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A Mass-Balance Ecopath Model of Coastal Areas in the Mekong Delta, Vietnam

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Abstract

A mass-balance Ecopath model of coastal areas in the Mekong Delta has been constructed for a quantitative description of the trophic structure of the ecosystem. The model is used to estimate the important biological parameters and relationships among the different ecologically important groups. The model is based on the data collected from bottom trawling. There are 14 functional groups based on 58 species from coastal areas in the Mekong Delta survey such as shrimps, squids, crabs, mackerel, small pelagics, demersal fishes, benthic feeders, predator fishes and trash fish. The biomass value was estimated from catch production and bottom trawling surveys. Results show that the estimated total biomass of exploited resources was 3.99 ton.km-2. The values of Ecotrophic Efficiency (EE) in the model are high (>0.5) for most groups of high trophic level. The results showed that those groups exploited by small mesh size and small living organisms were being heavily preyed upon in the ecosystem.

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Introduction

Vietnam has a coastline 3260 km long and the Exclusive Economic Zone covers more than one million km^2 of which 660,000 ha are of tidal areas (plus 300,000 to 400,000 ha of straits, bays and lagoons). The fisheries sector plays an important role in the social and economic development of Vietnam. The sector is estimated to contribute 4% to the Vietnamese GDP, and fish provides about 40% of the animal protein consumption (Vietnam's Ministry of Fisheries and the World Bank 2005). There are five fishery ecological economic zones in Vietnam and the Mekong Delta is the most important area of fisheries and aquaculture in the country. It is the nation's largest aquatic products' breeding and exploiting place with an aquatic breeding area of 1.1 million hectares, accounting for 55% of the nation's Vietnam. Annually, it supplies over 42% of the country's output of exploited aquatic products and approximately 67% of the output of bred aquatic products, and provides 60% of the aquatic export volume (Dinh 2007). The Mekong delta has a 700 km coastline and a sea territory of 360,000 km^2 and is known for its abundant potential in marine resources. Marine fisheries production consists mainly of pelagic and demersal fishes, which contribute 80 to 90% of fisheries yield (Thuoc and Long 1997). The remaining percentage is contributed by valuable invertebrates such as penaeid and acetes shrimps, crabs, lobsters, cuttlefish, squids and molluscs. Among these, penaeid shrimps and cuttlefish are the most important species for export (Son and Thuoc 2003).

In the past decade, the Mekong Delta fisheries sector has achieved considerable growth. However, the sector suffers from many serious problems that need to be resolved to ensure their sustainable development. Such problems include over-fishing in the coastal area, degradation of the marine environment and coastal resources, underdeveloped infrastructure, and lack of effective resource management.

The objective of this paper is to establish a first mass-balance Ecopath Model of coastal areas in the Mekong Delta (Vietnam). The report presents indicative action programs for improving fisheries management and attaining sustainable development of coastal fisheries in the Mekong Delta.

Since the Ecopath model requires a limited amount of data, hence it is applicable to a wide range of fisheries systems (Pauly 1998). In recent years, more than 100 Ecopath models have been elaborated in the world (www.ecopath.org). The Ecopath package which includes Ecosim and Ecospace has a huge potential use in ecosystem management (Christensen et al. 2005).

Material and Methods

The study region

Total study area is 4286 km^2 and extends from $105^o46'E$ to $106^o18'E$, $8^o55'N$ to $9^o21'N$. Six sampling sites were randomly chosen (Fig. 1).

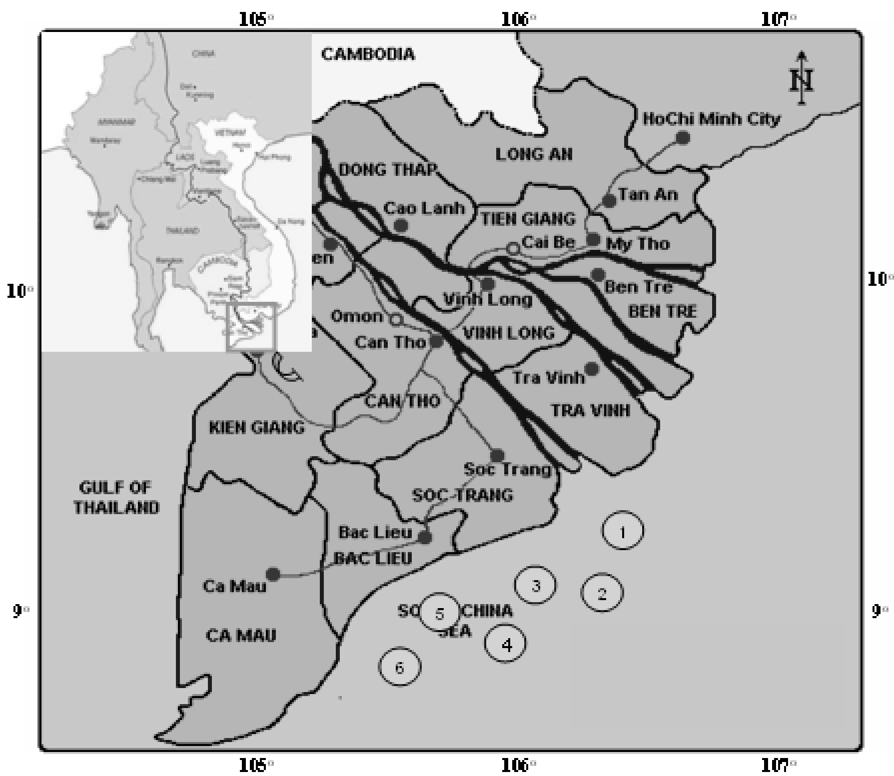

Fig. 1. Map showing of the Coastal areas in the Mekong Delta

The Ecopath Model

The Ecopath model was originally designed for a coral reef ecosystem by Polovina (1984). A software associated to this model was further developed by Christensen and Pauly (1992) who made it available in a well-documented user-friendly software. More recently, the Ecopath software was developed to allow dynamic simulation modeling based on mass-balanced models. For this purpose, Walter et al. (1997, 1999) developed two additional subroutines i.e., Ecosim and Ecospace. In the original version of Ecopath, it is assumed that the ecosystem modeled is in steady state for each of the living groups, which implies that inputs equal outputs.

In terms of utilisation of energy it can be expressed as;

$$\boldsymbol{Q = P + R + U},$$

where;

Q is consumption, *P* production, *R* respiration, and *U* unassimilated food.

In terms of utilisation of production, the implications of a steady state will be expressed as follows for an arbitrary time period and for each element *i* of an ecosystem:

$$B_i * (P/B)_i * EE_i = \sum_{j=1}^{n} Bj * (Q/B)_j * DC_{ij} + EX_i$$

Where;

Bi is the biomass of function group *i* during the period covered (usually, a year);

$(P/B)_i$ the production/biomass ratio;

EE_i the ecotrophic efficiency, i.e., the fraction of the production that is utilized within the system by predators or exported, mostly by the fishery;

$(Q/B)_i$, the relative food consumption of *i*; and

DC_{ij} is the fraction of prey *i* in the diet of predator *j*;

EX_i represents what is exported from the ecosystem, mostly through fisheries. The simultaneous linear equations using the Ecopath model states that the production and consumption are balanced within an ecosystem.

The Ecopath model allows the construction of a snapshot of the ecosystem under a mass-balance situation. The purpose of the model is not only to verify the previously published biomass estimates, but also to identify the capacity of the ecosystem to adapt to various pressures including antrophic ones (Villanueva 2004). Constructing an Ecopath model consists mainly of the following steps:

i) Identification of the area and period for which the model will be constructed on an ecosystem;
ii) definition of all functional groups (boxes), from primary producers to top predators, to be included;

iii) setting of values for the parameters such as production/biomass ratio *(P/B)*, consumption ratio *(Q/B)*, biomass *(B)* and ecotrophic efficiency *(EE)* for each functional group;

iv) entry of the catches (including discards when they are known and important compared to the amount of fish which are considered in the landings) for every captured fish species and, when possible, for each of the various fishing gears used in the area;

v) entry of diet consumption matrix *(DC)* expressing the diet fraction of predator/prey relationship in the model;

vi) ensuring the balance of the models (mass input equals output for each box).

Implementation of the Ecopath Model of coastal areas in the Mekong Delta

The Ecopath model of coastal areas in the Mekong Delta is based on the monthly data collected from bottom trawlings along the coastal areas in the Mekong Delta ecosystem survey project from January 2000 to December 2005. The model will be used to estimate some important biological parameters and the relationship among the different groups of coastal areas in the Mekong Delta.

The functional groups considered for the implementation of the present ecopath model were categorized according to the indications of Yodzis and Winemiller (1999). Feeding ecology were based on information documented by Mohsin and Ambak (1996) and recorded in Fishbase Fröese and Pauly (2009) and some stomach content analyses of 58 species from the coastal areas in the Mekong delta were also carried out. The functional groups and their species composition are provided on table 1.

The biomass (B) per functional group is estimated using; **B = Y/F**

where, Y is the total annual catch over the time period considered in the model and F is the fishing mortality

From our surveys on population dynamics (Dinh et al., in press; Dinh et al. 2010), it appears that the exploitation rate (E = F/Z) is often between 0. 3 to 0.6 for heavily exploited fish and shrimp species. Therefore, we considered an average value of 0.5 meaning that: **F= (P/B)/2** where, the P/B ratio is equivalent to the instantaneous rate of total mortality (Z) (Allen 1971). For fish and shrimps, Z was estimated from field surveys (Dinh et al., in press; Dinh et al. 2010).

It should be noted that this is the optimum value of the exploitation rate for a sustainable fishery as suggested by Gulland and Garcia (1984). This assumption was regarded relevant as the catch and fishing effort remains more or less constant during the early 2000 in the area. In addition, fishermen have no specific target species in the catch.

The biomass per functional group data integrated in the Ecopath model of coastal areas in the Mekong Delta is summarized in table 2.

Estimates of phytoplankton biomass and primary production are based from Nguyen Tac An (2004). Zooplankton biomass is from Tong Ling et al. (2000) and Haputhantri et al. (2007).

No biomass data were available for the microzoobenthos and benthic producer groups so their respective biomasses were estimated by the model after setting their ecotrophic efficiencies to 0.95.

The P/B values for groups other than fish and shrimps were adapted from Haputhantri et al. (2007).

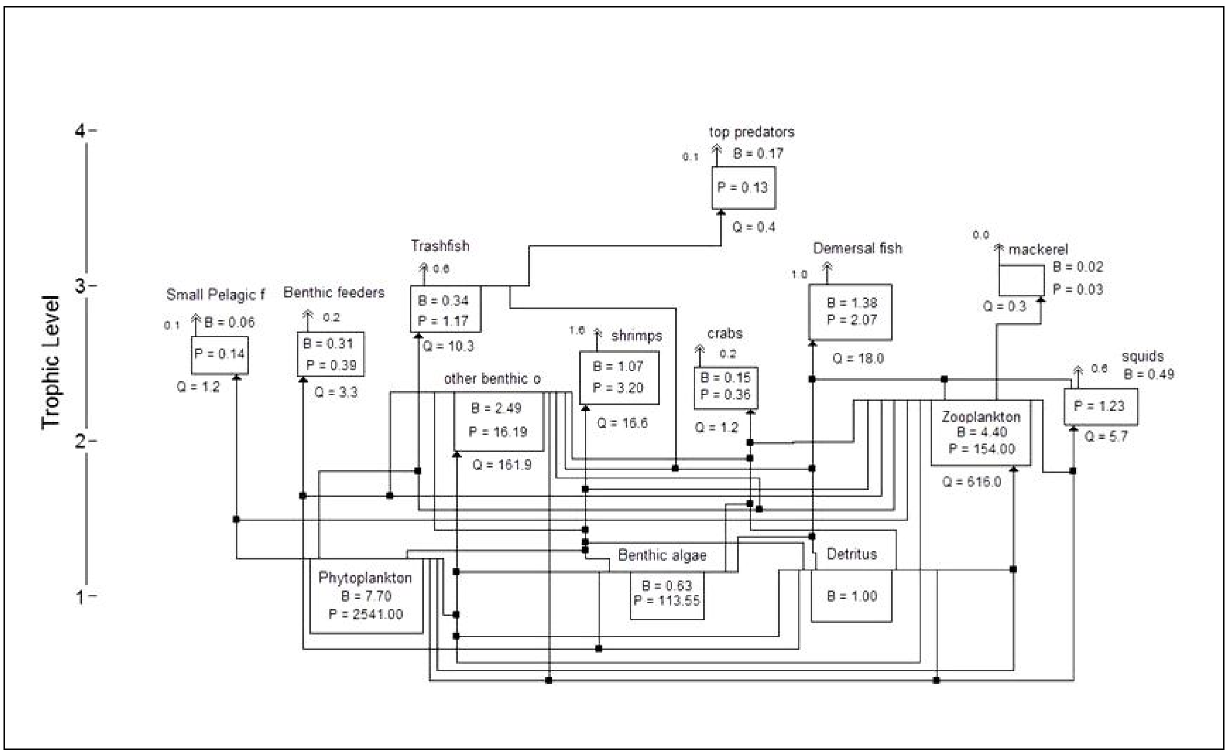

Fig. 2. Flow chart of trophic interactions in the Ecopath model of coastal areas in the Mekong Delta

Table 1. Ecopath functional groups for the coastal areas in the Mekong Delta

No.	Ecopath group	Scientific name
1	Top Predators	*Trichiurus haumela*
		Trichiurus lepturus
		Lates calcarifer
		Plotosus anguilaris
		Epinephelus areolatus
		Epinephelus akaara
		Epinephelus fasciatus
2	Mackerel	*Scoberomorus guttatus*
		Scoberomorus commerson
3	Benthic feeders	*Soleidae*
		Sillago sihama
		Cociella crocodiles
		Hoplichthys sp
		Rogadius asper
		Dasyatis bleekeri
		Parapercis barbata
		Upeneus suphureus
4	Demersal fish	*Trachynocephalus myops*
		Saurida tumbil
		Pristipomoides filamentosus
		Siniperca chuatsi
		Pseudobagrus fulvidraco
		Ophiocara porocephala
		Polydactylus plebejus
		Clupanodon punctatus
		Argyrosomus argentus
		Argyrosomus nibe
		Spotted maigre
		Arius thalassinus
5	Small pelagic	*Harpodon nehereus*
		Selaroides leptolepis
		Pampus argenteus
		Formio niger
		Decapterus maruadsi
6	Trash fish	*Harengula sp*
		Commersonii anchovy
		Rastrelliger brachysoma
		Selaroides leptolepis
		Cynoglossa lingua

Table 1 *(cont.)*

7	Shrimps	*Parapenaeopsis cultrirostris*
		Parapenaeopsis hardwickii
		Parapenaeopsis hungerfordi
		Matapenaeus tenuipes
		Metapenaeus affinis
		Metapenaeopsis barbata
		Penaeus merguiensis
		Penaeus monodon
8	Crabs	*Portunus pelagicus*
		Callappa pelagicus
		Portunus sangui
		Portunus pelagicus
		Callappa pelagicus
		Portunus sangui
9	Squids	*Sepioteuthis lessoniana*
		Sepia inermis
		Loligo spp
		Octopus ocelatus

Table 2. The biomass of species functional groups in the Ecopath Model of Coastal Areas in the Mekong Delta

Species Group	Catch (ton/Km^2/yr)	P/B =Z	(P/B)/2 = F	Biomass (ton/km^2) B = Catch/F
Top Predators	0.064	0.75	0.375	0.171
Mackerel	0.017	2	1	0.017
Benthic Feeders	0.196	1.25	0.625	0.314
Demersal Fish	1.036	1.5	0.75	1.381
Small Pelagic Fish	0.073	2.5	1.25	0.058
Trashfish	0.585	3.4	1.7	0.344
Shrimps	1.602	3	1.5	1.068
Crabs	0.183	2.5	1.25	0.146
Squids	0.616	2.5	1.25	0.493

The Q/B values in the present exercise are from similar functional groups in the ecopath models of the Brunei Darussalam-South China Sea (Silvestre et al. 1993) and the Georges Bank Ecosystem (Sissenwine et al. 1984).

The basic parameters for the Ecopath model of coastal areas in the Mekong Delta are presented in table 3.

Estimates of diet composition for trophic groups in the coastal Mekong Delta Model are presented in table 4.

The pedigree index, which expresses the quality and robustness of the model, has been computed with the appropriate subroutine of Ecopath. This routine requires the user to indicate the type of sources of each parameter or value which was incorporated into the model: local detailed study, local qualitative data, data from other models for similar groups, in similar ecosystems, computation from a predictive empirical model, figure computed with Ecopath.

Table 3. Basic parameter for the groups considered in the Ecopath model of coastal Mekong Delta what is computed by the model to be put in italics

No.	**Group name**	**Trophic level**	**Biomass (t/km²)**	**P/B (/year)**	**Q/B (/year)**	**Ecotrophic efficiency**	**Production/ consumption**
1	Top Predators	*3.63*	0.17	0.75	2.25	*0.772*	*0.333*
2	Mackerel	*3.03*	0.017	2	20	*0.812*	*0.1*
3	Benthic Feeders	*2.56*	0.313	1.25	10.5	*0.648*	*0.119*
4	Demersal Fish	*2.83*	1.381	1.5	13	*0.8*	*0.115*
5	Small Pelagic Fish	*2.56*	0.058	2.5	21	*0.868*	*0.119*
6	Trash fish	*2.85*	0.344	3.4	30	*0.791*	*0.113*
7	Shrimps	*2.41*	1.068	3	15.5	*0.622*	*0.194*
8	Crabs	*2.34*	0.146	2.5	8.5	*0.622*	*0.294*
9	Squids	*2.22*	0.493	2.5	11.5	*0.858*	*0.217*
10	Other Benthic Organisms	*2.13*	2.49	6.5	65	*0.95*	*0.1*
11	Zooplankton	*2.05*	4.4	35	140	*0.42*	*0.25*
12	Phytoplankton	*1*	7.7	330	-	*0.225*	-
13	Benthic Algae	*1*	*0.631*	180	-	0.95	-
14	Detritus	*1*	1	-	-	*0.034*	-

Table 4. Diet composition of species functional groups in coastal Mekong Delta

No.	**Prey**	**Predator**										
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	Top predators	0.09										
2	Mackerel	0.01	0.02									
3	Benthic feeders	0.15										
4	Demersal fish	0.18	0.04		0.03							
5	Small pelagic fish	0.03	0.05			0.02						
6	Trashfish	0.20	0.15	0.01	0.01							
7	Shrimps	0.04		0.01				0.02	0.01			
8	Crabs	0.02	0.01	0.01	0.01							
9	Squids	0.06	0.08	0.01	0.01							
10	Other benthic organisms	0.12	0.12	0.35	0.32		0.10	0.20	0.20	0.10	0.02	
11	Zooplankton	0.10	0.30	0.10	0.35	0.50	0.70	0.15	0.10	0.10	0.10	0.05
12	Phytoplankton		0.20	0.01		0.47	0.20	0.18		0.75	0.05	0.90
13	Benthic algae			0.25	0.17			0.10	0.30		0.63	
14	Detritus		0.03	0.25	0.10	0.01		0.35	0.39	0.05	0.20	0.05
	Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 5. Flows originating from primary producers (Units: Ton/km^2/year)

Trophic level	Flows					
	Import	**Consumed by Predators**	**Catch**	**Flow to Detritus**	**Respiration**	**Throughput**
V		0	0.002	0.004	0.01	0.017
IV		0.017	0.13	0.399	1.062	1.607
III		1.607	1.78	9.344	28.325	41.057
II		41.057	1.363	111.481	526.438	680.339
I	0	680.339	0	1974.215	0	2654.554
Sum	**0**	**723.02**	**3.275**	**2095.444**	**555.835**	**3377.574**

Results

The estimated total biomass of exploited resources (fish and invertebrates) is 3.99 ton km^{-2}. The values of Ecotrophic Efficiency (EE) are elevated (>0.5) for all exploited groups. Computed values of phytoplankton and zooplankton, on the other hand, are very low expressing a poor use of the lower trophic levels by the whole ecosystem. Groups that are already heavily exploited by fisheries were also being heavily predated. According to Christensen and Pauly (1993), EE values near to 1 indicate that the groups are being heavily preyed or fished, leaving no individuals to die of old age. For the present model, the pedigree index was computed as 0.574, a value which conforms to the gauge of overall quality discussed by Christensen et al. (2005). The original inputs were further validated by the consistency of the gross efficiency P/Q values which were within the expected range by reference to the diet composition of each group.

A simplified flow chart showing trophic interactions in the coastal Mekong Delta is shown on figure 2. It presents the estimated trophic level of the 14 functional groups, the biomass and production, and the main flows from and to each box. The chart shows the two food paths; plankton path and benthic community path.

From the trophic point of view, five trophic levels *sensu* Lindeman (1942) were identified in the ecosystem with the proper subroutine of Ecopath. The highest catches belonged to trophic level 3 and to a lesser extent, to trophic level 2 (Table 5).

The transfer efficiencies (less than 10%) are very low at any trophic level below 5 (Table 6); the low EE for zooplankton and phytoplankton might be responsible for this. The main flow from trophic level 1 originated from phytoplankton, as commonly recorded in such ecosystems (Haputhantri et al. 2007).

The mixed trophic impact routine of Ecopath, as designed following the suggestion of Ulanowicz and Puccia (1990) (Fig. 3) was used for a quantitative analysis of the direct and indirect interactions of a 10% increase of any group on the abundance of other ones. It showed the potential relative impacts of each group on the others, which are comparable between groups. It can be seen that the strongest positive impact would come from the increase of groups of lower trophic levels, meaning, despite their poor utilization, the ecosystem was clearly bottom up regulated. In addition, it confirmed that the two types of fisheries (gill nets and trawls) are impacting their own target population independently from each other.

Table 6. The transfer efficiencies at various trophic levels of the coastal Mekong Delta model

Source \ Trophic Level	I	II	III	IV	V	VI
Producer		6.2	8.3	9.1	12.4	
Detritus		7.2	8.5	9.7	12.9	
All flows		6.3	8.3	9.2	12.4	17
Proportion of total flow originating from detritus: 0.39						
Transfer efficiencies (calc. as geometric mean for TL II-IV)						
From primary producers: 7.8%						
From detritus: 8.4%						
Total: 7.8%						

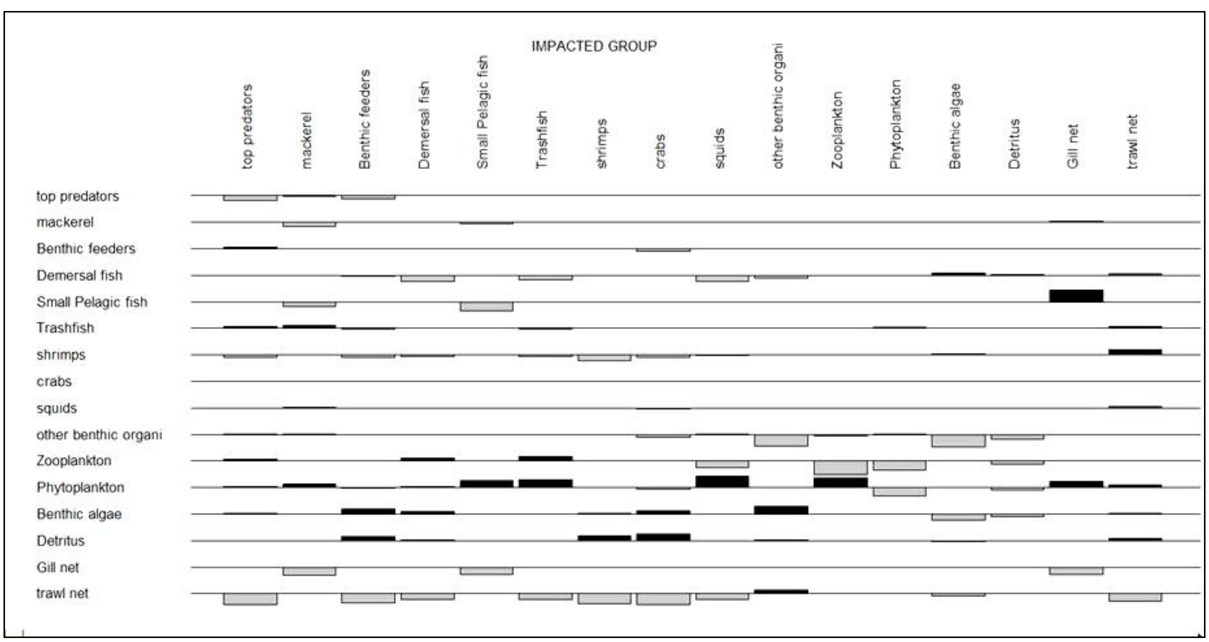

Fig. 3. Mixed trophic impacts for the each group in the coastal Mekong Delta ecosystem

Discussion

The Ecopath model is used to describe the trophic relationships in the coastal ecosystem of the Mekong Delta and (Vietnam) facilitates the understanding of the general dynamics of this ecosystem.

However, some uncertainties were observed during the implementation of the model. For instance it is difficult to fix P/B and Q/B values as they are available for one or only a few species within one group of the model.

Preparation of the predator-prey feeding matrix for the model was also a difficult task due to lack of previous studies on feeding ecology in this ecosystem. Most of the qualitative data were provided by several studies on other ecosystems and were then converted into a quantitative form which might substantially influence the final results.

The trophic level of catch is 2.57 due to the relative importance of species belonging to intermediate trophic levels. The gross efficiency (GE) of catch (0.0016) is in agreement with earlier findings for various marine environments (Christensen and Pauly 1993), but much lower than that observed in the San Miguel Bay, Philippines: 0.0160 (Bundy and Pauly 2001). In contrast, the West African marine ecosystems display lower values of the GE of the catch: less than 0.001 (Palomares et al. 2003).

The biomass of the exploited resources (fish and invertebrates) is quite low (about 4 ton.km^{-2} but is similar to the value computed by Haputhantri et al. (2007) in the coastal zone of Sri Lanka (5.1) and by Christensen (1999) in the gulf of Thailand (4.5). This value is less, however, compared to that estimated by Duan et al. (2009) in the Pearl River Delta (7.16).

Conclusions

A first attempt to model the trophic situation of the coastal Mekong Delta ecosystem is made. It resulted in a trophic network model quantifying biomasses of standing stocks and exchanges of matter and energy between system components for the 2000-2005 period such as the estimated total fish biomass was 3.99 ton.km^{-2}. Species are distributed in four trophic levels and where trophic levels 2 and 3 play an important role in the energetic transfer either as prey or capture stocks. The Ecotrophic Efficiency (EE) of exploited groups are high (>0.50) which implies that groups exploited by small mesh size and small living organisms are being heavily preyed upon in the ecosystem.

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