Bay of Bengal Large Marine Ecosystem Project

An exploratory ecosystem model of the Bay of Bengal Large Marine Ecosystem

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Abstract

The trend towards ecosystem-based management requires the development of tools to gain insights in ecosystem functioning and the impact of fishing on ecosystem structure. This study aims at developing one of such tools, an ecosystem model of the Bay of Bengal built with the Ecopath and Ecosim software. The Bay was divided in three sections considered relatively independent from each other while migrating species were assumed to occupy the entire study area. The available data and the methods to develop the model are described. The static model (Ecopath) was built to represent year 1978 and synthesise available population dynamics and fisheries data. A preliminary Ecosim model was set up to allow exploring interactions between functional groups and the impact of fishing. Time series of abundance, catches and effort were assembled for four functional groups for this purpose.

The Ecopath model is one image of the ecosystem that results from the data available and the choices that were made for each parameter at the input, stage and when balancing the model. Several crucial gaps in biomass estimates and level of exploitation were noted. Changing the assumptions would lead to different biomasses and P/B values and possibly, the strength of the foodweb links. Given the lack of time series to fit the model to a larger number of functional groups, and the use of commercial CPUEs as abundance indices for large pelagics, the uncertainty of temporal simulations is large.

As it stands, the model is a great framework to articulate data, improve research questions, and determine what important piece of information would be useful to gather to answer the most crucial questions. It can be modified and expanded as data become available. The results from temporal simulations should not be used to give quantitative management advice. Instead, current Ecosim simulations could be used as a tool to explore food web dynamics and effects of fishing.

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Introduction

The Bay of Bengal LME is an embayment of the northeastern Indian Ocean bordered by Sri Lanka, India, Bangladesh, Malaysia, Thailand, Myanmar, Indonesia and the Maldives (Figure 1). It is influenced by the second largest hydrologic region in the world, the Ganges-Brahmaputra-Meghna (GBM) Basin (Heileman et al. 2009). The region is also affected by monsoons, storm surges and tsunamis leading to strong seasonality in water characteristics and in productivity (Heileman et al. 2009).

The ecosystem is also under high pressure from fisheries including destructive practices and high bycatch levels (Heileman et al. 2009), and from habitat destruction and pollution(Holmgren 1994). For instance, the demand for *Penaeus monodon* larvae for aquaculture has resulted in large catches of other shrimp larvae and zooplankton that is probably having an impact on the ecosystem (Mahmood et al. 1994). Also, the damming of some rivers has destroyed some fisheries and reduced habitat for hilsa (Milton 2010).

The Bay of Bengal Large Marine Ecosystem (BOBLME) Project (http://www.boblme.org/) is a collaborative effort between the United Nations Food and Agriculture Organization (FAO) and the countries bordering the Bay of Bengal to improve regional management of fisheries and the marine environment. The aim of the BOBLME project is to identify threats to the marine ecosystem, improve the livelihoods of coastal communities and secure food resources of the Bay of Bengal. One of its goals is to improve the management of coastal and marine natural resources. Increasingly, fisheries management is moving towards Ecosystem Approaches to Fisheries in the hope of developing strategies providing the right incentive structure for stakeholders (Hilborn et al. 2005) and to protect the ecosystem structure and functioning (FAO 2001 ; Pikitch et al. 2004; Babcock et al. 2005; Gavaris 2009). This requires the development of tools to gain insights in ecosystem functioning and to explore management strategies. In the case of the Bay of Bengal, the first caveat in this process was the gaps in knowledge in the total amount of biomass extracted from the ecosystem. Recent work from the University of British Columbia (UBC) Sea Around Us Project (SAUP) team filled this gap by complementing the FAO database with estimates of illegal, unreported and unregulated catches (IUU) in the region (Zeller et al. 2013).

Several ecosystem models have been published in the study area in the last 20 years. Typically they cover a country coastal area such as the west coast of Peninsular Malaysia (Alias 2003), the southeast coast of India (Antony et al. 2010), and Bangladesh (Mustafa 2003; Rashed-Un-Nabi and Hadayet Ullah 2012; Ullah et al. 2012). Several models are available for the Gulf of Thailand (Christensen 1998; Vibunpant et al. 2003) and the South China Sea (Garces et al. 2003; Chen et al. 2008a; b; Hong et al. 2008; Chen et al. 2009). Each model was built with a specific goal in mind, to explore the effects of fishing in general, the effects of one specific fishery (e.g. Rashed-Un-Nabi and Hadayet Ullah 2012), or the role of a group of species (Antony et al. 2010).

The present report describes the construction of an ecosystem model for the Bay of Bengal in 1978, using the Ecopath with Ecosim (EwE) software (Walters et al. 1997; Christensen and Walters 2004), including all available data on population dynamics, biomass estimates, and diet compositions. This model was built to cover the entire Bay of Bengal divided in 3 geographic regions and focusses more specifically on pelagic fisheries: hilsa, bigeye tuna, yellowfin tuna, and blue and striped marlins. For these species, times series of biomass estimates or CPUEs, and fishing effort where included to provide a first trial in an Ecosim temporal simulation model (Christensen and Walters 2004; Christensen and Walters 2005) for the period 1978-2010.Other species, demersal and pelagics were grouped as a function of their habitat, and their economic importance for fisheries, preparing for future expansions of the model.

Methods

Ecopath with Ecosim

An Ecopath model describes the trophic interactions, synthesizing ecological and fisheries data of an ecosystem at a given time (Walters et al. 1997; Christensen and Walters 2004). These models account for the biomass of each functional group of species, their diet composition, production per unit of biomass (*P/B*, per year), consumption per unit of biomass (*Q/B*, per year), mortality rate from natural causes (*M*) and fishing (*F*), accumulation of biomass and net migration rate (all rates are annual). The principle behind this ecosystem modelling approach is that, on a yearly basis, biomass and energy in an ecosystem are conserved.

The proportion of the mortality of each group that is accounted by the model (fishing, predation, biomass accumulation, migration) is called ecotrophic efficiency (*EE*). Typically, when biomass estimates are absent, an EE value is provided and the biomass left to estimate by Ecopath. The P/B is considered equal to total mortality under equilibrium condition (Allen 1971) since production and losses would be equal. The total mortality (Z) is thus computed as the sum of fishing mortality (F) and natural mortality (M) which includes mortality by predation.

Ecosim is a tool for dynamic simulations based on the Ecopath model, an instantaneous image of the ecosystem at a given time (Christensen and Pauly 1992b; Walters et al. 1997; Christensen and Walters 2004). Ecosimuses a system of differential equations to describe changes in biomass and flows with the system by accounting for change in predation and fishing

$$\frac{DB_i}{dt} = g_i \sum_j Q_{ji} - \sum_j Q_{ij} + I_i - (M_{0,i} + F_i + e_i) B_i \qquad \text{eq. 1}$$

where g_i is the net growth efficiency; Q_{ji} and Q_{ij} are the consumption of group *j* by group *i* and the consumption of group *i* by group *j* respectively; $I_i$the immigration in t/km^2; $M_{0,i}$the annual instantaneous rate of non-predatory natural mortality; $F_i$the annual rate of fishing mortality; and $e_i$the emigration rate. The estimation of consumption of prey *i* by predator *j* (Q_{ij}) at each time step is based on the foraging arena theory (Walters and Kitchell 2001; Christensen and Walters 2004) and calculated as:

$$Q_{ij} = (a_{ij} v_{ij} B_i B_j) / (2v_{ij} + a_{ij} B_j) \qquad \text{eq. 2}$$

where a_{ij} is the rate of effective search for prey *i*, *v* (vulnerability) is the rate of exchange between the vulnerable and invulnerable prey biomass pools. The estimate of $a_{ij}$is obtained by solving equation 2 using parameters from the Ecopath model and conditional on the value of *v* (default value=2). Low vulnerability ($1>v_{ij}<1.5$) implies a donor-control or type II functional response, while a large value implies that a change in biomass of the predator will cause a corresponding change in the mortality rate of its prey. Model fitting is achieved by estimating vulnerability values that minimizes the sum of squares of differences between model predictions and times series of biomass and catch.

Study area and model structure

The study area is the Bay of Bengal defined as the LME Bay of Bengal extended to include the northern Sumatra and the Maldives (Figure1). The study area covers 6,205,000 km^2 of which 12% are on the continental shelf (< 200 m, Table 1).

Based on 2 transects on the coast and the open seas in the western Bay of Bengal, the sea surface temperature varies from 17 to 29°C in the first 100 m, for an average of about 25°C while the first 50 m are mostly above 26°C (Prasanna Kumar et al. 2007, figure 2). Below 100 m, the temperature declines rapidly from 20°C to less than 12°C at 300 m (figure 2 in Prasanna Kumar et al. 2007). For modelling purposes, water temperature is assumed to be 26°C on the shelf and 12°C in deeper waters (the average temperature at about 250 m). The oxygen minimum zone reaches as high as 50 m at some time of the year and can become a constraint for the biota but this factor is not included in the model.

The Bay of Bengal was divided in 3 regions: 1. the Maldives and open waters; 2. Sri Lanka, Indian coast, and Bengladesh; 3. the eastern coast of the Bay that covers the coast of Myanmar, Thailand, Malaysia, Sumatra and the Andaman and Nicobar Islands (Figure 1). In the Maldives, characterised by a very small reef area, the fisheries pursued mainly tuna and other large pelagics. Region 2 is characterised by a relatively small shelf under the influence of several rivers. Bangladesh and the West Bengal (India) are the most strongly influenced by the

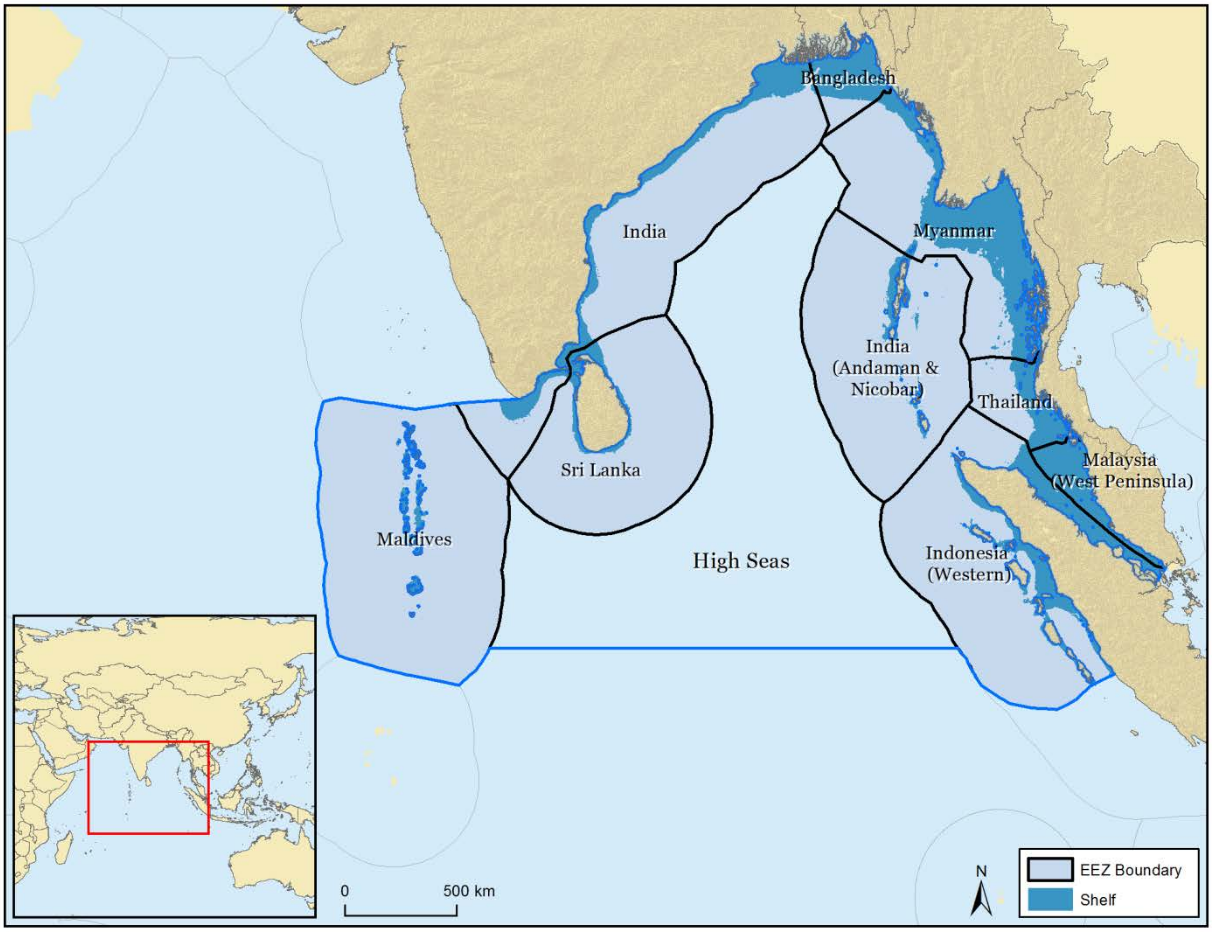

Figure 1. Map of the study area, the Bay of Bengal LME and the Maldives. Source UBC SAUP.

Table 1. Shelf and EEZ surface area by country and region of the study area.

Region	Entity	EEZ Area (km^2)	% total	Shelf Area (km^2)	% shelf
1	Maldives	915,423	14.8	30,998	3
1	High Seas	1,929,874	31.1	0	0
2	Bangladesh	84,846	1.4	64,007	75
2	India	666,670	10.7	118,304	18
2	Sri Lanka	530,943	8.6	31,352	6
3	India (Andaman & Nicobar)	659,573	10.6	219,820	33
3	Indonesia (Western)	719,333	11.6	133,939	19
3	Malaysia (West Peninsula)	68,317	1.1	67,717	99
3	Myanmar	511,356	8.2	219,820	43
3	Thailand	118,717	1.9	50,210	42
		6,205,051	**100**	**936,168**	

Bramaputra-Ganges river system. Region 3 has a larger shelf, but is less influenced from river discharge than region 2.

In each region, coastal fish and invertebrates, identified with the region number, are assumed to be relatively isolated from other regions. Some groups are assumed to occupy the whole study area (e.g. oceanic sharks and tuna-like) or straddle 2 regions or all three (e.g. hilsa, Indian mackerel, coastal sharks, coastal scombrids, jellyfish). The area used for each group is listed in Appendix A1.2.

Catch, effort and CPUE

Catch

We used the catches provided by the UBC Sea Around Us Project (SAUP) structured by country, sectors (subsistence, artisanal, industrial, tuna), and taxa, combining landings statistics and estimates of unreported catches (Zeller et al. 2013). Catches labeled miscellaneous fish, Perciformes and Pleuronectiformes were attributed to functional groups of the same region in equal proportions between fish groups (Appendix A1). Catches labeled as Scombrids and Scombroidei were attributed to functional groups tuna-like and coastal scombrids and Indian mackerel. Tuna catches labeled Thuninni were attributed to both tuna-like and coastal scombrids.

Landings (IUU + landings) and discards were summed by region defined as where the fish was caught regardless of the fishing country. Catches from unknown fishing grounds were assigned to the same region as that of the fishing country. The 1978 catches input into the Ecopath model are the sum of all landings and discards (Appendix A2.1) because the distinction is not necessary to balance the model and because in Ecosim, it is not yet possible to input separate times series of discards. Thus, the temporal simulations (Ecosim) will run with total catch time series.

Since catches were not reconstructed on the basis of effort (Zeller et al. 2013), it is difficult to link effort and fishing sectors which are defined differently among countries.In addition, the subsistence catch is derived from questionnaires, per capita consumption, and human population size, and thus not directly linked on the number of inshore boats. **For the time being, artisanal and subsistence catches are grouped under small-scale and attributed to small vessels.**

Effort

Effort by type of boats has recently been estimated for the Indian fleet during the period 1950-2005, compiled by size of boats and engine power (horse power, hp)(Bhathal 2013). The small-scale fleet includes non-motorized traditional vessels and motorized traditional vessels with outboard motors of less than 50 hp (usually 7-9 hp). Industrial includes vessels using inboard motors of 50 hp and above and deep-sea fishing vessels using engines of 120 hp and above. The industrial effort (labeled large vessels, A2.2) includes that of the large trawlers, fishing for lobsters, prawns and catching demersal fishes. The total effort account for the horse power and the number of days fished in a year (hp days, Appendix A2.2).

The number of boats by type (inboard, outboard and non-motorised) was available for Sri Lanka (Joseph 1999; Samarayanke 2003) but it does not directly correspond to the catch statistics sectors (Zeller et al. 2013). The Sri Lanka boats with inboard engines (9 m long, 3.5 GT) may correspond to the industrial fleet catches while the boats with or without outboard engines can be attributed to the artisanal sector. In absence of correspondence between the Indian (hp days) and Sri Lanka (number of boats) data on effort, and absence of data in Bangladesh, the Indian effort (small-scale and industrial fleets) was used as a representative trend for region 2.

For all other countries, it was not possible to obtain fishing effort. Most measurements of effort by type of boats (mechanised, non-mechanised, large vessels) cover only a few years and are known to be incomplete especially for small-scale fisheries. A reconstruction of effort time series is underway for several regions of the world at the UBC Fisheries Centre but there are still serious difficulties for the estimation for the small-scale and subsistence fishery (Krista Greer, UBC Fisheries Centre, pers. comm.).

Effort for hilsa consists of the number of boats in both marine and freshwater in Bangladesh (R. Sharma, IOTC, pers. comm.)(see Appendix A2.3). It was used as a proxy for the total effort on the species assuming that effort evolved the same way in other countries (and especially West Bengal). This assumption seems viable as Bangladesh was responsible for most of the catch (63-85%) over the study period. However, the effort time series encompassed the period 1987-2006 only. It was extrapolated to 1978 by assuming that effort increased by only 10% from 1978 to 1987 because fishing has not changed dramatically before 1987, but it changed considerably in fleet and spatial structure in the early 1990s (R. Sharma, pers. comm.) (Figure 2). Between 2006 and 2010 effort was held constant at the 2006 level.

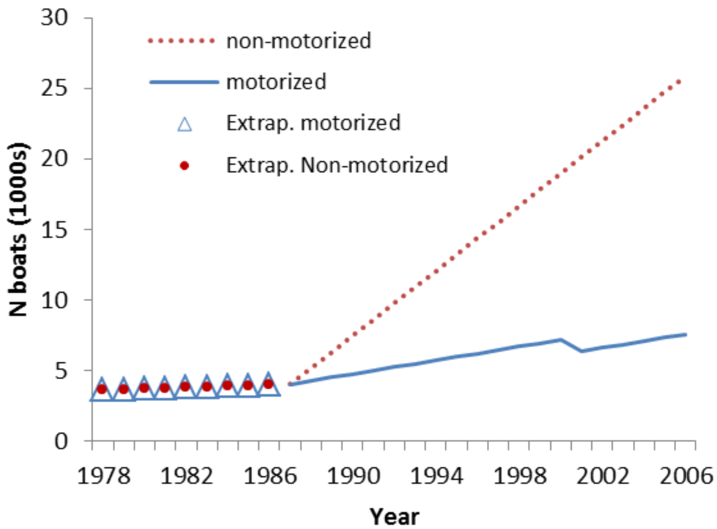

Figure 2. Nominal fishing effort for hilsa in number of boats as compiled for the stock assessment study (lines) and extrapolations from 1978 to 1986 (symbols)

CPUE and fleet

Measures of catch per unit effort (CPUE) are available for Indian mackerel (1995-2009), skipjack (*Katsuwonus pelamis* in theMaldives, 1985-2011), kawakawa (*Euthynnus affinis*,2004-2011), bigeye tuna (*Thunnus obesus*,1960-2012), yellowfin tuna (*Thunnus albacares*, 1963-2012), striped (*Kajikia audax*) and blue (*Makaira nigricans*) marlins (1971-2012), and 12 shark species in Sri Lanka (1972-2011) (Rishi Sharma, IOTC, Seychelles, pers. comm.). These could be used as time series of abundance but they still have to be paired with effort or fishing mortality to drive the model which is only possible for four of these species.

The fleet structure for the model consist of two general fleets, industrial and small-scale, in region 2 and only one general fleet each in regions 1 and 3, a fleet dedicated to hilsa, and three fleets dedicated for yellowfin tuna, bigeye tuna and marlins respectively (Appendix A2.1). For each fleet a time series of effort is required. In absence of data for regions 1 and 3 and given that it would be unrealistic to assume no increase in effort since 1978, effort was assumed to increase linearly 3-fold between 1978 and 2010, which is half of the increase of the Indian small-scale fleet. Ecosim uses relative time series of effort so that hp days or number of hooks were rescaled to start at 1 in 1978 (Appendix A2.4).

Large pelagics effort and CPUE time series (contributed by Rishi Sharma, IOTC)

Effort and CPUE series were estimated for **bigeye and yellowfin tuna** based on data provided by Far Seas Research Agency, Japan (Dr. Matsumoto pers. comm.) on aggregated data of the Japanese longline fleet from 1960-2012 (52 years). Appendix A2.4 shows the data rescaled by fleets and areas of the Indian Ocean. For the yellowfin dataset, 5 areas are used to stratify the Indian Ocean and the NE Indian Ocean overlapping the BOB area is used. Effort is measured as the total number of hooks deployed by the area/region and by year (and quarter). For the bigeye tuna, three areas are used to stratify the CPUE data, and the eastern Indian Ocean that overlays the BOB area is used as to display effort and CPUE trends over time (data provided by Dr. Matsumoto, Far Seas Research Agency, Japan).

For **marlins**, data aggregated for the entire Indian ocean is used to measure trends in CPUE and effort based on the Japanese and Taiwanese LL fleet from 1971 to 2012, though data across species of marlins were aggregated based on equal weights (for blue and striped marlin) as catches for these species are not well disaggregated in the data.

For little tuna, like skipjack, data used were based on boat days of the pole and line fleet operating in the western Indian Ocean off the Maldives atolls (data provided by Dr. S. Adam, Marine Research Center, Maldives; see Appendix A2.4). The same type of data set was usedfor mackerel tuna (kawakawa). In both cases, the effort in number of boat-days was stratified by month and quarter though finally aggregated on a yearly basis. Data was limited and only available from 2004-2011 (8 years) and for this reason, were not used with Ecosim.

Fish

Of the 723 species listed for the Bay of Bengal, about 315 had growth, longevity or diet information. These speciesare listed in Appendix A1.3,grouped into functional groups. The name of fish functional groups is either based on the family name (e.g. Carangids) or the body size (Small, Medium, Large), the habitat (pelagic, oceanic, coastal), and their feeding habit: invertivore (inv) or piscivore (pisc). When assigned to a specific region, the name of a functional group starts with the region number (e.g. 2 L pisc).

Diets

Diets for fish were mainly taken from Fishbase (Froese and Pauly 2013) using preferably local and regional studies (see sources in AppendixA3.1). Diets from the FAO area 57 account for 8% (N=12), other parts of the Indian Ocean 9%, the South China Sea 15%, and the Pacific (mainly western) 55%. Most diets for large pelagics (sharks, tuna-like, scombrids) were obtained from Atlantic waters.

Diets were compiled in a spreadsheet following the breakdown found in each publication. Foreign diet items were assigned a functional group based on size, trophic level and habitat similarity. In a large number of cases, a part of the diet is not defined (bony fish, finfish, etc.). These items were allocated to functional groups as a function of habitat and size possibilities. Thus, there is large uncertainty in the diet of several groups. In addition, some species considered as separate functional groups (e.g. hilsa, Indian mackerel) may be under-represented in diets, especially for diets from outside the study area.

Coastal diet items consumed by large pelagics (sharks, tuna-like, scombrids) and other functional groups distributed in the whole area, were allocated by region in the same proportion as the region's shelf area(3.3%, 22.8%, and 73.9% for regions 1, 2 and 3 respectively). This assumes that these species were distributed or obtainedfood equally on shelves as a function of the area available. Thisallocation works well for region 1 especially, the Maldives being a good area for sharks for instance, but with such a small shelf that the biomass of coastal fish is rather small compared to other regions. Being that there is more shelf area in region 3, most the predation on coastal fish for these groups would occur in region3, an assumption that is debatable. The diets of hilsa and Indian mackerel were allocated to regions in proportion of the catch by region, assuming that catch reflects abundance.

Fish surveys

Estimates of biomass present in the area was obtained from the summary of the Dr. Fridtjof Nansen Programme 1975–1993(Sætersdal et al. 1999) that covered Sri Lanka and the eastern coast of the Bay of Bengal, from Bangladesh to northern Sumatra, in 1978-1980. The survey did not cover India and the results for the Maldives are exploratory only as the vessel was too big to maneuver efficiently among atolls (Strømme 1983). The survey was conducted using acoustics on the shelf (< 200 m depth) paired with trawl surveys conducted by local vessels. The report presented biomass estimates for pelagics and semi-demersals separately and then the trawl catch rates (kg/hour) for each family, and by country, and portion of the coasts in some cases (Myanmar, Sri Lanka, and Thailand). In some areas, biomasses varied greatly among seasons so semi-annual surveys were averaged to provide an annual biomass. The biomass of each family was calculated as the global tonnage for a category of fish (pelagic, semi-demersal) multiplied by the proportion of the weight they represent in the trawl survey. When indications of dominant species were given, they were used to allocate the biomass to functional groups. The highest biomass is estimated to be around Sri Lanka and Bangladesh (Table 2) which corresponds pretty well to the map of primary production from 1997-2010 (http://www.lme.noaa.gov/index.php?option=com_content&view=category&layout=blog&id=50&Itemid=82).

In absence of biomass estimates for the east coast of India, estimates of densities for the Bangladesh coast were used for the West Bengal (14% of the Indian coast, Bhathal 2005) while the estimates for the Sri Lanka coast was used for the reminder of the Indian coast (*This will be named rule 1 in the following sections*). Ideally, estimates for the Indian coast would be added to the next version of the model. In a given region, the average biomass is weighted by the surface of each coast section.

The 1983 Dr. Fridtjof Nansen survey in the Maldives (Strømme 1983)recorded mainly deep-water species such as *Peristedion adeni*, *Synagrops* spp.,*Chlorophthalmus* spp.and species from the Myctophidae familybut also a few small pelagics (*Cubiceps* sp, *Spratelloides gracilis*), cephalopods, jellyfish, a few elasmobranch and caranx. It is difficult to attribute the estimated total biomass to any specific groups.

Table 2. Resulting fish density (t/km^2) in each country surveyed by the Fridtjof Nansen programme and area covered compared to shelf area estimated by the SAUP.

	Density (t/km^2)		**Area (km^2)**	
Country	**Pelagic**	**Demersal**	**Nansen**	**SAUP**
Sri Lanka	4.42	8.89	23,010	31,352
Myanmar	2.98	2.27	29,067	219,820
Bangladesh	3.23	3.15	41,211	64,007
Malaysia	3.19	0.62	41,211	67,717
Thailand	1.83	0.74	41,211	50,210
Sumatra	1.88	2.67	85,857	133,939

The 1986-1988 survey (Anderson et al. 1992) covers a few exploited groups, on and around the reefs (snapper, emperor, groupers, jacks, sharks), in 3 different habitats (atoll basins, outer atoll reef, and shallow reefs) throughout the Maldives. Reef fish were deemed not heavily exploited in the early 1990s as the Maldives is a tuna fishing nation(Anderson et al. 1992). The biomass of each group was obtained by using the average proportion in the survey catch and the total biomass collected in each habitat. Nowadays however, reef fish are heavily exploited to supply the tourist consumption in resorts (Hemmings et al. 2011).

As the area surveyed does not include the whole shelf (Table 2), the density of coastal species (Lpisc, Carangids, S pelagics, L pisc comm, SM inv, SM pisc, milkfish plus, hilsa and Indian mackerel) are assumed to be the same across the country continental shelf. For convenience and comparability species densities were first calculated for their habitat in each region. Typically, oceanic species (e.g. large tuna-like, oceanic sharks) are attributed to the entire study area, while coastal species are restricted to the EEZ of each region. Coastal scombrids are assumed to constitute only one stock travelling in all EEZ of the Bay of Bengal (69% of the area), while deep water species were assumed to be present in all deep waters (85% of the study area) (Table 1).

Natural mortality

In absence of direct measurement, natural mortality (M) is usually estimated using various empirical methods based on catch curves of unexploited populations, longevity, and other empirical relationships (see Kenchington 2013 for a review). None of these methods are valid for all species and all types of life history. I used two different empirical relationships: Pauly's (1980) equation based on growth and water temperature, and Hoenig's empirical relationship based on longevity (Tmax, Hoenig 1983). The temperature used in Pauly's equation is 26°C for most fish except demersal fish with distribution deeper than 50 m for which a value of 12°C was assumed.

Estimates based on Pauly's equation M_P are sensitive to growth rate, increasing with von Bertalanffy's *k*. Growth parameters varying widely among populations and samples/studies, several values were extracted, mainly from

Fishbase (Froese and Pauly 2013), to illustrate the potential level of variation. Unless only one valid growth equation was available a high and a low value were used to calculate M_P, leading to estimates that can easily vary by 100% or more (Appendix A4: spreadsheet). Estimates based on Hoenig's equation (M_H) are sensitive to estimates of longevity that can be seriously underestimated in heavily exploited populations. Thus, when several estimates of longevity were found, the highest estimate was chosen. For each functional group, a minimum and maximum estimate was calculated based on the average over all species for which one or several estimates were produced. The minimal estimate was preferred for large fish while the highest estimate was preferred for smaller species to account for predation (Table 3).

The estimates for tuna-like groups (tuna, sailfish, marlin, bonito) based on M_H were often similar to the lowest of average M_P estimate (Appendix4). This corresponds very well with the large growth rate often observed for these species. A large growth rate is useful to avoid predation and decreased mortality rate in early stages of development and is followed by lower mortality for the rest of their life span. For instance, the growth rate estimated for *Acanthocybium solandri* is very high (Zischke et al. 2013) while longevity is close to 10 years, showing the discrepancy between some life histories and the principle behind some empirical equations.

Table 3. Natural mortality used in the model compared to the average minimum and maximum values in each functional groups.

Fish groups	M min	Mmax	M used
Oceanic sharks	0.17	0.22	0.17
Coastal elasmobranch	0.35	0.43	0.35
Tuna-like	0.32	0.69	0.32
Coastal scombrids	0.56	0.97	0.56
S bathy	2.14	3.97	2.14 *a*
ML bathy			0.37*a*
L pisc	0.42	0.60	0.42
Carangids	0.41	0.65	0.41
S pelagics	1.69	2.29	2.29
L pisc comm	0.39	0.66	0.39
SM inv	1.08	1.47	1.47
SM pisc	1.08	1.23	1.23
Milkfish plus	0.28	0.36	0.28
Hilsa	0.95	1.61	1.61
Indian mackerel	1.52	2.34	1.52
Bigeye tuna	0.20	0.40	0.20
Yellowfin tuna	0.21	0.63	0.21
Marlins	0.26	0.61	0.26

a based on 1 species

P/B and P/Q

The production per unit of biomass (P/B) was calculated as the sum of natural (M) and fishing (F) mortalities. Fishing mortality is the ratio catch/biomass often called exploitation rate. Fwas highly dependent of the biomass estimated from survey and was often found to be too high when biomass was underestimated.

As discussed in the natural mortality section, measurement of growth is highly variable and is likely to create large uncertainty in the calculation of the consumption per unit of biomass (Q/B). In addition, empirical equations generally used to calculate Q/B from growth parameters, temperature and type of diet (Christensen and Pauly 1992a) or with the addition of the aspect ratio of the caudal fin (Palomares and Pauly 1998) tend to overestimate Q/B and result in very low gross efficiency GE=P/Q (Guénette 2005). Instead, P/Q was set at 0.15 for large fish (except for tuna and sharks), 0.2 for small and medium fish, and 0.25 for small pelagics.

Sharks and rays

Sharks and rays were classified in oceanic and coastal species of which sharks are the largest component because of the information available and their presence in reported landings. Catches were labeled by species or by more generic names (family, order) that did not allow differentiating between oceanic and coastal sharks. In the Maldives, coastal sharks were traditionally fished and became the target of an important fishery in the 1970s because of higher demand. Oceanic sharks constituted roughly half the catch at the beginning but accounted for 70% of the catch in 1998 (Anderson and Waheed 1999). It was thus assumed that in region 1, the proportion of oceanic shark increased linearly from 50% to 70% between 1992 and 1998. There was no indication that this was the case in other regions except in Sri Lanka wherethe fishery expanded beyond the continental shelf with driftnets, increasing the catch of pelagic sharks starting in the 1970s (Joseph 1999). Thus, catches were assumed to contain half coastal sharks for the whole time series in region 2 and 3.

Oceanic sharks are assumed to be present in the whole study area. In region 1, the biomass for the Maldives (Anderson et al. 1992) was estimated at 0.6 t/km^2 on the shelf, assuming equal biomasses for oceanic and coastal sharks (Table 4). Using this estimate and assuming a lower density for the open oceans, set at half that of the shelf (an arbitrary choice that could be re-examined by local experts), the average weighted by surface area results in a biomass of oceanic sharks of 0.21 t/km^2, leading to C/B=0.01. In region 2, the biomass for oceanic shark was estimated at 0.19 t/km^2, assuming that the biomass for Bangladesh waters was representative of the whole region, leading to C/B= 0.31. Biomasses from region 3 were ignored being smaller than the catch (Table 4). The weighted average biomass based on region 1 and 2 yielded a biomass for oceanic shark of 0.20 t/km^2 for the Bay of Bengal and a fishing mortality of 0.08/year (Table 4).

Coastal sharks are restricted to EEZs (69% of the study area) which includes the continental shelves and some open waters but excludes the high seas. The weighted average results in a biomass of 0.118 t/km2 and C/B=0.31, a relatively large estimate that may be plausible.

Table 4. Sharks biomass, catches and F by region as derived from surveys and catch statistics. See text for the derivation of resulting biomasses.

Region	Biomass t/km^2	Catch t/km^2/year	F=C/B /year	area km^2*b*
Oceanic sharks				
1	0.21	0.002	0.01	2,845,297
2	0.19 *a*	0.06	0.31	1,282,459
3	0.003	0.01	3.45	2,077,295
Result	0.20	0.037	0.08	6,205,051
Coastal sharks				
1	0.02	0.008	0.40	915,423
2	0.19 *a*	0.086	0.46	1,282,459
3	0.02	0.019	1.02	2,077,295
Result	0.118	0.037	0.31	4,275,177

a based on Bangladesh only
b areas differ whether high seas are included or not in region 1

Tuna-like and scombrids

Tuna-like species are large tuna, marlins, swordfish that are large-bodied with oceanic distribution, present in 100% of study area. Four of these species were considered separately because time series of CPUE and effort were available and it would be possible to try to fit the times series in Ecosim: yellowfin tuna, bigeye tuna, and marlins composed of 2 species, the blue and striped marlins. There are no estimates of biomass for these species while catches amount to 0.004, 0.006, and 0.0009 t/km^2/year for yellowfin (YFT), bigeye (BET), and marlins respectively.

Table 5. Tuna-like and coastal scombrids biomasses, catches and F by region as derived from surveys and catch statistics. See text for the derivation of resulting biomasses.

Region	Biomass t/km^2	Catch t/km^2/year	F=C/B /year	Area km^2*b*
Tuna-like				
1	0.035	0.012	0.35	2,845,297
2	0.124 *a*	0.031	0.25	1,282,459
3	0.008 *c*	0.024	3.09	2,077,295
Result	0.124	0.017	0.14	6,205,051
Coastal scombrids				
1	-	0.006	-	915,423
2	0.15	0.077	0.51	1,282,459
3	0.01	0.036	3.79	2,077,295
Result	0.15	0.042	0.28	4,275,177

a based on Sri Lanka only
b areas differ whether high seas are included or not in region 1
c based on Myanmar only

In the Maldives, based on surveys, the tuna-like biomass is estimated at 0.05 t/km^2; assuming that this would be representative of the EEZ, and assuming half the density in open waters, the resulting biomass would amount to 0.035 t/km^2 (Table 5). In Bangladesh, there is no record of tuna-like species in catches or surveys. The biomass density for region 2 is thus based on estimates from Sri Lanka, assuming that the Indian coast would hold similar density as that of Sri Lanka (see rule 1 in the fish surveys section). The resulting biomass and F amount to 0.12 t/km^2 and 0.25/year respectively in region 2. In region 3, the tuna-like biomass estimate based on surveys from Myanmar alone is too low (0.008 t/km^2), compared to catches (0.02 t/km^2). I assumed that densities were similar to that of region 2 based on the estimate from Sri Lanka. The resulting biomass 0.124 t/km^2 leads to an F of 0.14 (Table 5).

Coastal scombrids are smaller species of the Scombridae family such as bonito *Sarda orientalis*, kawakawa *Euthynnus affinis* and Indo-Pacific king mackerel *Scomberomorus guttatus*. Their distribution covers 69% of the study area, excluding the high seas. The biomass of coastal scombrids is based on Bangladesh and Sri Lanka estimates (region 2) that amounts to 0.15 t/km^2 and F=0.28/year.

Bathypelagic species

Bathypelagic species were divided in small (S bathy) and medium and large (ML bathy) to account for differences in productivity. These species are important for large pelagics species in open oceans but they also play a role in the diet of other species that live on the shelf especially when the shelf is narrow and the slope steep. In the Maldives, for instance, the acoustic survey around the atolls showed more mesopelagics (S bathy) than small pelagics (Strømme 1983). The biomass of mesopelagics (3.28 t/km^2) was obtained from estimates provided by Lam and Pauly (2005)based on Gjøsaeter (1978). Bathypelagic species are assumed to be distributed in deeper waters, or 85% of the study area (5,268,883 km^2). There is no estimate of biomass for ML bathy so the value of EE was set at 0.9.

Large piscivores (Lpisc)

The group Lpisc is composed of barracudas (Sphyraenidae), hairtails (Trichiuridae), dolphinfish (*Coryphaena hippurus*), threadfins (Polynemidae), needlefish (Belonidae), and eel-like fish (Muraenidae, Congridae, Muraenesocidae).

In region 3, the biomass is estimated at 0.39 t/km^2 on the shelf, leading to F =0.68/year, which may be a very large exploitation rate for the late 1970s (Table 6). The resulting P/B would be very high (1.1/year) for such large-bodied species. The estimates are inexistent or too low compared to catches in regions 1 and 2, so an EE of 0.9 was assumed for all three regions. Assuming a lower level of fishing in the 1970s, F was set at half that of region 3 in all regions.

Table 6. L pisc biomass, catches, and F by region as obtained from surveys and catch statistics. Densities are presented for the shelf area.

Region	Biomass t/km^2	Catch t/km^2/year	F=C/B /year
1	-	0.09	-
2	0.12	1.83	14.7
3	0.39	0.26	0.68

Carangids

The carangids group is composed of trevally, scad, and pomfret, all members of the Carangidae family. Biomass estimates from surveys (0.35-1.77 t/km^2) led to F values of 0.35-0.82 /year in the three regions (Table 7). In the Maldives (region 1), the biomass estimate is probably low since it is based on the 1986-88 surveyAnderson et al. 1992)(see the calculation in the section L pisc comm). In region 3, the exploitation rate is relatively high (0.82; P/B=1.24) for the 1970s and could be revisited.

Table 7. Carangids biomasses, catches, and F by region as obtained from surveys and catch statistics. Densities are presented for the shelf area.

Region	Biomass t/km^2	Catch t/km^2/year	F=C/B /year
1	0.48	0.18	0.37
2	1.77	0.62	0.35
3	0.35	0.29	0.82

Small pelagics (Spel)

The small pelagics include mainly sardines (Clupeidae), anchovies (Engraulidae), halfbeaks (Hemiramphidae) and flyingfish (Exocoetidae). Initially considered separately, they were grouped because there is little knowledge of their biomass and exploitation rate.

There was no biomass estimate for region 1, although there were indications that small pelagics were not very abundant in the Maldives compared to mesopelagics (Strømme 1983). The biomass was left to be estimated using EE=0.95 and assuming a relatively low fishing mortality (F=0.1). In region 3, this group was estimated at 0.64 t/km^2, leading to F=0.65/year. In region 2 the biomass was badly underestimated and was left to be estimated by Ecopath assuming the same fishing mortality as region 3 and EE=0.95.

Table 8. Spel biomass, catches, and F by region as obtained from surveys and catch statistics. Densities are presented for the shelf area.

Region	Biomass t/km^2	Catch t/km^2/year	F=C/B /year
1	-	0.07	-
2	0.52	3.15	6.05
3	0.64	0.42	0.65

Large piscivores of commercial interest (Lpisc comm)

This functional group is composed of snappers (Lutjanidae), groupers (Serranidae), croakers (Sciaenidae), emperors (Lethrinidae), and lizardfish and Bombay duck (Synodontidae). All these families are targeted by fisheries and could be considered separately if there were better information on their exploitation.

Region 1

In the Maldives, the 1986-1988 survey (Anderson et al. 1992) covers mainly this functional group, in 3 different habitats (atoll basins, outer atoll reef, and shallow reefs) throughout the EEZ. Reef fish were deemed not heavily exploited in the early 1990s as the Maldives (Anderson et al. 1992) but their exploitation increased since then (see Figure 3) to supply the tourist consumption(Hemmings et al. 2011). The biomass of each group was obtained by combining the average proportion in the survey catch and the total biomass (sharks, tuna, carangids, Lpisc comm, and others) collected in each habitat. The **shallow reefs** pose a problem because the total biomass was not estimated due to the large variability and uncertainty using handlines. A crude estimate was obtained by combining various sources of information and a method similar to that described in the most recent survey for groupers in the Maldives (Darwin Reef Fish Project 2011). Anderson et al.(1992) provided a crude estimate of MSY based on the Philippines reefs (1-2 t/km^2, I used 1.5). Using the Cadima equation (MSY=0.5* (F + M) *avg biom, Garcia et al. 1989), M= 0.22 (the values estimated for groupers in the study area vary from 0.22-0.42, Appendix4), F=0.05 (a low estimate of mortality), the average biomass would amount to 38,889 t for the entire functional groupin the shallow reefs areas. Using the average percentage of **groupers** caught in night and day sampling (16%, Anderson et al. 1992), groupers biomass is estimated at 6,178 t or 1.8 t/km^2, while the biomass estimates for groupers in atolls basins and in deep reef slopes amount to 0.45 and 2 t/km^2 respectively. The value for the 1986-1988 survey in shallow areas is lower than that estimated using a more recent survey (3.4 t/km^2, Table 9) (Darwin Reef Fish Project 2011).

The same calculation for the entire L pisc comm functional group (groupers, snappers, emperors) and all habitats leads to a biomass of 4.48 t/km^2, catches of 0.15 t/km^2 and F=C/B=0.03 in 1986-88. I assumed a similar value of F for the period 1978-1980. Estimates for Carangids were obtained in the same manner in region 1, assuming they comprise 16% of the catch in shallow reefs.

The fishery for grouper started late in the area compared with snappers for instance (Figure 3) and remained below 1000 t during the whole time series. In 1986-88 the catch is estimated at 40 t which means a ratio C/B of 0.006 compared with 0.029 in 2010 (Table 9). The Darwin Reef Fish Project(2011) estimated the catch for 2010-2011 at 950 t based on exports augmented with 20% in transport mortality, for a total of 1140 t, more than twice as much as the reconstructed catch from SAUP. This results in a larger C/B of 0.03,a low exploitation rate that would suggest a sustainable fishery. In contrast, there are reports of catch decline, rarity of some species, decrease in mean length, and increasing proportion of immature in the catch since 1987-1991 (Darwin Reef Fish Project 2011). The mixed signals may be due to the overestimation of biomass and underestimation of catch, and perhaps a lack of information by species.

Table 9. Estimate of biomass in the Maldives for the L pisc comm group (total biomass) and groupers (Anderson et al. 1992) compared to a more recent survey (Darwin Reef Fish Project 2011) in shallow reef areas.

			Total biomass estimate				**Groupers'biomass estimate**					
Study	**Year**	**Area**	**Biomass** [a]		**MSY used**		**Biomass**		**MSY**		**Catch SAUP**	**C/B**
		km^2	t	t/km^2	t	t/km^2	t	t/km^2	t	t/km^2	t	/year
(Anderson et al. 1992)	1986-88	3,500	**38,889**	**11**	5,250	1.5	**6,178**[b]	**1.77**			40	0.006
(Darwin Reef Fish Project 2011)	2010-11	4,513					15,486	3.43	2,118	0.47	443[c]	0.029

[a] computed using the MSY estimate and Cadima's equation

[b] 16% of total biomass of sampled groups

[c] 2010 only from SAUP compared with the estimate of 1140 t in (Darwin Reef Fish Project 2011).

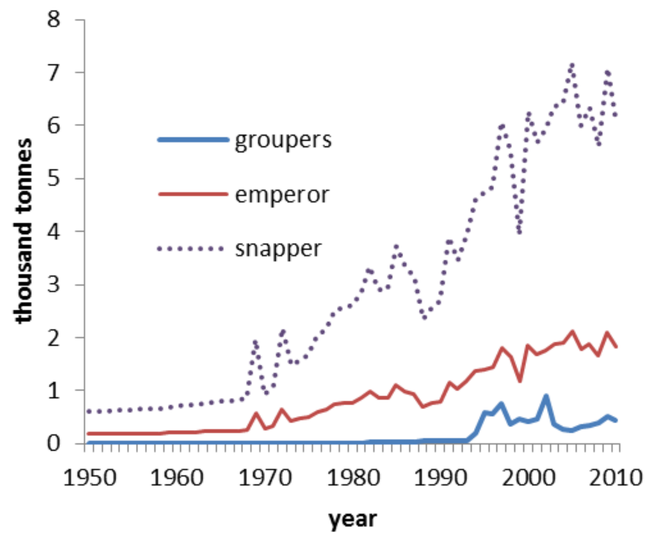

Figure 3. **Catches of three families composing the functional group L pisc comm. in region 1 (SAUP compilation Zeller et al. 2013).**

Regions 2 and 3

In region 2, the biomass estimate from the survey (4.42 t/km^2) leads to an F value of 0.51/year (Table 10). In region 3 the biomass is estimated at 0.24 t/km^2, probably an underestimate, leading to F = 1.6/year. The biomass for region 3 was left to be estimated by the model with a P/B equal to that of region 2, assumed to be more reasonable.

Table 10. L pisc comm biomass, catches, and F by region as obtained from surveys and catch statistics. Densities are presented for the shelf area.

Region	Biomass t/km^2	Catch t/km^2/year	F=C/B /year
1	4.48	0.15	0.03
2	4.42	2.24	0.51
3	0.24	0.39	1.60

Other coastal fishes

The other coastal fishes are demersal and benthopelagic species of small and medium body size divided into invertivores (SM inv), piscivores (SM pisc), and Milkfish plus. The invertivores include seabreams (Sparidae), spinefoot (Siganidae), mullet (Mugilidae), surgeonfish (Acanthuridae), parrotfish (Scaridae), goatfish (Mullidae), ponyfish (Leiognatidae) and several others (Appendix A4). The piscivores include grunts and sweetlips (Haemulidae), threadfins (Nemipteridae), turkeyfish (Scorpaenidae) and many other species. Milkfish plus are large invertivore fish including *Chanos chanos*, *Pangasius pangasius*, and *Netuma thalassina*. Very little is known of their exploitation rate and population dynamics. They were separated for ecological reasons (predator-prey relationships) more than for the necessities of the model dynamics. There are no biomass estimates except for SM inv in region 3 which is probably too low (0.63 t/km^2). The exploitation rate was assumed to be relatively low for these species (F=0.1) and EE=0.95.

Hilsa

Currently, the main species of hilsa fishery of Bangladesh is *Tenualosa ilisha* that contributes more than 99% of the total hilsa catches(Milton 2010). For modelling purposes, hilsa is considered as a single stock that is straddling regions 2 and 3 in the Bay of Bengal (Milton 2010; BOBLME 2012).

Catches reconstructed by the Sea Around Us Team (Zeller et al. 2013) were compared with the compilation used for the stock assessment performed in 2012 (BOBLME 2012) for Bangladesh. Marine catches estimated by the SAUP team is 10% higher (Figure 4, Appendix A5), probably because of the effort in accounting for discards, subsistence fishery, and unreported catches. The inland catch statistics from both sources (FAO[1] and the assessment document (BOBLME 2012)) are very similar (Figure 4).

The earliest estimate of inland catches is for 1984 in Bangladesh (90,000 t) and 1992 in India (39,298 t). Assuming that inland catches were at least as large in 1978, the total catch amounts to 143,521 t in Bangladesh and 80,190 t in India. Malaysian catches are rather modest (4,569 t) and composed of *Tenualosa macrura* (Rudolf Hermes, FAO, pers. comm.)while in Myanmar, hilsa catches are undistinguishable from other clupeids and cannot be included here (A6). In 1978, the marine catch estimated for Bangladesh constitutes about 60% of that of the entire Bay of Bengal.

The recent stock assessment performed in 2012 provides a time series of biomass based on Bangladesh marine and freshwater catches and CPUE time series for the period 1984-2006, and CPUE time series compiled for Bangladesh fishery (BOBLME 2012). The biomass estimate was obtained using a surplus production model for the period 1987-20006,and projections were made until 2010 based on observed catches and projected effort reductions (Rishi Sharma, pers. comm.).According to the assessment, exploitation rate (=C/B) for this stock increased from 0.14 in 1987 to 0.29 in 2006. The biomass was scaled for the Bay of Bengal (B_{tot}) by using the 1987 C/B ratio (0.14/year) to divide the estimated Bay of Bengal catch (regions 2 and 3) for a minimum estimated biomass of 1,581,156 t or 1.75 t/km^2.

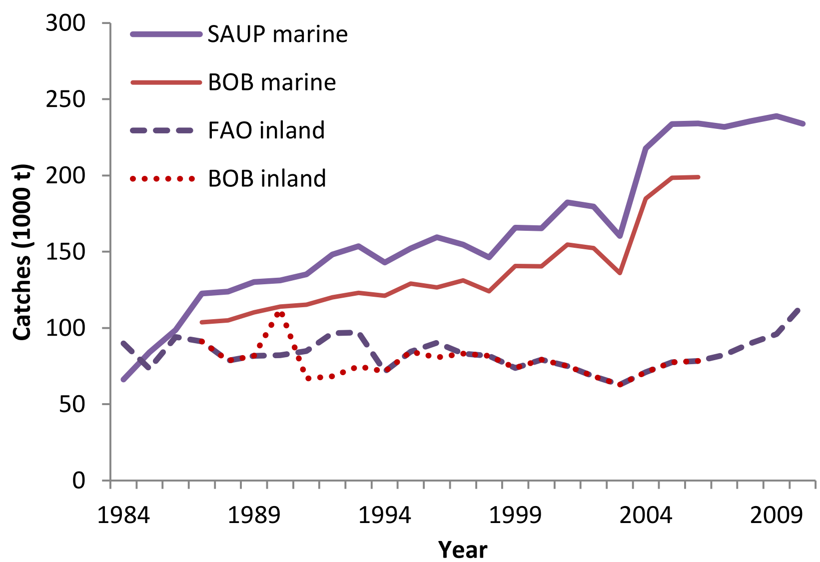

Figure 4. Hilsa catches in marine waters and inland in Bangladesh, as reconstructed by the Sea Around Us Project (SAUP), FAO, and the Bay of Bengal team (BOB).

Based on the assessment, it was concluded that the stock was below optimal yield in both Bangladesh and India and that current catch levels may not be sustainable (BOBLME 2012). In the 1960s, hilsa was composed mainly of 3-year-old while 90% of the commercial catches was composed of fish of less than 1 year old in 1999, showing signs of overfishing (Milton 2010). Also, a larger portion of the habitat is exploited nowadays. The depletion may have been partially masked by the introduction of mechanised boats and nylon twine in the early 1980s, which allowed the fishery to move from rivers and coastal areas to increasingly wider areas of the Bay extending up to 200-250 km from the coastline (Milton 2010). Rivers constitute an important habitat as juveniles spend 7 months growing in rivers and then spend most of their lives in the ocean (Amin et al. 2008; Milton 2010). Thus, the damming of some rivers destroyed some fisheries and reduced habitat and hilsa production (Milton 2010). These aspects of the life history are not included in the model.

[1]FishStatJ 2010, http://www.fao.org/fishery/statistics/software/fishstat/en

Indian mackerel

Indian mackerel (mainly *Rastrelliger kanagurta*) straddles region 2 and 3. Noble et al. (1992) present the earliest stock assessment for Indian mackerel along the Indian coast. Natural mortality was estimated at 1 /year based on maturity at 1 year old and Rikhter and Evanov (1976) method. F was estimated at 1.9/year on the west coast of India for the period 1984-1988 using length cohort analysis (Noble et al. 1992). The authors concluded that the stock was exploited at higher levels than F_{MSY} and that fishing mortality should be decreased by 61%. In contrast,based on catch curves, Abdussamad et al. (2010) estimated fishing mortality at 3.5 to 7 per year between 1997 and 2007 along the Tuticorin coast (Tamil Nadu).

Table 11. Indian mackerel biomass, catches, and F by region as obtained from surveys and catch statistics. Densities are presented for the shelf area.

Region	Biomass t/km^2	Catch $t/km^2/year$	F=C/B /year
2	0.79	0.61	0.77
3	0.06	0.24	4.28
Total	0.23	0.33	1.44

The estimated biomass based on the survey amounts to 0.79 t/km^2 in region 2, leading to ratio C/B=0.77/year (Table 11). In region 3, the biomass estimate is too low, as the catch is 4 times higher. Assuming, F=0.77/year, the biomass would be at least of 0.43 t/km^2 for regions 2 and 3. Again, an exploitation rate of 0.77 /year seems high for the late 1970s.

Benthic invertebrates

Benthic animals were first divided into crustaceans, macrobenthos, and meiobenthos. The separation between crustaceans (shrimps and crabs) and other species of macrobenthos was felt necessary for predator-prey relationships and the important commercial shrimp and crab/lobster fisheries especially in Bangladesh (Holmgren 1994). However, the available biomass estimates were given for both groups in aggregation (Holmgren 1994; Ansari et al. 2012). As a first trial, 25% of the estimated biomass of benthic invertebrates was arbitrarily assigned to crustaceans and 75% to the macrobenthosgroup (Table 12). In region 3, biomasses were based on Myanmar, Thailand and Andaman only. In region 2, data was only available for the Indian coast. In region 1, crustaceans and other macrobenthos were grouped for lack of information and the biomass was left to be estimated by Ecopath using an EE of 0.8. The P/B ratio was assumed to be similar to the one calculated for the Mauritanian coast (0.15/year, Guénette et al. 2014). The P/Q ratio (0.15) was taken from Jarre-Teichmann (1996).

These biomasses were estimated in coastal habitats and ignore deep-water crustaceans. For instance, Suman et al. (2006) sampled 7124 km^2 at depth between 200 m and 1000 m and estimated the biomass of shrimps (e.g. *Aristeus virilis*, *Acanthephyra armata*, *Heterocarpus* sp.) and deep-sea scampi (*Nephropsis stewarti* and *Puerulus angulatus*) at 0.2 t/km^2, a relatively small biomass compared to coastal areas. The authors state that the coastal fishery for shrimps in Indonesia is now taking 268% of the maximum sustainable yield.

Meiobenthos biomass was obtained from Holmgren (1994). The P/B ratio (9/year) was taken from (Gerlach 1971). The P/Q ratio was set at the same value as that of the macrobenthos (0.15). The biomasses retained for the EEZ assumed that the biomass in deeper waters were half that of the shelf.

Table 12. Crustaceans and macrobenthos biomass, catches, and F by region as obtained from surveys and catch statistics. Densities are presented for the shelf area.

Region	Group	Biomass t/km^2	Catch $t/km^2/year$	F=C/B /year
1	macrobenthos	-	2.1E-06	-
2	crustaceans	6.82	2.24	0.33
	macrobenthos	13.65	4.47	0.03
	meiobenthos	13.84	-	-
3	crustaceans	2.78	0.63	0.23
	macrobenthos	8.35	0.09	0.01
	meiobenthos	6.86	-	-

Jellyfish

Jellyfishes can be important in ecosystems and swarm in coastal areas in large numbers for short periods of time (Mills 2001; Hay 2006; Lynam et al. 2006; Brotz et al. 2012). However, the level of knowledge is rather low in the study area. In absence of local biomass estimate, the value for FAO area 57 used for global modelling was kept (Alder et al. 2007; Christensen et al. 2009). P/B=3/year was taken from Guénette (2005) and P/Q=0.3 from Arai (1996). The diet was also taken from Arai (1996).

Cephalopods

There is not much information on cephalopods in the study area. In Bangladesh, *Sepia* sp, *Loligo* sp and *Octopus vulgaris* were observed in the 10-100 m depth zone (Hossain 2004).

Octopus mortality was estimated at 0.1/month for a life span of about 1.5 year and adults dying massively after spawning (Morocco population, Robert et al. 2010). Thus, M was estimated at 1.2 /year. Q/B was estimated by the model using a P/Q value of 0.3. Other cephalopods were assumed to have similar natural mortality and P/Q ratio as octopus. The biomasses derived from trawl survey (in region 3 only) underestimated the biomass at levels below catches. Thus, the biomass was left to be estimated by EwE using EE=0.9. Diet compositions were derived from qualitative and quantitative studies for *Octopus vulgaris*(Gonçalves 1991), *Loligo forbesi* and *L. vulgaris*(Rost Martins 1982; Pierce et al. 1994; Hanlon and Messenger 1996), *Loligo pealei*(Vovk 1985), and *Illex illecebrosus*(Froerman 1984).

Zooplankton

The biomass of zooplankton estimated based on 2 transects in the Bay of Bengal aggregated mesozooplankton (copepods, fish and invertebrate larvae, etc.) as well as larger and carnivorous zooplankton such as chaetognaths and euphausids. Thus, the group labeled zooplankton includes both herbivorous and carnivorous zooplankton.

In region 2, the biomass is of the estimate for coastal and open waters of India (Prasanna Kumar et al. 2007, table 2). The average was weighted by surface area, coastal waters representing 18% of the Indian EEZ (Table 13).The biomass estimate derived for Thailand was not very high (2 t/km^2) probably not representative of region 3, and was not used in the model. Biomass of regions 1 and 3 was left to be estimated by Ecopath using EE=0.6. P/B=24 and Q/B=112 was based on Aydin et al.(2003).

Table 13. Estimates of zooplankton available in the study area. WW=wet weight

Country	Location	Biomass	Unit	Source	Resulting biomass g /m^2
Thailand	coastal	20	mg WW/m^3	(Holmgren 1994)	2 *a*
India	coastal	16.93	g WW/m^2	(Prasanna Kumar et al. 2007, table2)	10.7
	open seas	9.36	g WW/m^2		

a assuming a mean depth of 100 m; not used

Primary producers

Current estimates of phytoplankton production were obtained from the Sea Around Us Project (www.seaaroundus.org/). The production in mgC/m^2/day was transformed in wet weight per year (WW t/km^2/year) by assuming a ratio C:WW of 1:9 (Pauly and Christensen 1995). Primary production estimated from other studies is provided for comparison (Table 14).

Assuming a P/B ratio of 100/year, the standing biomass would be estimated at 12 t/km^2 in region 1, 29 t/km^2 in region 2 and 21 t/km^2 in region 3. in comparison, the standing biomass was estimated at 9 t/km^2 on the Indian coast and (7 t/km^2) offshore of India (table 2 in Prasanna Kumar et al. 2007).

Benthic primary producers such as seaweeds are known to be important in some areas of the Bay of Bengal, but very little is known about their biomasses and exploitation. The group has been included as a place holder and for diet purposes. The P/B (4.1/year) was derived from detailed work performed in Mauritania (Vermaat et al. 1993). A low EE was assumed for this group.

Table 14. Estimates of primary productivity by country EEZ obtained from the Sea Around Us Project (SAUP) web page compared with other sources. WW=wet weight; PP=primary production

Region	Entity	EEZ Area (km^2)	PP g WW/m2/year		
			SAUP, current	**Prasanna Kumar et al. (2007), 2001-2006[a]**	**Holmgren (1994)<1982[a]**
1	Maldives	915,423	1261		
1	High Seas	1,929,874	1179	757	
2	Bangladesh	84,846	5614		
2	India	666,670	3324	1065 [b]	1440
2	Sri Lanka	530,943	1994		
3	India (Andaman & Nicobar)	659,573	1501		
3	Indonesia (Western)	719,333	1820		
3	Malaysia (West Peninsula)	68,317	4293		
3	Myanmar	511,356	3088		
3	Thailand	118,717	2332		
		6,205,051			

[a] Using the gC:WW=1:9 to convert PP values
[b] coastal area only

Birds and mammals

Only a few species of marine birds have been listed for the Bay of Bengal, and only partial population estimates mostly outdated, are available for the Bay of Bengal (Mondreti et al. 2013). From the estimates provided in the review document, the region counts a minimum of about 76,000 marine birds (~ 20 tonnes) for which very little is known. At this point the inclusion of marine birds in the model would act mainly as a place holder.

Marine mammals are also not very well known in terms of species composition and abundance. Some estimates are available for *Orcaella brevirostris* and *Neophocaena phocaenoides* in coastal waters of Bangladesh (Smith et al. 2008). Afsal et al. (2008) describe the distribution and number of sightings of 10 species compiled from 35 opportunistic surveys in Indian Seas (continental and Andaman & Nicobar Islands). Another 16 species are known to occur in Indian waters but were not observed during the survey. No biomass estimates were derived from these observations.

Detritus

Detritus biomass (*D*, in gC/m2) was estimated using an empirical equation [Pauly, 1993 #3095] based on primary production and depth of the photic zone:

$Log_{10}D=-2.41 + 0.954Log_{10}(PP) + 0.863Log_{10}(E)$

where PP is primary production in $gC/m^2/year$, and E the euphotic zone (set at 40 m). Using PP of 1206, 2925 and 2141 $gWW/m^2/year$ for regions 1, 2 and 3 respectively, and a conversion ratio C:WW of 1:9 (Pauly and Christensen 1995),the total detritus biomass was estimated at 137 t/km^2.

Balancing the model

Using the input values (see Table 15 for parameters and Appendix A3.2 for initial diet composition), Ecopath solves simultaneous linear equations and estimates the missing parameters, often the Ecotrophic Efficiency (EE) value. The balancing process is done manually by checking inconsistencies in data, adjusting biomasses, P/B ratio, and diet composition, starting with parameters that were deemed less reliable(see user guide for more detail on this). As such, diet compositions are often modified on account of the uncertainty caused by seasonal and individual variation and sampling error. Overestimates of the proportion of rare prey in the diet of an abundant predator is a common source of excessive mortality. The biomasses of several functional groups were deemed uncertain and especially, in region 3 where they were systematically lower per unit area of shelf that in other regions. Thus biomasses were often modified to provide enough prey to predators and balance the model.

In all regions, consumption on carangids was too high, mainly because of biases in SM pisc diet composition in addition to over predation from coastal scombrids and tuna-like groups. The biomass of carangids was increased in all regions and especially in region 3 where the initial biomass was estimated at 0.35 t/km^2; and needed to be increased 10-fold (Table 16). Also, the problematic diets were modified (Table 17). In region 1, some of the problems with carangids were caused by a large biomass of Lpisc as estimated by Ecopath. To decrease the biomass, L pisc cannibalism was decreased and its importance in the diet of other fish (e.g. SM pisc, carangids) was decreased.

The biomass of benthic invertebrates was increased in all regions to accommodate predation pressure, and P/B was increased for SM inv in all regions. Cephalopods are a largely unknown component although they are an important predator in the system. To maintain their biomass at lower levels and reduce pressure on fish, cephalopod cannibalism was reduced. Finally, hilsa biomass was increased from 1.75 to 2.4 t/km^2 and that of Indian mackerel from 0.43 to 1.9 t/km^2.

Finally, after balancing, some groups seem to be not very well modelled. For instance, the group 1L pisc comm with its large biomass has an estimated EE of 0.4 which can indicate bias in diet or overestimate of their biomass or P/B. The same can be said for S bathy as a large portion of their production is unexplained by the model. The biomass of oceanic shark does not seem to be too low resulting in an EE of 0.58, meaning that the mortality unexplained by the model is very high. In contrast, EE is very high for coastal elasmobranch, which is caused in part by the relatively highcatch relative to biomass input in the model.

A word of caution: It is important to remember that the current Ecopath model is one image of the ecosystem given the data available and choices made for each parameter at the input stage and the modifications made to balance the model. Changing the assumptions would change biomasses and P/B values and possibly the strength of the foodweb links.

Table 15. Summary of the input parameters into Ecopath

	Group name	Habitat area (fraction)	Biomass in habitat area (t/km²)	P/B (/year)	Q/B (/year)	EE	P/Q	Unassimil. / consumption	Detritus import (t/km²/year)
1	Oceanic sharks	1	0.202	0.249			0.15	0.2	0
2	Coastal elasmobranch	0.689	0.118	0.66			0.15	0.2	0
3	Tuna-like	1	0.124	0.46			0.2	0.2	0
4	Coastal scombrids	0.689	0.151	0.84			0.2	0.2	0
5	Jellyfish	1	0.5	3			0.3	0.2	0
6	Cephalopods	1		1.2		0.9	0.3	0.2	0
7	S bathy	0.849	3.28	2.14			0.25	0.2	0
8	ML bathy	0.849		0.37		0.9	0.2	0.2	0
9	1 L pisc	0.005		0.76		0.9	0.2	0.2	0
10	1 Carangids	0.005	0.48	0.78			0.2	0.2	0
11	1 S pelagics	0.005		2.39		0.95	0.25	0.2	0
12	1 L pisc comm	0.005	4.48	0.42			0.2	0.2	0
13	1 SM inv	0.005		1.57		0.95	0.25	0.2	0
14	1 SM pisc	0.005		1.33		0.95	0.25	0.2	0
15	1 Macrobenthos	0.459		2		0.8	0.15	0.2	0
16	1 Meiobenthos	0.459		9		0.8	0.15	0.2	0
17	1 Zooplankton	0.459		24	112	0.6		0.2	0
18	2 L pisc	0.034		0.76		0.9	0.2	0.2	0
19	2 Carangids	0.034	1.77	0.76			0.2	0.2	0
20	2 S pelagics	0.034		2.94		0.95	0.25	0.2	0
21	2 L pisc comm	0.034	4.42	0.89			0.2	0.2	0
22	2 Milkfish plus	0.034		0.38		0.95	0.2	0.2	0
23	2 SM inv	0.034		1.57		0.95	0.25	0.2	0
24	2 SM pisc	0.034		1.33		0.95	0.25	0.2	0
25	2 Crustaceans	0.034	3.98	2			0.15	0.2	0
26	2 Macrobenthos	0.207	7.96	2			0.15	0.2	0
27	2 Meiobenthos	0.207	8.07	9			0.15	0.2	0
28	2 Zooplankton	0.207	11	24	112			0.2	0
29	2,3 Hilsa	0.146	1.75	1.76			0.25	0.2	0
30	2,3 Indian mackerel	0.146	0.43	2.29			0.2	0.2	0
31	3 L pisc	0.111		0.76		0.9	0.2	0.2	0
32	3 Carangids	0.111	0.348	1.24			0.2	0.2	0
33	3 S pelagics	0.111	0.643	2.29			0.25	0.2	0
34	3 L pisc comm	0.111		0.89		0.9	0.2	0.2	0
35	3 Milkfish plus	0.111		0.38		0.9	0.2	0.2	0
36	3 SM inv	0.111	0.625	1.57			0.25	0.2	0
37	3 SM pisc	0.111		1.33		0.95	0.25	0.2	0
38	3 Crustaceans	0.335	1.854	2			0.15	0.2	0
39	3 Macrobenthos	0.335	5.563	2			0.15	0.2	0
40	3 Meiobenthos	0.335	4.57	9			0.15	0.2	0
41	3 Zooplankton	0.335		24	112	0.6		0.2	0
42	1 Phytoplankton	0.459	12.1	100				0	0
43	2 Phytoplankton	0.207	29.3	100				0	0
44	3 Phytoplankton	0.335	21.4	100				0	0
45	Benthic plants	0.689		4.1		0.4		0	0
46	Bigeye tuna	1		0.33		0.9	0.2	0.2	0
47	Yellowfin tuna	1		0.34		0.9	0.2	0.2	0
48	Marlins	1		0.39		0.9	0.2	0.2	0
49	Detritus	1	137			0		0	0

Table 16. Parameters of the **balanced** model. The values in bold indicate parameters estimated by Ecopath.

	Group name	Trophic level	Fraction of habitat area	Biomass in habitat area (t/km²)	Biomass (t/km²)	P/B (/year)	Q/B (/year)	EE	P/Q
1	Oceanic sharks	**4.22**	1	0.202	0.202	0.249	**1.66**	**0.582**	0.15
2	Coastal elasmobranch	**4.17**	0.689	0.118	0.081	0.66	**4.4**	**0.944**	0.15
3	Tuna-like	**4.55**	1	0.15	0.150	0.46	**2.3**	**0.894**	0.2
4	Coastal scombrids	**4.25**	0.689	0.151	0.104	0.84	**4.2**	**0.598**	0.2
5	Jellyfish	**3**	1	0.5	0.500	3	**10**	**0.066**	0.3
6	Cephalopods	**3.89**	1	**0.569**	0.569	1.2	**4**	0.9	0.3
7	S bathy	**3**	0.849	3.28	2.785	2.14	**8.56**	**0.132**	0.25
8	ML bathy	**3.51**	0.849	**0.270**	0.230	0.37	**1.85**	0.9	0.2
9	1 L pisc	**4.08**	0.005	**1.780**	0.009	0.76	**3.8**	0.9	0.2
10	1 Carangids	**3.96**	0.005	2.2	0.011	0.78	**3.9**	**0.968**	0.2
11	1 S pelagics	**3.10**	0.005	**5.446**	0.027	2.39	**9.56**	0.95	0.25
12	1 L pisc comm	**3.84**	0.005	4.48	0.022	0.42	**2.1**	**0.400**	0.2
13	1 SM inv	**3.08**	0.005	**7.970**	0.040	2	**8**	0.95	0.25
14	1 SM pisc	**3.60**	0.005	**5.723**	0.029	1.33	**5.32**	0.95	0.25
15	1 Macrobenthos	**2.37**	0.459	**1.337**	0.614	2	**13.33**	0.8	0.15
16	1 Meiobenthos	**2**	0.459	**0.502**	0.230	9	**60**	0.8	0.15
17	1 Zooplankton	**2**	0.459	**1.822**	0.836	24	112	0.6	**0.21**
18	2 L pisc	**4.10**	0.034	**4.431**	0.151	0.76	**3.8**	0.9	0.2
19	2 Carangids	**3.98**	0.034	5	0.170	0.76	**3.8**	**0.920**	0.2
20	2 S pelagics	**3.13**	0.034	**7.746**	0.263	2.94	**11.76**	0.95	0.25
21	2 L pisc comm	**3.90**	0.034	4.42	0.150	0.89	**4.45**	**0.919**	0.2
22	2 Milkfish plus	**3.50**	0.034	**4.104**	0.140	0.38	**1.9**	0.95	0.2
23	2 SM inv	**3.11**	0.034	**12.127**	0.412	2	**8**	0.95	0.25
24	2 SM pisc	**3.68**	0.034	**8.793**	0.299	1.33	**5.32**	0.95	0.25
25	2 Crustaceans	**2.62**	0.034	24	0.816	3	**20**	**0.892**	0.15
26	2 Macrobenthos	**2.34**	0.207	12	2.484	2.5	**16.67**	**0.847**	0.15
27	2 Meiobenthos	**2**	0.207	10	2.070	9	**60**	**0.816**	0.15
28	2 Zooplankton	**2**	0.207	11	2.277	24	112	**0.281**	**0.21**
29	2,3 Hilsa	**2.36**	0.146	2.4	0.350	1.76	**7.04**	**0.935**	0.25
30	2,3 Indian mackerel	**3.05**	0.146	1.9	0.277	2.5	**12.5**	**0.934**	0.2
31	3 L pisc	**4.23**	0.111	**1.662**	0.185	0.76	**3.8**	0.9	0.2
32	3 Carangids	**3.98**	0.111	3.5	0.389	1.24	**6.2**	**0.983**	0.2
33	3 S pelagics	**3.15**	0.111	5.6	0.622	2.29	**9.16**	**0.925**	0.25
34	3 L pisc comm	**3.94**	0.111	**1.472**	0.163	0.89	**4.45**	0.9	0.2
35	3 Milkfish plus	**3.52**	0.111	**1.604**	0.178	0.38	**1.9**	0.9	0.2
36	3 SM inv	**3.13**	0.111	8	0.888	2	**8**	**0.929**	0.25
37	3 SM pisc	**3.75**	0.111	**6.120**	0.679	1.33	**5.32**	0.95	0.25
38	3 Crustaceans	**2.63**	0.335	9	3.015	3	**20**	**0.948**	0.15
39	3 Macrobenthos	**2.37**	0.335	13	4.355	2	**13.33**	**0.944**	0.15
40	3 Meiobenthos	**2**	0.335	13	4.355	9	**60**	**0.928**	0.15
41	3 Zooplankton	**2**	0.335	**6.971**	2.335	24	112	0.6	**0.21**
42	1 Phytoplankton	**1**	0.459	12.1	5.554	100	0	**0.153**	
43	2 Phytoplankton	**1**	0.207	29.3	6.065	100	0	**0.389**	
44	3 Phytoplankton	**1**	0.335	21.4	7.169	100	0	**0.337**	
45	Benthic plants	**1**	0.689	**1.139**	0.784	4.1	0	0.4	
46	Bigeye tuna	**4.43**	1	**0.014**	0.014	0.33	1.65	0.9	0.2
47	Yellowfin tuna	**4.76**	1	**0.022**	0.022	0.34	1.7	0.9	0.2
48	Marlins	**4.67**	1	**0.003**	0.003	0.39	1.95	0.9	0.2
49	Detritus	**1**	1	137	137			**0.332**	

Table 17. Diet matrix from balanced model. Values in bold differ from the original diet by 0.1% or more.

Prey	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 Oceanic shark	0.0066	0.0295	0	0	0	0	0	0	0	0	0	0	0	0	0
2 Coastal shark ray	0.0129	0.0581	0	0	0	0	0	0	0	0	0	0	0	0	0
3 Tuna-like	0.0834	0.0018	0.0306	0	0	0	0	0.0019	0.0030	0	0	0	0	0	0
4 Coastal scombrids	0.0111	0.0018	**0.0490**	0	0	0	0	0.0019	0	0	0	0	0	0	0
5 Jellyfish	0.0100	0	0	0	0	0	0	0	0	0.0125	0	0	0.0053	0	0
6 Cephalopods	0.1605	0.0110	0.1124	0.0322	0	0.0100	0	0.0640	0.0666	0.0631	0.0002	0.0236	**0.0026**	0.0103	0
7 1 S bathy	0.0379	0.0000	0.0561	**0.0220**	0	**0.1100**	0	**0.0750**	**0.1260**	**0.0331**	0	**0.0874**	0.0000	**0.0650**	0
8 1 ML bathy	0.0658	0.0053	0.0246	0	0	0	0	0.0290	**0.0628**	0.0000	0	**0.0370**	0	0	0
9 1 L pisc	0.0027	0.0032	0.0005	0.0003	0	0	0	0.0030	0.0150	0.0152	0	0.0121	0	0.0013	0
10 1 Carangids	0.0007	0.0008	0.0020	0.002	0	0.0010	0	0	0.0200	0.0300	0.0001	0.02	0	0.0001	0
11 1 S pelagics	0.0012	0.0010	0.0083	0.0093	0	0.0019	0	0.0066	0.2702	0.2290	0.0223	0.04	**0.0240**	0.0800	0
12 1 L pisc comm	0.0006	0.0005	0	0	0	0	0	0	0.0225	0.0110	0	0.012	0.0004	0.0045	0
13 1 SM inv	0.0019	0.0038	**0.0088**	**0.0360**	0	0.0037	0	0.0053	0.1548	0.2371	**0.0198**	0.1603	0.0078	0.0869	0
14 1 SM pisc	0.0030	0.0032	0.0019	0.0010	0	0.0037	0	0.0106	0.0496	0.0837	0.0123	0.1097	0.0010	0.0373	0
15 1 Macrobenthos	0.0012	0.0000	0.0000	0.0038	0	0.0460	0	0.1961	0.1840	0.1737	**0.1970**	0.4634	0.5940	0.7013	0.05
16 1 Meiobenthos	0.0004	0	0	0	0	0	0	0	0	0.0004	**0.0250**	0	**0.050**3	0.0001	0.20
17 1 Zooplankton	0.0024	0	0.0005	0.0004	0	0	0.4585	0.1509	0.0245	**0.090**0	0.6810	0.0345	0.1307	0.0123	0.10
18 2 L pisc	0.0188	0.0222	0.0033	0.0023	0	0	0	0.0042	0	0	0	0	0	0	0
19 2 Carangids	0.0050	0.0058	0.0582	0.0409	0	0.0010	0	0	0	0	0	0	0	0	0
20 2 S pelagics	0.0082	0.0072	0.0569	0.0641	0	**0.0200**	0	0.0030	0	0	0	0	0	0	0
21 2 L pisc comm	0.0041	0.0037	0	0	0	0	0	0	0	0	0	0	0	0	0
22 2 Mikfish plus	0.0013	0.0010	0.0068	1.E-06	0	0	0	0	0	0	0	0	0	0	0
23 2 SM inv	0.0128	0.0261	0.0060	0.0300	0	**0.0304**	0	0.002	0	0	0	0	0	0	0
24 2 SM pisc	0.0210	0.0224	0.0133	0.0071	0	0.0254	0	0.0048	0	0	0	0	0	0	0
25 2 Crustaceans	5E-05	0.0646	0.0000	0.0198	0	0.0570	0	0	0	0	0	0	0	0	0
26 2 Macrobenthos	0.0080	0.0233	0	0.0064	0	**0.05**	0	0.0884	0	0	0	0	0	0	0
27 2 Meiobenthos	0.0029	0	0	0	0	0.0104	0	0	0	0	0	0	0	0	0
28 2 Zooplankton	0.0166	0	0.0038	0.0002	0	0	0.2067	0.0680	0	0	0	0	0	0	0
29 2,3 Hilsa	0.0413	0.0208	0.0226	0.0168	0	0.0100	0	0	0	0	0	0	0	0	0
30 2,3 Indian mackerel	0.0290	0.0226	0.0327	0.0619	0	0.0251	0	0.0019	0	0	0	0	0	0	0
31 3 L pisc	0.0607	0.0718	0.0106	0.0075	0	0	0	0.0068	0	0	0	0	0	0	0
32 3 Carangids	0.0163	0.0188	0.1884	0.1324	0	0.0200	0	0	0	0	0	0	0	0	0
33 3 S pelagics	0.0264	0.0232	0.1843	0.2075	0	0.0350	0	0.0049	0	0	0	0	0	0	0
34 3 L pisc comm	0.0133	0.0121	0	0	0	0	0	0	0	0	0	0	0	0	0
35 3 Milkfish plus	0.0041	0.0034	0.0221	5E-06	0	0	0	0	0	0	0	0	0	0	0
36 3 SM inv	0.0415	0.0844	0.0403	0.1876	0	0.0821	0	0.0039	0	0	0	0	0	0	0
37 3 SM pisc	0.0679	0.0725	0.0432	0.0229	0	0.0821	0	0.0078	0	0	0	0	0	0	0
38 3 Crustaceans	1E-04	0.2091	0.0000	0.0640	0	0.3483	0	0	0	0	0	0	0	0	0
39 3 Macrobenthos	0.0257	0.0755	0	0.0207	0	0.0268	0	0.1432	0	0	0	0	0	0	0
40 3 Meiobenthos	0.0092	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 3 Zooplankton	0.0538	0	0.0122	0.0007	1	0	0.3348	0.1101	0	0	0	0	0	0	0
42 1 Phytoplankton	0.0021	0	0	0	0	0	0	0	0	0.0117	0.0340	0	0.0345	0	0.10
43 2 Phytoplankton	0.0144	0	0.0008	0	0	0	0	0	0	0	0	0	0	0	0
44 3 Phytoplankton	0.0466	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45 Benthic plants	0.0016	0	0.0002	0	0	0	0	0	0.0010	0	0	0.0003	0.1161	0.0001	0
46 Bigeye tuna	0.0000	0	0.0000	0	0	0	0	0	0.0000	0	0	0	0.0000	0.0000	0
47 Yellowfin tuna	0.0000	0	0.0000	0	0	0	0	0	0.0000	0	0	0	0.0000	0.0000	0
48 Marlins	0.0000	0	0.0000	0	0	0	0	0	0.0000	0	0	0	0.0000	0.0000	0
49 Detritus	0.0405	0.0086	0	0	0	0	0	0	0	0.0092	0.0084	0	0.0327	0	0.55
50 Import	0.0043	0.0798	0	0	0	0	0	0.0058	0	0	0.0001	0	0.0010	0.0002	0

Prey \ predator	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1 Oceanic shark	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2 Coastal shark ray	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3 Tuna-like	0	0	0.0030	0	0	0	0	0	0	0	0	0	0	0
4 Coastal scombrids	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5 Jellyfish	0	0	0	0.0125	0	0	0	0.0053	0	0	0	0	0	0
6 Cephalopods	0	0	0.0666	0.0631	0.0002	0.0236	0.0206	0.0016	0.0103	0	0	0	0	0
7 1 S bathy	0	0	**0.0600**	**0.0340**	0	**0.0624**	0	0	**0.0290**	0	0	0	0	0
8 1 ML bathy	0	0	0.0190	0	0	0.0027	0	0	0	0	0	0	0	0
9 1 L pisc	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10 1 Carangids	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11 1 S pelagics	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12 1 L pisc comm	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13 1 SM inv	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14 1 SM pisc	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15 1 Macrobenthos	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 1 Meiobenthos	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17 1 Zooplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18 2 L pisc	0	0	0.0150	0.0080	0	0.0121	0	0	0.0000	0	0	0	0	0
19 2 Carangids	0	0	0.0100	0.0153	0.0032	0.0200	0	0.0019	0.0050	0	0	0	0	0
20 2 S pelagics	0	0	**0.2610**	0.1579	0.0139	0.0606	0	**0.0210**	**0.0770**	0	0	0	0	0
21 2 L pisc comm	0	0	0.0225	0.0110	0	0.0120	0.0260	0.0004	0.0045	0	0	0	0	0
22 2 Mikfish plus	0	0	0.0329	0.0001	0	0.0128	0	0	0.0027	0	0	0	0	0
23 2 SM inv	0	0	**0.1719**	0.2370	0.0188	0.1476	0.0260	0.0078	**0.0942**	0	0	0	0	0
24 2 SM pisc	0	0	**0.0600**	0.0837	0.0123	0.1097	0	0.0010	0.0373	0	0	0	0	0
25 2 Crustaceans	0	0	0.1610	0.1183	0.1000	**0.2796**	0.2440	0.1500	0.3500	0.01	0	0	0	0
26 2 Macrobenthos	0	0	0.0229	0.0554	0.0940	0.1837	0.6571	**0.4440**	**0.3500**	**0.04**	0.03	0	0	0
27 2 Meiobenthos	0	0	0.0000	0.0004	0.0101	0	0	0.0473	0.0001	0.40	0.20	0	0	0
28 2 Zooplankton	0	0	0.0245	0.0533	0.6810	0.0345	0.0003	0.1307	0.0123	0.15	0.10	0	0	0.2928
29 2,3 Hilsa	0	0	0.0395	0.0576	0.0155	0.0127	0.0260	0.0025	0.0172	0	0	0	0	0
30 2,3 Indian mackerel	0	0	0.0292	0.0711	0.0084	0.0253	0	0.0020	0.0100	0	0	0	0	0
31 3 L pisc	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 3 Carangids	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 3 S pelagics	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34 3 L pisc comm	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35 3 Milkfish plus	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36 3 SM inv	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 3 SM pisc	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38 3 Crustaceans	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39 3 Macrobenthos	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40 3 Meiobenthos	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41 3 Zooplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0046
42 1 Phytoplankton	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0
43 2 Phytoplankton	0	0	0	0.0117	0.0340	0	0	0.0345	0	0	**0.12**	0	0.90	0.4974
44 3 Phytoplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0079
45 Benthic plants	0	0	0.0010	0	0	0.0003	0	0.1161	0.0001	0	0	0	0	0.0160
46 Bigeye tuna	0	0	0.0000	0	0	0.0000	0	0.0000	0.0000	0	0	0	0	0.0000
47 Yellowfin tuna	0	0	0.0000	0	0	0.0000	0	0.0000	0.0000	0	0	0	0	0.0000
48 Marlins	0	0	0.0000	0	0	0.0000	0	0.0000	0.0000	0	0	0	0	0.0000
49 Detritus	1	0.1	0	0.0092	0.0084	0	0	0.0327	0	0.40	0.55	1	0.10	0
50 Import	0	0	0	0	0.0001	0	0	0.0010	0.0002	0	0	0	0	0.1814

	Prey \ predator	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**46**	**47**	**48**
1	Oceanic shark	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Coastal shark ray	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Tuna-like	0	0.0030	0	0	0	0	0	0	0	0	0	0	0.0216	0	0.0313
4	Coastal scombrids	0	0	0	0	0	0	0	0	0	0	0	0	0.0216	0	0.07443
5	Jellyfish	0	0	0.0125	0	0	0	0.0053	0	0	0	0	0	0	0	0
6	Cephalopods	0	0.0666	0.0631	0.0002	0.0236	0.0206	0.0016	0.0103	0	0	0	0	0.061	0.7741	0.19763
7	1 S bathy	0	0.0147	0.0760	0	0.0414	0	0	0.0200	0	0	0	0	0.1946	0.0152	0
8	1 ML bathy	0	0.0028	0	0	0.0027	0	0	0	0	0	0	0	0.3243	0	0.0588
9	1 L pisc	0	0	0	0	0	0	0	0	0	0	0	0	0.0021	0	0.0024
10	1 Carangids	0	0	0	0	0	0	0	0	0	0	0	0	0.0021	0.0005	0.0040
11	1 S pelagics	0	0	0	0	0	0	0	0	0	0	0	0	0.0021	0.0005	0.0075
12	1 L pisc comm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	1 SM inv	0	0	0	0	0	0	0	0	0	0	0	0	0.0021	0.0020	0.0021
14	1 SM pisc	0	0	0	0	0	0	0	0	0	0	0	0	0.0011	0.0012	0.0016
15	1 Macrobenthos	0	0	0	0	0	0	0	0	0	0	0	0	0.0011	0	0.0010
16	1 Meiobenthos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	1 Zooplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	2 L pisc	0	0	0	0	0	0	0	0	0	0	0	0	0.0148	0	0.0170
19	2 Carangids	0	0	0	0	0	0	0	0	0	0	0	0	0.0148	0.0035	0.0277
20	2 S pelagics	0	0	0	0	0	0	0	0	0	0	0	0	0.0148	0.0035	0.0514
21	2 L pisc comm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	2 Mikfish plus	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0131	0
23	2 SM inv	0	0	0	0	0	0	0	0	0	0	0	0	0.0148	0.0136	0.0143
24	2 SM pisc	0	0	0	0	0	0	0	0	0	0	0	0	0.0074	0.0080	0.0107
25	2 Crustaceans	0	0	0	0	0	0	0	0	0	0	0	0	0.0071	0	0.0071
26	2 Macrobenthos	0.1509	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	2 Meiobenthos	0.0541	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	2 Zooplankton	0.1260	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	2,3 Hilsa	0.0100	0.0395	0.0300	0.0155	0.0127	0.0260	0.0025	0.0172	0	0	0	0	0.0324	0.0152	0
30	2,3 Indian mackerel	0.0277	0.0292	0.0500	0.0084	0.0253	0	0.0020	0.0110	0	0	0	0	0.0216	0.0152	0.0450
31	3 L pisc	0	0.0200	0.0050	0	0.0121	0	0	0.0013	0	0	0	0	0.0479	0	0.0545
32	3 Carangids	0	0.1352	0.0153	0.0020	0.0414	0	0.0019	0.0200	0	0	0	0	0.0479	0.0112	0.0896
33	3 S pelagics	**0.018**	0.2410	0.1200	0.0139	0.0606	0	**0.0180**	**0.0670**	0	0	0	0	0.0479	0.0112	0.1663
34	3 L pisc comm	0	0.0225	0.0110	0	0.0120	0.0260	0.0004	0.0045	0	0	0	0	0	0	0
35	3 Milkfish plus	0	0.0329	0.0001	0	0.0128	0	0	0.0027	0	0	0	0	0	0.0424	0
36	3 SM inv	0	0.1220	0.2370	0.0188	0.1476	0.0260	0.0078	**0.0942**	0	0	0	0	0.04798	0.0434	0.0462
37	3 SM pisc	0	**0.0616**	**0.0937**	0.0123	0.1097	0	0.0010	0.0373	0	0	0	0	0.0240	0.0258	0.0346
38	3 Crustaceans	0	0.1610	0.1183	0.1609	0.2796	0.2440	0.1701	0.4933	0.05	0	0	0	0.0229	0	0.0231
39	3 Macrobenthos	0.1976	0.0229	0.0554	0.0331	0.1837	0.6571	0.4239	0.2080	0	0.05	0	0	0	0	0
40	3 Meiobenthos	0.0709	0	0.0004	0.0101	0	0	0.0473	0.0001	0.40	0.20	0	0	0	0	0
41	3 Zooplankton	0.1650	0.0245	**0.0910**	0.6820	0.0345	0.0003	**0.1340**	0.0123	0.15	0.10	0	0	0	0	0
42	1 Phytoplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	2 Phytoplankton	0.0541	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	3 Phytoplankton	0.0709	0	0.0117	0.0340	0	0	0.0345	0	0	0.1	0	0.90	0	0	0
45	Benthic plants	0	0.0010	0	0	0.0003	0	0.1161	0.0001	0	0	0	0	0	0	0
46	Detritus	0	0.0000	0	0	0.0000	0	0.0000	0.0000	0	0	0	0	0	0	0.0156
47	Import	0	0.0000	0	0	0.0000	0	0.0000	0.0000	0	0	0	0	0	0	0.0156

Uncertainty and pedigree

As detailed above there is a large degree of uncertainty in the data supporting the model. It is possible to quantify the level of uncertainty by attributing level of confidence based on the source of the data and its precision (Christensen and Walters 2004). The pedigree routine describes the data source and assigning a coefficient of variation by comparing the general description of the data to a pre-defined table for each type of input parameters (biomass, P/B, Q/B, diet, catch). The rank (order from the top) of a category is named index. Each category is characterised by associated with an index value between 0 and 1 describing how well the parameter is rooted in local data and a confidence interval expressed as a percentage of the mean.

The pedigree assumes that locally derived data (e.g. field sampling, local diets) represent local conditions than data from elsewhere or values derived from empirical relationships or other models.
Specifying the pedigree of data used to build the Ecopath model is pertinent in the present study, as it:

- Provides a clear overview of how well the Bay of Bengal Ecopath model parameters are based on local, field-based data;
- Provides a basis for computing an overall index of model 'quality' using a scale ranging from 0 to 1 (a model has high quality when it is constructed mainly using precise estimates of various parameters, based on data from the system to be represented by the model); and
- Provides parameter ranges used for subsequent Monte Carlo uncertainty evaluation (in Ecosim).

This biomas scale was based on the observation that the functional groups' biomass is difficult to estimate accurately, and that there are different levels of uncertainty depending on the pedigree of data used (Table 18). This also applies to biomass estimates that are obtained from other models, where local conditions may be different.

Table 18. Model Pedigree definitions for biomass

Index	Description	Index value	Confidence interval (%)
1	Estimated by Ecopath	0.0	80
2	From other models	0.0	80
3	Based on professional judgement (guesstimate)	0.0	80
4	Approximate or indirect method	0.4	50
5	Sampling based, low precision	0.7	30
6	Sampling based, high precision	1.0	10

Most functional groups in the ecosystem model were not sampled with precision or not sampled at all. Some biomass estimates were based on a few samples or on extensive sampling in a restricted area (e.g. zooplankton, meibenthos) and were assigned an index value of 0.7 (index= 5). Estimates for large pelagics and several other groups were based on a combination of low precision sampling and of jugement on their spatial distribution and densities in deep waters and for this reason were considered as guestimates. The estimate for jellyfish being taken from the FAO 57 model was assigned an index of 2. In several cases, missing estimates from the Indian coasts were approximated from contiguous territories which always decreased the index assigned to the biomass parameter. Although obtained from a stock assessment the biomass estimate for hilsa is given classified as obtained from an indirect method (index= 4), that is a stock assessment model and its inherent uncertainty and the assumptions that had to be made to produce an estimate for 1987-1980.

The scale for**P/B and Q/B ratios**(Table 19) is based on the principle that these ratios are highly conservative parameters that are functions of species' size and population dynamics, i.e. characteristics for which there is ample information available (e.g., from empirical models or FishBase; (Froese and Pauly 2013).

In this model, P/B values were obtained from the addition of M computed using empirical relationships based on growth information from local studies or other ecosystems, and an estimate of F which was often only a guesstimate. For this reason, the estimates for this parameter was classified as 4, empirical relationships (Table 19)

Table 19. Model Pedigree definitions for Production/Biomass and Consumption/Biomass ratios

Index	Description	Index value	Confidence Interval (%)
1	Estimated by Ecopath	0.0	80
2	Professional judgement (guesstimate)	0.1	70
3	From other models	0.2	60
4	Empirical relationships	0.5	50
5	Similar group/species, similar system, low precision	0.6	40
6	Similar group/species, same system, low precision	0.7	30
7	Same group/species, similar system	0.8	20
8	Same group/species, same system	1.0	10

Species' diet compositions can be highly variable and thus locally observed diets tend to be more reliable than those derived from other systems and/or species groups.Pedigree definitions were modified from default values for diets (Table 20).

The large pelagics diets were mainly obtained from studies in other ecosystems and assumptions were made about the allocation of the diet in various areas thus, they were classified as 4. The diet of several most functional groups was assigned an index of 5 because they were a compilation of studies carried out in various locations and varying in quality (food items to local quantitative studies; see Appendix A3). The diet ofinvertebrates (benthic and pelagics) are typically a compilation of general knowledge for several species and were attributed the lowest index.

Table 20. Model Pedigree definitions for diet compositions

Index	Description	Index value	Confidence Interval (%)
1	General knowledge of related group/species	0.0	80
2	From other models	0.0	80
3	Qualitative diet composition	0.2	60
4	all types of diet, different systems, + allocation	0.5	60
5	Quantitative but limited diet composition study	0.7	50
6	Quantitative, detailed, diet composition study	1.0	30

All catches were given the highest score (6, Local study, High precision/complete) because it was based on extensive studies that included estimates of illegal, unreported and unregulated catches, completing the FAO data base (see the Catch, effort and CPUE section above). However, this may be an over-estimate of the precision given the assumptions that were made for spatial distributions and species compositions.

Ecosim model

A preliminary Ecosim model was set up to allow exploring interactions between functional groups and the impact of fishing. To run the model, a CSV file (comma delimited) was assembled, containing:
1. Effort time series for each region and four specific functional groups: hilsa, yellowfin and bigeye tunas, and marlins (see the section Catch, effort and CPUE and Appendix 2) (the relative industrial effort for India including the industrial fleet and large trawlers and labeled large vessels in A2.2);
2. Relative biomass time series for hilsa (biomass from assessment) and large pelagics (commercial CPUE);
3. Catch time series for each functional group.
The rules to build this type of file are described in the user's guide. The model was fitted using the automatic fitting procedure and considering only the groups for which the sum of squares (SS) is sensitive to vulnerabilities (v) and excluding benthic invertebrates and bathypelagics.

The fit to catches and relative biomass indices are not very good for either hilsa or the 3 large pelagic groups (Figure 5 and 6). The biomass trend predicted for hilsa shows no sign of decline contrary to the biomass trend from the stock assessment. Catches are either overestimated (e.g. hilsa and marlins) or under estimated by the model (e.g. bigeye and yellowfin tunas). At first sight, the predicted biomass indices seem to match the observed values, but a closer examination shows that although this is true at the end of the simulations, the predicted bigeye biomass does not decrease as much in the 1980s as the observed values suggest. The problem with tunas in this kind of model, in addition to the uncertainty of commercial CPUEs, is the migratory nature of these fish and the changes in spatial allocation of fishing effort which is not captured here. In addition, several of these species were already declining before 1978, the onset of this model (R. Sharma, pers. comm).

The fit to catches is variable among the other functional groups (Figure 6). Predicted catches for sharks, and small fish (SM inv, SM pisc and Spelagics) do not fit the observed catches very well. The reasons for this are numerous. The effort trends are approximates for regions 1 and 2 and could lead to error in predicted catches. However, predicted catches are not necessarily worse in these regions than in region 2. Also, using the same effort for all species implies that relative abundances do not change over time and that there is no variation in which species are targeted by the fishery during the study period which may not be the case.

There are no biomass trends for most species which means there are no constraints in the model and no guidance for what is possible. Trends for 2 Lpisc constitute a good example of these types of problems. The biomass is predicted to decrease abruptly in the 1980s (Figure 7) while fishing mortality increases from about 0.5 in 1978 to reach close to 4 at the end of the time series while predicted catches become lower than the observed. This poses at least two questions beyond that of the validity of the initial biomass: 1. Was F equal to 0.5 in 1978; and 2. Has fishing mortality increased on these species as fast as effort did? These are difficult questions to answer without knowledge on fishing habits during the time period and about biomass trends.

Another example is how the predictions for hilsa biomass trends are dramatically different when the Indian industrial effort is slightly changed by considering only the industrial vessels the large vessels time series (A2.2). Appendix 6 shows a new series of plots similar to figures 5-7 for this alternative scenario. The predicted trend for hilsa biomass would change from a flat line when the large vessels time series is used (Figure 5) to a declining trend when only industrial vessels are considered (Figure A6.1); none of these simulations fit hilsa very well. The sudden change is caused by changes in trends of other functional groups trends in biomass (not shown, but see changes in the trends in catches in A6.2 compared to Figure 6) induced by the simulated fishery in region 2 leading to different estimations of vulnerabilities. Also note the small change in level of catch fo 2 L pisc in Figure 7 and Figure A6.3.

A word of caution: It should be kept in mind that, for instance, the effort time series in region 1 and 3 are approximates, and the abundance indices for large pelagics are based on commercial CPUEs that are often biased. Also, abundance trends are missing for most functional groups, a lack of constraints resulting in very variable trends (e.g. hilsa).

Thus, results from temporal simulations should not be used to give quantitative management advice. Instead, current Ecosim simulations could be used as a tool to explore food web dynamics and effects of fishing. It could also be used as a framework to devise what important piece of information would be useful to gather to answer the most crucial questions.

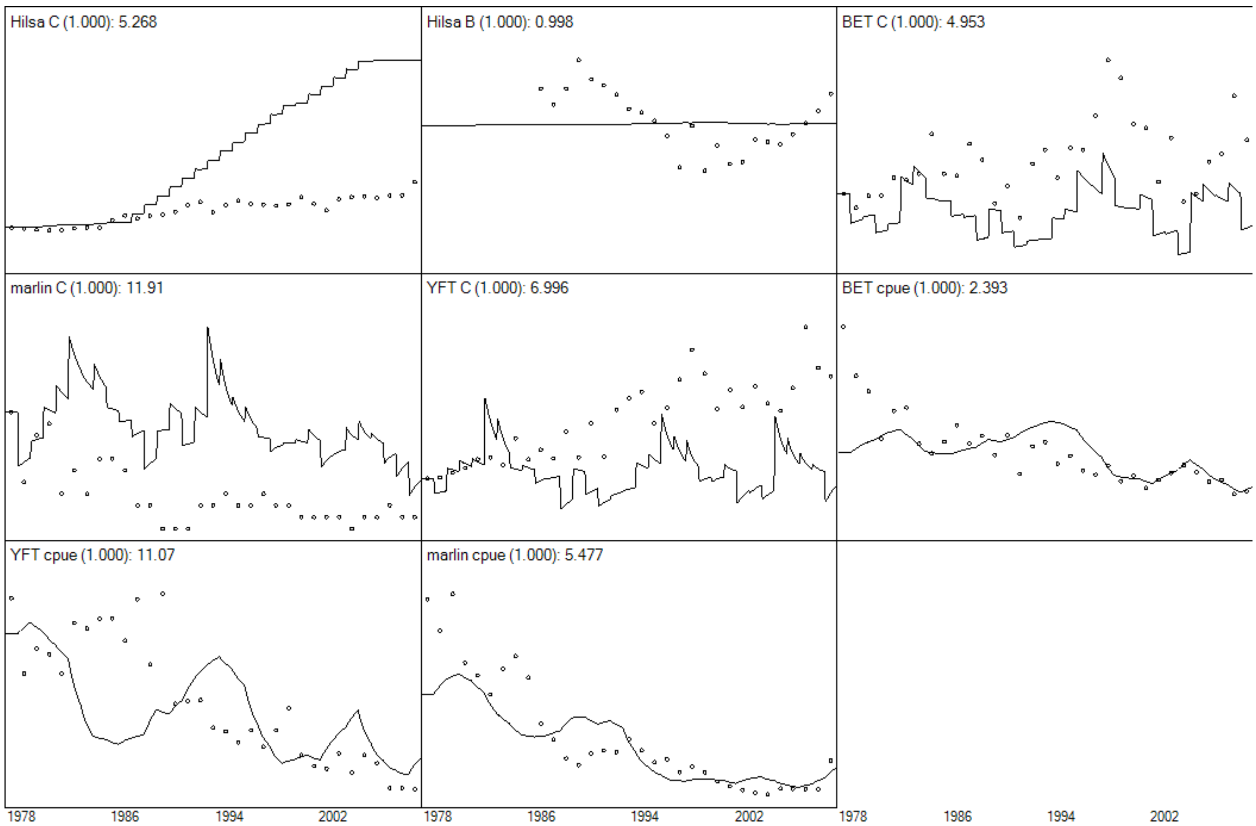

Figure 5. Observed (dots) and predicted (lines) relative abundance (B or CPUE) and catches (C) for hilsa, marlins, yellowfin tuna (YFT) and bigeye tuna (BET). The numbers besides the name is the sum of squares. The region 2 industrial fleet includes industrial vessels and large trawlers (Large vessels time series in A2.2).

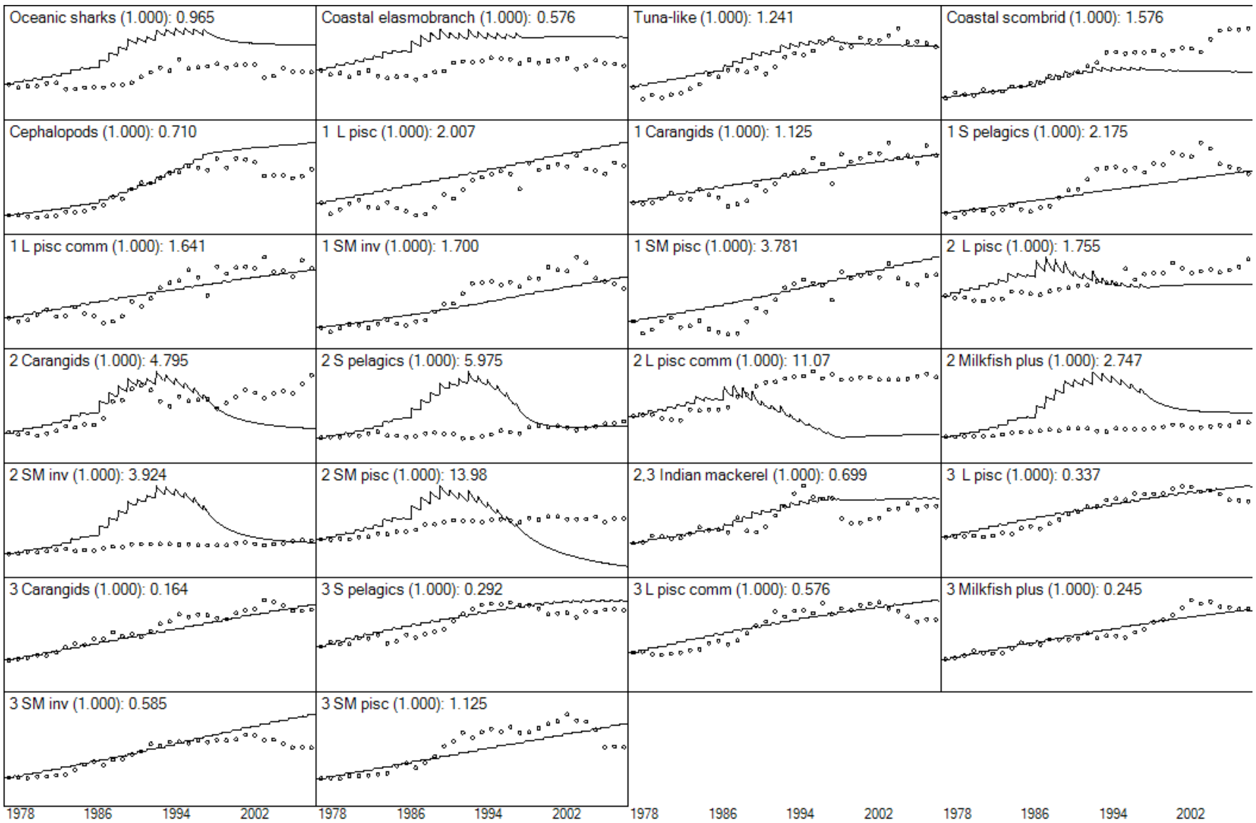

Figure 6. Observed (dots) and predicted (lines) catches for other species. The numbers besides the name is the sum of squares.The region 2 industrial fleet includes industrial vessels and large trawlers (Large vessels time series in A2.2)

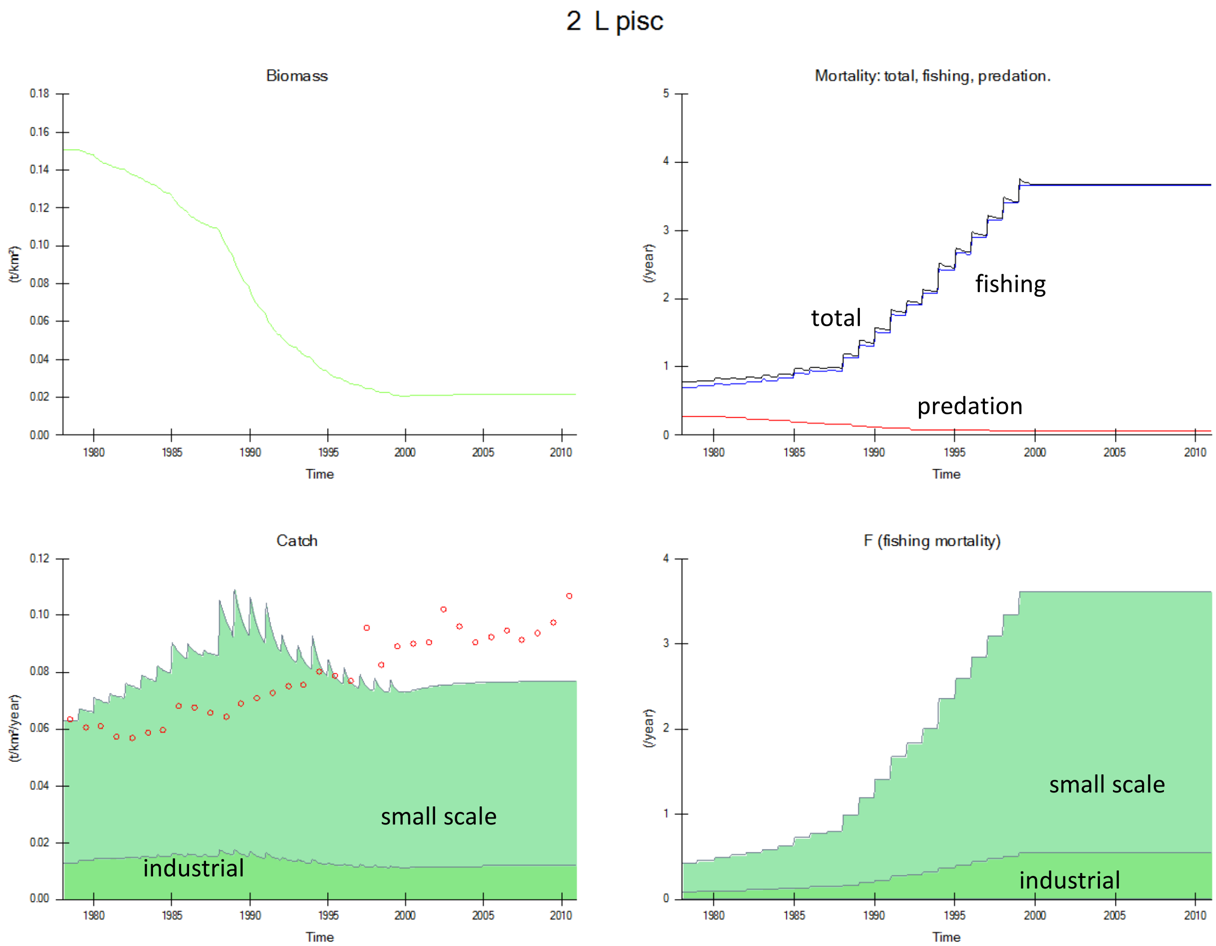

Figure 7. Predicted trends in biomass, catches, and mortality (lines) and observed catches (dots) for the functional group 2 L pisc. The solid green areas represent the catch or fishing mortality caused by the each of the fleet in region 2. The region 2 industrial fleet includes industrial vessels and large trawlers (Large vessels time series in A2.2)

Future improvements

The model was presented in a workshop and training course held in Phuket (8-12 September 2014) which led to several discussions and suggestions to improve the model. These suggestions are listed below.

On the allocation of biomass and diets across the three regions of the Bay of Bengal for widely distributed species (e.g. sharks, large pelagics).

- it can be assumed that Indian mackerel biomass would be allocated regions 2 and 3 proportionally to the catch
- juvenile tuna tend to aggregate in the Maldives and along the coast of Indonesia
- 10% hilsa biomass should be allocated to region 3 (instead of 2% used in the current model)

However, participants remarked that it would be more practical to start from national models for which there would be better information.

The exploration of the BOB model led to remarks on the composition of sharks functional groups which should be divided in large and small species, and into juveniles and adults to reflect the changes in habitat with age. Also, hilsa would be modelledmore adequately if juveniles were considered separately given their freshwater habitat.

A wider discussion about the model revealed the participant's interests in developing national or sub-regional models to address local issues. For instance, the issues regarding hilsa and similar species would be addressed better in a sub-regional model including Bangladesh and the north coast of Myanmar. Information gathered for these sub-regional models could be used to inform and improve the BOBLME model.Given the available surveys in each country and the useful information about biomasses and habitat preferences they provide, it would be possible to build a spatially explicit model (Ecospace) of the Bay of Bengal. This would remove the problems in allocating the biomass and diets in the 3 sub-regions.

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Appendices

A1 Functional groups.

A1.1 Allocation of catch species to functional groups.

Catch Name	Functional group	Catch Name	Functional group
Abalistes stellaris	SM pisc	*Auxis* spp.	coastal scombrid
Acanthocybium solandri	tuna-like	*Auxis thazard*	coastal scombrid
Acanthopagrus latus	SM inv	*Auxis thazard thazard*	coastal scombrid
Acanthuridae	SM inv	Batoidea	oceanic, coastal sharks
Acanthurus	SM inv	Belonidae	L pisc
Acanthurus lineatus	SM inv	Billfishes	tuna-like
Acetes	shrimps	Bivalvia	macrobenthos
Aethaloperca rogaa	L pisc comm	*Bohadschia marmorata*	macrobenthos
Alectis ciliaris	Carangids	Bothidae	SM inv
Alectis indica	Carangids	Brachyura	Crabs
Alepes	Carangids	*Bramidae*	SM pisc
Alepisaurus ferox	ML bathy	*Bregmaceros mcclellandi*	S pelagics
Alopias	Oceanic shark	*Caesio*	SM inv
Alopias pelagicus	oceanic sharks	*Caesio caerulaurea*	SM inv
Alopias spp.	Oceanic shark	*Caesio lunaris*	SM inv
Alopias superciliosus	oceanic sharks	Caesionidae	SM inv
Alopias vulpinus	oceanic sharks	Carangidae	Carangids
Aluterus	SM inv	Carangoides	Carangids
Ambassidae	S pisc inv	Carangoides coeruleopinnatus	Carangids
Amblygaster sirm	S pelagics	Carangoides ferdau	Carangids
Anchoviella	S pelagics	Carangoides malabaricus	Carangids
Anguilla	L pisc	Carangoides orthogrammus	Carangids
Anguilliformes	L pisc	*Caranx*	Carangids
Anodontostoma chacunda	S pelagics	*Caranx hippos*	Carangids
Aphareus rutilans	L pisc comm	*Caranx ignobilis*	Carangids
Apogonidae	SM inv	*Caranx lugubris*	Carangids
Aprion virescens	L pisc comm	*Caranx melampygus*	Carangids
Aquatic invertebrates	macrobenthos	*Caranx sexfasciatus*	Carangids
Arcidae	macrobenthos	**Carcharhinidae**	coastal elasmobranch[a]
Ariidae	Milkfish, Minv Mpisc	**Carcharhinidae**	oceanic, coastal sharks
Ariomma indicum	SM pisc	***Carcharhinus***	coastal elasmobranch [a]
Arius	SM inv	***Carcharhinus***	oceanic, coastal sharks
Atherinomorus lacunosus	SM inv	*Carcharhinus albimarginatus*	coastal elasmobranch
Auxis	coastal scombrid	*Carcharhinus amblyrhynchos*	coastal elasmobranch
Auxis rochei	coastal scombrid	*Carcharhinus falciformis*	oceanic sharks
Auxis rochei rochei	coastal scombrid	*Carcharhinus limbatus*	coastal elasmobranch
Carcharhinus melanopterus	coastal elasmobranch	*Carcharhinus longimanus*	oceanic sharks

Catch Name	Functional group	Catch Name	Functional group
Carcharhinus obscurus	coastal elasmobranch	*Elagatis bipinnulata*	Carangids
Carcharhinus sorrah	coastal elasmobranch	Elasmobranchii	oceanic, coastal sharks
Centrophorus granulosus	oceanic sharks	*Eleutheronema tetradactylum*	L pisc
Centropomidae	L pisc	*Encrasicholina heteroloba*	S pelagics
Cephalopholis argus	L pisc comm	Engraulidae	S pelagics
Cephalopholis boenak	L pisc comm	Ephippidae	M inv, L pisc
Cephalopholis miniata	L pisc comm	*Epinephelus*	L pisc comm
Cephalopoda	cephalopods	*Epinephelus fuscoguttatus*	L pisc comm
Cephea	jellyfish	*Epinephelus polyphekadion*	L pisc comm
Chanos chanos	Milkfish plus	*Epinephelus tauvina*	L pisc comm
Charybdis	Crabs	*Euthynnus affinis*	coastal scombrid
Chirocentrus	L pisc	Exocoetidae	S pelagics
Chirocentrus dorab	L pisc	*Fenneropenaeus indicus*	shrimps
Chirocentrus nudus	L pisc	*Fenneropenaeus merguiensis*	shrimps
Clams or cockles and arkshells	macrobenthos	Fistulariidae	L pisc
Clupeidae	S pelagics	*Galeocerdo cuvier*	coastal elasmobranch
Clupeiformes	S pelagics	Gastropoda	macrobenthos
Clupeoids	S pelagics	*Gazza minuta*	SM inv
Congresox talabonoides	L pisc	Gerreidae	SM inv
Congridae	l bathy, L pisc	*Gerres*	SM inv
Coryphaena	L pisc	*Gnathanodon speciosus*	Carangids
Coryphaena hippurus	L pisc	Gobiidae	S inv, M pisc
Crassostrea	macrobenthos	Gymnosarda unicolor	coastal scombrid
Crassostrea madrasensis	macrobenthos	Haemulidae	SM pisc
Cynoglossidae	SM coast inv	*Harpadon nehereus*	L pisc comm
Cynoglossus	SM coast inv	*Harpago chiragra*	macrobenthos
Dasyatidae	oceanic, coastal sharks	Hemiramphidae	S pelagics
Dasyatis	coastal elasmobranch	*Hemiramphus*	S pelagics
Decapoda	crab, shrimp	*Hexanchus griseus*	oceanic sharks
Decapterus	Carangids	*Hilsa kelee*	Hilsa
Decapterus russelli	Carangids	Himantura	coastal elasmobranch
Diodon	Milkfish plus	Holocentridae	SM inv, pisc
Drepane	SM pisc	*Holothuria atra*	macrobenthos
Drepane punctata	SM pisc	*Holothuria edulis*	macrobenthos
Dussumieria	S pelagics	*Holothuriidae*	macrobenthos
Dussumieria elopsoides	S pelagics	Holothuroidea	macrobenthos
Hyporhamphus	S pelagics	Homaridae and Palinuridae	Crabs
Ilisha elongata	Hilsa	*Lutjanus gibbus*	L pisc comm
Istiompax indica	tuna-like	*Lutjanus johnii*	L pisc comm
Istiophoridae	tuna-like	*Lutjanus lutjanus*	L pisc comm
Istiophorus	tuna-like	*Lutjanus malabaricus*	L pisc comm
Istiophorus platypterus	tuna-like	*Macolor macularis*	L pisc comm

Catch Name	Functional group	Catch Name	Functional group
Isurus	oceanic sharks	*Macolor niger*	L pisc comm
Isurus oxyrinchus	oceanic sharks	*Makaira*	tuna-like
Isurus paucus	oceanic sharks	*Makaira indica*	tuna-like
Isurus spp	oceanic sharks	*Makaira mazara*	Marlins
Kajikia audax	Marlins	*Makaira nigricans*	tuna-like
Katsuwonus pelamis	tuna-like	Marine fishes not identified	Miscellaneous fishes
Kawakawa	coastal scombrid	Marine pelagic fishes nei	Miscellaneous fishes
Labridae	L pisc	*Marsupenaeus japonicus*	shrimps
Lactarius lactarius	S pelagics	*Megalaspis cordyla*	Carangids
Lambis lambis	macrobenthos	*Megalops cyprinoides*	L pisc
Lamma nasus	oceanic sharks	*Melicertus latisulcatus*	shrimps
Lamnidae	oceanic sharks	*Meretrix*	macrobenthos
Lamniformes	oceanic, coastal sharks	*Metapenaeus*	shrimps
Lates calcarifer	L pisc	*Metapenaeus monoceros*	shrimps
Latidae	L pisc	Miscellaneous aquatic invertebrates	macrobenthos
Leiognathidae	SM inv	Miscellaneous crustaceans	crab, shrimp
Leiognathus	SM inv	Miscellaneous fishes	Miscellaneous fishes
Lethrinidae	L pisc comm	Miscellaneous marine crustaceans	crab, shrimp
Lethrinus	L pisc comm	Miscellaneous marine molluscs	macrobenthos
Lethrinus harak	L pisc comm	Miscellaneous molluscs	macrobenthos
Lethrinus microdon	L pisc comm	Miscellaneous shrimps	shrimps
Lethrinus nebulosus	L pisc comm	*Modiolus*	macrobenthos
Lethrinus olivaceus	L pisc comm	Monacanthidae	SM inv
Lethrinus rubrioperculatus	L pisc comm	*Mugil*	SM inv
Lethrinus xanthochilus	L pisc comm	Mugilidae	M inv, S inv
Liza	SM inv	Mullidae	SM inv
Lobotes surinamensis	L pisc	Muraenesocidae	L pisc
Loliginidae	cephalopods	*Muraenesox*	L pisc
Loligo	cephalopods	*Muraenesox cinereus*	L pisc
Loligonidae	cephalopods	Myliobatidae	coastal elasmobranch
Lutjanidae	L pisc comm	*Lutjanus bohar*	L pisc comm
Lutjanus	L pisc comm	Nemipteridae	SM pisc
Lutjanus argentimaculatus	L pisc comm	*Nemipterus*	SM pisc
Netuma thalassina	Milkfish plus	*Nemipterus japonicus*	SM pisc
Octopoda	cephalopods	*Plectropomus laevis*	L pisc comm
Octopodidae	cephalopods	*Plectropomus pessuliferus*	L pisc comm
Octopus	cephalopods	Pleuronectidae	SM pisc
Octopus vulgaris	cephalopods	Pleuronectiformes	Pleuronectiformes
Otolithoides	L pisc comm	Plotosidae	L pisc
Palaemonidae	shrimps	Plotosus	L pisc
Palinuridae	Crabs	Polynemidae	L pisc, SM inv

Catch Name	Functional group	Catch Name	Functional group
Palinurus	Crabs	*Polynemus*	L pisc, SM inv
Pampus	SM inv	Pomacentridae	SM inv
Pampus argenteus	SM inv	*Pomadasys*	SM pisc
Pampus chinensis	SM inv	*Pomadasys argenteus*	SM pisc
Panulirus	Crabs	Portunidae	Crabs
Panulirus homarus	Crabs	*Portunus*	Crabs
Panulirus longipes	Crabs	*Portunus pelagicus*	Crabs
Panulirus penicillatus	Crabs	*Priacanthus*	SM pisc
Panulirus polyphagus	Crabs	*Prionace glauca*	oceanic sharks
Panulirus versicolor	Crabs	Pristipomoides	L pisc comm
Paphia	macrobenthos	*Psettodes erumei*	SM pisc
Parapenaeopsis	shrimps	Psettodidae	SM pisc
Parapenaeopsis hardwickii	shrimps	*Pseudocarcharias kamoharai*	oceanic sharks
Parapenaeopsis sculptilis	shrimps	*Pseudorhombus*	SM pisc
Parastromateus niger	Carangids	*Pseudotolithus*	L pisc comm
Pectinidae	macrobenthos	*Pseudotriakis microdon*	oceanic sharks
Pellona	S pelagics	*Rachycentron canadum*	L pisc
Pellona ditchela	S pelagics	Rajiformes	oceanic, coastal sharks
Penaeidae	shrimps	*Rastrelliger*	Indian mackerel
Penaeus	shrimps	*Rastrelliger brachysoma*	Indian mackerel
Penaeus monodon	shrimps	*Rastrelliger kanagurta*	Indian mackerel
Penaeus semisulcatus	shrimps	*Rhincodon typus*	oceanic sharks
Pennahia	L pisc comm	Rhinobatidae	coastal elasmobranch
Pennahia argentata	L pisc comm	Rhizostomatidae	jellyfish
Perciformes	Perciformes	*Rhopilema*	jellyfish
Perna viridis	macrobenthos	*Rhynchobatus djiddensis*	coastal elasmobranch
Pinctada margaritifera	macrobenthos	*Saccostrea cuccullata*	macrobenthos
Platycephalidae	L pisc	*Sardinella*	S pelagics
Platycephalus indicus	L pisc	*Sardinella fimbriata*	S pelagics
Plectorhinchus	SM pisc	*Sardinella gibbosa*	S pelagics
Plectropomus areolatus	L pisc comm	*Sardinella lemuru*	S pelagics
Saurida	L pisc comm	*Sardinella longiceps*	S pelagics
Saurida tumbil	L pisc comm	Selachimorpha	oceanic, coastal sharks
Scarus	SM inv	Selachimorpha (Pleurotremata)	oceanic, coastal sharks
Scatophagus argus	SM inv	*Selar boops*	SM inv
Sciaenidae	L pisc comm	*Selar crumenophthalmus*	Carangids
Scolopsis	SM pisc	*Selaroides leptolepis*	SM inv
Scomber	Indian mackerel	Sepia	cephalopods
Scomberoides	Carangids	Sepiidae	cephalopods
Scomberoides commersonnianus	Carangids	*Sepioteuthis lessoniana*	cephalopods
Scomberoides lysan	Carangids	Sergestidae	shrimps
Scomberomorini	coastal scombrid	*Seriola rivoliana*	Carangids

Catch Name	Functional group	Catch Name	Functional group
Serranidae	L pisc comm	*Seriolina nigrofasciata*	Carangids
Sharks or rays and chimaeras	oceanic, coastal sharks	*Thenus orientalis*	Crabs
Shrimps and prawns	shrimps	*Thryssa*	S pelagics
Shrimps andprawns	shrimps	Thunnini	tuna-like, scombrids[b]
Siganidae	SM inv	*Thunnus*	tuna-like
Siganus	SM inv	*Thunnus alalunga*	tuna-like
Siganus canaliculatus	SM inv	*Thunnus albacares*	Yellowfin tuna
Sillaginidae	SM inv	*Thunnus maccoyii*	tuna-like
Sillago	SM inv	*Thunnus obesus*	Bigeye tuna
Sillago sihama	SM inv	*Thunnus tonggol*	coastal scombrid
Siluriformes	Milkfish, Minv Mpisc	*Trachipterus*	ML bathy
Soleidae	Sinv, M pisc	Triacanthidae	SM inv
Solenocera crassicornis	shrimps	*Triaenodon obesus*	coastal elasmobranch
Sparidae	SM inv	Trichiuridae	L pisc
Sphyraena	L pisc	*Trichiurus*	L pisc
Sphyraena jello	L pisc	*Trichiurus lepturus*	L pisc
Sphyraenidae	L pisc	*Tridacna*	macrobenthos
Sphyrna	oceanic sharks	*Trochus*	macrobenthos
Sphyrna lewini	oceanic sharks	*Trochus niloticus*	macrobenthos
Sphyrna mokarran	oceanic sharks	*Turbo*	macrobenthos
Sphyrna	oceanic sharks	*Upeneus*	SM inv
Sphyrna zygaena	oceanic sharks	*Upeneus sulphureus*	SM inv
Sphyrnidae	oceanic sharks	*Upeneus vittatus*	SM inv
Spratelloides delicatulus	S pelagics	Uranoscopus	SM pisc
Spratelloides gracilis	S pelagics	*Variola louti*	L pisc comm
Squillidae	shrimps	Veneridae	macrobenthos
Stichopus	macrobenthos	*Xiphias gladius*	tuna-like
Stolephorus	S pelagics	Xiphioidei	tuna-like
Stomatopoda	shrimps	*Zenarchopterus dispar*	S pelagics
Stromateidae	SM inv		
Synodontidae	L pisc comm		
Tegillarca granosa	macrobenthos		
Tenualosa ilisha	Hilsa		
Tenualosa toli	Hilsa		
Terapon	SM pisc		
Terapon jarbua	SM pisc		
Terapontidae	SM pisc		
Tetraodontidae	milkfish, SM inv		
Tetrapturus angustirostris	tuna-like		
Tetrapturus audax	tuna-like		

a. based on list of species in the Andaman catch data base
b. for the catch from the tuna database only

A1.2 Area considered for each functional group.

Group name	area (km^2)	proportion	explanation
Oceanic sharks	6,205,051	1	All regions
Coastal elasmobranch	4,275,177	0.689	All regions
Tuna-like	6,205,051	1	All regions
Coastal scombrid	4,275,177	0.689	EEZ without high seas
Jellyfish	6,205,051	1	All regions
Cephalopods	6,205,051	1	All regions
S bathy	5,268,883	0.849	Deep waters only
ML bathy	5,268,883	0.849	Deep waters only
1 L pisc	30,998	0.005	Shelf of region 1
1 Carangids	30,998	0.005	Shelf of region 1
1 S pelagics	30,998	0.005	Shelf of region 1
1 L pisc comm	30,998	0.005	Shelf of region 1
1 SM inv	30,998	0.005	Shelf of region 1
1 SM pisc	30,998	0.005	Shelf of region 1
1 Macrobenthos	2,845,297	0.459	EEZ of region 1
1 Meiobenthos	2,845,297	0.459	EEZ of region 1
1 Zooplankton	2,845,297	0.459	EEZ of region 1
2 L pisc	213,663	0.034	Shelf of region 2
2 Carangids	213,663	0.034	Shelf of region 2
2 S pelagics	213,663	0.034	Shelf of region 2
2 L pisc comm	213,663	0.034	Shelf of region 2
2 Milkfish plus	213,663	0.034	Shelf of region 2
2 SM inv	213,663	0.034	Shelf of region 2
2 SM pisc	213,663	0.034	Shelf of region 2
2 Crustaceans	213,663	0.034	Shelf of region 2
2 Macrobenthos	1,282,459	0.207	EEZ of region 2
2 Meiobenthos	1,282,459	0.207	EEZ of region 2
2 Zooplankton	1,282,459	0.207	EEZ of region 2
2,3 Hilsa	905,170	0.146	Shelf of regions 2 and 3
2,3 Indian mackerel	905,170	0.146	Shelf of regions 2 and 3
3 L pisc	691,507	0.111	Shelf of region 3
3 Carangids	691,507	0.111	Shelf of region 3
3 S pelagics	691,507	0.111	Shelf of region 3
3 L pisc comm	691,507	0.111	Shelf of region 3
3 Milkfish plus	691,507	0.111	Shelf of region 3
3 SM inv	691,507	0.111	Shelf of region 3
3 SM pisc	691,507	0.111	Shelf of region 3
3 Crustaceans	2,077,295	0.335	EEZ of region 3
3 Macrobenthos	2,077,295	0.335	EEZ of region 3
3 Meiobenthos	2,077,295	0.335	EEZ of region 3
3 Zooplankton	2,077,295	0.335	EEZ of region 3
1 Phytoplankton	2,845,297	0.459	EEZ of region 1
2 Phytoplankton	1,282,459	0.207	EEZ of region 2
3 Phytoplankton	2,077,295	0.335	EEZ of region 3
0 plants	4,275,177	0.689	EEZ without high seas
Bigeye tuna	6,205,051	1	All regions
Yellowfin tuna	6,205,051	1	All regions
Marlins	6,205,051	1	All regions

A1.3 Functional groups composition

Functional group	Species list
Oceanic sharks	*Isurus paucus, Isurus oxyrinchus, Alopias vulpinus, Alopias pelagicus, Prionace glauca, Carcharhinus longimanus, Sphyrna lewini, Sphyrna mokarran, Sphyrna zygaena, Carcharhinus falciformis, Alopias superciliosus, Hexanchus griseus, Rhincodon typus, Pteroplatytrygon violacea, Dalatias licha, Echinorhinus brucus, Centrophorus moluccensis Centrophorus uyato, Centroscyllium ornatum, Centrophorus niaukang, Centrophorus squamosus, Centrophorus tessellatus, Centrophorus granulosus, Pseudotriakis microdon, Pseudocarcharias kamoharai, Carcharhinus amblyrhynchoides*
Coastal elasmobranch	*Galeocerdo cuvier, Triaenodon obesus, Carcharhinus melanopterus, Carcharhinus limbatus, Carcharhinus dussumieri, Carcharhinus macloti, Carcharhinus albimarginatus, Rhizoprionodon acutus, Scoliodon laticaudus, Scoliodon walbeehmil, Carcharhinus sorrah, Mustelus manazo, Mustelus mosis, Carcharhinus albimarginatus, Carcharhinus altimus, Stegostoma fasciatum, Nebrius ferrugineus, Chiloscyllium indicum, Chiloscyllium griseum, Eusphyra blochii, Odontaspis ferox, Carcharhinus amblyrhynchos, Loxodon macrorhinus, Rhynchobatus djiddensis, Glaucostegus granulatus, Dasyatis microps,Himantura undulate, Himantura alcockii, Himantura marginata, Himantura imbricate, Himantura uarnak, Himantura jenkinsii, Himantura bleekeri, Aetobatus narinari, Rhinoptera javanica, Mobula japonica, Aetomylaeus nichofii, Mobula eregoodootenkee, Aetomylaeus maculatus, Aetomylaeus vespertilio*
Tuna-like	*Katsuwonus pelamis, Acanthocybium solandri, Thunnus alalunga, Tetrapturus angustirostris, Istiophorus platypterus, Istiompax indica, Makaira nigricans, Xiphias gladius*
Bigeye tuna	*Thunnus obesus*
Yellowfin tuna	*Thunnus albacares*
Marlins	*Kajikia audax, Makaira mazara*
Coastal scombrids	*Auxis thazard thazard, Sarda orientalis, Auxis rochei rochei, Euthynnus affinis, Thunnus tonggol, Scomberomorus commerson, Scomberomorus guttatus, Scomberomorus lineolatus, Gymnosarda unicolor*
Carangids	*Carangoides fulvoguttatus, Caranx sexfasciatus, Gnathanodon speciosus, Caranx melampygus, Seriolina nigrofasciata, Carangoides orthogrammus, Carangoides equula, Carangoides chrysophrys, Carangoides malabaricus, Carangoides hedlandensis, Carangoides ferdau, Carangoides coeruleopinnatus, Carangoides talamparoides, Carangoides armatus, Caranx ignobilis, Alectis indica, Scomberoides lysan, Scomberoides commersonnianus, Alectis ciliaris, Elagatis bipinnulata, Seriola rivoliana, Caranx lugubris, Megalaspis cordyla, Selar crumenophthalmus, Uraspis helvola, Parastromateus niger, Alepes djedaba, Decapterus macrosoma, Decapterus russelli*
L pisc	*Sphyraena jello, Sphyraena barracuda, Sphyraena obtusata, Lates calcarifer, Pristis perotteti, Lepturacanthus savala, Trichiurus lepturus, Coryphaena hippurus, Coryphaena equiselis, Pomatomus saltatrix, Albula vulpes, Ablennes hians, Tylosurus crocodilus crocodilus, Strongylura leiura, Chirocentrus dorab, Chirocentrus nudus, Cheilinus undulatus, Strophidon sathete, Brotula multibarbata, Platycephalus indicus, Rachycentron canadum, Muraenesox bagio, Muraenesox cinereus, Congresox talabonoides, Fistularia petimba, Fistularia commersonii, Lobotes surinamensis, Leptomelanosoma indicum, Eleutheronema tetradactylum, Plotosus canius, Conger cinereus, Megalops cyprinoides*
L pisc comm	*Epinephelus fuscoguttatus, Epinephelus lanceolatus, Epinephelus coioides, Epinephelus flavocaeruleus, Epinephelus malabaricus, Epinephelus latifasciatus, Epinephelus multinotatus, Epinephelus polyphekadion, Plectropomus areolatus, Plectropomus pessuliferus, Plectropomus laevis, Variola louti, Epinephelus morrhua, Cephalopholis argus, Aethaloperca rogaa, Epinephelus chlorostigma, Epinephelus undulosus, Epinephelus fasciatus, Epinephelus areolatus, Epinephelus bleekeri, Epinephelus tauvina, Cephalopholis miniata, Cephalopholis boenak,* *Etelis coruscans, Lutjanus erythropterus, Lutjanus johnii, Lutjanus malabaricus, Lutjanus sanguineus, Lutjanus sebae, Lutjanus argentimaculatus, Aphareus rutilans, Aprion virescens, Etelis carbunculus, Etelis radiosus, Pristipomoides filamentosus, Pristipomoides multidens, Lutjanus ehrenbergii, Lutjanus monostigma, Lutjanus vitta, Lutjanus fulvus, Lutjanus lutjanus, Lutjanus carponotatus, Lutjanus rivulatus, Lutjanus gibbus, Lutjanus kasmira, Lipocheilus carnolabrum, Pristipomoides auricilla, Pristipomoides sieboldii, Pristipomoides zonatus, Lutjanus quinquelineatus, Lutjanus fulviflamma, Lutjanus bohar, Macolor macularis, Macolor niger*

Functional group	Species list
	Protonibea diacanthus, Otolithoides biauritus, Otolithoides pama, Pterotolithus maculatus, Otolithes ruber, Otolithes cuvieri, Johnius carutta, Johnius dussumieri, Johnius borneensis, Johnius macrorhynus, Pennahia anea, Pennahia argentata *Lethrinus ornatus, Lethrinus nebulosus, Lethrinus microdon, Lethrinus harak, Lethrinus olivaceus, Lethrinus lentjan, Lethrinus erythracanthus, Wattsia mossambica, Gymnocranius grandoculis, Lethrinus xanthochilus, Lethrinus rubrioperculatus,* *Saurida tumbil, Saurida undosquamis, Harpadon nehereus*
Milkfish plus	*Chamos chanos, Panfasius pangasius, Netuma thalassina, Diodon, hystrix, Arothron stellatus*
SM inv	*Acanthopagrus latus, Acanthopagrus berda, Rhabdosargus sarba, Pampus argenteus, Pampus chinensis, Acanthurus triostegus, Acanthurus leucosternon,* *Siganus canaliculatus, Siganus guttatu, Siganus fuscescens, Siganus argenteus, Siganus corallinus, Siganus lineatus, Siganus puelloides, Myripristis murdjan, Kyphosus cinerascens, Monotaxis grandoculis, Sillago sihama, Sillago aeolus, Sillago chondropus, Sillaginopsis panijus, Gymnocranius griseus, Scatophagus argus, Mugil cephalus, Chelon planiceps, Chelon macrolepis, Moolgarda seheli Liza subviridis, Valamugil cunnesius, Valamugil speigleri, Cynoglossus arel, Cynoglossus puncticeps, Cynoglossus lingua, Cynoglossus bilineatus, Arius maculatus, Arius venosus, Mene maculata, Caesio caerulaurea, Caesio lunaris* *Acanthurus auranticavus, Acanthurus bariene, Acanthurus dussumieri, Acanthurus guttatus, Acanthurus lineatus, Acanthurus mata, Acanthurus nigricans, Acanthurus nigricauda, Acanthurus nigrofuscus, Acanthurus tennentii, Acanthurus thompsoni, Acanthurus xanthopterus, Aluterus monoceros, Aluterus scriptus, Scarus festivus, Scarus ghobban, Scarus prasiognathos, Scarus quoyi Scarus rubroviolaceus, Scarus tricolor, Chelonodon patoca, Arothron immaculatus, Platax orbicularis, Cynoglossus lida* *Chelmon rostratus, Chaetodon plebeius, Chaetodon vagabundus, Polydactylus multiradiatus, Polydactylus multiradiatu, Nemipterus furcosus, Triacanthus biaculeatus, Liza parsia, Plotosus lineatus,* *Centropyge bicolor, Nuchequula blochii, Nuchequula gerreoides, Secutor ruconius, Nuchequula blochii, Nuchequula gerreoides, Secutor ruconius, Leiognathus daura, Leiognathus brevirostris, Gazza minuta, Equulites leuciscus, Eubleekeria splendens, Leiognathus equulus, Photopectoralis bindus, Secutor insidiator* *Gerres filamentosus, Pentaprion longimanus, Gerres oyena, Selaroides leptolepis, Selar boops, Pterocaesio pisang, Johnius coitor, Grammatobothus polyophthalmus, Engyprosopon grandisquama, Petroscirtes breviceps, Amphiprion ocellaris, Atherinomorus lacunosus, Pseudocheilinus hexataenia, Halichoeres melanurus, Thalassoma amblycephalum, Apogon coccineus, Apogon crassiceps, Apogon doryssa, Apogon ellioti, Fusigobius maximus, Periophthalmodon schlosseri, Oxyurichthys microlepis, Paramonacanthus japonicus, Paramonacanthus curtorhynchos, Aseraggodes umbratilis, Pardachirus pavoninus, Upeneus sulphureus, Upeneus moluccensis, Upeneus vittatus*
SM pisc	*Argyrops spinifer, Saurida gracilis, Dactyloptena orientalis, Atule mate, Priacanthus macracanthus, Priacanthus tayenus, Priacanthus hamrur, Pseudorhombus arsius, Pseudorhombus javanicus, Psettodes erumei, Glossogobius giuris, Abalistes stellaris, Scomberoides tol, Naucrates ductor, Drepane punctata, Drepane longimana, Taractichthys steindachneri, Neoniphon sammara, Sciades sona, Terapon theraps, Terapon jarbua, Pterois miles, Pterois russelii, Pterois volitans, Scorpaenopsis diabolus, Scorpaenopsis oxycephala, Brachirus orientalis, Synaptura albomaculata,* *Diagramma pictum, Pomadasys argenteus, Pomadasys maculatus, Pomadasys argyreus, Pomadasys furcatus, Pomadasys olivaceus, Plectorhinchus pictus, Plectorhinchus albovittatus, Plectorhinchus chaetodonoides, Plectorhinchus gibbosus, Plectorhinchus lineatus, Plectorhinchus picus, Plectorhinchus vittatus,* *Nemipterus peronei, Nemipterus bathybius, Nemipterus bipunctatus, Nemipterus randalli, Nemipterus hexodon, Nemipterus japonicus, Nemipterus nematophorus, Parascolopsis inermis,*

Functional group	Species list
	Scolopsis bilineata, Scolopsis vosmeri, Scolopsis xenochrous, Onigocia macrolepis, Synodus hoshinonis Brachypleura novaezeelandiae, Dendrophysa russelii, Eleotris fusca, Ambassis gymnocephalus, Filimanus heptadactyla, Polynemus paradiseus, Syngnathoides biaculeatus, Ephippus orbis, Ariomma indicum, Dendrochirus biocellatus, Dendrochirus brachypterus, Dendrochirus zebra, Pterois antennata, Pterois radiata, Scorpaenodes albaiensis
Indian Mackerel	*Rastrelliger kanagurta, Rastrelliger brachysoma, Rastrelliger faughni*
Hilsa	***Tenualosa ilisha,*** *Tenualosa toli, Hilsa kelee, Ilisha melastoma, Ilisha filigera, Ilisha megaloptera, Ilisha elongata, Gudusia chapra*
Small pelagics	*Anodontostoma chacunda, Sardinella longiceps, Sardinella fimbriata, Dussumieria elopsoides, Nematalosa nasus, Herklotsichthys quadrimaculatus, Spratelloides delicatulus, Sardinella gibbosa, Sardinella melanura, Sardinella albella, Sardinella lemuru, Opisthopterus tardoore, Spratelloides gracilis, Amblygaster sirm, Dussumieria acuta, Raconda russeliana, Escualosa thoracata, Bregmaceros mcclellandi* *Coilia reynaldi, Thryssa vitrirostris, Coilia dussumieri, Setipinna taty, Stolephorus commersonnii, Thryssa dussumieri, Thryssa mystax, Encrasicholina devisi, Encrasicholina heteroloba, Stolephorus insularis, Thryssa baelama, Stolephorus waitei, Stolephorus indicus, Thryssa hamiltonii, Coilia ramcarati, Encrasicholina punctifer* *Atropus atropos, Lactarius lactarius, Pellona ditchela, Alepes melanoptera, Hemiramphus convexus, Rhynchorhamphus georgii, Cheilopogon spilopterus, Parexocoetus mento, Exocoetus volitans, Hirundichthys coromandelensis, Cheilopogon abei, Cheilopogon atrisignis, Cheilopogon cyanopterus, Cheilopogon furcatus, Cheilopogon nigricans, Cheilopogon suttoni, Hyporhamphus limbatus, Hyporhamphus unicuspis, Hyporhamphus balinensis, Zenarchopterus dispar*
S bathy	Myctophidae, Stomiidae, Diretmidae
ML bathy	e.g.*Pontinus macrocephalus, Arctozenus risso, Nemichthys scolopaceus, Lampris guttatus, Alepisaurus ferox, Trachipterus jacksonensis*
jellyfish	e.g. Cephea, Rhizostomatidae, Rhopilema, Scyphozoa (based on catches)
cephalopods	*Sepia* sp, *Loligo* sp, *Octopus vulgaris*
Macrobenthos	*shrimps, prawns, lobsterx, crabs, molluscs, worms, small benthic crustaceans*
Meiobenthos	*e,g, benthic copepods*
zooplankton	*copepods, fish and invertebrate eggs, euphausiids, chaetognats, siphonophora*

A2 Catch, effort and CPUEs

A2.1 Total catch (t/km2/year) per fleet and functional group as input in Ecopath for year 1978.

BET= bigeye tuna, YFT= yellowfin tuna. The total catch in t is divided by the area of the entire study area.

	Group name	Region1	Region3	Region 2 industrial	Region 2 small-scale	Hilsa	BET	YFT	Marlins	Total
1	Oceanic sharks	0.001	0.0035	0.008082	0.00391	0	0	0	0	0.016493
2	Coastal elasmobranch	0.001198	0.006461	0.008798	0.009074	0	0	0	0	0.025531
3	Tuna-like	0.005722	0.004945	0.001569	0.004825	0	0	0	0	0.01706
4	Coastal scombrids	0.001283	0.012144	0.002552	0.01328	0	0	0	0	0.02926
5	Jellyfish	0	0.000112	0.000134	0	0	0	0	0	0.000246
6	Cephalopods	0	0.013	0.003117	0.003597	0	0	0	0	0.019715
7	S bathy	0	0	0	0	0	0	0	0	0
8	ML bathy	0.000251	0	0.000632	0.00258	0	0	0	0	0.003463
9	1 L pisc	0.000448	0	0	0	0	0	0	0	0.000448
10	1 Carangids	0.000877	0	0	0	0	0	0	0	0.000877
11	1 S pelagics	0.000341	0	0	0	0	0	0	0	0.000341
12	1 L pisc comm	0.00075	0	0	0	0	0	0	0	0.00075
13	1 SM inv	0.000348	0	0	0	0	0	0	0	0.000348
14	1 SM pisc	0.000223	0	0	0	0	0	0	0	0.000223
15	1 Macrobenthos	3.07E-07	0	0	0	0	0	0	0	3.07E-07
16	1 Meiobenthos	0	0	0	0	0	0	0	0	0
17	1 Zooplankton	0	0	0	0	0	0	0	0	0
18	2 L pisc	0	0	0.01281	0.049802	0	0	0	0	0.062613
19	2 Carangids	0	0	0.004471	0.01644	0	0	0	0	0.020911
20	2 S pelagics	0	0	0.023344	0.08478	0	0	0	0	0.108124
21	2 L pisc comm	0	0	0.011675	0.065067	0	0	0	0	0.076742
22	2 Milkfish plus	0	0	0.002048	0.012956	0	0	0	0	0.015004
23	2 SM inv	0	0	0.025159	0.067588	0	0	0	0	0.092747
24	2 SM pisc	0	0	0.005138	0.026823	0	0	0	0	0.031961
25	2 Crustaceans	0	0	0.041264	0.035892	0	0	0	0	0.077156
26	2 Macrobenthos	0	0	0.001875	0.014206	0	0	0	0	0.016081
27	2 Meiobenthos	0	0	0	0	0	0	0	0	0
28	2 Zooplankton	0	0	0	0	0	0	0	0	0
29	2,3 Hilsa	0	0	0	0	0.03662	0	0	0	0.036623
30	2,3 Indian mackerel	0	0.026994	0.016928	0.004008	0	0	0	0	0.04793
31	3 L pisc	0	0.029437	0	0	0	0	0	0	0.029437
32	3 Carangids	0	0.031914	0	0	0	0	0	0	0.031914
33	3 S pelagics	0	0.046784	0	0	0	0	0	0	0.046784
34	3 L pisc comm	0	0.042999	0	0	0	0	0	0	0.042999
35	3 Milkfish plus	0	0.006744	0	0	0	0	0	0	0.006744
36	3 SM inv	0	0.043341	0	0	0	0	0	0	0.043341
37	3 SM pisc	0	0.031763	0	0	0	0	0	0	0.031763
38	3 Crustaceans	0	0.070085	0	0	0	0	0	0	0.070085
39	3 Macrobenthos	0	0.010223	0	0	0	0	0	0	0.010223
40	3 Meiobenthos	0	0	0	0	0	0	0	0	0
41	3 Zooplankton	0	0	0	0	0	0	0	0	0
42	1 Phytoplankton	0	0	0	0	0	0	0	0	0
43	2 Phytoplankton	0	0	0	0	0	0	0	0	0
44	3 Phytoplankton	0	0	0	0	0	0	0	0	0
45	Benthic plants	0	0	0	0	0	0	0	0	0
46	Bigeye tuna	0	0	0	0	0	0.004	0	0	0.004
47	Yellowfin tuna	0	0	0	0	0	0	0.0065	0	0.0065
48	Marlins	0	0	0	0	0	0	0	0.0011	0.0011
49	Detritus	0	0	0	0	0	0	0	0	0
50	Sum	0.012441	0.380447	0.169596	0.414828	0.036623	0.004	0.0065	0.0011	1.025534

A2.2. Effort in horse power days for the east coast of India (Bhathal 2013) and relative effort as used for region 2 in Ecosim.

	Marine fishing effort in horse power days			Relative effort for region 2		
	Small-scale	**Industrial**	**Large trawlers**	**Small-scale**	**All industrial** *a*	**Industrial only** *b*
1978	95,482,790	53,782,186	2,315,460	1	1	1
1979	102,335,975	57,186,311	2,970,688	1.072	1.072	1.063
1980	108,636,178	61,228,736	4,283,750	1.138	1.168	1.138
1981	112,113,803	64,684,161	4,307,393	1.174	1.230	1.203
1982	117,647,129	70,187,123	4,497,938	1.232	1.331	1.305
1983	124,238,927	76,740,390	3,256,759	1.301	1.426	1.427
1984	130,951,700	83,406,468	3,084,113	1.371	1.542	1.551
1985	143,445,594	95,821,044	4,101,788	1.502	1.781	1.782
1986	150,505,299	102,733,189	4,496,053	1.576	1.911	1.910
1987	154,487,496	108,202,947	2,053,794	1.618	1.965	2.012
1988	181,710,800	136,865,740	2,451,666	1.903	2.483	2.545
1989	212,923,659	166,580,613	2,758,574	2.230	3.019	3.097
1990	246,342,990	196,892,566	3,010,675	2.580	3.563	3.661
1991	293,766,283	235,343,022	2,909,193	3.077	4.247	4.376
1992	320,745,757	257,653,290	2,780,838	3.359	4.643	4.791
1993	347,515,519	283,497,874	2,596,934	3.640	5.100	5.271
1994	401,001,786	335,259,000	2,355,627	4.200	6.018	6.234
1995	440,934,984	370,550,807	1,910,840	4.618	6.640	6.890
1996	481,578,826	406,553,257	1,544,876	5.044	7.275	7.559
1997	522,935,045	443,268,084	1,203,612	5.477	7.923	8.242
1998	565,479,216	480,696,473	896,642	5.922	8.585	8.938
1999	608,737,772	518,839,247	929,483	6.375	9.265	9.647
2000	608,737,772	518,839,247	889,852	6.375	9.265	9.647
2001	608,737,772	518,839,247	894,039	6.375	9.265	9.647
2002	608,737,772	518,839,247	891,919	6.375	9.265	9.647
2003	608,737,772	518,839,247	905,565	6.375	9.265	9.647
2004	608,737,772	518,839,247	919,428	6.375	9.265	9.647
2005	608,737,772	518,839,247	918,256	6.375	9.265	9.647

a includes large trawlers; used in the Ecosim model section

b excludes large trawlers; used to generate Ecosim results found in Appendix A6.

A2.3. Biomass, catch, and fishing effort directed to ***hilsa*** *compiled for Bangladesh, the extrapolation for 1978-1986, and the resulting fishing effort time series used in Ecosim (relative value).*

Both catches and biomass densities are for the entire study area.

	Effort in number of boats[a]		Extrapolation back to 1978					
	Non-motorized	motorized	Non-motorized	Motorized	Total	Relative effort[b]	Biomass t/km^2 [c]	Catches t/km^2
1978			3633	3639	7272	1		0.037
1979			3678	3684	7362	1.012		0.036
1980			3723	3729	7451	1.025		0.035
1981			3768	3774	7541	1.037		0.035
1982			3812	3818	7631	1.049		0.035
1983			3857	3863	7721	1.062		0.036
1984			3902	3908	7810	1.074		0.037
1985			3947	3953	7900	1.086		0.037
1986			3992	3998	7990	1.099		0.043
1987	4037	4043			8080	1.111	0.219	0.046
1988	5186	4284			9470	1.302	0.200	0.044
1989	6336	4525			10861	1.494	0.219	0.046
1990	7486	4766			12252	1.685	0.253	0.047
1991	8635	5007			13643	1.876	0.230	0.049
1992	9785	5248			15033	2.067	0.223	0.055
1993	10935	5490			16424	2.259	0.212	0.057
1994	12084	5731			17815	2.450	0.195	0.049
1995	13234	5972			19205	2.641	0.191	0.055
1996	14383	6213			20596	2.832	0.181	0.058
1997	15533	6454			21987	3.024	0.163	0.056
1998	16683	6695			23378	3.215	0.126	0.055
1999	17832	6936			24768	3.406	0.175	0.054
2000	18982	7177			26159	3.597	0.122	0.055
2001	20132	6377			26509	3.645	0.152	0.061
2002	21281	6618			27899	3.837	0.130	0.056
2003	22431	6859			29290	4.028	0.132	0.051
2004	23581	7100			30681	4.219	0.159	0.059
2005	24730	7341			32072	4.410	0.156	0.061
2006	25880	7582			33462	4.602	0.153	0.062
2007						*5.522*	0.165	0.060
2008						*5.522*	0.178	0.062
2009						*5.522*	0.193	0.062
2010						*5.522*	0.213	0.073

[a] from (BOBLME 2012)

[b] the time series was continued to 2010 by assuming constant effort from 2006 to 2010 (Rishi Sharma, pers. comm., IOTC)

[c] Rishi Sharma, pers. comm., IOTC, based on results of single species model described in (BOBLME 2012)

A2.4 Effort by large pelagic fleet contributed by Rishi Sharma, IOTC.

	Striped Marlin		Blue Marlin		marlins				
Year	Taiwan	Japan	Taiwan	Japan	*a*	Bigeye	Yellowfin	Kawakawa	Skipjack
1960						1.42			
1961						1.44			
1962						1.47			
1963						1.28	0.54		
1964						1.35	0.63		
1965						1.15	0.49		
1966						1.27	0.67		
1967						1.25	0.53		
1968						1.13	0.53		
1969						1.18	0.53		
1970						1.11	0.63		
1971		1.38		1.49	1.44	0.86	0.48		
1972		1.43		2.04	1.74	1.03	0.42		
1973		2.62		2.34	2.48	0.97	0.51		
1974		2.39		2.10	2.24	1.02	0.33		
1975		2.68		1.66	2.17	1.02	0.29		
1976		2.36		1.90	2.13	1.46	0.37		
1977		5.64		2.69	4.17	2.07	0.42		
1978		4.49		2.06	3.28	2.08	0.38		
1979		3.99		1.58	2.79	1.61	0.24		
1980	2.93	4.41	1.05	2.32	3.37	1.45	0.29		
1981	2.47	2.76	1.25	1.80	2.28	0.99	0.28		
1982	1.54	2.47	1.03	1.69	2.08	1.26	0.24		
1983	0.99	1.39	1.15	2.17	1.78	1.30	0.34		
1984	1.35	2.39	1.42	1.98	2.18	0.94	0.33		
1985	1.63	2.49	1.15	2.29	2.39	0.85	0.34		1.46
1986	2.12	2.44	1.49	1.65	2.04	0.96	0.34		1.37
1987	1.37	1.10	1.26	1.54	1.32	1.12	0.30		1.37
1988	1.06	0.83	1.03	1.31	1.07	0.95	0.38		1.43
1989	0.79	0.60	0.77	0.93	0.77	1.02	0.26		1.34
1990	0.46	0.50	0.57	0.83	0.67	0.83	0.39		1.37
1991	1.10	0.88	0.70	0.81	0.85	1.02	0.19		1.37
1992	1.02	0.84	0.88	0.95	0.90	0.65	0.19		1.34
1993	0.83	0.76	0.78	0.98	0.87	0.92	0.20		1.28
1994	1.78	0.92	0.76	1.23	1.07	0.96	0.15		1.31
1995	1.43	0.99	0.86	0.80	0.90	0.75	0.14		1.23
1996	1.21	0.77	0.89	0.66	0.71	0.82	0.12		1.11
1997	1.05	0.57	1.15	0.94	0.76	0.68	0.14		1.07
1998	0.68	0.29	1.04	0.82	0.55	0.64	0.11		0.97
1999	0.88	0.50	1.33	0.77	0.64	0.73	0.14		0.93
2000	0.62	0.35	1.15	0.75	0.55	0.58	0.18		0.83
2001	0.73	0.31	1.02	0.50	0.41	0.63	0.10		0.93
2002	0.65	0.25	1.06	0.42	0.33	0.51	0.08		0.88
2003	0.58	0.17	0.96	0.37	0.27	0.59	0.07		1.00
2004	0.61	0.11	0.86	0.35	0.23	0.66	0.10	0.86	0.68
2005	0.37	0.11	0.83	0.30	0.20	0.73	0.06	1.09	0.80
2006	0.30	0.17	0.78	0.43	0.30	0.67	0.10	0.75	0.78
2007	0.15	0.14	0.62	0.44	0.29	0.57	0.08	1.41	0.55
2008	0.31	0.22	0.79	0.35	0.29	0.59	0.04	0.82	0.51
2009	0.16	0.21	0.87	0.36	0.29	0.45	0.04	1.16	0.46
2010	0.41	0.93	1.11	0.54	0.74	0.48	0.03	1.01	0.37
2011	0.42	1.12	1.40	0.70	0.91	0.82	0.03	0.91	0.28

a based on the Japanese index

A3 Diet compositions

A3.1 Source of fish diets.

References labeled FB paired with a number correspond to Fishbase document number; FB, items are species for which there is only a list of food items.

Species	Location	Source
Indian mackerel		
Rastrelliger kanagurta		FB
Rastrelliger kanagurta		FB
Hilsa		
Tenualosa ilisha	Bangladesh, freshwater to marine	FB 4837
Tenualosa ilisha	marine, Bangladesh	(Dutta et al. 2013)
Oceanic sharks		
Pteroplatytrygon violacea		FB, items
Carcharhinus falciformis	NW Atlantic USA	FB 37512
Alopias superciliosus	NW Atlantic USA	FB 37512
Alopias vulpinus	NW Atlantic USA	FB 37512
Alopias vulpinus		FB, items
Isurus oxyrinchus	NW Atlantic	FB 37512
Isurus oxyrinchus	NW Atlantic	FB 37512
Prionace glauca	NW Atlantic	FB 37512
Prionace glauca	Monterey Bay California	FB 28071
Isurus paucus	NW Atlantic	FB 37512
Centrophorus squamosus	S Africa	FB 12473
Coastal elasmobranch		
Rhizoprionodon acutus	Australia	FB 13356
Carcharhinus limbatus	South Africa 1978-91	FB 26970
Galeocerdo cuvier	NW Atlantic	FB 37512
Himantura uarnak	Kuwait	food items +FB 37858
Mustelus manazo	Japan	FB 47252
Tuna-like		
Thunnus albacares	Andaman sea	(Panjarat 1999)
Katsuwonus pelamis	Mozambique 1989	FB 9035
Thunnus obesus	Solomon Is. June 1993	FB 28765
Xiphias gladius	North BOB	(Nootmorn et al. 2008)
Xiphias gladius	Algeria, Annaba Gulf 1986-87	FB 419911
Xiphias gladius	North +Tropical Atlantic	FB 76866
Makaira nigricans	SW equatorial Atlantiqc 1992-1993	FB 51769
Istiompax indica	Malaysia east coast 93-94	FB 53850
Istiophorus platypterus	Malaysia 1993-94	FB 53850
Acanthocybium solandri	G Mexico USA	FB 28119
Coastal scombrids		
Scomberomorus commerson	Solomon Is	FB 30531
Scomberomorus commerson	Malaysia east coast 1993-94	FB 53850
Euthynnus affinis	Solomon Is	FB 30531
Euthynnus affinis	Taiwan 2000-2001	FB 53677
Sarda orientalis		FB, items
Thunnus tonggol	Malaysia	FB 53850
ML bathy		
Alepisaurus ferox	Hawaii may 1990	FB 12036
Arctozenus risso	Kuril Is 87-92	FB 41668
Nemichthys scolopaceus	USA Newfoundland	FB 37512
Carangids		
Carangoides chrysophrys	New Caledonia 1985-98	FB 55797
Alectis indica		FB, items

Selar crumenophthalmus	Thailand 1985	FB 26908
Decapterus russelli	Manila Bay, Philippines	FB 761
Megalaspis cordyla	Solomon Is	FB 30531
Caranx sexfasciatus	Malaysia	FB 53850
Caranx melampygus	Hawaii	FB 6057
Alectis ciliaris	Columbia	FB 56479
Elagatis bipinnulata	Brazil	FB 89206
Carangoides ferdau	Malaysia 93-94	FB 53850
Carangoides ferdau	New Caledonia 85-97	FB 55797
L pisc		
Albula vulpes	Florida	FB 30204
Tylosurus crocodilus crocodilus	Solomon Is	FB 30531
Chirocentrus dorab	Solomon Is	FB 30531
Sphyraena jello	Malaysia 1993-94	FB 53850
Sphyraena jello		FB, items
Sphyraena barracuda	Puerto Rico 1958-1961	FB 33
Sphyraena obtusata	Malaysia 1993-94	FB 53850
Sphyraena obtusata	Solomon Is	FB 30531
Brotula multibarbata	Hawaii	FB 13550
Rachycentron canadum	Malaysia	FB 53850
Trichiurus lepturus	W India, 1978	FB 4424
Lepturacanthus savala		FB, items
Coryphaena hippurus	Malaysia 1993-94	FB 53850
Pomatomus saltatrix	Brazil	FB 42756
Megalops cyprinoides	New Caledonia	FB 55797
L pisc comm		
Lethrinus rubrioperculatus	New Caledonia 85-97	FB 55797
Lethrinus xanthochilus	New Caledonia 85-97	FB 55797
Lutjanus bohar	New Caledonia 85-97	FB 55797
Epinephelus polyphekadion	New Caledonia 85-97	FB 55797
Variola louti	New Caledonia 85-97	FB 55797
Etelis coruscans	Hawaii	FB 8925
Lutjanus johnii	Gulf Carpentaria, Australia	FB 6932
Lutjanus malabaricus	Malaysia	FB 53850
Lutjanus sebae	Australia	FB 6932
Aprion virescens	Hawaii	FB 8925
Etelis carbunculus	Hawaii	FB 8926
Pristipomoides filamentosus	East coast Malaysia	FB 53850
Pristipomoides auricilla	N Marianas 1984	FB 13792
Lutjanus vitta	Australia	FB 6932
Lutjanus fulvus	New Caledonia	FB 55797
Lutjanus carponotatus	Australia	FB 26866
Lutjanus quinquelineatus	New Caledonia	FB 55797
Saurida tumbil	India, 1964-1968	FB 6931
Cephalopholis miniata	Egypt, Red Sea, 1978-83	FB 6775
Epinephelus areolatus	New Caledonia 1985-97	FB 55797
Epinephelus areolatus	Australia, Gulf Carpentaria 1990	FB 6932
Epinephelus coioides	New Caledonia 1985-97	FB 55797
Epinephelus malabaricus	New Caledonia 1985-97	FB 55797
Lethrinus nebulosus	New Caledonia 1985-97	FB 55797
Lethrinus nebulosus	Australia, Gulf Carpentaria 1990	FB 6932
Lutjanus argentimaculatus	New Caledonia 1985-1997	FB 55797
Pristipomoides sieboldii	Hawaii 1987-89	FB 8925
Pristipomoides zonatus	Hawaii 1987-90	FB 8926
Pristipomoides zonatus	N Marianas Pathfinder reef	FB 13792
Lethrinus harak	New Caledonia 1985-97	FB 55797

Saurida undosquamis	India, NW BOB	FB 6931
Gymnocranius grandoculis	New Caledonia 85-87	FB 55797
Lutjanus gibbus	Malaysia 85-97	FB 55797
Lutjanus kasmira	New Caledonia 85-97	FB 55797
Lutjanus fulviflamma	New Caledonia	FB, items
S pelagics		
Sardinella gibbosa		FB, items
Stolephorus indicus	Singapore	FB 51145
Stolephorus insularis	Solomon Is	FB 32754
Thryssa mystax	Kuwait	items + FB 37858
Herklotsichthys quadrimaculatus	Kiribati 89-91	FB 9004
Encrasicholina devisi	Solomon Is	FB 32754
Spratelloides delicatulus	Solomon Is	FB 32754
Spratelloides gracilis	Solomon Is	FB 32754
Amblygaster sirm	Indonesia	FB 823
SM inv		
Upeneus sulphureus	Red Sea 1984	FB 6292
Pampus argenteus	Orissa, India BOB 1972	FB 37087
Pampus argenteus	Orissa, India BOB 1973	FB 37087
Pampus chinensis		FB, items
Acanthopagrus berda		FB, items
Acanthopagrus latus	Kuwait NW Arabian sea	FB 37858
Mugil cephalus	Spain Valencia, summer	FB 50467
Gerres filamentosus	New Caledonia	FB 55797
Myripristis murdjan	Hawaii	FB 13550
Myripristis murdjan	Madagascar	FB 78108
Monotaxis grandoculis	Hawaii 69-70	FB 13550
Siganus fuscescens		FB, items
Siganus guttatus		FB, items
Sillago sihama	Australia 78	FB 9638
Moolgarda seheli		FB, items
Cynoglossus arel	India	FB 5260
Chaetodon plebeius	Ryukyu Is	FB 6110
Chaetodon vagabundus	Ryukyu Is	FB 6110
Nuchequula gerreoides	Singapore	FB 51145
Secutor ruconius	China	FB 26569
Grammatobothus polyophthalmus	New Caledonia 85-97	FB 55797
Gazza minuta	Solomon Is	FB 30531
Petroscirtes breviceps		FB, items
Centropyge bicolor		FB, items
Atherinomorus lacunosus	Marshall Is 1972	FB 13784
Pentaprion longimanus	Thailand	FB 26908
Pseudocheilinus hexataenia	Ryukyu Is	FB 6110
Halichoeres melanurus	Ryukyu Is	FB 6110
Thalassoma amblycephalum	Ryukyu Is	FB 6110
Scatophagus argus	New Caledonia 85-97	FB 55797
Selaroides leptolepis	Thailand 1985	FB 26908
Pterocaesio pisang	Japan	FB 36318
Upeneus moluccensis	New Caledonia 85-97	FB 55797
Upeneus vittatus	New Caledonia 85-97	FB 55797
Nemipterus furcosus	Australia 1990	FB 6932
Equulites leuciscus	Thailand	FB 26908
Photopectoralis bindus	Thailand	FB 26908
Pentaprion longimanus	Thailand	FB 26908
Acanthurus lineatus	Guam	FB 6155

Acanthurus nigrofuscus	Ryuku Is	FB 6110
Acanthurus xanthopterus	NA	FB, items
Apogon crassiceps	NA	FB, items
Apogon ellioti	G. Thailand 1985	FB 26908
Scarus ghobban	Ryulu Is, Philippines	FB6110, FB43166
Scarus quoyi	Philippines 1991	FB 43166
Aluterus monoceros	Colombia	FB 46593
Aluterus scriptus	Puerto Rico	FB 33
SM pisc		
Argyrops spinifer	Australia Gulf Carpentaria 1990	FB 6932
Dendrochirus brachypterus	New Caledonia 85-97	FB 55797
Dendrochirus zebra	Ryuku Is	FB 6110
Plectorhinchus gibbosus	New Caledonia 85-97	FB 55797
Onigocia macrolepis	New Caledonia 85-97	FB 55797
Abalistes stellaris	New Caledonia 85-97	FB 55797
Eleotris fusca	Japan 1998	FB 54520
Nemipterus hexodon	Australia 1990	FB 6932
Atule mate	Thailand	FB 26908
Neoniphon sammara	Madagascar	FB 78108
Pomadasys argenteus	New Caledonia 85-97	FB 55797
Nemipterus peronii	Australia, Gulf Carpentaria 1990	FB 6932
Diagramma pictum	New Caledonia 1985-98	FB 55797
Diagramma pictum	Australia Gulf Carpentaria	FB 6932
Priacanthus tayenus	Gulf Thailand	FB 26908
Priacanthus hamrur	India east coast 1993	FB 30941
Psettodes erumei	India Porto novo 1972-73	FB 6003
Plectorhinchus pictus	East coast Peninsular Malaysia 93-94	FB 53850
Milkfish plus		
Netuma thalassina	Kuwait Arabian Gulf	FB 37858,
Netuma thalassina	Australia, G Carpentaria 1990	FB 6932
Diodon hystrix	Hawaii	FB 3921
Arothron stellatus	New Caledonia 1985-97	FB 55797

A3.2 Original diet matrix

Prey	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 Oceanic shark	0.0066	0.0295	0	0	0	0	0	0	0	0	0	0	0	0	0
2 Coastal shark ray	0.0129	0.0581	0	0	0	0	0	0	0	0	0	0	0	0	0
3 Tuna-like	0.0834	0.0018	0.0306	0	0	0	0	0.0019	0.0030	0	0	0	0	0	0
4 Coastal scombrids	0.0111	0.0018	0.0426	0	0	0	0	0.0019	0	0	0	0	0	0	0
5 Jellyfish	0.0100	0.0000	0.0000	0	0	0	0	0	0	0.0125	0	0	0.0053	0	0
6 Cephalopods	0.1605	0.0110	0.1124	0.0322	0	0.075	0	0.0640	0.0666	0.0631	0.0002	0.0236	0.0016	0.0103	0
7 1 S bathy	0.0379	0.0000	0.0561	0.0177	0	0.017	0	0.0691	0.0147	0.0271	0	0.0414	0	0.0010	0
8 1 ML bathy	0.0658	0.0053	0.0246	0	0	0	0	0.0290	0.0028	0	0	0.0027	0	0	0
9 1 L pisc	0.0027	0.0032	0.0005	0.0003	0	0	0	0.0093	0.0316	0.0152	0	0.0121	0	0.0013	0
10 1 Carangids	0.0007	0.0008	0.0084	0.0059	0	0.0025	0	0	0.1747	0.0729	0.0188	0.0541	0.0044	0.0645	0
11 1 S pelagics	0.0012	0.0010	0.0083	0.0093	0	0.0019	0	0.0066	0.2702	0.2290	0.0223	0.0859	0.0170	0.0800	0
12 1 L pisc comm	0.0006	0.0005	0	0	0	0	0	0	0.0225	0.0110	0	0.0120	0.0004	0.0045	0
13 1 SM inv	0.0019	0.0038	0.0018	0.0084	0	0.0037	0	0.0053	0.1548	0.2371	0.0188	0.1604	0.0078	0.0869	0
14 1 SM pisc	0.0030	0.0032	0.0019	0.0010	0	0.0037	0	0.0106	0.0496	0.0837	0.0123	0.1097	0.0072	0.0373	0
15 1 Macrobenthos	0.0012	0.0000	0.0000	0.0037	0	0.0460	0	0.1961	0.1840	0.1737	0.1940	0.4633	0.5940	0.7013	0.05
16 1 Meiobenthos	0.0004	0.0000	0.0000	0	0	0	0	0	0	0.0004	0.0101	0	0.0473	0.0001	0.20
17 1 Zooplankton	0.0024	0.0000	0.0005	0.0004	0	0	0.4585	0.1509	0.0245	0.0533	0.6810	0.0345	0.1307	0.0123	0.10
18 2 L pisc	0.0188	0.0222	0.0033	0.0023	0	0	0	0.0041	0	0	0	0	0	0	0
19 2 Carangids	0.0050	0.0058	0.0582	0.0409	0	0.0174	0	0	0	0	0	0	0	0	0
20 2 S pelagics	0.0082	0.0072	0.0569	0.0641	0	0.0086	0	0.0029	0	0	0	0	0	0	0
21 2 L pisc comm	0.0041	0.0037	0.0000	0	0	0	0	0	0	0	0	0	0	0	0
22 2 Mikfish plus	0.0013	0.0010	0.0068	1.5E-06	0	0	0	0	0	0	0	0	0	0	0
23 2 SM inv	0.0128	0.0261	0.0125	0.0580	0	0.0254	0	0.0024	0	0	0	0	0	0	0
24 2 SM pisc	0.0210	0.0224	0.0133	0.0071	0	0.0254	0	0.0048	0	0	0	0	0	0	0
25 2 Crustaceans	0.0000	0.0646	0.0000	0.0198	0	0.1076	0	0	0	0	0	0	0	0	0
26 2 Macrobenthos	0.0080	0.0233	0.0000	0.0064	0	0	0	0.0884	0	0	0	0	0	0	0
27 2 Meiobenthos	0.0029	0.0000	0.0000	0	0	0.0104	0	0	0	0	0	0	0	0	0
28 2 Zooplankton	0.0166	0.0000	0.0038	0.0002	0	0	0.2067	0.0680	0	0	0	0	0	0	0
29 2,3 Hilsa	0.0413	0.0208	0.0226	0.0168	0	0.010033128	0	0	0	0	0	0	0	0	0
30 2,3 Indian mackerel	0.0290	0.0226	0.0327	0.0619	0	0.025082821	0	0.0019	0	0	0	0	0	0	0
31 3 L pisc	0.0607	0.0718	0.0106	0.0075	0	0	0	0.0068	0	0	0	0	0	0	0
32 3 Carangids	0.0163	0.0188	0.1884	0.1324	0	0.0563	0	0	0	0	0	0	0	0	0
33 3 S pelagics	0.0264	0.0232	0.1843	0.2075	0	0.0240	0	0.0049	0	0	0	0	0	0	0
34 3 L pisc comm	0.0133	0.0121	0.0000	0	0	0	0	0	0	0	0	0	0	0	0
35 3 Milkfish plus	0.0041	0.0034	0.0221	4.77526E-06	0	0	0	0	0	0	0	0	0	0	0
36 3 SM inv	0.0415	0.0844	0.0403	0.1876	0	0.0821	0	0.0039	0	0	0	0	0	0	0
37 3 SM pisc	0.0679	0.0725	0.0432	0.0229	0	0.0821	0	0.0078	0	0	0	0	0	0	0
38 3 Crustaceans	0.0001	0.2091	0.0000	0.0640	0	0.3483	0	0	0	0	0	0	0	0	0
39 3 Macrobenthos	0.0257	0.0755	0.0000	0.0207	0	0.0268	0	0.1432	0	0	0	0	0	0	0
40 3 Meiobenthos	0.0092	0	0.0000	0	0	0	0	0	0	0	0	0	0	0	0
41 3 Zooplankton	0.0538	0	0.0122	0.0007	1	0	0.3348	0.1101	0	0	0	0	0	0	0
42 1 Phytoplankton	0.0021	0	0	0	0	0	0	0	0	0.0117	0.0340	0	0.0345	0	0.10
43 2 Phytoplankton	0.0144	0	0.0008	0	0	0	0	0	0	0	0	0	0	0	0
44 3 Phytoplankton	0.0466	0	0.0000	0	0	0	0	0	0	0	0	0	0	0	0
45 Benthic plants	0.0016	0	0.0002	0	0	0	0	0	0.0010	0	0	0.0003	0.1161	0.0001	0
46 Bigeye tuna	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47 Yellowfin tuna	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48 Marlins	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49 Detritus	0.0405	0.0086	0	0	0	0	0	0	0	0.0092	0.0084	0	0.0327	0	0.55
50 Import	0.0043	0.0809	0	0	0	0	0	0.0058	0	0	0.0001	0	0.0010	0.0002	0

	Prey \ predator	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	Oceanic shark	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Coastal shark ray	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Tuna-like	0	0	0.0030	0	0	0	0	0	0	0	0	0	0	0
4	Coastal scombrids	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Jellyfish	0	0	0	0.0125	0	0	0	0.0053	0	0	0	0	0	0
6	Cephalopods	0	0	0.0666	0.0631	0.0002	0.0236	0.0206	0.0016	0.0103	0	0	0	0	0
7	1 S bathy	0	0	0.0147	0.0271	0	0.0414	0	0	0.0010	0	0	0	0	0
8	1 ML bathy	0	0	0.0028	0	0	0.0027	0	0	0	0	0	0	0	0
9	1 L pisc	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	1 Carangids	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	1 S pelagics	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	1 L pisc comm	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	1 SM inv	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	1 SM pisc	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	1 Macrobenthos	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	1 Meiobenthos	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	1 Zooplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	2 L pisc	0	0	0.0316	0.0152	0	0.0121	0	0	0.0013	0	0	0	0	0
19	2 Carangids	0	0	0.1352	0.0153	0.0032	0.0414	0	0.0019	0.0473	0	0	0	0	0
20	2 S pelagics	0	0	0.2410	0.1579	0.0139	0.0606	0	0.0150	0.0590	0	0	0	0	0
21	2 L pisc comm	0	0	0.0225	0.0110	0	0.0120	0.0260	0.0004	0.0045	0	0	0	0	0
22	2 Mikfish plus	0	0	0.0329	0.0001	0	0.0128	0	0	0.0027	0	0	0	0	0
23	2 SM inv	0	0	0.1220	0.2370	0.0188	0.1476	0.0260	0.0078	0.0842	0	0	0	0	0
24	2 SM pisc	0	0	0.0496	0.0837	0.0123	0.1097	0	0.0072	0.0373	0	0	0	0	0
25	2 Crustaceans	0	0	0.1610	0.1183	0.1609	0.2796	0.2440	0.1701	0.4933	0.05	0	0	0	0
26	2 Macrobenthos	0	0	0.0229	0.0554	0.0331	0.1837	0.6571	0.4239	0.2080	0	0.05	0	0	0
27	2 Meiobenthos	0	0	0	0.0004	0.0101	0	0	0.0473	0.0001	0.40	0.20	0	0	0
28	2 Zooplankton	0	0	0.0245	0.0533	0.6810	0.0345	0.0003	0.1307	0.0123	0.15	0.10	0	0	0.2928
29	2,3 Hilsa	0	0	0.0395	0.0576	0.0155	0.0127	0.0260	0.0025	0.0172	0	0	0	0	0
30	2,3 Indian mackerel	0	0	0.0292	0.0711	0.0084	0.0253	0	0.0020	0.0210	0	0	0	0	0
31	3 L pisc	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	3 Carangids	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	3 S pelagics	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	3 L pisc comm	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	3 Milkfish plus	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	3 SM inv	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	3 SM pisc	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	3 Crustaceans	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	3 Macrobenthos	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	3 Meiobenthos	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	3 Zooplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0046
42	1 Phytoplankton	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0
43	2 Phytoplankton	0	0	0	0.0117	0.0340	0	0	0.0345	0	0	0.10	0	0.9	0.4974
44	3 Phytoplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0079
45	Benthic plants	0	0	0.0010	0	0	0.0003	0	0.1161	0.0001	0	0	0	0	0.0160
46	Bigeye tuna	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	Yellowfin tuna	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	Marlins	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49	Detritus	1	0.1	0	0.0092	0.0084	0	0	0.0327	0	0.40	0.55	1	0.1	0
50	Import	0	0	0	0	0.0001	0	0	0.0010	0.0002	0	0	0	0	0.1814

	Prey \ predator	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**46**	**47**	**48**
1	Oceanic shark	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Coastal shark ray	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Tuna-like	0	0.0030	0	0	0	0	0	0	0	0	0	0	0.0216	0	0.0313
4	Coastal scombrids	0	0	0	0	0	0	0	0	0	0	0	0	0.0216	0	0.0744
5	Jellyfish	0	0	0.0125	0	0	0	0.0053	0	0	0	0	0	0	0	0
6	Cephalopods	0	0.0666	0.0631	0.0002	0.0236	0.0206	0.0016	0.0103	0	0	0	0	0.0610	0.7741	0.1976
7	1 S bathy	0	0.0147	0.0271	0	0.0414	0	0	0.0010	0	0	0	0	0.1946	0.0152	0
8	1 ML bathy	0	0.0028	0	0	0.0027	0	0	0	0	0	0	0	0.3243	0	0.0588
9	1 L pisc	0	0	0	0	0	0	0	0	0	0	0	0	0.0021	0	0.0025
10	1 Carangids	0	0	0	0	0	0	0	0	0	0	0	0	0.0021	0.0005	0.0040
11	1 S pelagics	0	0	0	0	0	0	0	0	0	0	0	0	0.0021	0.0005	0.0075
12	1 L pisc comm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	1 SM inv	0	0	0	0	0	0	0	0	0	0	0	0	0.0021	0.0020	0.0021
14	1 SM pisc	0	0	0	0	0	0	0	0	0	0	0	0	0.0011	0.0012	0.0016
15	1 Macrobenthos	0	0	0	0	0	0	0	0	0	0	0	0	0.0010	0	0.0010
16	1 Meiobenthos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	1 Zooplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	2 L pisc	0	0	0	0	0	0	0	0	0	0	0	0	0.0148	0	0.0170
19	2 Carangids	0	0	0	0	0	0	0	0	0	0	0	0	0.0148	0.0035	0.0277
20	2 S pelagics	0	0	0	0	0	0	0	0	0	0	0	0	0.0148	0.0035	0.0514
21	2 L pisc comm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	2 Mikfish plus	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0131	0
23	2 SM inv	0	0	0	0	0	0	0	0	0	0	0	0	0.0148	0.0136	0.0143
24	2 SM pisc	0	0	0	0	0	0	0	0	0	0	0	0	0.0074	0.0080	0.0107
25	2 Crustaceans	0	0	0	0	0	0	0	0	0	0	0	0	0.0071	0	0.0071
26	2 Macrobenthos	0.1509	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	2 Meiobenthos	0.0541	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	2 Zooplankton	0.1260	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	2,3 Hilsa	0.0277	0.0395	0.0576	0.0155	0.0127	0.0260	0.0025	0.0172	0	0	0	0	0.0324	0.0152	0
30	2,3 Indian mackerel	0.0277	0.0292	0.0711	0.0084	0.0253	0	0.0020	0.0210	0	0	0	0	0.0216	0.0152	0.0450
31	3 L pisc	0	0.0316	0.0152	0	0.0121	0	0	0.0013	0	0	0	0	0.0479	0	0.0550
32	3 Carangids	0	0.1352	0.0153	0.0032	0.0414	0	0.0019	0.0473	0	0	0	0	0.0479	0.0112	0.0896
33	3 S pelagics	0	0.2410	0.1579	0.0139	0.0606	0	0.0150	0.0590	0	0	0	0	0.0479	0.0112	0.1663
34	3 L pisc comm	0	0.0225	0.0110	0	0.0120	0.0260	0.0004	0.0045	0	0	0	0	0	0	0
35	3 Milkfish plus	0	0.0329	0.0001	0	0.0128	0	0	0.0027	0	0	0	0	0	0.0424	0
36	3 SM inv	0	0.1220	0.2370	0.0188	0.1476	0.0260	0.0078	0.0842	0	0	0	0	0.0479	0.0440	0.0462
37	3 SM pisc	0	0.0496	0.0837	0.0123	0.1097	0	0.0072	0.0373	0	0	0	0	0.0240	0.0258	0.0346
38	3 Crustaceans	0	0.1610	0.1183	0.1609	0.2796	0.2440	0.1701	0.4933	0.05	0	0	0	0.0229	0	0.0231
39	3 Macrobenthos	0.1976	0.0229	0.0554	0.0331	0.1837	0.6571	0.4239	0.2080	0	0.05	0	0	0	0	0
40	3 Meiobenthos	0.0709	0	0.0004	0.0101	0	0	0.0473	0.0001	0.40	0.20	0	0	0	0	0
41	3 Zooplankton	0.1650	0.0245	0.0533	0.6810	0.0345	0.0003	0.1307	0.0123	0.15	0.10	0	0	0	0	0
42	1 Phytoplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	2 Phytoplankton	0.0541	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	3 Phytoplankton	0.0709	0	0.0117	0.0340	0	0	0.0345	0	0	0.10	0	0.9	0	0	0
45	Benthic plants	0	0.0010	0	0	0.0003	0	0.1161	0.0001	0	0	0	0	0	0	0
46	Detritus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0156
47	Import	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0156

A4. Calculation of natural mortality.

The calculation is based on growth parameters and Pauly's equation (Mp) and maximum age and Hoenig's equation (Mh). See Excel spreadsheet Appendix 4.xls.

A5 Marine and inland catches by country for hilsa.

Table A6. Catches of hilsa as compiled by the UBC Fisheries Centre Sea Around Us Project Team (SAUP) and the inland catch from FAO statistics, compared with the catches for Bangladesh (BGD) compiled for the BOBLME stock assessement (BOB BGD). The shaded cells indicate extrapolation.

	SAUP, marine catch				FAO, inland catch [a]		sum inland + marine		
Year	Bangladesh	India	Malaysia	Total	Bangladesh	India	regions 2+3	Bangladesh	BOB BGD [b]
1950	6,270	302	426	6,998	...	...			
1951	6,602	332	417	7,351	...	...			
1952	6,940	332	493	7,765	...	...			
1953	7,278	342	435	8,055	...	...			
1954	7,617	367	385	8,369	...	...			
1955	7,955	425	382	8,762	...	...			
1956	8,292	262	388	8,943	...	...			
1957	8,630	288	379	9,298	...	...			
1958	10,765	19,638	413	30,815	...	...			
1959	12,899	25,714	410	39,023	...	...			
1960	15,044	33,653	513	49,211	...	...			
1961	17,200	8,456	615	26,271	...	...			
1962	19,332	11,808	661	31,801	...	...			
1963	21,469	8,946	1,071	31,487	...	...			
1964	23,606	11,091	992	35,689	...	...			
1965	25,744	11,470	1,128	38,341	...	...			
1966	27,880	10,905	1,377	40,161	...	...			
1967	30,016	8,745	1,768	40,529	...	...			
1968	32,152	9,559	1,959	43,670	...	...			
1969	34,288	9,333	1,878	45,498	...	...			
1970	36,414	11,399	1,842	49,655	...	...			
1971	38,560	13,117	2,091	53,768	...	...			
1972	40,695	14,770	2,060	57,526	...	...			
1973	42,831	9,734	2,463	55,028	...	...			
1974	44,976	8,329	3,103	56,408	...	...			
1975	47,101	6,361	2,940	56,402	...	...			
1976	49,251	8,682	2,859	60,791	...	...			
1977	51,384	9,665	3,364	64,414	...	...			
1978	53,521	40,892	3,535	97,948	90,000	39,298	227,246	143,521	
1979	55,653	33,881	3,347	92,881	90,000	39,298	222,179	145,653	
1980	57,786	26,129	4,222	88,137	90,000	39,298	217,435	147,786	
1981	59,917	21,793	4,043	85,754	90,000	39,298	215,052	149,917	
1982	62,052	19,758	4,867	86,677	90,000	39,298	215,975	152,052	
1983	64,183	25,172	5,104	94,460	90,000	39,298	223,758	154,183	
1984	66,314	27,798	4,569	98,680	90,000	39,298	227,978	156,314	
1985	84,012	22,871	7,020	113,903	73,328	39,298	226,529	157,340	
1986	98,799	25,104	7,119	131,022	94,133	39,298	264,453	192,932	
1987	122,489	27,478	7,572	157,539	91,167	39,298	288,004	213,656	194,981
1988	123,829	24,876	6,503	155,208	78,551	39,298	273,057	202,380	183,501
1989	130,118	28,083	7,408	165,608	81,641	39,298	286,547	211,759	191,962
1990	131,103	28,252	11,086	170,441	82,168	39,298	291,907	213,271	226,351
1991	135,265	38,139	8,822	182,226	84,806	39,298	306,330	220,071	182,167
1992	148,066	43,654	10,963	202,683	96,596	39,298	338,577	244,662	188,462
1993	153,614	47,218	10,198	211,030	96,950	47,255	355,235	250,564	197,830
1994	142,882	43,385	10,084	196,351	71,370	36,478	304,199	214,252	192,531
1995	152,228	45,664	9,481	207,373	84,420	49,441	341,234	236,648	213,535
1996	159,564	54,611	9,062	223,237	90,240	48,302	361,779	249,804	207,285
1997	154,682	53,670	9,245	217,597	83,230	44,519	345,346	237,912	214,434
1998	146,340	51,174	8,995	206,509	81,634	53,729	341,872	227,974	205,739
1999	165,849	43,915	8,642	218,406	73,809	44,810	337,025	239,658	214,519
2000	165,444	46,577	10,650	222,671	79,165	41,129	342,965	244,609	219,532
2001	182,233	48,784	9,647	240,664	75,060	64,599	380,323	257,293	229,714
2002	179,519	50,654	9,806	239,979	68,250	38,984	347,213	247,769	220,593
2003	160,421	43,558	10,815	214,794	62,944	36,724	314,462	223,365	199,032
2004	217,702	47,885	11,976	277,563	71,001	20,391	368,955	288,703	255,839
2005	233,594	36,531	16,478	286,603	77,499	15,409	379,511	311,093	275,862
2006	34,165	37,061	17,810	289,036	78,273	16,216	383,525	312,438	277,123

2007	231,689	29,024	20,332	281,045	82,445	11,721	375,211	314,134	280,328
2008	235,630	26,702	20,536	282,868	89,900	14,233	387,001	325,530	290,000
2009	238,999	24,127	16,315	279,441	95,970	12,381	387,792	334,969	298,458
2010	233,860	81,609	16,399	331,868	115,179	7,260	454,307	349,039	312,612

[a] shaded area are extrapolated from the earlier year of estimation: 1984 in Bangladesh and 1992 in India
[b] catches for inland and marine catches estimated for Bangladesh (BOBLME 2012)

A6. Alternative fitting results with Ecosim

Fitting of data using the Indian relative industrial effort excluding large trawlers (region 2) labeled "industrial only" in A2.2. The most remarkable difference with the other fitting exercise is the trend in Hilsa biomass.

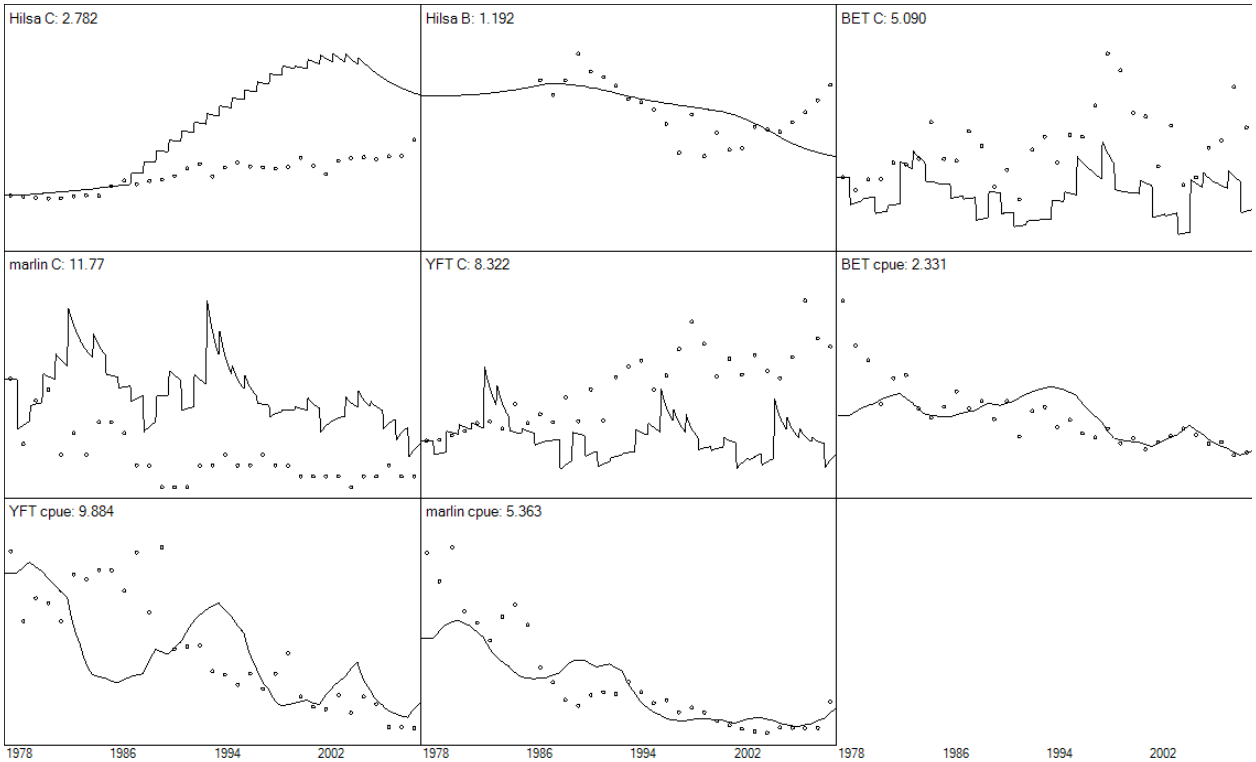

Figure A6.1. Observed (dots) and predicted (lines) relative abundance (B or CPUE) and catches (C) for hilsa, marlins, yellowfin tuna (YFT) and bigeye tuna (BET). The numbers besides the name is the sum of squares. The region 2 industrial fleet includes industrial vessels only (Industrial only time series in A2.2).

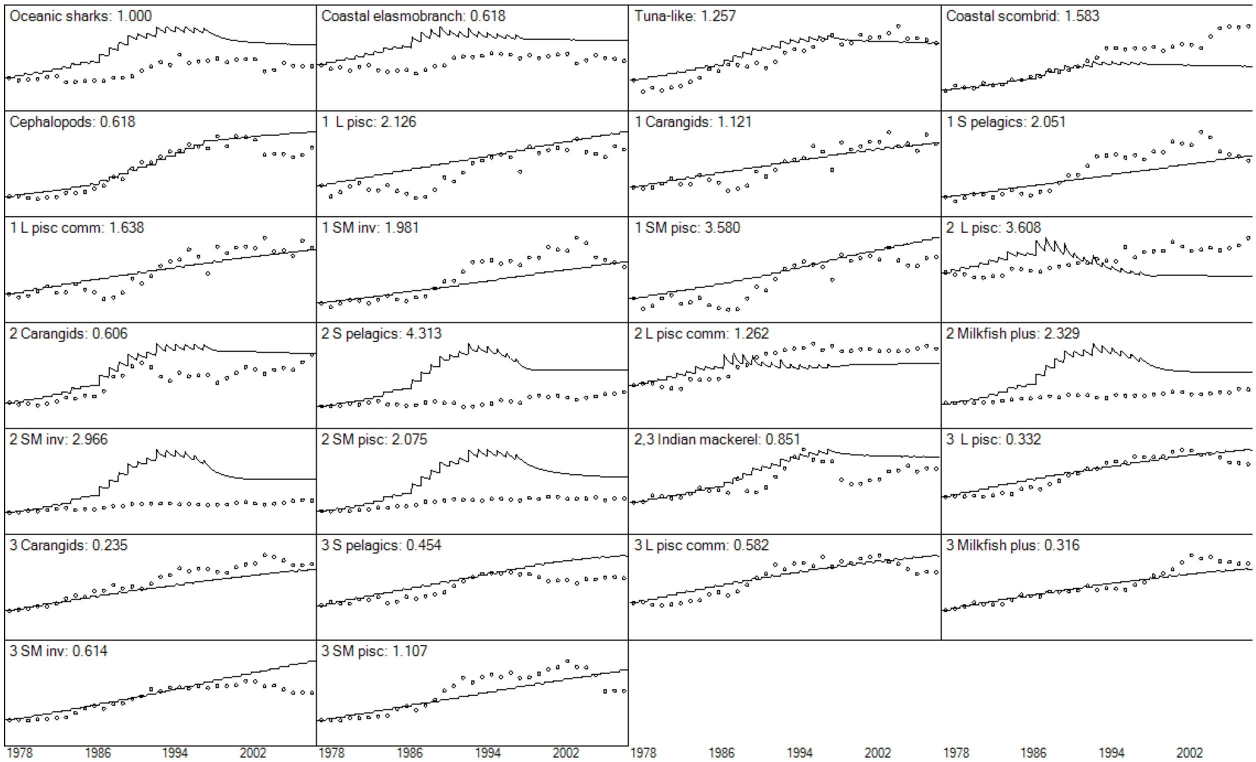

Figure A6.2. Observed (dots) and predicted (lines) catches for other species. The numbers besides the name is the sum of squares.The region 2 industrial fleet includes industrial vessels only (Industrial only time series in A2.2).

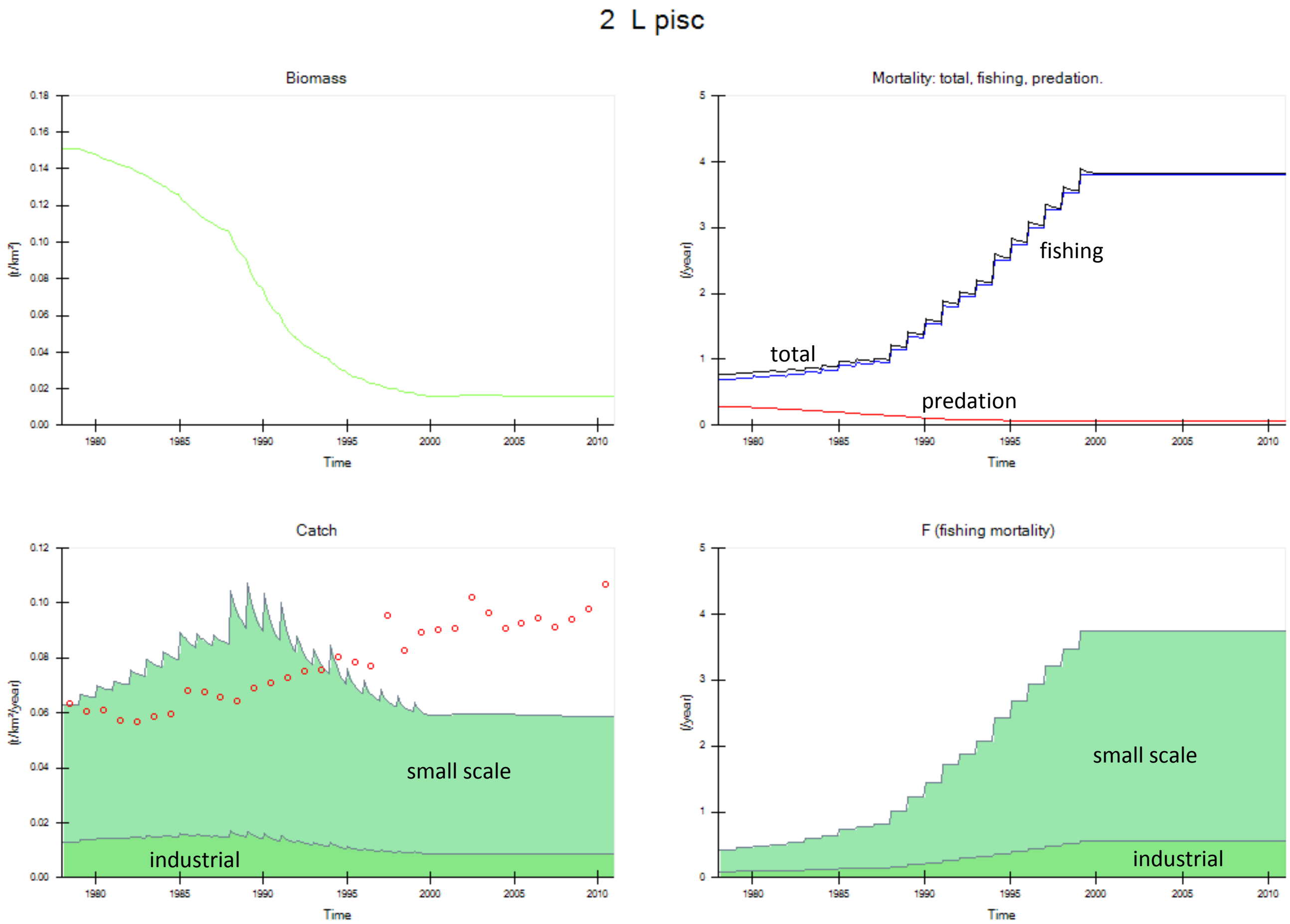

Figure A6.3. Predicted trends in biomass, catches, and mortality (lines) and observed catches (dots) for the functional group 2 L pisc. The solid green areas represent the catch or fishing mortality caused by the each of the fleet in region 2. The region 2 industrial fleet includes industrial vessels only (Industrial only time series in A2.2).

Bangladesh, India, Indonesia, Malaysia, Maldives, Myanmar, Sri Lanka and Thailand are working together through the Bay of Bengal Large Marine Ecosystem (BOBLME) Project to lay the foundations for a coordinated programme of action designed to better the lives of the coastal populations through improved regional management of the Bay of Bengal environment and its fisheries.

The Food and Agriculture Organization (FAO) is the implementing agency for the BOBLME Project.

The Project is funded principally by the Global Environment Facility (GEF), Norway, the Swedish International Development Cooperation Agency, the FAO, and the National Oceanic and Atmospheric Administration of the USA.

For more information, please visit www.boblme.org

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