg W_{\rm inf} - 1.965T + 0.083A + \\ & 0.532h + 0.398d, \end{aligned} \tag{3}$$

where $W_{\rm inf}$ represents the asymptotic weight that can be calculated from the asymptotic length $L_{\rm inf}$ (one of the VBGF parameter found from ELEFAN routine of FiSAT II package) and length-weight relationships (LWR) of the representative species derived from various sources (Table 3). T symbolizes the average annual temperature of that habitat which is expressed as 1 000/($T_{\rm c}$ + 273.1). Here $T_{\rm c}$ represents the annual average temperature of sea surface (27°C) (DoE, 2015). A signifies the ratio of the square of the caudal fin height and its surface area, and h and d are binary variables demonstrating the feeding class of the fish species, i.e., for detritivore (h=0, d=1) and herbivore (h=1, d=0) and for carnivore (h=0, d=0). The aspect ratio of the caudal fin (A), which is the indication of metabolic activity, was collected mostly from the Fishbase (Fröese and Pauly, 2006) and also from the laboratory works that were conducted in the Population Dynamics laboratory of Bangladesh Fisheries Research Institute (BFRI) during the data collection period. For other functional groups, Q/B was assembled from various literatures (Table 4).

2.3.4 *Diet composition of every group*

Still today, there is no complete investigations about trophic interactions of the coastal and marine ecosystem of Bangladesh. Only limited works have been done on diet composition of fishes in this area (Mazid, 1998; Mustafa and Mansura, 1994). Most of the studies are qualitative in nature where diet items of fish are frequently lumped together. Due to the deficiency of available data on diet composition of functional groups considered, Mustafa (2003), Fishbase (www.fishbase.org) data (Fröese and Pauly, 2006) and the study of Mohamed et al. (2005) were used to complete the diet matrix of this study (Table A2 in Appendix).

Table 3. Life history parameters of the functional fish groups that were selected for ECOPATH model in the maritime ecosystem of BoB, Bangladesh

Representative species	L_{inf} /cm	K/a^{-1}	Z/a^{-1}	F/a^{-1}	M/a^{-1}	E	Reference
1. Sharks							
Scoliodon laticaudus	74	0.68	3.91	2.94	0.97	0.75	Mathew and Devraj (1997)
2. Rays							
Rhinobatus granulosus	97	0.38	2.56	1.02	1.44	0.4	Mohamed et al. (2005)
3. Diadromous (pelagic)							
Tenualosa ilisha	60.0	0.82	3.77	2.49	1.28	0.66	Amin et al. (2002)
Ilisha filigera	35.0	0.75	3.37	1.95	1.42	0.58	Mustafa (1999)
4. Minor pelagics							
Coilia dusumieri	16.8	1.30	2.61	1.60	1.01	0.61	Mustafa (1999)
Gudusia chapra	11.03	1.72	3.43	1.7	1.73	0.49	Islam (2003)
Setipinna spp.	17.33	1.8	8.34	5.33	3.01	0.64	Nabi (2007)
Escualosa thoracata	12.20	1.2	9.84	7.29	2.55	0.74	Nabi (2007)
Bregmaceros mcclellandii	11.03	0.83	3.53	1.48	2.06	0.42	Nabi (2007)
5. Medium pelagics							
Rastrelliger kanagurta	27.8	0.9	4.92	3.21	1.71	0.65	Mustafa (1999)
Parastromateus niger	41.0	0.59	3.05	1.66	1.39	0.54	Mustafa (1999)
Megalaspis cordyla	38.5	0.54	2.86	1.44	1.11	0.51	Mustafa (1999)
6. Minor mesopelagics							
Leiognathus eqqulus	28.0	1.08	3.2	2.5	0.7	0.78	Haque (1998)
7. Medium mesopelagics							
Lepturacanthus savala	108.0	0.75	2.96	1.72	1.24	0.58	Haque (1998)
Pampus chinensis	38.1	0.67	2.56	1.23	1.33	0.48	Haque (1998)
Pampus argenteus	29.8	0.53	2.40	1.10	1.3	0.46	Haque (1998)
8. Medium demersal							
Lates calcarifer	87.5	0.6	1.62	0.95	0.67	0.58	Haque (1998)
Eleutheronema tetradactylum	38.1	0.18	4.4	3.5	0.85	0.87	Islam et al. (1993)
Polynemus pradiseus	20.5	0.48	4.38	3.17	1.21	0.72	Nabi (2007)
Sillaginopsis panijus	43.3	0.38	3.6	2.7	0.86	0.76	Islam et al. (1993)
9. Minor demersal							
Harpadon nehereus	29.4	1.5	4.18	3.01	1.17	0.72	Mustafa et al. (1998)
10. Panaeid shrimp							
Penaeus monodon	31.5	0.95	4.75	1.74	3.01	0.37	Mustafa (1999)
Metapenaeus monoceros	17.9	1.5	6.51	2.70	3.81	0.42	Mustafa (1999)
11. Other shrimp							
Macrobrachium rosenbergii	35.5	0.34	8.5	4.57	3.94	0.54	Islam et al. (1993)
12. Other crustaceans							
Lobstars	58.0	0.43	7.9	1.67	6.23	0.21	Islam et al. (1993)
Crabs (*Scylla serrata*)	96.5	0.55	6.9	2.41	4.49	0.35	Islam et al. (1993)
13. Cephalopods							
Squid (*Loligo*)	44.7	0.21	3.5	1.02	2.48	0.29	Islam et al. (1993)

Note: L_{inf} means length (infinitive), K growth co-efficient, Z total mortality, F fishing mortality, M natural mortality, and E exploitation rate.

Table 4. Production-consumption data sources for non-fish groups

Ecological groups	Production/biomass (P/B)	Consumption/biomass (Q/B)	Ecotrophic efficiency (EE)
Sharks	Joseph and Devaraj (1997)	Mohamed et al. (2005)	computed by ECOPATH
Rays	Mustafa (1999)	calculated in this study	computed by ECOPATH
Penaeid shrimp	calculated in this study	calculated in this study	computed by ECOPATH
Other shrimp	calculated in this study	calculated in this study	computed by ECOPATH
Other Crustaceans	calculated in this study	Arreguín-Sánchez et al. (1993)	computed by ECOPATH
Cephalopods	calculated in this study	Christensen and Pauly (1993)	computed by ECOPATH
Gastropods	Fishbase (2006)	Guénette (2014)	computed by ECOPATH
Benthos	Silvestre et al. (1993)	Silvestre et al. (1993)	computed by ECOPATH
Aquatic invertebrates	Guénette (2014)	Guénette (2014)	computed by ECOPATH
Zooplankton	Arreguín-Sánchez et al. (1993)	Arreguín-Sánchez et al. (1993)	computed by ECOPATH
Phytoplankton	computed by ECOPATH	–	fixed value

2.3.5 *Ecotrophic efficiency*

It provides the fraction of the yield of a group that is consumed within the system (i.e., transported through the trophic web) or caught by any fishery. In most cases, maintenance of the input values that provide the output fraction of EE between 0 and 1 are not possible as EE by definition, it's fraction lies between 0 and 1. The EE is used to be computed from additional parameters in the Ecopath model since there is no field calculation to assess this parameter (Christensen et al., 2000).

2.3.6 *Estimation of pedigree index*

It categorizes the given input sources of an Ecopath through computing the type of source data on which it is based and specifying the probable uncertainty associated with the input. The main principles used here is that input estimated from native data (i.e., from the area covered by the model in question) as a rule is better than the data from elsewhere, be it a guesstimate, derived from other models or derived from empirical relationships. Three scales meet the above principles here, firstly for biomass assessing, second one for the estimating of P/B and Q/B and the rest for diet composition that are varied between 0 to 1. When the score is close to 0 that indicates the used input data is not rooted within local data, whereas value close to 1 means that are fully rooted within local data. The measure of fit (t*) is also computed to define how well rooted the given model is in local data.

2.4 *Evaluating the model through mass balancing method*

The parametrization of Ecopath is based on it's master Eq. (1) which requires mass-balancing states of the functional groups. For this reason, the input parameters need to be adjusted in a style to maintain the EE values less than 1. This practice depends on the understanding of which adjustments need to be done (Kavanagh et al., 2004). Primarily, input parameters like biomass, production-consumption rate, food consumption and fishing catch records were set into the basic input tools sheet of the package. Biomass accumulation value was taken as zero as the model was considered to describe an average for one year. Initial running of the routine provided the P/Q ratio and EE, but some of them were not balanced as EE values were greater than 1 which pointed out their higher demand in relation with sustainability. Initially EE values were found in case of diadromous pelagic (0.86), minor pelagic (0.96), medium mesopelagic (0.89), minor demersal (0.98), medium demersal (0.99), Gastropods (0.68) and benthos (1.26). On the other hand, some groups showed the exceeded value (one) of respiration/assimilation, which is not possible because respiration value cannot be exceeded from assimilation (Christensen et al., 2000). Thus, new run continues with the revised entries of biomass and diet composition values of the previous run, till to the achievement of mass balance. New run was also performed to obtain EE and gross efficiency values of all groups as it should be less than one. In order to get mass-balance, diet matrix need to be adjusted because of its variation and instability of food sources and feeding habits throughout the groups. The foremost output of Ecopath modeling is the assessment of trophic levels which sometimes may be beyond expectation. In this case, one must check the diet matrix of the input data and also compare the data with the trophic levels of same or similar species data of Fishbase.

3 Results

3.1 *Basic input and output variables*

The basic estimated parameters as well as basic input variables of the mass-balanced ecosystem models of maritime ecosystem of BoB, Bangladesh are listed in Table 5 and pre-balancing diagnostics of the maritime ecosystem BoB, Bangladesh model are illustrated in Fig. 3. Under this study, mean trophic level was found 2.53, with the highest value obtained from sharks (3.45) and rays (3.04) groups followed by medium demersal (2.80) and gastropods (2.85), while the lowest value was obtained from phytoplankton (Table 5). In case of estimating ecotrophic efficiency, most of the commercial fisheries groups were showed greater EE values (EE>0.8) in where, penaeid shrimps showed the higher EE value (0.99) followed by cephalopods (0.98), while sharks showed lower value (0.16). Typically, the EE values of all functional groups of this system were less than 1 while P/Q values for each group were within the permissible range from 0.1 to 0.3. Most of the P/Q values under this study were in between 0.103 and 0.296 that cover the balanced-model requirements. The highest net efficiency value was obtained from the rays and minor demersal groups (0.37). In case of respiration-assimilation ratio, benthos showed the highest ratio (0.87) whereas shrimps, rays and crustaceans showed the lower ratio (Table 5). In this system, the maximum omnivory index was found from the apex predators, e.g., rays group (0.61) followed by sharks (0.49).

The life-history parameters and production-consumption data of non-fish groups are presented in Tables 3 and 4. Most of the fish groups showed the lower fishing mortality rate over the predation mortalities. In addition, maximum prey overlaps were detected for benthos and zooplankton groups. The relative and absolute results of flows and biomasses are showed in Table 6. In case of cycles and pathways, mean length of pathways from prey to predator was found 6.33 and the total number of pathway was 680.

The resource biomass assembly of the BoB, Bangladesh maritime ecosystem model points out that it is predominantly a low trophic level driven ecosystem. However, the assessed pedigree index of the BoB maritime ecosystem was found 0.631 (Table 7) that conformed the developing stage of overall quality of an Ecopath approach as discussed by Christensen et al. (2005). Another finding of this study, Shanon diversity index of the maritime ecosystem of BoB was found 1.56 that was also within a satisfactory level (Table 7).

3.2 *Ecosystem (food-web) structure and trophic analysis*

A more concisely web-like figure is displayed in the Fig. 4 to designate the whole interactions or trophic relationships and energy flows of the resettled maritime ecosystem of the Bay of Bengal, Bangladesh. In the flow diagram, the greatest flows were observed from phytoplankton to zooplankton and from detritus to aquatic invertebrates, benthos and others in this system.

3.2.1 *Transfer efficiencies (TEs)*

There are two major flows or food chains can be recognized under this study, a foraging or grazing (phytoplankton-based) flow and a detritus-based flow (Fig. 4). Eight discrete trophic levels (TL, from I to VIII) including all the functional groups of the BoB are also displayed in the Table 6. The transfer efficiencies (TEs) of this system, from primary producers was 11.09% and from the detritus was 8.8%. Proportion of total flow originating from detritus was 0.30. Trophic level I, which was comprised of detritus and primary producers further considered for the flows analyses that related to each group. Flows were mostly connected to TL I-III and declined gradually from TL to upper.

3.2.2 *Mixed trophic impact (MTI)*

The result of MTI illustrates both negative and positive im-

Table 5. Input values and estimated parameters (bold) achieved after mass-balancing using auto-mass balance routine of ECOPATH model of BoB, Bangladesh

Group name	TL	B/t·km^{-2}	(P/B)/a^{-1}	(Q/B)/a^{-1}	EE	P/Q	R/A	NE	OI
1 Sharks and rays	**3.45**	0.42	3.50	12.8	**0.16**	**0.173**	**0.66**	**0.34**	**0.49**
2 Rays	**3.03**	0.76	0.55	8.6	**0.68**	**0.206**	**0.63**	**0.37**	**0.61**
3 Diadromous (pelagic)	**2.02**	1.11	3.77	13.1	**0.77**	**0.287**	**0.64**	**0.36**	**0.11**
4 Minor pelagics	**2.27**	1.56	5.57	25.8	**0.58**	**0.216**	**0.73**	**0.27**	**0.27**
5 Medium pelagics	**2.34**	0.42	3.76	18.9	**0.80**	**0.198**	**0.75**	**0.25**	**0.31**
6 Medium mesopelagics	**2.31**	1.38	3.04	10.6	**0.92**	**0.286**	**0.64**	**0.36**	**0.26**
7 Minor mesopelagics	**2.36**	1.05	3.2	12.8	**0.81**	**0.25**	**0.69**	**0.31**	**0.27**
8 Medium demersal	**2.80**	1.3	3.5	13.1	**0.86**	**0.267**	**0.66**	**0.33**	**0.48**
9 Minor demersal	**2.54**	1.65	4.18	14.1	**0.46**	**0.296**	**0.63**	**0.37**	**0.43**
10 Penaeid shrimp	**2.40**	0.74	5.63	22.8	**0.99**	**0.247**	**0.69**	**0.31**	**0.33**
11 Other shrimp	**2.59**	0.82	8.5	29.2	**0.80**	**0.291**	**0.63**	**0.36**	**0.49**
12 Other crustaceans	**2.34**	0.76	7.4	25.4	**0.46**	**0.291**	**0.63**	**0.36**	**0.31**
13 Cephalopods	**2.65**	0.7	3.5	22.9	**0.98**	**0.153**	**0.81**	**0.19**	**0.43**
14 Gastropods	**2.85**	0.85	5.3	23.5	**0.29**	**0.225**	**0.72**	**0.28**	**0.50**
15 Benthos	**2.44**	1.69	6.8	66.34	**0.69**	**0.103**	**0.87**	**0.12**	**0.35**
16 Aquatic invertebrates	**2.34**	13	11	45	**0.24**	**0.24**	**0.69**	**0.31**	**0.26**
17 Zooplankton	**2.11**	27	34	119	**0.61**	**0.286**	**0.64**	**0.36**	**0.11**
18 Phytoplankton	**1**	58	100	0	**0.57**		–	–	**0**
19 Detritus	**1**	9.8	3.5	12.8	**0.15**		–	–	**0**

Note: TL represents trophic level, B biomass, P/B production rate, Q/B consumption rate, EE ecotrophic efficiency, R/A respiration-assimilation ratio, NE net efficiency, and OI omnivory index.

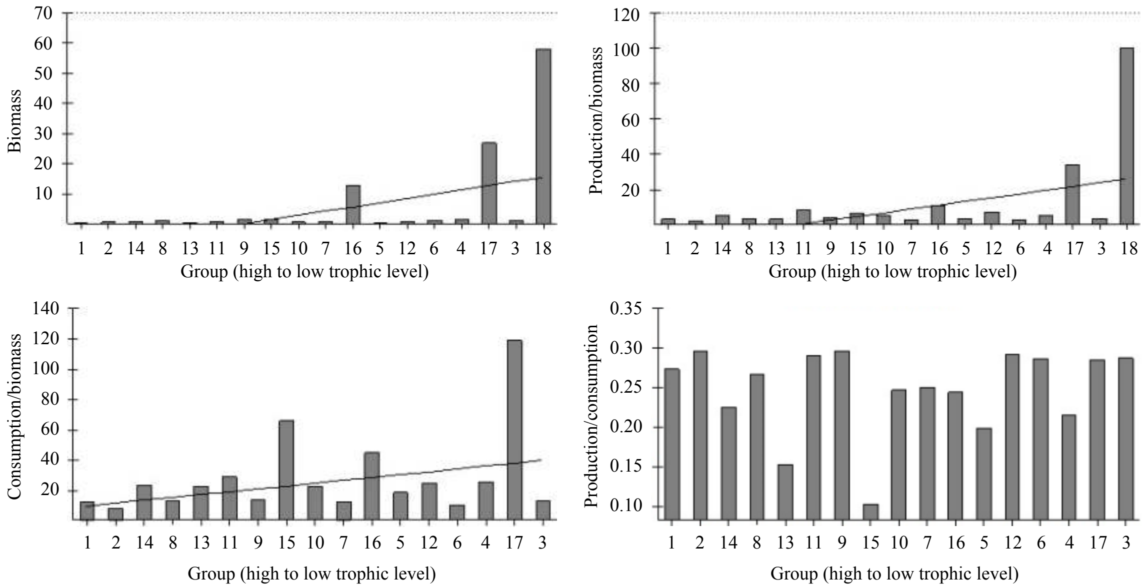

Fig. 3. Pre-balancing diagnostics of basic inputs to construct well-adjusted maritime ecosystem model of BoB, Bangladesh.

pacts among every part of the system (Fig. 5). MTI routine is a tool for indicating the possible impact of direct and indirect interactions (including competition) in a steady-state system (Ulanowlcz and Puccia, 1990). The groups with the most positive impact on most of the other groups were detritus, phytoplankton and benthos. Interestingly, some of the pelagics, shrimps and minor demersal fish groups were also expressed similar trends of positive impact on the fishing gears, i.e., SBN, log lines and others (Fig. 5). In contrast, most of the demersals, shrimp groups and crustaceans showed the greater negative impacts on other groups. Predator-prey relations, competition and cascading impacts were seen among the parts while most of the groups exerted a negative impact on itself perhaps due to competition for food and habitation (Christensen et al., 2005). In addition, zooplankton expressed its cannibalistic behavior through produced greater negative impact on itself.

3.3 *Over-all system statistics or ecosystem properties*

The over-all system statistics of the maritime ecosystem of the BoB maritime ecosystem of Bangladesh are presented in Table 7. The total system throughput (TST) of this ecosystem now has been reached to 13 753.08 t/(km^2·a), in where 30.16% generated from consumption, 26.27% from exports and 15.9% from respiration while 27.65% ultimately flowing into detritus. The values of ascendancy and overhead were 35.4% and 64.61%, respectively, which somewhat revealed the system maturity of the maritime

Table 6. Tropic level flows from primary producers and detritus (t/(km^2·a)) and transfer efficiencies (%) for each TL of the maritime ecosystem of the Bay of Bengal, Bangladesh

Trophic level	Flow				
	Consumption by predators	Export	Flow to detritus	Respiration	Throughput
Tropic level flows from primary producers					
IX		0.000	0.000	0.000	0.000
VIII		0.000 011	0.000 006	0.000 064	0.000 120
VII		0.000 273	0.000 104	0.001 38	0.002 64
VI		0.004 47	0.001 92	0.033 1	0.058 4
V		0.097 9	0.041 6	0.469	0.868
IV		1.476	0.374	5.064	11.38
III		18.29	1.786	92.33	152.4
II		264.8	2.952	1 154	1 895
I	0.000	3 317	0.000	2 483	0.000
Sum	0.000	3 601	5.155	3 735	2 060
Tropic level flows from detritus					
IX		0.000	0.000	0.000	0.000
VIII		0.000	0.000	0.000	0.000
VII		0.000 011	0.000 006	0.000 062	0.000 122
VI		0.000 313	0.000 097	0.001 26	0.002 49
V		0.004 16	0.001 83	0.026 9	0.047 6
IV		0.080 4	0.037 5	0.445	0.826
III		1.389	0.367	4.454	9.641
II		15.85	4.956	64.18	115.7
I	0.000	200.7	3 603	0.000	0.000
Sum	0.000	218.0	3 609	69.11	126.3

Source	Trophic level							
	II	III	IV	V	VI	VII	VIII	IX
Producer	12.17	12.53	10.11	9.451	6.528	8.563		
Detritus	7.873	10.01	8.490	7.444	9.865			
All flows	11.89	11.21	10.000	9.348	6.664	8.548	8.226	

Proportion of total flow originating from detritus: 0.30

Transfer efficiencies (calculated as geometric mean for TL II–IV)

From primary producers: 11.09%

From detritus: 9.93%

Total: 11.02%

ecosystem of BoB (Table 7). Finally, comparative study of the functional characteristics of maritime ecosystem model of BoB, Bangladesh with some other marine ecosystem models are displayed in Table 8.

4 Discussion

The relative biomass of the ecological groups of this study initially estimated from the Ecopath model that revealed considerable differences due to three issues. First, all groups were not equally captured through the all gears and same catchability was not found in every gear types. Therefore, some may be under or over-exploited in the survey. Second, Ecopath computes the biomass by the data of given catch. So, the larger the catch, the greater the biomass estimate. Lastly, the estimated catch data was mostly on group-wise rather than species-wise which may led to comparatively diverge catch value for different species. The estimated biomasses of the BoB maritime ecosystem varied from 0.42 to 1.65 mainly for targeted catch groups, i.e., demersal fishery and lowest for sharks group due to absence of large predators.

Diet matrix preparation for this Ecopath model was the most difficult task due to lack of earlier studies on feeding ecology. In order to make the study realistic some stomach content studies and diet isolations have been done. But most of the qualitative data provided by external studies were converted into a quantitative form for preparing the diet matrix. Although this model contains many groups (19 groups), the diet matrix comprises some low proportions. In fact, these values are hard to determine from field data. This nature might be significantly influenced the ultimate result.

Production-consumption (P/Q) rate of less than 0.3 may assist as a diagnostic feature in a balanced model. In most cases, the P/Q values of all possible functional groups range from 0.05 to 0.3, but some exceptions may happen in case of coral reefs, fish larvae, nauplii, bacteria and other minute, fast-growing organisms. The present study supports this concept for all groups which was 0.103 to 0.296. Demersal groups showed higher P/Q ratio than most of the pelagic groups (Table 5), this may be due to higher consumption rate of benthic communities and some predatory behavior of few demersal species. Nevertheless, pelagic species are typically herbivores and generally dependent on phytoplankton and detritus.

One of the most significant feature of an ecosystem is to assess the EE (Christensen et al., 2000) which is mainly the fraction of production consumed by predators. In the BoB model, the EE

Table 7. The over-all system statistics of the maritime ecosystem of BoB (no unit for indices and ratios)

Parameter	Value	Unit
Sum of all consumption	4 149.14	t/(km^2·a)
Sum of all exports	3 613.73	t/(km^2·a)
Sum of all respiratory flows	2 186.27	t/(km^2·a)
Sum of all flows into detritus	3 803.94	t/(km^2·a)
Total system throughput	13 753.08	t/(km^2·a)
Sum of all production	6 933.04	t/(km^2·a)
Mean trophic level of the catch	2.53	
Gross efficiency (catch/net primary production)	0.001 8	
Calculated total net primary production	5 800	t/(km^2·a)
Total primary production/total respiration	2.65	
Net system production	3 613.73	t/(km^2·a)
Total primary production/total biomass	51.24	
Total biomass/total throughput	0.008	a^{-1}
Total biomass (excluding detritus)	113.2	t/km^2
Total catch	10.5	t/(km^2·a)
Connectance index	0.325	
System omnivory index	0.285	
Ascendancy	35.4	
Overhead	64.61	
Ecopath pedigree index	0.631	
Measure of fit (t^*)	3.25	
Shannon diversity index	1.56	
Throughput cycled (excluding detritus)	328.2	t/(km^2·a)
Predatory cycling index	5.34	percentage of throughput without detritus
Throughput cycled (including detritus)	403	t/(km^2·a)
Finn's cycling index	2.93	percentage of total throughput
Finn's mean path length	2.47	

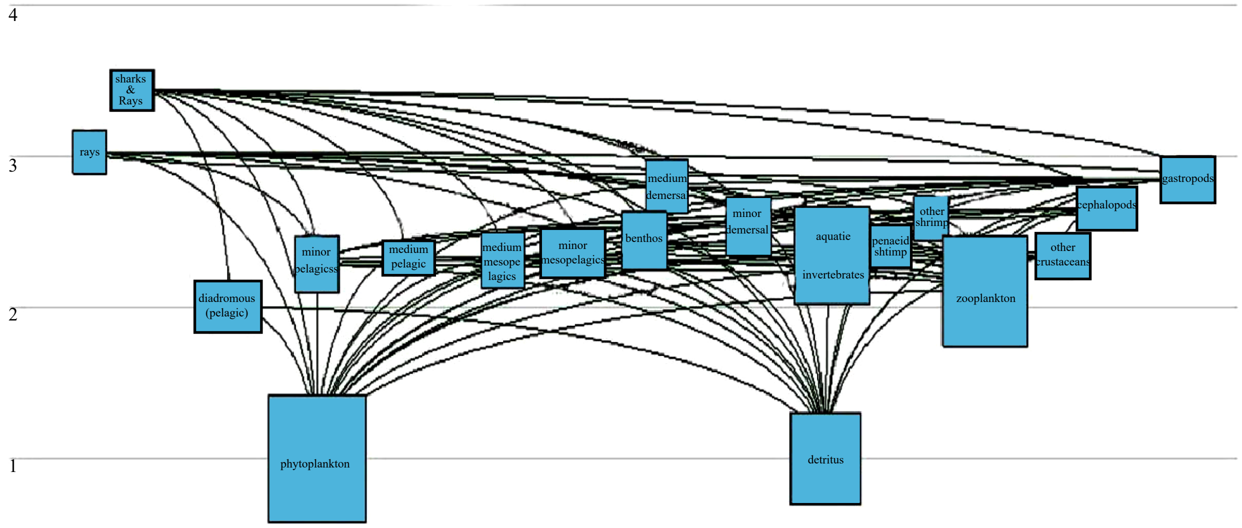

Fig. 4. Flow diagram of the trophic-interactions within the maritime ecosystem of the BoB, Bangladesh.

values varied extensively from 0.24 to 0.99 (Table 5). Normally, just over the zero value points out the "group" was not consumed until now by any other groups throughout the system while close or equal to 1 designates that heavily preyed, leaving no individuals to die of old age. Only sharks (0.16) showed lower EE value which was realistic and expected as for the top predator (Christensen et al., 2000). In addition, in both cases of phytoplankton and detritus, the EE values were less than 1.0 that was settled with the systems proposed by Christensen and Pauly (1992) that indicates more producers will be entered than exiting. However, the estimated EE value of detritus (0.15) which was the lowest among the groups probably due to absence of typical primary consumers in the ecosystem. Out of all targeted groups, the estimated EE value of penaeid shrimps and cephalopods were shown the highest values over 0.9 (Table 5) that were likely to be the consequence of greater fishing pressure and predation.

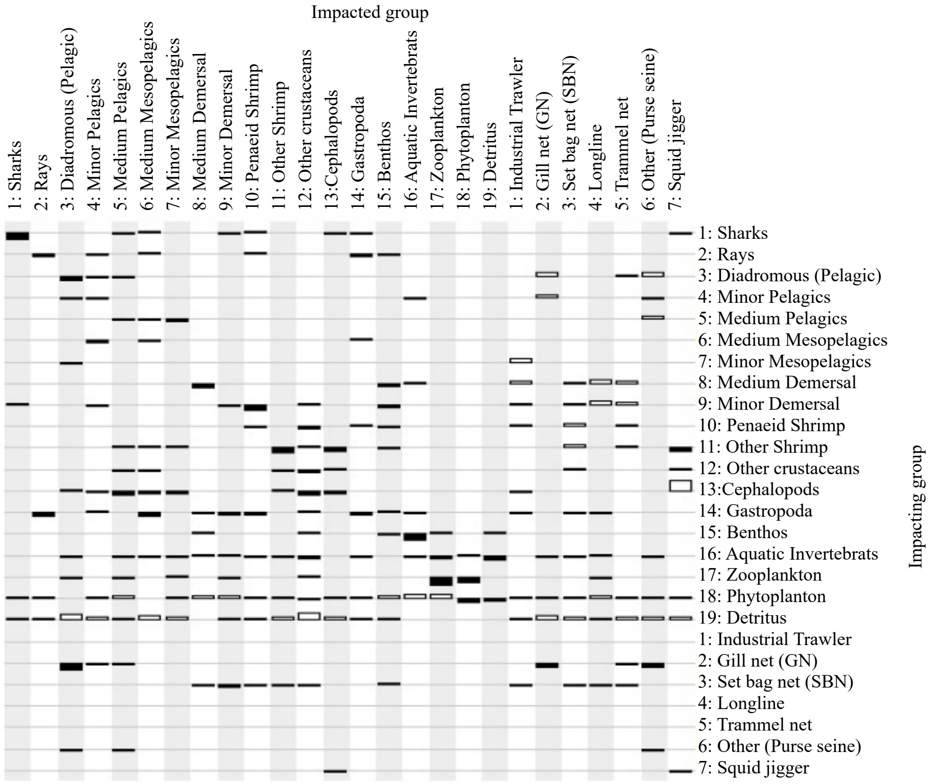

Fig. 5. The direct and indirect impacts of the ecological groups and fishing fleets that mentioned at the upper and right side of the histograms (rows) and the upward bars represent positive impacts and downwards demonstrate negative impacts.

Table 8. Comparison of the maritime ecosystem of BoB, Bangladesh with other ecosystems

Name of the ecosystems	Throughput	Catch/PP	PP/*B*	*B*/*T*	Net system production	OI	Ascendancy	Cycling index	Path length
British Columbia Shelf$^{1)}$	1 237.0	–	21.1	0.18	4 106	0.14	40.1		2.03
Yacutan$^{1)}$	2 362	0.003	27.4	0.036	370	0.134	44.0	2.8	2.84
Sarawak, Malaysia$^{2)}$	1 414	0.004	19.37	0.02	273	0.22			
Brunei, Southeast Asia$^{1)}$	1 816	0.000 8	28.6	0.018	300	0.201	29.4	16.3	2.8
Northern Gulf of Mexico$^{1)}$	1 790	0.000 2	7.0	0.015	19	0.195	39.1	2.1	3.03
San Pedro Bay, Leyte, Phillipinnes$^{3)}$	183 960	0.001 1	46.81	0.008	1 879.8	0.29			
Peru 70 (upwelling)$^{1)}$	18 800	0.001 7	87.5	0.012	14 709	0.169	38.1	8.7	3.63
Bering Sea 80$^{4)}$	5 692	0.002 1	4.9	0.050	–356	0.157	30.9	11.1	3.51
Karnataka Arabian Sea$^{5)}$	11 522	0.001 6	29.9	0.012	904	0.299	33.0	6.03	2.81
Coastal ecosystem of BoB$^{6)}$	2 628	0.001 5	14.69	0.026	264.24	0.224	38.7	10	2.58
Marine ecosystem of BoB*	13 753	0.001 8	51.24	0.008	3 614	0.285	35.4	2.93	2.47

Note: $^{1)}$ Christensen and Pauly (1993); $^{2)}$ Garces et al. (2003); $^{3)}$ Campos (2003); $^{4)}$ Trites et al. (1999); $^{5)}$ Mohamed et al. (2005); $^{6)}$ Ullah et al. (2012); and * the present study. *T* symbolizes the total throughput.

Similar reports was found from Islam et al. (1993) that penaeid shrimps were highly exploited throughout the maritime waters of the BoB.

Mean trophic level is the vital index of the complete exploitation level of fisheries groups low in the food web and its effect on predator and prey species. Fishing down the marine food web, in which fishing fleets gradually target species minimum in the food web, may or may not be the reason for decline in global mean trophic levels of catches. The BoB maritime ecosystem had a mean trophic level of 2.53, with the highest 3.45 (sharks) and lowest being 1 (phytoplankton and detritus) (Fig. 4). Except predators maximum group's biomass and ecological production occupied the place at around TL III (Table 6). Ecopath generally computes trophic levels higher than IV (Ulanowicz, 1995). A total of six TLs were counted in this study (Table 6), which may be due to the cannibalistic characters of the peak trophic levels (Haputhantri et al., 2008). Therefore, the trophic accumulation routine in Ecopath gathered the 19 groups in a normal food chain with ten trophic levels where primary producers (TL I) comprised detritus and phytoplankton (Table 6). The result displayed that the maximum flow of the system was transferred from secondary consumers mainly composed of zooplankton group followed by TL I where phytoplankton was the single contributor. This output reveals the significance of zooplankton for the activation of trophic level of the BoB maritime ecosystem which is dominated by lower trophic level of fisheries resources as reported by Hossain (2004). For each group, the flow to the detritus contains non-absorption rate of diet and those components of the group that die of old age, diseases, etc. The detritus flow indicates that almost every functional group of the BoB maritime ecosystem are severely exploited by either excessive fishing pressure or predation along with other mortalities, i.e., cannibalism (Table 6).

Gross efficiency of the system was 0.001 8 indicates less crowd of target fisheries in the food chain. Actually increasing trend of gross efficiency index represents the fisheries “development” which is generally much lesser than 1.0 as globally it is about 0.000 2. This results is almost similar with Mohamed et al. (2005) and Ullah et al. (2012). In addition, the average transfer efficiency (TE) was 11.02% where flows from phytoplankton were demonstrated more essential than flows from detritus demonstrating a significant planktonic food chain throughout the maritime ecosystem of BoB (Table 6). Actually, TE acts as an index of the significance of detritus in a system. The TEs for TL II, as suggested by Ryther (1969), are 15% for marine areas, but the most common range is 10%–20% (Odum, 1971; Barnes and Hughes, 1988). However, the accounted of all flows was 11.89% (Table 6) which covers the above range demonstrating ecosystem maturity (Odum, 1971). In addition, estimated TEs of the TLs III, IV and V of this study were within the standardize range of 10%–20% for coastal zones (Odum, 1971; Barnes and Hughes, 1988). Hence, the existence of some dominating fish groups having higher EE value around TL III may be the basis of the higher TE in TL III.

Mixed trophic impacts may be direct or indirect, i.e., as for a prey; a group causes a positive impact on others while as a direct predator, impact is negative. In the current observation, zooplankton, phytoplankton, and detritus were showed positive impact on most other groups. The impact was greater on their direct consumers, i.e., most of the pelagic fishes depend on either phytoplankton or detritus or both. Negative impacts were due to benthos or zooplankton as a consumer of aquatic invertebrates, phytoplankton, and detritus or as a competitor for the same food source. Phytoplankton and detritus were shown a significant positive impact on pelagic groups and moderately positive on some of the demersal groups whereas a very few impact found on penaeid shrimps and cephalopods (Fig. 5). The system package designated that the impact on detritus would be negative since detritus normally accompanied by phytoplankton in the regimes of several primary consumers. Thus, upsurge of phytoplankton would stimulate primary consumers to forage more detritus. Zooplankton was significantly negative impacted on themselves due to the existence of greater quantity of carnivory zooplankton and relatively low negative impacted on phytoplankton also indicates existence of herbivory zooplankton in that ecosystem. Remarkable positive impacts of detritus was observed on most of the functional groups whereas detritus had neither positive nor negative impact on itself in that ecosystem. Comparable results are also observed in other ecosystems (Christensen and Pauly, 1993). Fishing fleets were also negatively affected several groups, i.e., pelagic groups were negatively impacted by Gill net whereas demersal by SBN operations. Thus, it can be concluded that increased fishing pressure by gillnet and SBN in the BoB maritime ecosystem would have generated more negative impact on fish groups, especially on the demersal and predators.

The TST is the sum of all flows (e.g., total consumption, total respiration, total export and total flows to detritus) in a system which represents the “size” of the entire system in relation to flow (Ulanowicz, 1986). The estimated TST (13 753 t/(km^2·a)) for the BoB was relatively higher (Table 7) but consistent with tropical marine ecosystems with much turnover. This result was also similar (Table 8) with the studies of San-Pedro Bay, Phillipines by Campos (2003) and Karnataka, India by Mohamed et al. (2005).

The ratio of total primary production (PP) and total respiration (R) is considered by Odum (1971) to be a significant ratio to describe the “maturity” of an ecosystem. Previously, system need to be developed for balancing as the production is expected to exceed respiration, that providing a ratio greater than 1. Finally, in “mature” systems, the PP/R ratio should be 1; when energy is constant that is roughly balanced by maintenance (Odum, 1971). The PP/R value was found 2.65 which was higher than 1, thus, it is concluded that the BoB marine ecosystem is not so developed or still in developing stage. The net system production value of 3 613.7 t/(km^2·a) was assessed for the BoB maritime ecosystem, which again points out the developing nature of the ecosystem but little bit matured too comparing with the other studies. Generally, system production is greater in immature systems and nearby zero in maturity stages. The net system production value of British Columbia shelf ecosystem were also provided 4 106 t/(km^2·a) (Table 8) which was greater than the current value. This may be happened due to absence of large predators as well as lower trophic level as this system completely based on TLII to TLIII. Moreover, the ratio between a system’s PP and total biomass (B) was 51.24, which was higher and also indicates some sorts of immaturity. Beacause, production exceeds respiration largely in immature systems and therefore it will influence the system’s PP/B ratio which dimension is per unit time, and it can take any positive value.

The available ecosystem energy flow directly supports the total system biomass which can be expected to rise maximum for the utmost maturity stages of a system (Odum, 1971). The ratio of B/TST is directly proportional to the system maturity, where the estimated value tends to be low during the ecosystem development stage and increases as a purpose of maturity (Christensen, 1995). From the present study, system biomass/throughput ratio was found 0.008 being lower compared with those given by Ullah et al. (2012), Mohamed et al. (2005), and Garces et al. (2003), which showed the status of comparative maturity of the ecosystem (Table 8). The yield of a group throughout a system is size-specific that has been revealed that the inverse of a group’s production/biomass ratio is a degree of size (Christensen and Pauly, 1993). However, the estimated total biomass (excluding detritus) 113.2 t/km^2 was higher than the study of Ullah et al. (2012) but lower than the value of Mohamed et al. (2005), as their study based on the adjacent area of the BoB. But the total catch (10.5) was comparatively higher than the above studies which may be due to excessive artisanal fishing pressure in Bangladeshi waters.

The trophic flows to detritus were observed highest for zooplankton and smallest for top predators. For each group, the flow to the detritus contains non-absorption rate of diet and those components of the group that die of old age, diseases, etc. The detritus flow indicates that almost every functional group of the BoB maritime ecosystem are severely exploited by either excessive fishing pressure or predation along with other mortalities, i.e., cannibalism (Table 6). The cycling matter and energy flow is considered as a vital process of any active natural ecosystems (Odum, 1969). The percentage of cycling index is the fraction of an ecosystem's throughput that was developed by Finn (1976). It was basically intended to calculate Odum's (1969) system maturity. However, its explanation was not as simple as originally conceived that intensify recycling as a system matures. Detritus played a supreme role in all flows (cycled) in the BoB model where the total cycled flow was 328.2 t/(km^2·a). The Finn's cycling index was obtained 2.93%, which was lower compared with the study by Mohamed et al. (2005) for Karnataka, India and Ullah et al. (2012) for coastal ecosystem of BoB. Similar close output was reported by Christensen and Pauly (1993) for Yacutan and northern Gulf of Mexico. Actually, Finn's cycling index gives the proportion of flow in a system that is recycled compared with total system throughput and immature systems give lower value while matured provide higher. Finn's mean path length is the measurement of the mean quantity of groups that a unit of flux will experience from it's entry into the system until it leaves the system. Over-all 680 pathways was obtained from the BoB maritime ecosystem and the mean length of pathways was computed as 6.33, found little bit higher when compared with the range (2.86–4.95) reported by Baird and Ulanowicz (1993) for the four estuaries. But the lower number of pathways proves the simplified feature of that ecosystem and it is cycled through detrital pathways.

The connectance index (CI) and system omnivory index (SOI) of the BoB maritime ecosystem was 0.322 and 0.285, respectively. In fact, the CI can be predictable and associated with maturity which can be define by the ratio of "the quantity of actual links with the number of possible links". The connectance index are mostly determined by the level of taxonomic aspect used to characterize prey groups. On the other hand, the system omnivory index is proposed as a substitute which is defined as the mean omnivory index of all consumer's weight-mass by the logarithm of each consumer's consumption. The SOI is a measurement of how the diet interactions are scattered between trophic levels. The SOI is stimulated by apparent drawbacks of the CI. In the development stage of a ecosystem, CI would be close to 1 in most systems and increase maturity reduce the value of connectance. Moreover, a prey having the same "score" in case of connectance index whether it supports 1%, 10% or 100% of its higher trophic's diet.

Another important fact is ascendancy which is a measurement of system growth and development of network links whereas proportion of a system's capacity not considered. When the system's capacity is considered, it is known as system's overhead, which was the reserved energy of an ecosystem (Ulanowlcz and Norden, 1990). The relative values of ascendancy (35.4) and system's overhead (64.6) of the maritime ecosystem of BoB indicated the ecosystem's stability and some sorts of maturity. This proved that maritime ecosystem of BoB have significant backup strength also have the capacity to control any pressure situations through fast reformation to the original stages.

5 Conclusions

The software outputs indicate that maritime ecosystem of BoB is steadily reaching to the system maturity, although it is still considered as developing phase. Excessive artisanal fishing pressure is the main hindrance to develop ecosystem quality. One of the major challenge for this multispecies ecological modelling was the scarce of studies on the feeding ecology of the various functional groups. Therefore, further studies should be required in order to get more specific estimations for a multispecies approach to improve basic inputs of the system and also improve the catch landing statistics of the national record.

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Appendix:

Table A1. Ecological or functional groups used in ECOPATH model including estimated total catch and percent composition of the maritime ecosystem of the BoB, Bangladesh

Ecological or functional group	Major families or species	Total catch/t	Catch composition/%	Explanation (Habitat/Fishing type)
1. Sharks	Carcharihinidae	3 245	0.97	down to 30 m depth mostly longline, SBN and gillnet
	Squalidae			
	Sphyrnidae			
	Rajidae			
2. Rays	Rhinobatidae	2 005	0.001	down to 30 m depth mostly longline, SBN
	Dasyatidae			
3. Diadromous (pelagic)	*Tenualosa ilisha*	215 500	39.8	0–100 m depth, mostly by gillnet
	Tenualosa toli			
4. Minor pelagics	Muglidae	17 530	3.2	down to 10 m depth mostly SBN, gillnet and few catch by trawls and purse seines
	Gobidae			
	Setipinna spp.			
	Coilia dusumieri			
	Gudusia chapra			
	Other Clupeids (Sardines)			
	Engraulidae (Anchovies)			
	Exocoetidae (Flying fish)			
5. Medium pelagics	Scombridae	29 352	5.4	10–100 m depth mostly gillnet and few catch by trawls
	Scomberomurus guttatus			
	Rastrelliger kanagurta			
	Other Mackerals			
	Euthunnus affinis			
	Parastromateus niger			
	Megalaspis cordyla			
	Pterotolithus maculatus			
	Decapterus spp.			
6. Minor mesopelagics	Leiognathidae	6 240	1.15	10–100 m depth mostly gillnet catch
7. Medium mesopelagics	*Lepturacanthus savala*	27 843	5.15	10–100 m depth mostly SBN and gillnet, slightly by trawls
	Pampus chinensis			
	Pampus argenteus			
	Trichiuridae			
8. Medium demersal	*Lates calcarifer*	141 434	27.7	0–100 m depth mostly SBN and gillnet, slightly by trawls and trammel netlongline also used in fishing
	Lutjanidae (Snappers)			
	Synodontidae (Bombay duck)			
	Sciaenidae (Jew fish)			
	Pomadasidae			
	Johnius argenteus			
	Polynemus indicus			
	Acanthopagrus latus			
	Ariidae			
	Lethrinidae			
	Eleutheronema spp.			
	Otolithes spp.			
	Protonibea diacanthus			
	Otolithoides spp.			
9. Minor demersal	Nemipteridae	47 528	8.8	0–100 m depth mostly SBN and gillnet, slightly by trawls
	Harpodon nehereus			
	Saurida tumbil			
	Serranidae (Groupers)			

to be continued

Continued from Table A1

Ecological or functional group	Major families or species	Total catch/t	Catch composition/%	Explanation (Habitat/Fishing type)
	Agryrops spinifer Sparidae *Cynoglossus* spp. Tetradontidae Priacanthidae *Tricanthus* spp. Platycephalidae			
10. Penaeid shrimp	*Penaeus monodon* Other Penaeids *Metapenaeus monceros* *Metapenaeus spinulatus* *Parapenaeopsis stylifera*	34 523	6.4	0–90 m depth mostly by SBN and major target species by shrimp trawls
11. Other shrimp	*Metapenaeus rossenbergii** *Ascetes indicus*	9 019	1.67	0–40 m depth, mostly by SBN * estuarine catch
12. Other crustaceans	Lobstars Crabs	2 017	0.37	10–50 m depth and intertidal zone
13. Cephalopods	Loligo Sepia Octopus	4 356	0.8	10–100 m depth mostly by catch of various gear and some catch by squid jiggers
14. Mollusks	Bivalves,			
15. Benthos	Annelids, Polychaetes, worms	–	–	0–40 m depth
16. Aquatic invertebrates	Meiobenthos, Jelly fish, etc.	–	–	0–50 m depth
17. Zooplankton	Copepods, etc.	–	–	
18. Phytoplankton				
19. Detritus				

Table A2. Estimates of diet consumption for functional groups in the maritime ecosystem of the BOB, Bangladesh

	Prey/predator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Sharks	0.15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Rays	0	0.14	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0	0
3	Diadromous (pelagic)	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	Minor pelagics	0.005	0.05	0	0	0.031	0.071	0	0	0.04	0	0	0	0.076	0	0	0	0
5	Medium pelagics	0.06	0	0	0	0	0	0	0	0	0	0	0	0.03	0	0	0	0
6	Medium Mesopelagics	0.042	0	0	0	0.054	0	0	0	0	0	0	0	0.08	0.08	0	0	0
7	Minor mesopelagics	0.08	0	0	0	0.085	0	0	0	0	0	0	0	0.055	0.01	0	0	0
8	Medium demersal	0.067	0	0	0	0	0	0	0.1	0	0	0	0	0	0.05	0	0	0
9	Minor demersal	0.182	0.04	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0	0
10	Penaeid shrimp	0	0	0	0	0	0	0	0	0.065	0	0	0.009	0	0.08	0	0	0
11	Other shrimp	0	0.05	0	0	0	0	0	0	0	0	0.13	0.052	0	0	0	0	0
12	Other crustaceans	0	0	0	0	0	0	0	0	0	0.034	0	0.01	0.08	0	0	0	0
13	Cephalopods	0.134	0	0	0	0	0	0	0	0	0	0.06	0	0	0	0	0	0
14	Gastropoda	0.05	0.08	0	0	0	0	0	0	0	0	0	0	0	0.02	0	0	0
15	Benthos	0.06	0.1	0	0	0	0	0	0.155	0.081	0.046	0.048	0.02	0.01	0	0	0	0
16	Aquatic invertebrats	0	0.1	0	0.125	0	0	0	0.119	0.152	0.049	0.018	0	0.118	0.03	0.175	0	0
17	Zooplankton	0	0.1	0	0.1	0.1	0.2	0.321	0.216	0.072	0.2	0.171	0.177	0.05	0.25	0.181	0.31	0.1
18	Phytoplankton	0.1	0.18	0.3	0.327	0.45	0.239	0.315	0.285	0.338	0.358	0.109	0.014	0.217	0.2	0.388	0.55	0.9
19	Detritus	0.05	0.16	0.7	0.448	0.28	0.49	0.364	0.125	0.252	0.313	0.464	0.718	0.284	0.18	0.256	0.14	0
20	Import	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	Sum	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
22	(1–Sum)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0