

Trophic Model of the Coastal Ecosystem in the waters of Bangladesh, Bay of Bengal

M. Golam Mustafa

Marine Fisheries and Technology Station
Bangladesh Fisheries Research Institute
Cox's Bazaar, Bangladesh

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Abstract

A trophic model of the coastal ecosystem in the waters of Bangladesh, Bay of Bengal (from the shoreline to 150 m depth) is presented. The model consists of 15 ecological groups. The biomasses of the groups (particularly the demersal species) were estimated from demersal trawl surveys conducted in the area between 1984 and 1986. The model estimated that the average trophic level of the trawl fishery catch was 2.7 in these years.

Introduction

Fisheries are important to the economy and food security in Bangladesh. They account for 4 - 5% of the Gross Domestic Product, 8 - 10% of export earnings and 70 - 80% of the animal protein intake in the country. About 12 million people are directly or indirectly associated with various fishery activities (Mazid 1998).

Bangladesh marine fisheries primarily target shrimp and finfish in the Bay of Bengal. A range of gears are used from small craft in the coastal waters, including drifting gillnet, fixed gillnet, set bag net, trammel net, and hook and line. There are also about 70 large trawlers fishing for shrimps and finfishes further offshore, between 30 m and 80 m depth.

The drift gillnets, targeting diadromous *Hilsha* spp., dominate the inshore areas, operating almost year-round. Fixed gillnets also target *Hilsha* spp., but only for a few months at river mouths. There are two types of set bag nets. Larger ones operate in the coastal areas (8 m - 10 m) while smaller ones are deployed in the estuarine and riverine areas. Hook

and line fishing is seasonal, usually during the calmer winter months. These fishers target croakers, catfishes, groupers, skates, rays and sharks. The seine netters operate very near to shore and target small fish.

The trawlers mainly target larger shrimps (*Penaeus monodon*, *P. semisulcatus*, *P. merguensis* and *P. indicus*). However, small shrimps (*Metapenaeus monoceros*, *M. brevicornis*, *M. spinulatus*, *M. brevirostris*, *Metapenaeopsis toluensis*, *Parapeneopsis stylifera* and *Solenocera indica*) and finfishes also contribute to the catch.

The demersal shrimps and finfishes are economically important resources in the waters off Bangladesh and surveys have been carried out, by both national and international agencies, to assess the resources (Mohiuddin et al. 1980). From these surveys estimates of standing stock and potential yield have been made (Chowdhury et al. 1979; Karim 1978; Khan et al. 1989; Khan et al. 1983; Lambouef 1987; Mustafa et al. 1987; Mustafa et al. 1996; West 1973). There have also been studies of the population dynamics of different fish and

shrimps based on analysis of length-frequency data (Khan and Mustafa 1989; Khan et al. 1985; Khan et al. 1987; Khan et al. 1986; Mustafa 1989; Mustafa 1993; Mustafa 1994a; Mustafa 1994b; Mustafa 1995; Mustafa 1996; Mustafa 1999; Mustafa and Khan 1988; Mustafa and Khan 1993; Mustafa and Azadi 1995; Mustafa et al. 1989; Mustafa et al. 1995; Mustafa et al. 1998; Quddus et al. 1994). However, information on fishing effort and sustainable stock levels is limited. There are reports of declining availability of the target shrimp species in the offshore trawl catch (Van Zalinge 1986). The total shrimp production increased from 1 697 t in 1981 - 82 to 5 518 t in 1984 - 85. It thereafter declined to around 3 000 t in 1989 - 90 (Mustafa and Khan 1993). Finfish landings increased from 1 300 t in 1978 - 79 to 7 400 t in 1985 - 86 and have fluctuated since then. About 50 - 65% of the finfish caught are being discarded at sea as by-catch (Shahidhullah 1986).

To date the emphasis has been on single-species assessment and ecosystem modeling of the coastal waters of Bangladesh has not been done. However, there is widespread recognition of the need to move toward ecosystem-based approaches in fisheries management. For conservation and sustainable exploitation of the fisheries, scientific management incorporating ecosystem considerations is important. However, proper management and utilization of fishery resources in developing countries are generally inhibited by lack of appropriate information about the ecosystem components. Quantitative assessment of trophic interactions has important implications to understanding and managing multispecies fisheries in the Bay of Bengal. The availability of ecosystem modeling software enables a first attempt at analysis of the coastal fisheries ecosystem off Bangladesh.

Hence, a study of the ecosystem and fisheries interaction in the Bay of Bengal is of high interest. This study aims to construct a trophic model of the coastal fisheries off Bangladesh as a first step in this direction.

Material and Methods

The Study Area

In 1974 Bangladesh declared an EEZ (Exclusive Economic Zone) reaching 200 nm (322 km) offshore, with an average depth of 10 m (Mahmood

1977) As a result about 166 000 km² of the Bay of Bengal is now under the jurisdiction of the country for exploration, exploitation, conservation and management (see Table 1 for a depth profile). The average depth of the Bay of Bengal within Bangladesh territorial limits is about 10 m (Mahmood 1977).

Table 1. The area of the depth zones within the Exclusive Economic Zone of Bangladesh, up to 200 m (Khan et al. 1997).

Depth (m)	Area (km ²)
< 10	24,000
10 - 24	8,400
25 - 49	4,800
50 - 74	5,580
75 - 99	13,410
100 - 200	10,250
Total Continental Shelf	66,440
Total EEZ	166,000

The oceanography of the Bay of Bengal is dominated by three main factors: (i) wind direction; (ii) precipitation; and (iii) river discharges, all impacting on fish distribution and abundance. Surface currents in this region run clockwise from January to July and counter clockwise from August to December, consistent with the direction of the monsoon winds (Lamboeuf 1987). Three main rivers (the Ganges, Brahmaputra and Meghna) drain vast areas of the Himalayas, India and Bangladesh and discharge into the Bay of Bengal. The rivers render the surface waters of the northern part of the Bay almost riverine during the post-monsoon months (September and October); the lowest salinity (10.5 ppt) is observed during this time (Mustafa and Prova Dey 1994). In comparison, near-estuarine conditions prevail from January to June. The highest salinity (936 ppt) is reported in March (Mustafa and Prova Dey 1994). Strong salinity gradients exist from March to July and September to October, with hyper-saline conditions occurring from October to July. Thus, sea surface temperatures (SST) are highest in September (24.8°C) and lowest in January and February (24.1°C) (Mustafa and Prova Dey 1994).

Important fish families that contribute 56 - 76% of total demersal biomass are Ariidae (12%), Sciaenidae (10%), Nemipteridae (9%), Trichiuridae, Carangidae, Scombridae, Mullidae, Leiognathidae, Synodontidae and Clupeidae (Lamboeuf 1987). Rays, sharks, cuttlefish and squids are particularly abundant in the commercial trawl catch. Among penaeid shrimps, *Penaeus monodon*, *P. semisulcatus*, *Metapenaeus monoceros*, *Parapenaeopsis styliifera*, *P. sculptilis* and *Solenocera indica* are the major species caught. The brown shrimp *M. monoceros* accounts for about 56% of the total shrimp catch. Tiger shrimp *P. monodon* is the main targeted species because of its high price and export value, but a 17% decline between 1980 - 81 and 1990 - 91 has been reported by Mustafa and Khan (1993). Boats operate mainly in near-shore areas. Fixed gill nets also target *Hilsha* spp. but only for a few months at river mouths. There are two types of set bag nets. Larger ones operate in the coastal areas with average depth

of 8 to 10 m and smaller ones are deployed in the estuarine areas as well as in a river where tidal effect is high. Trawlers operate in a deeper part of the Bay of Bengal. The shrimp and fish trawlers were imported from Thailand, Japan and some European countries. In 2000, 41 shrimp trawlers and 15 fish trawlers were operating in the off-shore trawling grounds. Hook and line fishing is seasonal, usually during winter months when the sea is calmer. Most of the fishers target croakers, catfishes, groupers, skates, rays, and sharks. Most of the seines operate very near to shore and target small fishes.

The Survey Area and Trawl Stations

Fig. 1 shows the trawl survey area and survey trawl stations used as the source of data for this study. The survey area is bounded in the north and east by the 10 m depth contour, as trawling in shallow waters was not possible due to the presence of

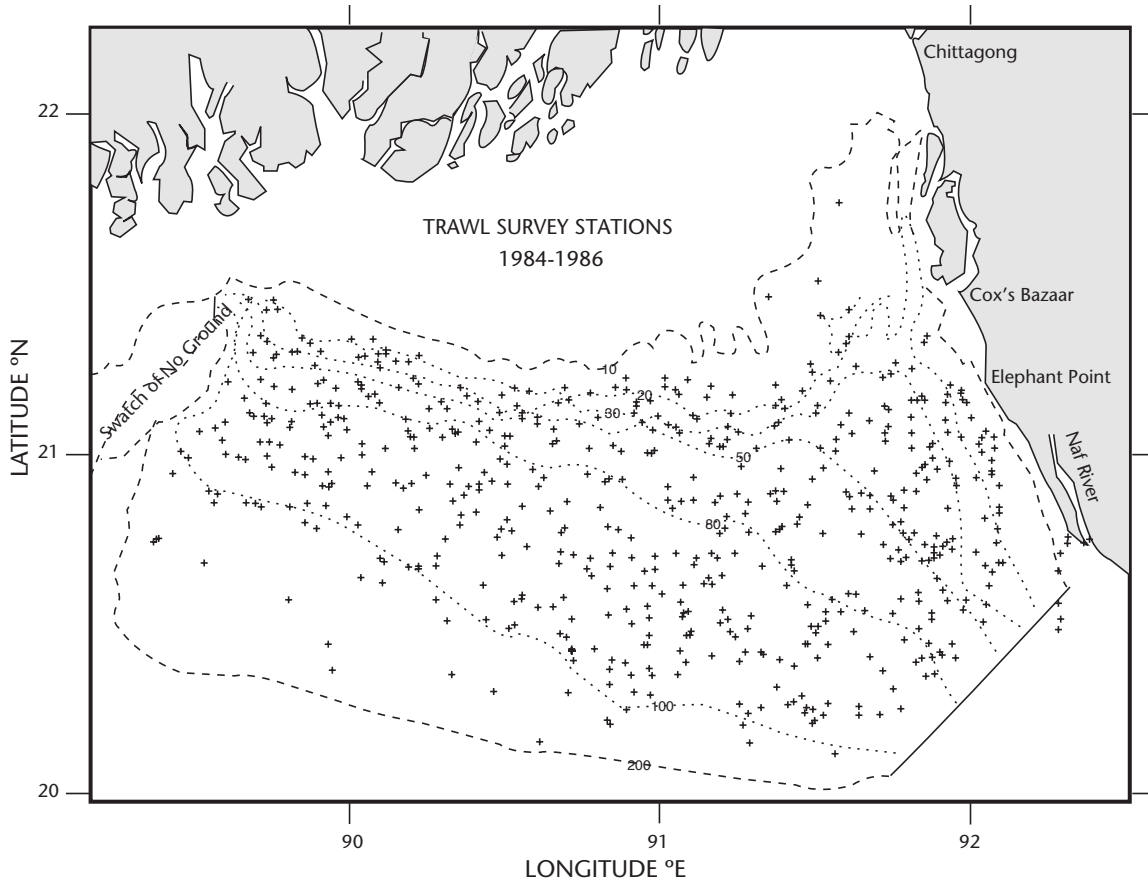


Fig. 1. The coastal waters of Bangladesh, Bay of Bengal, that are covered by the ecosystem model and the trawl survey stations (1984 to 1986) used for biomass estimation.

artisanal fishing gears. To the south, the boundary was set at the 200 m depth contour. In the south-east, a line drawn at 45° (from the southern end of St. Martin islands) was taken as the limit of the survey area towards Burma. In the west the survey was limited to the eastern edge of the area known as “Swatch of No Ground” (described in Khan et al. this vol.). Fifty trawl stations were selected randomly prior to each cruise covering the entire survey area.

The surveys were conducted between September 1984 and December 1986 by the Marine Fisheries Survey Management Unit, Agrabad, Chittagong. The survey vessel used was the R.V. Anusandhani, a 32.4 m “multipurpose” research vessel principally designed for stern trawling. The trawl gear used was an Engel high-opening fish/shrimp bottom trawl with a cod-end mesh size of 32.0 mm. Detailed specification of the survey vessel and gear, and details of the operations are given in Khan et al. (this vol.). However, a summary is provided in Table 2.

Table 2. Summary of research survey hauls used for constructing the ecosystem model.

Cruise No.	Date/Duration	Valid hauls	Depth zone (m)				
			10 - 20	20 - 50	50 - 80	80 - 100	> 100
1	15 - 25 Sep. 1984	42	10	10	7	15	0
2	03 - 13 Oct. 1984	45	2	7	13	21	2
3	20 - 30 Oct. 1984	43	6	9	9	17	2
4	09 - 19 Nov. 1984	44	3	6	10	24	1
5	27 Nov. - 05 Dec. 1984	40	6	7	8	16	3
6	13 - 20 Dec. 1984	41	2	9	11	16	3
8	06 - 16 Jan. 1985	46	7	8	8	19	4
9	31 Jan. - 24 Feb. 1985	49	6	10	10	19	4
10	17 - 24 Feb. 1985	44	0	8	7	29	0
12	19 - 24 May 1985	13	3	4	3	3	0
13	12 - 17 Jul. 1985	13	4	8	1	0	0
14	21 - 24 Aug. 1985	3	0	3	0	0	0
15	28 Sep. - 6 Oct. 1985	12	0	3	7	2	0
16	22 - 31 Dec. 1985	35	4	8	5	11	7
20	25 Jan. - 4 Feb. 1986	41	2	10	9	16	7
22	02 - 11 Mar. 1986	31	3	14	7	6	1
24	02 - 11 Apr. 1986	22	0	4	5	7	6
26	12 - 21 May 1986	25	2	14	10	6	0
27	1 - 4 Jun. 1986	7	0	4	3	0	0
30	2 - 4, 15 - 21 Dec. 1986	26	0	5	12	9	0
	TOTAL	629	60	151	145	236	37

The Ecopath Model

The Ecopath software (Christensen et al. 2000; Pauly et al. 2000) was used to build a (trophic) model of the Bangladesh waters of the Bay of Bengal. As described in Christensen and Pauly (1992a and 1992b), the Ecopath model stems from the work of Polovina (1984b; 1985; Polovina and Ow 1983). The basic equation of Ecopath is,

$$B_i * (P/B_i) * EE_i - \sum_{j=1}^n B_j * (Q/B_j) * DC_{ji} - EX_i = 0 \quad (1)$$

where, B_i is the biomass of group i ; P/B_i is the production/biomass ratio of group i , which under steady-state conditions, is equal to the instantaneous coefficient of total mortality, Z (Allen 1971);

EE_i is the ecotrophic efficiency of group i ; B_j is the biomass of predator j ; Q/B_j is the consumption/biomass ratio for predator j ; DC_{ji} is the fraction of group i in the diet of predator j ; and EX_i is the sum of fisheries catches of i plus emigration to adjacent ecosystems.

Basically the approach is to model an ecosystem using a system of simultaneous linear equations (one for each group i in the system).

Ecological Groupings

The Ecopath model includes a total of 15 ecological groups (Table 3). Of these, 12 groups are exploited and the 3 remaining groups are zooplankton, phytoplankton and detritus.

Table 3. The ecological groups used in the Ecopath analysis of the coastal waters of Bangladesh, Bay of Bengal. The taxa contributing to each group is shown and their percentage by weight contribution to the trawl survey catches.

Group No.	Ecological group	Taxa	% of total catch weight	% in group
1	Sharks	Carcharhinidae	0.22	24.48
		<i>Carcharhinus</i> spp.	0.66	72.67
		<i>Sphyrna</i> spp.	0.02	1.65
		<i>Sphyrna blochii</i>	0.01	1.10
		<i>Rhizoprionodon</i> spp.	< 0.01	0.11
2	Medium pelagics	Scombridae	< 0.01	0.03
		<i>Scomberomorus</i> spp.	< 0.01	0.01
		<i>Scomberomorus guttatus</i>	0.19	1.66
		<i>S. commerson</i>	0.17	1.42
		<i>S. commersoni</i>	0.03	0.29
		<i>Rastrelliger</i> spp.	0.60	5.11
		<i>Rastrelliger kanagurta</i>	4.66	39.60
		<i>Rastrelliger brachysoma</i>	0.31	2.62
		<i>Rastrelliger faughni</i>	0.03	0.24
		<i>Sarda orientalis</i>	0.01	0.10
		<i>Euthunnus affinis</i>	0.04	0.32
		<i>Sphyrna</i> spp.	0.19	1.64
		<i>Sphyrna obtusata</i>	0.03	0.22
		<i>Sphyrna forsteri</i>	0.54	4.59
		Carangidae	0.03	0.23
		<i>Atropus</i> spp.	< 0.01	0.04
		<i>Atropus atropus</i>	0.75	6.35
		<i>Megalaspis cordyla</i>	0.95	8.10
		<i>Decapterus</i> spp.	0.17	1.44
		<i>Decapterus maruadsi</i>	1.56	13.23
		<i>Decapterus macrosoma</i>	0.01	0.09
		<i>Decapterus kurroides</i>	0.13	1.10
		Carangoides spp.	0.07	0.62
<i>Carangoides malabaricus</i>	0.12	1.04		
<i>Carangoides seriolina</i>	< 0.01	< 0.01		
<i>Alectis</i> spp.	0.01	0.08		

Table 3. The ecological groups used in the Ecopath analysis of the coastal waters of Bangladesh, Bay of Bengal. The taxa contributing to each group is shown and their percentage by weight contribution to the trawl survey catches. (continued)

Group No.	Ecological group	Taxa	% of total catch weight	% in group
2 (cont'd)	Medium pelagics	<i>Alepes melanoptera</i>	0.05	0.43
		<i>Caranx</i> spp.	0.02	0.13
		<i>Selar</i> spp.	0.26	2.24
		<i>Selar boops</i>	0.14	1.16
		<i>Selar crumenophthalmus</i>	< 0.01	0.03
		<i>Parastromateus niger</i>	0.44	3.73
		3	Medium mesopelagics	Trichiuridae
<i>Trichiurus lepturus</i>	0.05			0.72
<i>Lepturacanthus savala</i>	4.93			68.47
<i>Pampus argenteus</i>	1.87			25.94
<i>Pampus chinensis</i>	0.34			4.77
4	Medium demersals			<i>Pomadasys</i> spp.
		<i>Pomadasys hasta</i>	1.24	4.96
		<i>Pomadasys maculatus</i>	1.25	5.00
		<i>Polynemus indicus</i>	0.04	0.15
		<i>Polynemus paradiseus</i>	0.06	0.23
		<i>Polynemus sextarius</i>	0.07	0.27
		<i>Eleutheronema</i> spp.	< 0.01	0.02
		<i>Eleutheronema tetradactylum</i>	< 0.01	0.04
		<i>Lutjanus</i> spp.	0.36	1.44
		<i>Lutjanus johni</i>	0.63	2.50
		<i>Lutjanus malabaricus</i>	0.16	0.64
		<i>Lutjanus sanguineus</i>	0.03	0.11
		<i>Arius</i> spp.	11.58	46.28
		Sciaenidae	2.55	10.18
		<i>Johnius</i> spp.	1.48	5.92
		<i>Johnius argenteus</i>	3.30	13.17
		<i>Otolithes</i> spp.	0.96	3.82
		<i>Otolithes brauritus</i>	0.01	0.06
		<i>Otolithes maculatus</i>	0.19	0.77
		<i>Protonibea</i> spp.	0.12	0.46
		<i>Protonibea diacanthus</i>	0.18	0.72
		<i>Pennahia</i> spp.	0.50	1.98
		<i>Pennahia macropthalmus</i>	0.22	0.86
		<i>Chrysochir</i> spp.	0.04	0.14
<i>Chrysochir aureus</i>	0.02	0.07		
<i>Otolithoides</i> spp.	0.05	0.20		
5	Small demersals	<i>Nemipterus</i> spp.	4.71	17.24
		<i>Nemipterus japonicus</i>	7.71	28.23
		<i>Saurida</i> spp.	1.28	4.67
		<i>Saurida tumbil</i>	2.17	7.95
		<i>Saurida undosquamis</i>	0.63	2.30
		<i>Saurida elongata</i>	0.47	1.73
		<i>Upeneus</i> spp.	1.17	4.29
		<i>Upeneus sulphureus</i>	3.96	14.50
		<i>Upeneus moluccensis</i>	0.04	0.15
		<i>Priacanthus</i> spp.	1.24	4.52
		<i>Priacanthus hamrur</i>	0.64	2.35
		<i>Priacanthus maculatus</i>	0.07	0.26
		<i>Harpodon nehereus</i>	0.80	2.93
		<i>Cynoglossus cynoglossus</i>	0.19	0.67

Table 3. The ecological groups used in the Ecopath analysis of the coastal waters of Bangladesh, Bay of Bengal. The taxa contributing to each group is shown and their percentage by weight contribution to the trawl survey catches. (continued)

Group No.	Ecological group	Taxa	% of total catch weight	% in group
5 (cont'd)	Small demersals	<i>Tetradontidae</i>	0.25	0.93
		<i>Lagocephalus</i> spp.	0.02	0.07
		<i>Tricanthus</i> spp <i>Tricanthus</i>	0.29	1.06
		<i>Brevirostris</i>	0.77	2.81
		Sparidae	< 0.01	< 0.01
		<i>Agryrops</i> spp.	0.02	0.07
		<i>Agryrops spinifer</i>	0.12	0.44
		<i>Lactarius</i> spp.	< 0.01	< 0.01
		<i>Lactarius lactarius</i>	0.37	1.37
		Serranidae	< 0.05	< 0.01
		<i>Epinephelus</i> spp.	0.17	0.62
		Apogonidae	< 0.01	0.02
		<i>Apogon</i> spp.	0.19	0.70
		<i>Apogon novemfasciatus</i>	< 0.01	< 0.01
		Platycephalidae	0.01	0.05
6	Small mesopelagics	Leiognathidae	0.02	0.60
		<i>Leiognathus</i> spp.	3.81	98.91
		<i>Leiognathus bindus</i>	< 0.01	0.05
		<i>Leiognathus equulus</i>	0.02	0.44
7	Small pelagics	Clupeidae	0.21	2.86
		<i>Dussumeria</i> spp.	< 0.01	0.10
		<i>Dussumeria acuta</i>	0.13	1.75
		<i>Hilsa</i> spp.	0.05	0.72
		<i>Hilsa toli</i>	0.05	0.71
		<i>Hilsa kelee</i>	0.10	1.35
		<i>Ilisha</i> spp.	0.32	4.30
		<i>Ilisha filigera</i>	1.36	18.17
		<i>Raconda russeliana</i>	0.85	11.30
		<i>Sardinella</i> spp.	0.01	0.16
		<i>Stolephorus</i> spp.	0.06	0.83
		<i>Stolephorus heterolobus</i>	0.01	0.17
		<i>Stolephorus tri</i>	0.05	0.60
		<i>Stolephorus taty</i>	0.80	10.73
		<i>Thryssa</i> spp.	0.30	4.06
		<i>Thryssa setirostris</i>	0.19	2.55
		<i>Coilia</i> spp.	0.10	1.26
		<i>Coilia neglecta</i>	< 0.01	0.01
		<i>Coilia ramcarati</i>	< 0.01	0.05
		<i>Coilia dussumieri</i>	0.15	1.95
		<i>Mene maculata</i>	0.33	4.45
		<i>Therapon jarbua</i>	0.21	2.83
		<i>Therapon oxythymelus</i>	0.03	0.41
		<i>Therapon therapies</i>	< 0.01	0.05
		<i>Fistularia villosa</i>	0.13	1.67
		<i>Ephippus</i> spp.	0.04	0.57
		<i>Ephippus orbis</i>	0.08	1.06
		<i>Mugil</i> spp.	< 0.01	0.11
		<i>Liza subvirides</i>	< 0.01	< 0.01
		<i>Exocoetus</i> spp.	0.05	0.65
		<i>Elops machnata</i>	0.16	2.15
<i>Gerres</i> spp.	0.55	7.37		
<i>Gerres filamentosus</i>	0.28	3.71		
<i>P. longimanus</i>	0.84	11.26		

Table 3. The ecological groups used in the Ecopath analysis of the coastal waters of Bangladesh, Bay of Bengal. The taxa contributing to each group is shown and their percentage by weight contribution to the trawl survey catches. (continued)

Group No.	Ecological group	Taxa	% of total catch weight	% in group
8	Small discards	discards	4.95	100
9	Rays	Rays and Skates	3.91	100
10	Penaeidae	<i>Penaeus</i> spp. <i>Penaeus monodon</i> <i>Penaeus indicus</i> <i>Penaeus semisulcatus</i> <i>Penaeus japonicus</i> <i>Penaeus merguensis</i> <i>Metapenaeus monoceros</i> <i>Metapenaeus spinulatus</i> <i>Metapenaeus affinis</i> <i>Metapenaeus brevicornis</i> <i>Metapenaeopsis toluensis</i> <i>Parapenaeopsis</i> spp. <i>Parapenaeopsis stylifera</i> <i>Parapenaeopsis sculptilis</i> <i>Solenocera indica</i> Mixed shrimps	1.35 0.07 < 0.01 < 0.01 < 0.01 < 0.01 0.41 < 0.01 < 0.01 < 0.01 < 0.01 0.05 < 0.01 0.05 < 0.01 < 0.01	71.71 3.60 0.04 0.11 0.21 0.26 21.87 8.31 0.01 0.03 0.32 2.49 0.04 2.59 0.21 0.01
11	Other Crustaceans	Crabs Lobsters Other crustaceans	0.07 0.16 0.22	16.52 35.27 48.21
12	Cephalopoda	Cuttlefish and Squids	1.66	100
13	Zooplankton	Zooplankton	-	-
14	Phytoplankton	Phytoplankton	-	-
15	Detritus	Detritus	-	-

Model Parameterization (Sources of Input Parameters)

The trawl survey catch data (Table 3) were used to calculate biomass inputs except for the groups Penaeidae, other crustaceans and Cephalopoda, where biomass was estimated from shrimp cruise catch data (described in Khan et al. this vol.).

Biomass for each group was estimated using the “swept area” method. In order to reduce the variance, geometric rather than arithmetic means were employed (Pauly 1984). An escapement factor of 50% was used for the calculation of biomass. The average trawling speed was 3.0 knots. Biomass results given in this report refer to a trawl with an 18 m horizontal opening measured between trawl wing-tips; the distance covered by the trawl in 30

min is 1.5 nm, which gives an area swept by the net of about 0.05 km².

Table 4 shows the growth and mortality parameters for the species used to estimate P/B. In some groups (i.e. Penaeidae, other crustaceans and Cephalopoda), P/B ratios were adjusted to give EE values less than 1 and to make the respiration estimate positive. The consumption/biomass (Q/B) ratio was obtained for fish groups using the empirical formula of (Palomares and Pauly 1989). Consumption/biomass ratios for non-fish groups were taken from (Pauly et al. 1993).

A limited amount of work has been done in the study area on the diet composition of fish (Mansur et al. 1998; Mazid 1998; Mustafa and Mansura 1994). Many studies are qualitative in nature and

Table 4. Estimates of growth and mortality parameters for representative species

Ecological group	Species	L _∞ (cm)	K (year ⁻¹)	M (year ⁻¹)	F (year ⁻¹)	Z (year ⁻¹)	Source
Medium pelagics	<i>Parastromateus niger</i>	41.0	0.59	1.16	1.26	2.42	Mustafa (1999)
	<i>Megalaspis cordyla</i>	38.5	0.54	1.11	1.17	2.28	- do -
	<i>Rastrelliger kanagurta</i>	27.4	0.90	1.71	3.21	4.92	- do -
	<i>Megalaspis cordyla</i>	37.9	0.58	1.17	0.58	1.75	Ashrafal (1998)
Medium mesopelagics	<i>Lepturacanthus savala</i>	108.0	0.75	1.04	1.54	2.58	Ashrafal (1998)
	<i>Pampus argenteus</i>	29.8	0.53	1.18	0.79	1.97	- do -
	<i>Pampus chinensis</i>	38.1	0.67	1.29	0.83	2.12	- do -
	<i>Lepturacanthus savala</i>	106.5	0.80	1.08	0.81	1.89	Ashrafal (1998)
	<i>Lepturacanthus savala</i>	105.0	0.85	1.33	0.73	2.06	Mustafa and Khan (1993)
Medium demersals	<i>Pomadasys hasta</i>	58.8	0.52	0.97	0.72	1.69	Mustafa and Khan (1993)
	<i>Johnius argentatus</i>	50.0	0.72	1.25	5.63	6.88	Shahanaz (1996)
	<i>Johnius argentatus</i>	46.1	0.86	1.44	0.58	2.02	Ashrafal (1998)
	<i>Pomadasys hasta</i>	56.9	0.38	0.79	0.81	1.60	Mustafa and Azadi (1995)
Small pelagics	<i>Ilisha filigera</i>	35.0	0.75	1.42	1.95	3.37	Mustafa (1999)
	<i>Coilia dussumeri</i>	16.8	1.30	2.49	2.30	4.79	Amin (1997)
	<i>Ilisha filigera</i>	32.5	0.90	1.63	1.25	2.86	Ashrafal (1998)
Penaeidae	<i>Penaeus monodon</i> (male)	30.0	0.94	1.72	3.33	5.05	Mustafa (1999)
	<i>Penaeus monodon</i> (female)	32.1	0.97	1.72	2.13	3.85	- do -
	<i>Penaeus semisulcatus</i> (male)	23.5	.80	1.73	3.47	5.20	- do -
	<i>Penaeus semisulcatus</i> (female)	27.0	.90	1.72	2.98	4.70	- do -
	<i>Metapenaeus monoceros</i> (male)	16.5	1.50	2.75	3.68	6.43	- do -
	<i>Metapenaeus monoceros</i> (female)	19.4	1.52	2.65	3.94	6.59	- do -
	<i>Parapenaeopsis sculptilis</i>	16.8	1.25	2.43	2.93	5.36	Amin (1997)
	<i>Exopalaemon styliferus</i>	11.21	2.20	3.94	4.57	8.51	- do -
	<i>Penaeus monodon</i> (male)	28.8	1.20	2.03	5.86	7.90	Mustafa and Khan (1993)
	<i>Penaeus monodon</i> (female)	30.5	1.70	2.51	3.28	5.80	- do -
	<i>Metapenaeus monoceros</i> (male)	18.0	1.40	2.89	3.41	6.30	- do -
	<i>Metapenaeus monoceros</i> (female)	18.6	1.60	2.77	3.53	6.30	- do -
	<i>Lysmata ensirostris</i>	7.3	2.2	8.44	0.92	9.36	Aysha (1997)
	<i>Palaemon stylifera</i>	10.5	1.45	3.00	1.49	4.44	Mustafa et al. (1995)
Benthopelagic	<i>Ariomma indica</i>	22.0	1.12	2.10	3.43	5.53	Humayun et al. (1988)

fish are often lumped together as a single diet item. In cases where local diet compositions were not available, data from the literature summarized in FishBase were used.

Ecotrophic efficiency (EE) expresses the fraction of the total production consumed by predators or caught by a fishery. It usually ranges from 0.7 to 0.9 (Polovina 1984a; Polovina 1984b; Ricker 1969). In Ecopath, EE must either be entered (when biomass, P/B, or Q/B is unknown) or is estimated by the program (when biomass, P/B and Q/B are entered). The fraction (1-EE) is the proportion of the production directed towards the detritus box, from

which it may be exported out of the system. The program estimated EE for all groups except phytoplankton.

Table 5 gives estimates of biomass, catch and the instantaneous rate of fishing mortality (F) for the different groups. In most cases, biomass estimates from the demersal trawl survey during 1984 - 86 were used. Biomass estimate for penaeid shrimps based on the swept area method is probably an underestimate. There is no published data on biomass of zooplankton, phytoplankton and detritus for the study area. Input data for zooplankton were obtained from (Silvestre et al. 1993).

Table 5. Biomass (t), catches (t·year⁻¹) and instantaneous rate of fishing mortality (F; year⁻¹) for species groups in the Bangladesh waters of the Bay of Bengal.

Ecological group	Biomass (t)	Catches (t·year ⁻¹)	F (year ⁻¹)
Sharks	1713	949	0.55
Medium pelagics	22118	1360	0.06
Medium mesopelagics	13528	708	0.05
Medium demersals	47000	10538	0.22
Small demersals	51352	990	0.02
Small mesopelagics	7240	932	0.13
Small pelagics	14070	3724	0.27
Small discards	9308	11105	1.19
Rays	7353	809	0.11
Penaeidae	8014	3759	0.47
Other crustaceans	4771	863	0.18
Cephalopoda	5833	1286	0.22
TOTAL	188,000	37,023	

Results and Discussion

Table 6 gives input and output estimates of biomass, production/biomass (P/B), consumption/biomass (Q/B) ratio, and ecotrophic efficiency (EE) for the different groups for the Bay of Bengal. The P/B ratio is dependent on the estimates of F and M. The Q/B ratios for the finfishes (Groups 2 - 8, Table 3) based on the empirical formula of (Palomares and Pauly 1989) are comparable to those given by (Pauly 1989) for a number of tropical species. Estimates of ecotrophic efficiencies were high for most groups. It is reasonable to assume that most of the production in an exploited ecosystem will be predated upon or fished, except perhaps for the top predators. There is a certain amount of predation on these groups by skipjacks and sharks, which were not in the model so therefore not counted.

Table 7 shows the diet matrix for the different groups used in the model. Food and feeding studies carried out in the Bay have been largely qualitative requiring substantive resort to the literature and educated guesswork to convert values to quan-

titative estimates of diet composition. In most cases only minor adjustments were necessary to satisfy mass-balance constraints in the analysis.

Figure 2 shows trophic linkages of the coastal fisheries ecosystem in the Bangladesh waters of the Bay of Bengal. The small demersal, medium demersal, medium pelagic and small pelagic groups dominate the fish biomass. The major prey in the system are the small mesopelagic, small discards, penaeidae, cephalopoda and other crustaceans with consumption rates of 30.0, 18.0, 55.0, 22.4 and 15.5 t·km⁻²·year⁻¹, respectively. The trawl fishery in the years modeled is found to operate at a trophic level of 2.7.

Figure 3 presents mixed trophic impacts of the groups included in the Bay of Bengal ecosystem model. The mixed trophic impacts (Christensen and Pauly 1992a; Christensen and Pauly 1992b) suggest that fishing has an indirect positive impact on medium pelagics, medium demersals, and rays. However, fishing negatively impacts sharks, small mesopelagics, small pelagics and cephalopods, as they are the preferred targets of existing fisheries. The figure also shows: positive impacts of sharks on medium mesopelagics, small demersals, small mesopelagics and small pelagics; negative impacts of medium pelagics, and small and medium mesopelagics; and positive impacts of medium demersals on small discards and other crustaceans.

Table 8 presents respiration, assimilation and other important component parameters by group. Details of the calculation procedure for these parameters were described by Christensen and Pauly (1992a).

Detritus, generated mainly by phyto- and zooplankton, is one of the important groups in the ecosystem and major energy flows connect it to other groups. Table 9 presents flow to detritus (t·km⁻²·year⁻¹) from different groups. Table 10 presents the total mortality in its components, fishing, predation and other kinds of mortality. Other crustaceans, cephalopods, Penaeidae, and small mesopelagics show high predation mortality, while sharks as top predators have lower predation mortality, as may be expected. The penaeidae, medium demersals and small discards showed higher fishing mortality, due to demersal trawling in the fishing grounds. Table 10 presents the consumption by predation, export, flow to detritus, respiration and throughput for the different trophic levels.

Table 6. Basic input and output (in parenthesis) for the Ecopath model of the coastal waters of Bangladesh, Bay of Bengal. P/B = Production/Biomass ratio, Q/B = Consumption/Biomass ratio, EE = Ecotrophic efficiency.

Ecological group	Biomass (t-km ²)	P/B (year ⁻¹)	Q/B (year ⁻¹)	EE (year ⁻¹)
Large sharks	0.42	2.37	12.00	(0.03)
Medium pelagics	0.53	4.00	12.00	(0.96)
Medium mesopelagics	0.33	3.20	10.00	(0.93)
Medium demersals	1.13	2.20	6.00	(0.96)
Small demersals	1.23	3.10	8.00	(0.93)
Small mesopelagics	0.25	9.00	120.00	(0.95)
Small pelagics	0.35	2.20	10.00	(0.96)
Small discards	0.30	6.30	60.00	(0.95)
Rays	0.18	2.20	12.00	(0.94)
Penaedae	0.22	17.20	250.00	(0.95)
Other crustaceans	0.12	60.00	130.00	(0.97)
Cephalopoda	0.14	11.50	160.00	(0.12)
Zooplankton	10.00	35.00	150.00	(0.06)
Phytoplankton	13.00	(134.27)	–	0.80
Detritus	120.00	–	–	(0.17)

Table 7. Diet composition of the consumers in the trophic model of the coastal waters of Bangladesh, Bay of Bengal. Values represent the proportion (by weight or volume) each prey contributes to the diet of the predator. The numbers in the first row refer to the predator number (same as prey numbers given in first column).

Prey	Predator												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Large sharks													
2. Medium pelagics	0.40												
3. Medium mesopelagics	0.07	0.06							0.10				
4. Medium demersals	0.27			0.11									
5. Small demersals	0.13			0.33				0.01	0.10				
7. Small pelagics									0.30				
9. Rays	0.07												
10. Penaeidae				0.11	0.12						0.10		
11. Other crustaceans			0.20		0.17				0.09	0.05	0.10		
12. Cephalopoda				0.07	0.08				0.10				
13. Zooplankton		0.50	0.50	0.08	0.15	0.50	0.50	0.28		0.15		0.30	
14. Phytoplankton		0.31	0.30	0.09	0.24	0.40	0.40	0.28		0.40			0.90
15. Detritus				0.11	0.12	0.10	0.10	0.43		0.40	0.80	0.70	0.10
16. TOTAL	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

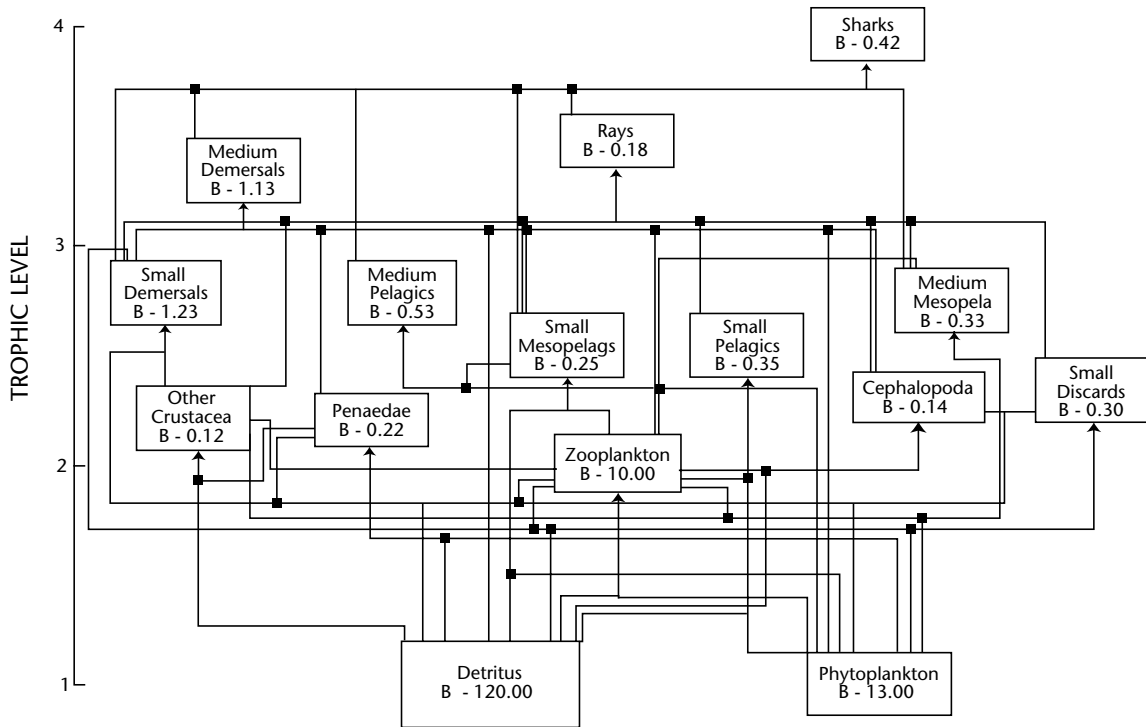


Fig. 2. Trophic model of the coastal waters of Bangladesh, Bay of Bengal. Only predator-prey links with flows of 0.1 t·km²·year⁻¹ or more are included. Groups are arranged after trophic levels on the Y-axis, and box size is a function of group biomass (indicated in t·km²)

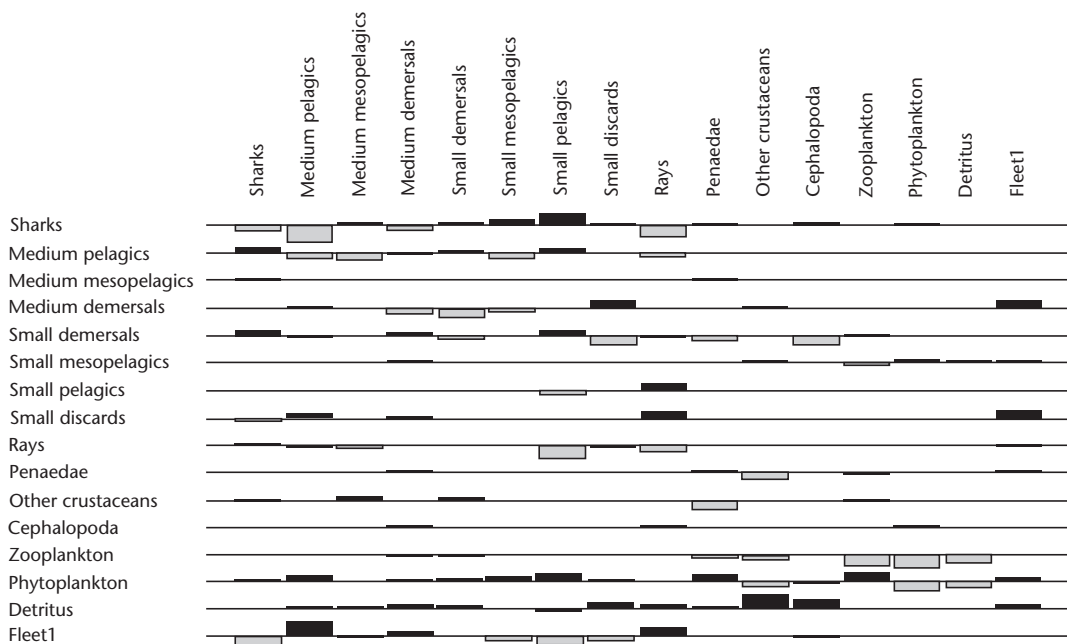


Fig. 3. Mixed trophic impacts in the Ecopath model of the coastal fisheries ecosystem in Bangladesh waters of the Bay of Bengal. The graph shows the direct or indirect trophic impacts the groups to the left (rows) have on the groups mentioned above (columns). Positive impacts are shown above and negative impacts below the baseline. The impacts are relative but comparable between the groups.

Table 8. Respiration, assimilation and other parameters by group.

Ecological group	Respiration (t·km⁻²·year⁻¹)	Assimilation (t·km⁻²·year⁻¹)	Respiration/ Assimilation	Production/ Respiration	Respiration/ Biomass
Large Sharks	2.03	3.02	0.67	0.49	4.83
Medium pelagics	2.98	5.11	0.58	0.71	5.60
Medium mesopelagics	1.56	2.60	0.60	0.67	4.80
Medium demersals	2.94	5.42	0.54	0.85	2.60
Small demersals	4.07	7.90	0.52	0.94	3.30
Small mesopelagics	21.75	24.00	0.91	0.10	87.00
Small pelagics	2.03	2.80	0.73	0.38	5.80
Small discards	12.51	14.40	0.87	0.15	41.70
Rays	1.31	1.70	0.77	0.30	7.40
Penaeidae	51.21	55.00	0.93	0.07	232.80
Other crustaceans	5.24	12.37	0.42	1.36	44.00
Cephalopoda	16.31	17.92	0.91	0.10	116.00
Zooplankton	850	1200	0.71	0.41	85.00

Table 9. Omnivory index, efficiency and flow to detritus of each ecological group.

Ecological group	Omnivory index	Net efficiency	Flow to detritus (t·km⁻²·year⁻¹)
Large sharks	0.15	0.33	2.98
Medium pelagics	0.18	0.42	1.34
Medium mesopelagics	0.24	0.40	0.72
Medium demersals	0.46	0.46	1.45
Small demersals	0.31	0.48	2.26
Small mesopelagics	0.00	0.09	6.12
Small pelagics	0.00	0.28	0.73
Small discards	0.02	0.13	3.67
Rays	0.03	0.23	0.45
Penaeidae	0.07	0.07	0.21
Other crustaceans	0.21	0.58	3.45
Cephalopoda	0.00	0.09	4.53
Zooplankton	0.00	0.29	606.49

Table 10. Components of the total mortality for the groups in the ecosystem. (All are instantaneous rates, expressed on an annual basis).

Ecological group	Total mortality (P/B=Z)	Fishing mortality (F)	Predation Mortality (M2)	Other mortality (M0)
Large sharks	2.37	0.08	0.00	2.29
Medium pelagics	4.00	0.06	3.79	0.15
Medium mesopelagics	3.20	0.06	2.92	0.22
Medium demersals	2.20	0.27	1.85	0.08
Small demersals	3.10	0.19	2.68	0.23
Small mesopelagics	9.00	0.13	8.38	0.49
Small pelagics	2.20	0.28	1.84	0.08
Small discards	6.30	0.68	5.39	0.23
Rays	2.20	0.19	1.90	0.11
Penaeidae	17.20	0.41	15.82	0.96
Other crustaceans	60.00	0.00	57.02	2.98
Cephalopoda	11.50	0.29	10.87	0.33
Zooplankton	35.00	0.00	4.35	30.65

Table 11. Total energy flow distribution by trophic level in the coastal ecosystem in the Bangladesh waters of the Bay of Bengal. All flows are in t·km²·year⁻¹.

Trophic level	Consumed by predators	Export	Flow to detritus	Respiration	Throughput
VI	0.00	0.00	0.00	0.00	0.00
V	0.00	0.00	0.02	0.03	0.04
IV	0.04	0.01	0.37	0.59	1.02
III	1.02	0.10	2.07	3.74	6.93
II	6.93	0.33	11.95	35.42	54.63
I	54.63	0.44	930.23	624.17	1 609.46
TOTAL	1 609.46	1 080.65	349.09	0.00	3 039.21

Conclusion

Ecopath was used to produce an ecosystem view of the coastal resources in the waters of Bangladesh, Bay of Bengal. It was especially useful with regard to estimating biomasses and trophic levels and produced results which are consistent with existing understanding of the resources. The present analy-

sis is only a first step toward ecosystem analysis and management, but is also a necessary step to evaluate where additional information is required to reach a level where the analysis becomes sufficiently robust. Much more work is required, however, to obtain the necessary ecological and economical parameters for more effective modeling and evaluation of management options.

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