A Trophic Model of the Coastal Fisheries Ecosystem off the West Coast of Sabah and Sarawak, Malaysia*

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Garces, L.R., M. Alias, A. Abu Talib, M. Mohamad-Norizam and G.T. Silvestre. 2003. A trophic model of the coastal fisheries ecosystem off the West Coast of Sabah and Sarawak, Malaysia, p. 333 - 352. *In* G. Silvestre, L. Garces, I. Stobutzki, M. Ahmed, R.A. Valmonte-Santos, C. Luna, L. Lachica-Aliño, P. Munro, V. Christensen and D. Pauly (eds.) Assessment, Management and Future Directions for Coastal Fisheries in Asian Countries. WorldFish Center Conference Proceedings 67, 1 120 p.

Abstract

A mass-balance steady-state trophic model of the coastal fisheries ecosystem off the West Coasts of Sabah and Sarawak, Malaysia (10 - 60 m depth) was constructed using the Ecopath software. The ecosystem models were partitioned into 29 ecological/trophic groups. The input values (e.g. biomasses) for selected groups were obtained from the research (trawl) surveys conducted in the area in 1972. The estimated mean trophic level of the fisheries catch for both models is about 3.3. The biomass values obtained from Ecopath when compared with the estimates of the fishery catch indicate a low level of exploitation of coastal fisheries resources in 1972.

Introduction

Fisheries catches from marine waters off Sabah and Sarawak contributed about 18% (200 933 t) and 9% (101 130 t) of the total marine fish landing of Malaysia in 1999, respectively (Department of Fisheries (DOF) 1999). About 59% of the catch is contributed by small scale (traditional) fisheries, and demersal fish constitute 39% of the catch in Sarawak (Talib et al., this vol.) On the other hand, both commercial and small scale fisheries play an equal role in Sabah and demersal fish constitute about 47% of the total landings.

A total of 13 research (trawl) surveys have been conducted off the coast of Sarawak and the West Coast of Sabah since 1972. The surveys were principally conducted to locate suitable grounds for trawling operations and subsequently to determine the abundance of demersal resources for the development of the trawl fishery (Talib et al. paper no 6).

The results of the trawl surveys in 1972 showed catch rates ranging from 149 to 261 $kg \cdot hr^{-1}$ from Sarawak coastal waters while relatively higher catch rates were obtained from the West Coast of Sabah, ranging from 476 to 576 $kg \cdot hr^{-1}$ (Latiff et al. 1976). The estimated demersal stock density ranged from 2.39 to 7.49 $t \cdot km^{-2}$ in Sarawak waters and 10.49 to 13.56 $t \cdot km^{-2}$ in Sabah. Based on the catch rates obtained in 1998, the trawl surveys in the Sarawak waters recorded a reduction of the average catch rate between 26% to 60%, while in Sabah reductions of between 82% to 88% were seen (Talib et al. paper no 6).

* WorldFish Center Contribution No. 1712

The Ecopath with Ecosim (EwE) software (Christensen et al. 2000), developed by the WorldFish Centre and the University of British Columbia, was used to construct a trophic model of the coastal fisheries resources off Sabah and Sarawak. Biomass estimates from trawl surveys in 1972, particularly the demersal species/groups, were utilized in the construction of the ecosystem models (Pauly 1996, noted that demersal trawl surveys represent the most straightforward way of finding how many and what kind of fish appears in a given area).

The Ecopath models when used with time series information (e.g. catch data or CPUE) in the Ecosim routine of the EwE software permit evaluation of the effects of changes in the ecosystem (such as a change in the fishery, artificial enhancement of recruitment and any other measurable change such as nutrient loading or pollution) to be accurately simulated and the outcome predicted (Christensen 1998; Supongpan et al. this vol.). Hence, the trophic models constructed can be used for future temporal and/or spatial analysis. The models can also be utilized to understand the ecosystem effects on the decline in biomass of most demersal resources in the area.

Materials and Methods

Study Area

The continental shelf off Sarawak has an area of about 125 000 km^2, of which 97 000 km^2 is trawlable[a] (see Fig. 1). The continental shelf (located between latitude 1º 30' N to 7º 07' N and longitude 109º 38' E to 114º 05' E) extends up to 220 m at its furthest point north of Tanjong Po in the south and its narrowest point at 30 nautical miles north of Tanjong Baram in the north. Beyond the 200 m isobath in this area, the depths drop to 1 000 m over a mean distance of 2.5 nautical miles.

The fisheries resources of Sarawak are such that major fishing effort is on muddy areas, mostly in the nearshore waters. In 1998, coastal demersal fish was reported as being overfished, while offshore demersal was being lightly exploited. Landing of marine fish by gear in 2000 was dominated by trawl nets, i.e. 70% of total gears.

The coastline of Sabah is about 1 600 km (from the boundary of Brunei Darusalam waters to Kudat on the northern tip of Sabah), and surrounded by the South China Sea and the Palawan Thrust on the northwest, the Celebes Sea on the southeast and the Sulu Sea on the east. The west coast is generally rocky and sandy, while mangrove swamps dominate the east coast. The continental shelf area (located between latitude 4º 50' N to 8º 24' N and longitude 112º 30' E to 117º 00' E) for the west coast of Sabah is roughly 28 000 km^2, with approximately 14 000 km^2 is trawlable[b].

The marine capture fisheries can be categorized into two sub-sectors, i.e. deep-sea fisheries and coastal fisheries. Deep-sea fishing contributes to roughly 30% of the total marine landings in Sabah, mostly pelagic fishes. Deep-sea resources are estimated to be about 140 000 t, of which roughly 11 000 t are demersal fish[c]. Most of the fishing activities however are concentrated within 30 nm from shore (categorized as coastal fisheries), with trawling being the main activity (mostly for prawns and finfishes).

The marine waters in the study area are influenced by monsoon patterns. Based on a recent study, the primary production during the southwest monsoon period varied between 0.13 to 0.88 gC·m^{-2} ·day^{-1} particularly in the coastal areas, and production rates were observed to be highest in waters off Brunei Darussalam and Sabah (SEAFDEC, 2000). Moreover, the total calculated biomass for chlorophyll ***a*** from a survey area of 243 000 km^2 was in the order of 1 870 and 2 070 t.

Trawl Survey

A total of 13 surveys have been conducted off the coast of Sarawak and the West Coast of Sabah since 1972 employing research vessels (Talib et al. paper no 6). In 1972, the trawl survey in the coastal waters off Sabah and Sarawak was conducted from 29 March to 1 May 1972. The survey area off the West Coast of Sabah covered about 20 209 km^2 while about 76 668 km^2 was surveyed off the coast of Sawarak waters (see Fig. 1). A total of 268 trawl stations/hauls were conducted between 10 - 60 m depth (see Fig. 2). Of this, 92 hauls were conducted off the West Coast of Sabah and 176 in Sarawak

[a] www.tracc.00server.com/Fisheries/desstructive_fishing/sarawak_trawl_fisheries.html
[b] www.tracc.00server.com/Fisheries/desstructive_fishing/fisheries_sabah.html
[c] www.iczm.sabah.gov.my/Reports/Coastal%20Profile%20Sabah/ch11/11-FISHERIES.html

waters. Detailed descriptions of the survey and fishing operations are presented in (Latiff et al., 1976). The trawl surveys were carried out using two research stern trawlers, namely, KK Jehanak (Penyelidik I) and KK Merah (Penyelidik II). The research vessels have an overall length (LOA) of 23 m and a displacement of 85 GT. The vessels were powered by 325 hp and 365 hp diesel engines, respectively. The trawl gear used was a standard German type otter trawl with cod-end mesh size of 40 mm. At each fishing station, trawling was conducted for about 1 hour with a towing speed of 2.8 knots. Fishing was conducted only during day-time hours (between 6 am to 6 pm).

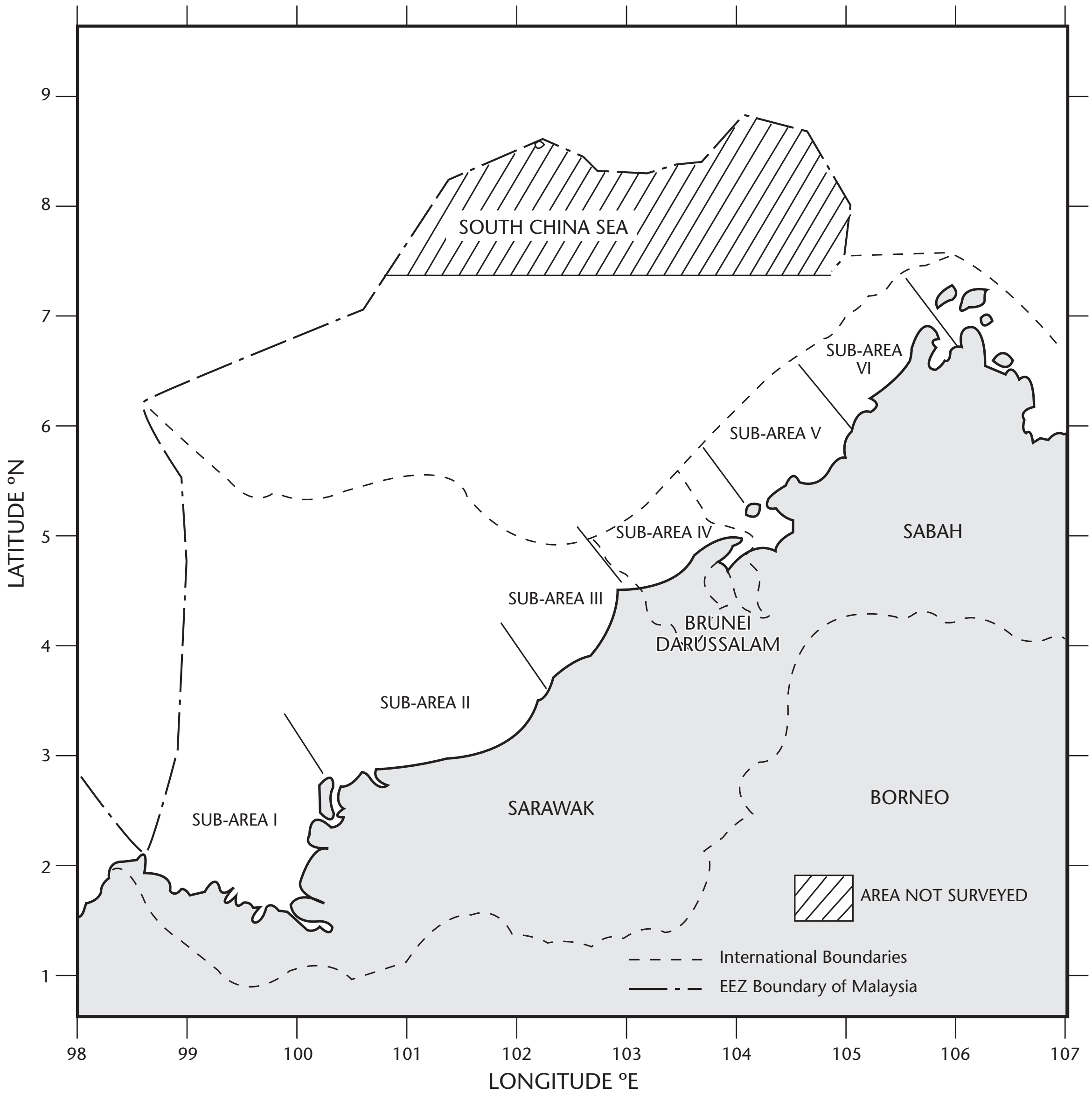

Fig. 1. Map of Sarawak and Sabah states showing the six sub-areas: Sub-areas I, II and III off the coast of Sarawak and Sub-areas IV, V and VI off the coast of Sabah.

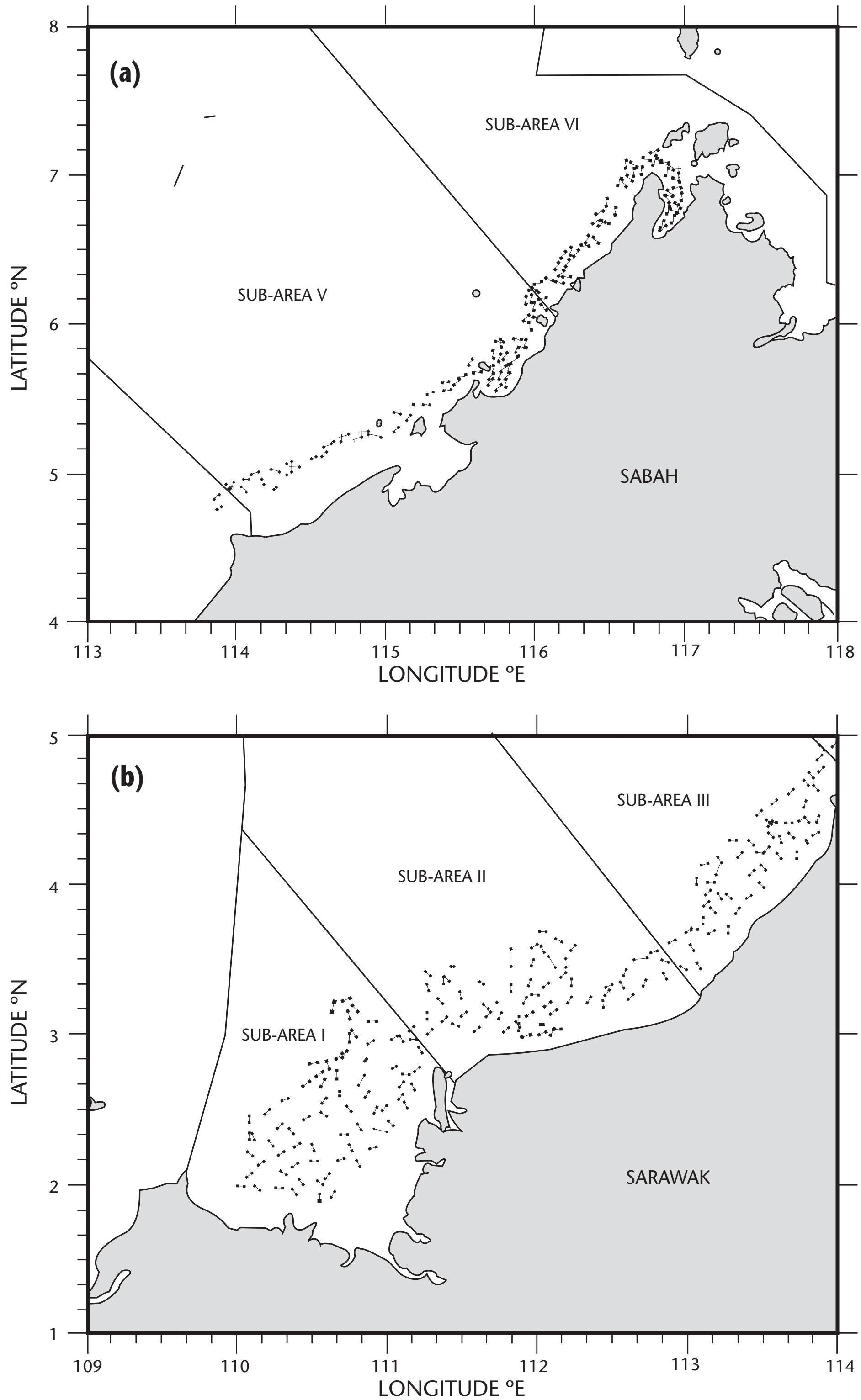

Fig. 2. Distributions of sampling stations during the 1972 surveys off the coast of Sabah (a) and Sarawak (b) using K.K. JENAHAK/K.K. MERAH.

Modeling Approach

The trophic model for Sabah and Sarawak was constructed using the Ecopath with Ecosim (EwE) software following the approach described in Christensen et al. (2000). Ecopath has been used to model a wide variety of aquatic ecosystems (Christensen and Pauly 1993). It is also used to analyze trophic interactions and state variables (biomasses) derived from quantitative steady state models of aquatic systems (Christensen and Pauly 1992a; Christensen and Pauly 1992b).

Ecopath combines the method described by (Polovina 1984) for estimation of biomass and food consumption of the various elements (species or groups of species) of an aquatic ecosystem with an approach by (Ulanowicz 1986) for analysis of flows between the elements of ecosystems.

The basic assumption of Ecopath is that the ecosystem being analyzed is in steady-state, which means that the flows in and out of each component (box) must be balanced over the time period studied. This assumption results in a system of biomass budget using a set of simultaneous linear equations (one for each group *i*) expressed as:

Production by (*i*) - all predation on (*i*) -
non predation losses of (*i*) - export of (*i*) = 0

Another way of expressing the basic equation is:

$$P_i - B_i \cdot M2_i - P_i (1-EE_i) - EX_i = 0 \qquad (1)$$

where P_i = the production of i; B_i = the biomass of *i*; $M2_i$ = the predation mortality of *i*; EE_i = the ecotrophic efficiency of *i*, that is part of the production that is either passed up the trophic level or exported; 1- EE_i = 'other mortality'; and EX_i = the export of *i*.

A predator group is connected to its prey groups by its consumption (QB*i*). Thus equation (1) can be re-expressed as:

$$B_i \cdot PB_i \cdot EE_i - \sum B_j \cdot QB_j \cdot DC_{ji} - EX_i = 0 \qquad (2)$$

where PB_i is the production/biomass ratio, QB_j is the consumption/biomass ratio of the predator (*j*), and Diet Composition (DC*ji*) is the fraction of prey (*i*) in the diet of predator (*j*).

Parameterization of the model calls for input of three of the following four parameters: B, P/B, Q/B and other mortality, for all groups of living organisms discerned in the model (Christensen and Pauly 1992a; Christensen et al. 2000). The fourth parameter is then calculated using a set of linear equations so as to ensure mass balance. For example, for any group (*i*), Ecotrophic Efficiency (EE) can be estimated if biomass (B) and production/biomass (PB) are known along with consumption/biomass (QB) and diet composition (DC) of all its predators. Input of fishery catches is also required. By using Ecopath with Ecosim software, all parameters are normalized to unit surface area using wet weights and expressing rates on an annual basis (Christensen et al. 2000).

Defining the Model Components

The model consisted of 29 ecological groups, i.e. 26 consumer groups, 2 producer (phytoplankton/algae) groups and a detritus group. The taxonomic composition of the groups is listed in Table 1 (see also Appendix A). The species composition and biomass data from the trawl surveys in 1972 and catch/landing data were used to assign the species/groups to the ecological groups. The aggregation process for this model was performed based on similarities in habitat, body size, growth and mortality rates and diet composition (Bundy and Pauly 2001). Such information (notably for fish) was mainly obtained from the FishBase database (Froese and Pauly 2000). Taxonomic groups with notable changes in abundance e.g. Lutjanidae, Balistidae (Silvestre 1990) were hence assigned to separate ecological groups for more detailed analysis using time series data. For some fish species (e.g. Leiognathidae, Nemipteridae), they were assigned to a separate ecological group because of their significant contribution to the fish catch as well as their relative abundance during the trawl survey.

Table 1. Taxonomic composition of the 29 ecological groups of the Sabah and Sarawak model.

Ecological Group	Representative Taxa
Large Predators	Carcharhinidae, Istiophoridae
Tuna	Scombridae (Tuna)
Large zoobenthos feeders	Dasyatidae, Rachycentridae
Intermediate predators	Ariidae, Centropomidae, Chirocentridae, Muraenesocidae, Plectorhynchidae, Plotosidae, Polynemidae, Pomadasyidae, Sphyraenidae, Trichiuridae
Lutjanids	Lutjanidae,
Serranids	Serranidae
Carangids	Carangidae (excluding trevally and scads)
Flatfishes/Soles	Psettodidae
Sciaenids	Sciaenidae
Small pelagics	Caesionidae, Carangidae (trevally), Carangidae (Scads), Hemiramphidae, Scombridae (mackerel)
Engraulids/Clupeids	Clupeidae, Engraulidae
Squids	Squids, Cephalopods
Demersal zoobenthos feeders	Bothidae, Centriscidae, Drepanidae, Formionidae, Gerridae, Lethtrinidae, Mugilidae, Scatophagidae, Siganidae, Sillaginidae, Stromatidae , Synodontidae, Theraponidae, Trash fish
Leiognathids	Leiognathidae
Mullids	Mullidae
Nemipterids	Nemipteridae
Balistids	Balistidae
Lactarids	Lactariidae
Reef Associated Fish	Scaridae, Labridae
Octopus/Sepia	Squids, Octopus
Crabs/Lobsters	Crabs, Lobsters
Shrimps	Penaeus spp.
Ecological group	Representative taxa
Small crustaceans	Sergestid shrimps, juvenile Penaeidae
Macrobenthos	Clams, Mollusc
Meiobenthos	–
Zooplankton	–
Macrobenthic algae	–
Phytoplankton	–
Detritus	–

Model Parameterization

Biomass

The biomass of the demersal fish groups was obtained from the trawl surveys conducted in the coastal waters off Sabah and Sarawak in 1972 (Latiff et al. 1976). Biomass (B) was estimated using the "swept-area" method (Pauly 1984) with the following formula:

$$B = \frac{C/f \cdot A}{a \cdot x_1}$$

where B = biomass, C/f = mean cpue, A = total survey area, a = swept area, and x_1 = proportion of fish in path of gear retained in net (0.5 in Southeast Asian waters).

The swept area is defined by:

$$a = t \cdot v \cdot h \cdot x_2$$

where t = time spent in trawling, v = trawling velocity, h = length of trawl's headrope, and x_2 = fraction of area swept over length of headrope (0.5 in Southeast Asian waters).

The biomass values from the trawl surveys (particularly for the demersal species/taxa) were used as input data and also as the basis for aggregation of the species according to ecological groups (see Table 1).

Other Parameters

Values for most of the other input parameters were taken from the existing Ecopath models e.g. Brunei Darussalam coastal waters (Silvestre et al. 1993) and East Coast Malaysia (Liew and Chan 1987). Various published models on marine systems in (Christensen and Pauly 1993) were also used as reference. Estimates of total mortality (Z) (Silvestre et al. 1993) for representative species of the various fish groups were used as first approximations of the P/B ratios. P/B ratios for the invertebrate and consumer groups were based on turnover rates reported in the literature Christensen and Pauly (1993). Input parameters for phytoplankton and detritus were derived from Silvestre et al. (1993). The basic input parameters are summarized in Table 2.

Fishery Catch

Catch data for the various species/groups were taken from (Ministry of Agriculture and Fisheries (MAF) 1972). In 1972, the total fish catch was estimated at 1.328 $t \cdot km^{-2} \cdot yr^{-1}$ and 0.211 $t \cdot km^{-2} \cdot yr^{-1}$ for Sabah and Sarawak, respectively. It is interesting to note that demersal zoobenthos feeders, intermediate predators and shrimps are the main groups that provide substantial contribution to fish catch in the study areas (see Table 2 a and b). To arrive at these values, the total landings reported in the annual statistics in 1972 were divided by the total area of the coastal waters covered by the model.

Diet Composition

Data for diet compositions were taken from gut content studies in FishBase (http://www.fishbase.org) and from published Ecopath models (Liew and Chan 1987; Silvestre et al. 1993). Other references used include: (Abitia-Cardenas et al. 1999; Blaber et al. 1990; de Lestang et al. 2000; Platell and Potter 2001; Salini et al. 1994; Velasco et al. 2001). The diet composition data used for model construction is given in Table 3.

Table 2a. Basic input parameters used in constructing the Ecopath model for Sarawak.

Ecological Group	Biomass ($t \cdot km^{-2} \cdot year^{-1}$)	P/B ($year^{-1}$)	Q/B ($year^{-1}$)	EE	Catch ($t \cdot km^{-2} \cdot year^{-1}$)
Large predators	0.11	–	9.50	0.50	0.010
Tuna	–	2.00	11.64	0.50	0.011
Large zoobenthos feeders	0.16	0.40	6.50	–	0.006
Intermediate predators	–	1.74	8.70	0.95	0.027
Lutjanids	0.19	–	8.70	0.95	0.002
Serranids	–	1.74	8.70	0.95	0.002
Carangids	–	2.07	8.70	0.95	0.004
Flatfishes/Soles	–	0.85	8.70	0.95	0.001
Sciaenids	0.08	–	8.70	0.95	0.009
Small pelagics	–	2.37	7.90	0.95	0.004
Engraulids/Clupeids	–	2.70	7.90	0.95	0.015
Squids	–	2.05	7.90	0.95	0.004
Demersal zoobenthos feeders	–	2.15	10.75	0.95	0.061
Leiognathids	0.85	–	10.75	0.95	0.006
Mullids	0.44	–	10.75	0.95	0.003
Nemipterids	0.16	–	10.75	0.95	0.001
Balistids	–	2.15	10.75	0.95	0.000
Lactarids	–	2.15	10.75	0.95	0.000
Reef associated fish	–	1.50	7.55	0.95	0.000
Octopus/Sepia	–	3.00	12.50	0.95	0.004
Crabs/Lobsters	–	4.00	21.90	0.95	0.002
Shrimps	–	4.00	21.90	0.95	0.034
Small Crustaceans	–	62.00	310.00	0.95	0.001
Macrobenthos	–	6.80	27.40	0.95	0.000
Meiobenthos	–	10.00	50.00	0.95	0.000
Zooplankton	–	67.00	280.00	0.95	0.000
Macrobenthic flora	–	15.35	–	0.03	0.000
Phytoplankton	–	71.20	–	.0500	0.000
Detritus	120.00	–	–	–	0.000

Note: P/B = Production/Biomass ratio, Q/B = Consumption/Biomass ratio, EE = ecotrophic efficiency.

Table 2b. Basic input parameters used in constructing the Ecopath model for Sabah.

Ecological Group	Biomass ($t \cdot km^{-2} \cdot year^{-1}$)	P/B ($year^{-1}$)	Q/B ($year^{-1}$)	EE	Catch ($t \cdot km^{-2} \cdot year^{-1}$)
Large predators	0.23	–	9.50	0.50	0.06
Tuna	–	2.00	11.64	0.50	0.03
Large zoobenthos feeders	0.15	0.40	6.50	–	0.03
Intermediate predators	–	1.74	8.70	0.95	0.17
Lutjanids	0.05	–	8.70	0.95	0.01
Serranids	–	1.74	8.70	0.95	0.01
Carangids	–	2.07	8.70	0.95	0.02
Flatfishes/Soles	–	0.85	8.70	0.95	0.05
Sciaenids	0.31	–	8.70	0.95	0.06
Small pelagics	–	2.37	7.90	0.95	0.02
Engraulids/Clupeids	–	2.70	7.90	0.95	0.09
Squids	–	2.05	7.90	0.95	0.02
Demersal zoobenthos feeders	–	2.15	10.75	0.95	0.38
Leiognathids	1.99	–	10.75	0.95	0.08
Mullids	1.26	–	10.75	0.95	0.02
Nemipterids	0.57	–	10.75	0.95	< 0.01
Balistids	–	2.15	10.75	0.95	< 0.01
Lactarids	–	2.15	10.75	0.95	< 0.01
Reef associated fish	–	1.50	7.55	0.95	< 0.01
Octopus/Sepia	–	3.00	12.50	0.95	0.02
Crabs/Lobsters	–	4.00	21.90	0.95	0.01
Shrimps	–	4.00	21.90	0.95	0.22
Small Crustaceans	–	62.00	310.00	0.95	< 0.01
Macrobenthos	–	6.80	27.40	0.95	< 0.01
Meiobenthos	–	10.00	50.00	0.95	0.00
Zooplankton	–	67.00	280.00	0.95	0.00
Macrobenthos flora	–	15.35	–	0.03	0.00
Phytoplankton	–	71.20	–	0.50	0.00
Detritus	120.00	–	–	–	0.00

Note: P/B = Production/Biomass ratio, Q/B = Consumption/Biomass ratio, EE = ecotrophic efficiency.

Table 3. The diet composition of the ecological groups used in the Ecopath analysis. The Predator numbers correspond to the prey numbers.

Prey	Predator																									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1. Large predators	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2. Tuna	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
3. Large zoobenthos feeders	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
4. International predators	0.20	0.22	–	0.01	–	–	0.01	–	0.01	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
5. Lutjanids	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
6. Serranids	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
7. Carangids	0.10	0.11	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
8. Flatfishes/Soles	0.02	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
9. Sciaenids	0.10	–	–	–	–	–	–	–	0.02	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
10. Small pelagics	0.20	0.11	–	0.05	0.05	0.05	0.05	–	–	0.01	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
11. Engraulids/Clupeids	0.10	0.22	–	0.10	–	0.05	0.05	–	0.03	–	–	0.01	–	–	–	–	–	–	–	–	–	–	–	–	–	–
12. Squids	0.10	0.11	–	0.05	–	–	0.05	0.05	–	–	–	–	–	–	–	0.02	–	–	–	–	–	–	–	–	–	–
13. Demersal zoobenthos feeder	0.04	0.11	–	0.13	0.30	0.20	0.15	0.15	0.05	0.01	–	–	0.01	–	–	–	–	–	–	–	–	–	–	–	–	–
14. Leiognathids	0.02	–	–	0.05	0.05	0.05	0.10	0.05	–	0.10	–	–	0.01	–	–	–	–	–	–	–	–	–	–	–	–	–
15. Mullids	0.02	–	–	0.05	0.05	0.10	0.10	0.05	–	0.01	–	–	0.01	–	–	–	–	–	–	–	–	–	–	–	–	–
16. Nemipterids	0.02	–	–	0.05	0.05	0.10	0.10	0.05	–	0.01	–	–	0.01	–	–	–	–	–	–	–	–	–	–	–	–	–
17. Balistids	0.02	–	–	0.02	0.05	0.10	0.10	–	–	–	–	–	0.01	–	–	–	–	–	–	–	–	–	–	–	–	–
18. Lactarids	0.02	–	–	0.05	0.05	0.05	0.10	0.05	–	0.01	–	–	0.01	–	–	–	–	–	–	–	–	–	–	–	–	–
19. Reef associated fish	0.02	–	–	0.01	0.05	0.10	0.02	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
20. Octopus/Sepia	0.02	–	0.10	–	0.05	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.02	–	–	–	–	–	–
21. Crabs/Lobsters	–	0.03	0.05	0.02	0.15	0.10	0.10	–	0.10	0.04	–	–	–	–	–	–	0.05	–	–	0.01	0.01	–	–	–	–	–
22. Shrimps	–	0.06	0.20	0.15	0.10	0.05	0.05	–	0.15	0.05	0.15	0.15	–	–	–	0.06	0.05	–	–	–	0.04	0.01	–	–	–	–
23. Small crustaceans	–	0.02	0.15	0.05	0.02	–	–	0.10	0.20	0.05	0.20	0.15	0.15	0.15	0.15	0.15	0.20	0.15	–	0.10	0.04	0.30	–	–	–	–
24. Macrobenthos	–	–	0.40	0.20	0.02	0.05	0.02	0.25	0.30	0.10	0.10	0.10	0.25	0.46	0.45	0.45	0.30	0.45	–	0.10	0.38	0.20	–	–	–	–
25. Meiobenthos	–	–	0.05	0.01	0.01	–	–	0.15	0.05	–	–	–	0.30	0.05	0.05	0.05	0.10	0.05	–	0.07	0.13	0.05	–	0.30	–	–
26. Zooplankton	–	–	–	–	–	–	–	–	0.05	0.50	0.40	0.44	0.20	0.24	0.20	0.20	0.20	0.24	0.10	0.10	0.03	–	0.40	0.10	0.05	0.05
27. Macrobenthic flora	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.60	–	0.02	–	–	0.10	–	–
28. Phytoplankton	–	–	–	–	–	–	–	–	–	0.20	0.10	0.10	–	0.05	0.10	–	–	0.05	0.30	0.10	–	0.05	0.50	0.05	0.05	0.70
29. Detritus	–	–	0.05	–	–	–	–	0.10	0.04	–	0.05	0.05	0.04	0.05	0.05	0.06	0.10	0.06	–	0.50	0.35	0.39	0.10	0.45	0.90	0.25
Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Results and Discussion

Trophic Model

The basic estimates of the Ecopath model for the coastal fisheries off Sarawak are presented in Table 4a; Table 4b presents the parameters estimated for the trophic model of the West Coast of Sabah. The biomass values obtained from Ecopath when compared with estimates of fishery catches given in Table 2 (a & b) imply a relatively low exploitation level of fishery resources in 1972. Under the assumption of steady state conditions, estimates of total mortality (Z) are reasonable estimates of turnover rates (P/B ratios). However, these values should be compared with independent fisheries assessments to confirm the estimates.

Fig. 3 presents a mixed trophic impact analysis for the Sarawak ecosystem. This analysis quantifies all direct and indirect trophic impacts (be it through predation or competition), and can be seen both as a sensitivity analysis (what groups are important), and as a measure of the groups and the fishing fleets relating to trophic importance. The figure also indicates that fishing fleets target mainly intermediate predators, carangids, demersal species groups (flatfishes/soles, sciaenids), small pelagics including engraulids/clupeids, and shrimps. The fleets have also shown negative impacts on large predators, tuna, large zoobenthos feeders, lutjanids and serranids since the fisheries are exploiting their prey.

It is interesting to note that a relatively higher phytoplankton biomass has been estimated for the Sabah Ecopath model compared to the Sarawak model. This trend is consistent with the generalization from the oceanographic study (SEAFDEC 2000) in the area, wherein relatively higher primary productivity values were obtained from the coastal waters off Sabah and Brunei Darussalam as compared to Sarawak waters. Primary production levels have an influence on fish abundance as well as biomass of fisheries resources in the study area.

Table 4a. Input and output parameters (in parenthesis) of the Ecopath model for Sarawak, 1972.

Ecological Group	Trophic level	Biomass ($t \cdot km^{-2} \cdot year^{-1}$)	P/B ($year^{-1}$)	Q/B ($year^{-1}$)	EE	Production/ Consumption
Large predators	4.4	(0.12)	0.26	(9.50)	(0.50)	0.03
Tuna	4.4	0.01	(2.00)	(11.64)	(0.50)	0.17
Large zoobenthos feeders	3.4	(0.16)	(0.40)	(6.50)	0.10	0.06
Intermediate predators	3.9	0.08	(1.74)	(8.70)	(0.95)	0.20
Lutjanids	4.0	(0.19)	0.01	(8.70)	(0.95)	< 0.01
Serranids	4.0	< 0.01	(1.74)	(8.70)	(0.95)	0.20
Carangids	4.1	0.06	(2.07)	(8.70)	(0.95)	0.24
Flatfishes/Soles	3.5	0.06	(0.85)	(8.70)	(0.95)	0.10
Sciaenids	3.5	(0.08)	1.76	(8.70)	(0.95)	0.20
Small pelagics	3.5	0.17	(2.37)	(7.90)	(0.95)	0.30
Engraulids/Clupeids	3.1	0.13	(2.70)	(7.90)	(0.95)	0.34
Squids	3.1	0.13	(2.05)	(7.90)	(0.95)	0.26
Demersal zoobenthos feeders	3.2	0.47	(2.15)	(10.75)	(0.95)	0.20
Leiognathids	3.2	(0.85)	0.36	(10.75)	(0.95)	0.03
Mullids	3.1	(0.44)	0.67	(10.75)	(0.95)	0.06
Nemipterids	3.3	(0.16)	1.92	(10.75)	(0.95)	0.18
Balistids	3.2	0.11	(2.15)	(10.75)	(0.95)	0.20
Lactarids	3.2	0.14	(2.15)	(10.75)	(0.95)	0.20
Reef associated fish	2.1	0.11	(1.50)	(7.55)	(0.95)	0.20
Octopus/Sepia	2.5	0.09	(3.00)	(12.50)	(0.95)	0.24
Crabs/Lobster	2.9	0.16	(4.00)	(21.90)	(0.95)	0.18
Shrimps	2.8	0.36	(4.00)	(21.90)	(0.95)	0.18
Small Crustaceans	2.4	0.12	(62.00)	(310 .90)	(0.95)	0.20
Macrobenthos	2.4	2.09	(6.80)	(27.40)	(0.95)	0.25
Meiobenthos	2.1	2.19	(10.00)	(50.00)	(0.95)	0.20
Zooplankton	2.1	0.66	(67.00)	(280.00)	(0.95)	0.24
Macrobenthic flora	1.0	13.64	(15.35)	–	(0.03)	–
Phytoplankton	1.0	4.45	(71.20)	–	(0.50)	–
Detritus	1.0	(120.00)	–	–	0.40	–

Note: P/B = Production/Biomass ratio, Q/B = Consumption/Biomass ratio, EE = ecotrophic efficiency.

Table 4b. Input and output parameters (in parenthesis) of the Ecopath model for Sabah, 1972.

Ecological Group	Trophic level	Biomass (t·km^{-2}·year^{-1})	P/B (year^{-1})	Q/B (year^{-1})	EE	Production/ Consumption
Large predators	4.4	(0.23)	0.55	(9.50)	(0.50)	0.06
Tuna	4.4	0.03	(2.00)	(11.64)	(0.50)	0.17
Large zoobenthos feeders	3.4	(0.15)	(0.40)	(6.50)	0.48	0.06
Intermediate predators	3.9	0.25	(1.74)	(8.70)	(0.95)	0.20
Lutjanids	4.0	(0.05)	0.22	(8.70)	(0.95)	0.03
Serranids	4.0	0.01	(1.74)	(8.70)	(0.95)	0.20
Carangids	4.1	0.14	(2.07)	(8.70)	(0.95)	0.24
Flatfishes/Soles	3.5	0.19	(0.85)	(8.70)	(0.95)	0.10
Sciaenids	3.5	(0.31)	1.13	(8.70)	(0.95)	0.13
Small pelagics	3.0	0.32	(2.37)	(7.90)	(0.95)	0.30
Engraulids/Clupeids	3.1	0.34	(2.70)	(7.90)	(0.95)	0.34
Squids	3.1	0.34	(2.05)	(7.90)	(0.95)	0.26
Demersal zoobenthos feeders	3.2	0.80	(2.15)	(10.75)	(0.95)	0.20
Leiognathids	3.2	(1.99)	0.30	(10.75)	(0.95)	0.03
Mullids	3.1	(1.26)	0.43	(10.75)	(0.95)	0.04
Nemipterids	3.3	(0.57)	0.94	(10.75)	(0.95)	0.09
Balistids	3.2	0.16	(2.15)	(10.75)	(0.95)	0.20
Lactarids	3.2	0.24	(2.15)	(10.75)	(0.95)	0.20
Reef associated fish	2.1	0.13	(1.50)	(7.55)	(0.95)	0.20
Octopus/Sepia	2.5	0.10	(3.00)	(12.50)	(0.95)	0.24
Crabs/Lobster	2.9	0.22	(4.00)	(21.90)	(0.95)	0.18
Shrimps	2.8	0.79	(4.00)	(21.90)	(0.95)	0.18
Small Crustaceans	2.4	0.27	(62.00)	(310 .00)	(0.95)	0.20
Macrobenthos	2.4	4.75	(6.80)	(27.40)	(0.95)	0.25
Meiobenthos	2.1	4.85	(10.00)	(50.00)	(0.95)	0.20
Zooplankton	2.1	1.50	(67.00)	(280.00)	(0.95)	0.24
Macrobenthic flora	1.0	29.76	(15.35)	–	(0.03)	–
Phytoplankton	1.0	10.06	(71.20)	–	(0.50)	–
Detritus	1.0	(120.00)	–	–	–	–

Note: P/B = Production/Biomass ratio, Q/B = Consumption/Biomass ratio, EE = ecotrophic efficiency.

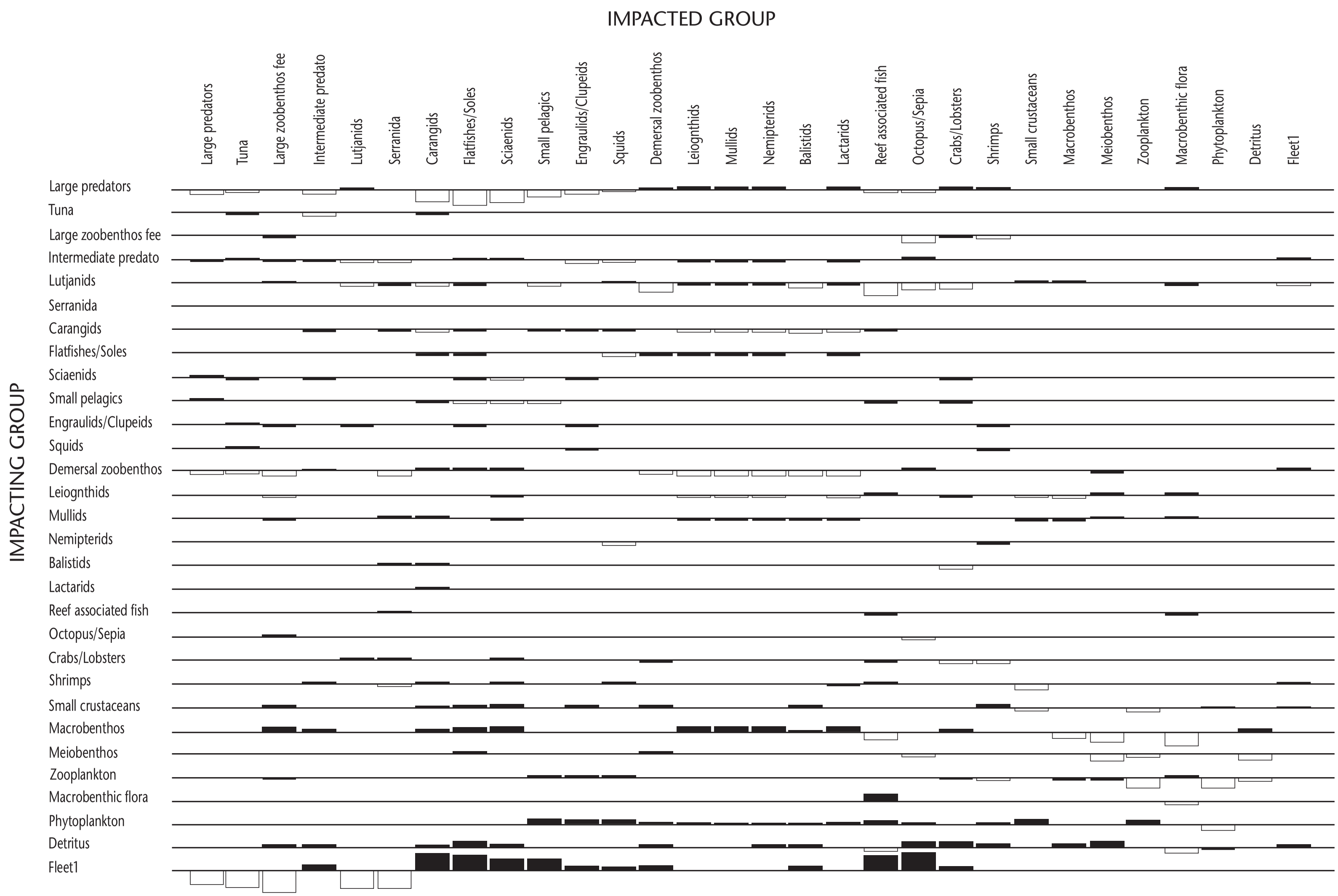

Fig. 3. Mixed trophic impacts in the Sarawak Ecopath model. The graph shows the direct or indirect trophic impacts the groups to the left (rows) have on the groups mentioned above (columns). Positive impacts are shown above the baseline, and negative below. The impacts are relative but comparable between groups.

The summary statistics of the trophic models for Sabah and Sarawak are presented in Table 5. Total throughput is estimated at 3 152 t•km^{-2}•year^{-1} for the trophic model for Sabah and 14 14 t•km^{-2} •year^{-1} for Sarawak. Mean trophic level of the fishery is 3.33 and 3.38, respectively. Biomass estimates for the various trophic levels (excluding detritus) for Sabah is 59.8 t•km^{-2}, and 27.2 t•km^{-2} for Sarawak. The relatively higher biomass in Sabah waters may justify the relatively higher fishery catches (see Table 2) compared to Sarawak. In addition, the sum of all production is also relatively higher in Sabah than Sarawak. It is interesting to note that the 1972 levels in biomass and production in these areas are comparable to the values obtained from the Ecopath model for Brunei Darussalam coastal fisheries (Silvestre et al. 1993), in which the ecosystem was considered as a system under a low level of fishing.

Other derived parameters indicate that the coastal ecosystem in the study areas is in a stage of development. These include: (1) a P/R ratio greater than 1; (2) relatively high net system production (Sabah: 605 t•km^{-2} and Sarawak: 273 t•km^{-2}); and (3) P/B ratio greater than 1. Moreover, these indicators may suggest that the system has been under a moderate level of exploitation. Generally this situation can drive development of the system back to earlier stages (Odum 1971).

Table 5. Summary of ecosystem parameter values for Ecopath models.

Parameter	Sabah	Sarawak
Sum of all consumption (t•km^{-2}•year^{-1})	972.4	434.6
Sum of all exports (t•km^{-2}•year^{-1})	605.5	273.0
Sum of all respiratory flows (t•km^{-2}•year^{-1})	567.7	253.4
Sum of all flows into detritus (t•km^{-2}•year^{-1})	1 006.4	453.3
Total system throughput (t•km^{-2}•year^{-1})	3 152.0	1 414.0
Sum of all production (t•km^{-2}•year^{-1})	1 383.0	616.0
Calculated total net primary production (t•km^{-2}•year^{-1})	1 173.2	536.4
Net system production (t•km^{-2}•year^{-1})	605.5	273.0
Total primary production/total respiration	2.07	2.08
Total primary production/total biomass (year^{-1})	19.62	19.37
Total biomass/total throughput (year)	)0.02	0.02
Total biomass (excluding detritus) (t•km^{-2})	59.8	27.2
Mean trophic level of the fisheries catch	3.33	3.38
Total catches (t•km^{-2}•year^{-1})	1.32	0.21
Gross efficiency (catch/net primary production)	0.0011	0.0004
Connectance Index	0.27	0.27
System Omnivory Index	0.22	0.22

It is suggested that these Ecopath models be utilized with time series information (e.g. catch data or CPUE) and that estimates (e.g. biomasses) be evaluated from fishery-independent surveys. As highlighted earlier, the Ecosim routine of the EwE software permits evaluation of the effects of changes in the ecosystem (such as a change in the fishery and any other measurable change such as nutrient loading or pollution) to be accurately simulated and the outcome predicted. In addition, the models can be used for temporal analysis and in understanding the declines in biomass and the associated changes in species composition due to the increased intensity of fishing from 1972 to the present.

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Appendix A. Taxonomic composition of the 29 ecological groups of the Sabah and Sarawak Ecopath models.

Ecological Group	Local name	English name	Family
Large Predators	Yu	Grey reef shark	Carcharhinidae
	Mersuji	Black marlin	Istiophoridae
Tuna	Aya/Tongkol	Longtail tuna	Scombridae
	Tenggiri	Indo-Pacific Spanish mackerel/Spotted Spanish mackerel	Scombridae
Large zoobenthos feeders	Pari	Pale-edged ray	Dasyatidae
	Aruan tasik	Black kingfish	Rachycentridae
Intermediate predators	Siakap	Barramundi/Giant seaperch	*Lates Calcarifes*
	Duri/Pulutan	Engraved catfish	Ariidae
	Duri/Jahan	Giant catfish	Ariidae
	Pedukang	Sea catfish	Ariidae
	Malong	Dagger tooth pike conger/Silver conger eel	Muraenesocidae
	Kaci	Painted sweetlips	Plectorhynchidae
	Semilang	Canine catfish eel	Plotosidae
	Kurau	Fourfinger threadfin	Polynemidae
	Ikan bulu	Blackhand paradise fish	Polynemidae
	Parang	Dorab wolf-herring	Chirocentridae
	Timah	Hairtail	Trichiuridae
	Gerut-gerut	Lined silver grunter	Pomadasyidae
	Alu-alu	Banded barracuda/Slender sea pike	Sphyraenidae
Lutjanids	Merah	Malabar red snapper	Lutjanidae
	Jenahak	John's snapper/Giant snapper	Lutjanidae
	Kerisi bali	Sharptooth snapper	Lutjanidae
	Remong	Bigeye snapper	Lutjanidae
Serranids	Kerapu	Six-banded grouper	Serranidae
Carangids	Bulan	Indo-Pacific tarpon	Carangidae
	Cermin	Horse mackerel/Malabar cavalla	Carangidae
	Cincaru	Hardtail scad	Carangidae
	Demudok	Blue trevally	Carangidae
	Jamah	Bigeye trevally	Carangidae
	Pisang-pisang	Rainbow runner	Carangidae
	Selunsong	Trevally	Carangidae
	Talang	Queenfish/Slender leatherskin	Carangidae

Appendix A. Taxonomic composition of the 29 ecological groups of the Sabah and Sarawak Ecopath models. (continued)

Ecological Group	Local name	English name	Family
Flatfishes/Soles	Lidah/Sebelah	Tongue soles	Psettodidae
Sciaenids	Gelama Panjang/Terusan	Sin croaker Croaker	Sciaenidae Sciaenidae
Small pelagics	Delah Pelata/Selar Selar kuning Selayang Jolong-jolong Kembong	Fusilier Herring trevally Yellowbanded scad Round scad Halfbeak Short bodied mackerel	Caesionidae Carangidae Carangidae Carangidae Hemiramphidae Scombridae
Engraulids/Clupeids	Kebasi Puput Terubuk Empirit Tamban Bilis Bulu ayam Impirang	Chacunda gizzard shad Slender shad/Elongate illisha Toli shad Longtail shad Fringescale sardinella Shorthead anchovy Grenadier anchovy Scaly hairfin anchovy	Clupeidae Clupeidae Clupeidae Clupeidae Clupeidae Engraulidae Engraulidae Engraulidae
Squids	Sotong biasa Sotong kereta/katak/ biasa	Squid Cephalopods	
Demersal zoobenthos feeders	Daun baharu Dengkis Bulus Mengkerong Lumi Sebelah Kerong-kerong Pelandok Belanak Bawal/Kilat Dueh/Bawal putih Dueh/Bawal hitam Dueh/Bawal tambak Kitang Ikan baja Ikan campur Kekapas/Kapas Kering/Lidi	Spotted sicklefish Rabbitfish Silver whiting Greater lizardfish Bombay duck Malayan flounder Large scale therapon Emperor Large scale mullet Pomfret Silver pomfret Black pomfret Chinese pomfret Spotted scad Trash fish Mixed fish Mojarra (long-rayed) Razorfish	Drepanidae Siganidae Sillaginidae Synodontidae Synodontidae Bothidae Theraponidae Lethrinidae Mugilidae Stromatidae Stromatidae Formionidae Stromatidae Scatophagidae Trash fish Mixed fish Gerridae Centriscidae
Leiognathids	Kikek Ikan baja	Common ponyfish Trash fish (~20%)	Leiognathidae Trash fish
Mullids	Biji nangka	Goatfishes	Mullidae
Nemipterids	Kerisi Pasir	Japanese threadfin breams Monocle bream	Nemipteridae Nemipteridae
Balistids	Jebong	Stary triggerfish	Balistidae
Lactarids	Shrumbu	False trevally	Lactariidae

Appendix A. Taxonomic composition of the 29 ecological groups of the Sabah and Sarawak Ecopath models. (continued)

Ecological Group	Local name	English name	Family
Reef Associated Fish	Bayan/Perenchong Pelayak	Parrot fish Ornate wrasse	Scaridae Labridae
Octpus/Sepia	Sotong kereta Sotong katak	Octopus Bobfins squid	– –
Crabs/Lobsters	Ketam Ketam suri Ketam laut Udang karang	Crab Crab Crab Lobster	– – –
Shrimps	Udang besar Udang sedang Udang kecil Uidang putih Udang minyak Udang merah ros Udang kulit keras Udang harimau	Big prawn Medium prawn Small prawn Banana prawn Greasyback prawn Pink prawn Rainbow prawn Tiger prawn	– – – – – –
Small crustaceans	Lain-lain udang/ Udang baring Udang penaeid/ baring	Other prawn/Sergesiid prawn Penaeid prawn/Sergesiid prawn	– –
Macrobenthos	Siput Kerang Tokoyong Ambai Ramin Lokan	Shell Clams Mollusc Mollusc Mollusc Mollusc	
Meiobenthos	–	–	–
Zooplankton	–	–	–
Macrobenthic algae	–	–	–
Phytoplankton	–	–	–
Detritus	–	–	–