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渤海生态通道模型初探*

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【摘要】 生态通道模式(Ecopath Model)是一种较为方便地研究生态系统结构,特别是水域生态系统结构的工具.它根据能量平衡原理,用线性齐次方程组描述生态系统中的生物组成和能量在各生物组成之间的流动过程,定量某些生态学参数,如生物量、生产量/生物量、消耗量/生物量、营养级和生态营养效率(EE, Ecotrophic Efficiency)等.它能够给出能量在生态通道上的流动量,便于对生态系统的特征和变化作深入的研究.本文主要根据1982～1983年渤海生态系统综合调查的渔业资源基础数据,建立了渤海生态系统初步生态通道模型.根据食性关系特点,渤海生态系统Ecopath模型由13个功能组(Box)构成.它们是小型浮游动物、大型浮游动物、小型软体动物、大型软体动物、小型甲壳类、大型甲壳类、草食性鱼类、小型中上层鱼类、底层鱼类、底栖鱼类、中上层顶级捕食鱼类、浮游植物和有机碎屑.功能组的划分,基本上可以覆盖渤海生态系统中生物能量的主要流动过程.模型采用每平方公里吨/年为主要参数单位,大部分功能组的生产量与生物量比值(P/B)和消耗量与生物量比值(Q/B)参数主要是根据相同纬度水域Ecopath模型中类似的功能组估算得到.在调试渤海生态通道模型时,考虑渤海生态系统是一个生态转换利用充分的水域,生态营养效率(EE)的值均取在0.808以上.模型估算出渤海可利用经济种类的生物量达到95×10^5t(每平方公里12.3t·km^{-2}),其中鱼类资源生物量为33.8×10^5t.上述数值比渤海生态系统综合调查结果数据和其它有关文章发表的渤海资源生物量(多根据拖网调查资料)的数值要高,其中小型中层鱼类生物量为渤海综合调查生物量的1.8倍.考虑到拖网调查方法往往对生物资源量估计偏低,可以认为渤海生态通道模型对生物量的评估数据是合理的.

关键词 生态通道模型 营养动力学模式 渤海生态系统 生物资源评估

A preliminary approach on mass-balance ecopath model of the Bohai Sea. TONG Ling, TANG Qisheng (*Yellow Sea Fisheries Research Institute, Chinese Academy of Fisheries Sciences, Qingdao* 266071), Daniel Pauly (*Fisheries Centre, University of British Columbia* 2204 *Main Mall, Vancouver, B.C., V6T 1Z4, Canada*). -*Chin. J. Appl. Ecol.*, 2000, **11**(3): 435～440.

A Bohai Sea mass-balance ecopath model is constructed on the basis of fisheries resources data from the ecosystem survey conducted from April 1982 to May 1983. It is the first ecopath model which consists of 13 function groups (boxes), and only covers the main trophic flow in the Bohai Sea ecosystem. P/B and Q/B parameters (P: production, B: biomass, Q: consumption) for most groups were estimated from similar function groups in other ecopath models of the same latitude regions around. The value of EE (Ecotrophic Efficiency) is the main parameter to check the equilibration of the model. The EE parameters in the model are of high value (>0.808) for most groups, because the fishing pressure was very high and small living organisms were being heavily preyed upon in the ecosystem. The biomass density of the species commercially utilized estimated by the model is 12.33 ton·km^{-2}. Even though the value is low compared with the density in other ecosystems, such as Caribbean coral reef ecosystem and the Southern B.C. shelf model, it is higher than the value published by some papers on the Bohai Sea using other methods. Considering the lower value estimated by the stock assessment using bottom trawl survey data, the output here is reasonable. It is concluded that the biomass of commercial fishing species in the sea is 950 thousand metric tons, and 338 thousand tons are fish species in the value.

Key words Ecopath model, Trophic dynamics modeling, Bohai Sea ecosystem, Stock assessment.

1 Introduction

The Bohai Sea is a semi-closed continental sea of China, which is nearly encircled by land only with a mouth about 90 km at the eastern apex that connects it to the Yellow Sea(Fig.1). The area of the sea is 77000 km^2 and the average depth of 18.7 m. Water temperature changes a lot resulting from the impact of the land climate. The highest SST is 26～30℃ in September and the lowest one is 1.2～4℃ in February. The sea is an ocean space with distinct productivity, strong fishing activity and complicated relationship of food web. It is also polluted heavily by industry and living sewage recently.

The Bohai Sea ecosystem depends on the amount of

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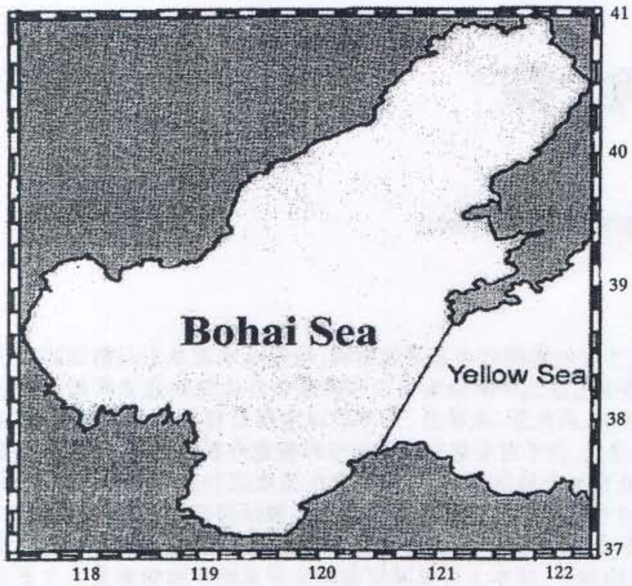

Fig.1 Map showing the Bohai Sea ecosystem region.

solar energy input and the organisms imported from several rivers. NO_3^--N and PO_4^+-P are basic nutrients supporting the primary productivity in the sea. The organic carbon is $112gC\cdot m^{-2}\cdot yr^{-1}$. The productivity is characterized by a seasonal and spatial variety with high level in spring and fall in the sea, but no much change between years. In the Bohai Sea, dominant small zooplankton are neritic brackishwater species, such as *Sagitta crassa*, *Labidocera euchaeta* and *Centropages mcmurrichi*[3]. The fishing effort in the sea has been increasing more and more since 1962, which led to a significant variation in the abundance and distribution of the most species in the area. The resources composition in the Bohai Sea changed a lot along with the increase of fishing effort to multi-species fish communities after 1962. The CPUE (catch per horse power) was 7.61 ton in 1962, but it went down to 0.88 ton in 1983. The traditional species fished in the area, such as small yellow croaker, slender shad, cutlasfish, were high valuable in the market, but the biomass of them declined then. The small pelagic fish and small crustacean species appeared much more in the landings and fluctuated much annually. The highest annual landing of *Acetes* reached 100 hundred metric tons ($1.3\ t\cdot km^{-2}$) in the sea. The highest catch of jelly fish was 280 hundred tons during the 1970s. This reflects a gradual transition in catch from long-lived, high trophic level, piscivotous bottom species toward short-lived, low trophic level invertebrates and planktivorous pelagic species[12]. The sea is an example of the ecosystem overfished toward smaller, high-turnover species exploited. It is a remark of Bohai Sea that small pelagic fish and jellyfish replaces large table fish as an over-exploited ecosystem[13].

2 Methodology and Ecopath Model

The approach of Ecopath model was originally described on coral reef ecosystem by Polovina[14] and was further developed by V. Christensen and D. Pauly[1] to make it available in a well-documented software running widely. Lately the Ecopath model developed to a new integrated Ecopath with Ecosim software for dynamic simulation modeling based on mass-balanced model by C. Walter[17]. In Ecopath model it is assumed that the ecosystem modeled is in steady state for each of the living groups, which implies that input equals output, i.e. $Q = P + R + U$, where Q is consumption, P production, R respiration, and U unassimilated food. The above equation can be structured around a system of linear equations for expressing mass-balance with the simplest form. It can be expressed for an arbitrary time period and for each element i of an ecosystem by the formula:

$$B_i\cdot(P/B)_i\cdot EE_i=\sum_{j=1}^{k}B_j\cdot(Q/B)_j\cdot DC_{ij}-EX_i$$

where B_i is the biomass of function group i during the period covered (conventionally, a year); $(P/B)_i$ production/biomass rate; EE_i ecotrophic efficiency, i.e., the fraction of the production that is utilized within the system for predation or export; C_i, the fish catch; B_j, the biomass of the predator j to prey i; $(Q/B)_i$, the relative food consumption ratio of i; and DC_{ij} is the fraction of prey i in the diet of predator j. The simultaneous linear equations using in Ecopath model states that the production and consumption are balance within an ecosystem.

The Ecopath model allows rapid construction and verification of a mass-balance model on ecosystem. The result of the model does not only verify the previously published biomass estimates, but also identify the biomass required for assessment of marine carrying capacity. To construct an Ecopath model can consist main of the following steps. (1) Identification of the area and period for which the model will be constructed on an ecosystem; (2) Definition of all functional groups (boxes), from primary producers to top predators in the ecosystem, to be included for the thermodynamic balance; (3) Setting parameters of production/biomass ratio (P/B), consumption ratio (Q/B), biomass (B) and ecotrophic efficiency (EE) for each function group, but only three of them are necessary as the basic input parameters in the model and also entry of the catches to every fishing species; (4) Entry of a diet consumption matrix (DC) expressing the diet fraction of predator/prey relationship in the model; (5) Modify the entries of P/B, Q/B, EE or the biomass to balance the Ecopath model (repeating above (3) and (4) steps) until the mass input equals output for each box.

The Kyoto Conference held in Japan in 1995 promoted a strengthened scientific basis for multi-species and ecosystem management to fisheries. Probably the most comprehensive of the approaches is Multi-Species Virtual Population Analysis (MSVPA), but the major drawback of MSVPA is that it requires a large amount data for application, including long time series of age information. Ecopath model relies on much less data and hence to be applicable in a much wider range of fisheries systems[11]. In recent years, several workshops on Ecopath approach were held, which led to nearly 100 Ecopath models applied in the world. The Ecopath with the latter category of Ecosim and Ecospace has a potential uses in ecosystem management[10].

3 The Bohai Sea Ecopath Model and Its Results

The Ecopath model of the Bohai Sea is going to construct a quantitative description of trophic structure on the ecosystem. The model can be used to estimate some important biological parameters and the relationship among the different groups in the Bohai Sea. The model is based on the month data from the bottom trawling of the Bohai Sea ecosystem survey project completed during April 1982 to May 1983[4]. It only presents a preliminary revelation of the trophic structure and flow in the sea between different function groups. The function group determination, like other Ecopath models, is based on the species feeding behavior, distribution and the function in the ecosystem. The function definition is little different with the taxonomy and the group name is only the designation in the model. All groups in the model cover the main trophic flows among the living marine groups and detritus.

The Ecopath model is the first mass-balance model in the Bohai Sea. It only has 13 function groups based on stomach contents inspection of 54 species from 1863 samples from the Bohai Sea survey[5]. The definition of function group is very rough because of the limited type of survey data available in the region. One primary producer of phytoplankton was identified. Zooplankton was split into two groups, microzooplankton and macrozooplankton. The former includes small herbivorous and carnivorous zooplankton and the latter mainly consists of jellyfish and *Acetes*. Benthic invertebrates were divided into small mollusca, large mollusca, small crustacean and large crustacean, most of which were commercial harvest in the sea but landing data were not well available. No biomass data for the species in the small invertebrate groups so the biomass was estimated by the model using the fixed ecotrophic efficiency (EE = 0.95). Biomass for the two large groups were obtained by summing up the biomass data from the survey[6]. Five fish function groups were identified in the model on the basis of 31 fish species which hold about 90% of total biomass for the fish community in the Bohai Sea. Herbivorous feeders group includes mainly *Mugil cephalus* and *Liza haematocheila*. Other four groups were small pelagic fish, demersal fish, benthic feeders and top pelagic feeders, which were important commercial fishing target[7]. The details of 13 function groups (box) in the Bohai Sea Ecopath model are summarized in the Table 1.

It is hard to find P/B and Q/B from one species to the whole group because many species are included in one function group in the model. We set the P/B and Q/B parameters in Bohai Sea model based on the ones from similar function group in the models of the Strait of Georgia by Dalsgaard, the Brunei Darussalam, South China Sea[16] and the Georges Bank[15]. The basic parameters of biomass (wet weight $t \cdot km^{-2}$), P/B, Q/B, EE and harvest for the 1982~1983 Ecopath model of the Bohai Sea ecosystem are presented in the Table 2, while the Table 3 shows the corresponding diet matrix. The detritus is estimated on the basis of the primary production of Carbon by the equation A5 of the empirical relationship method[9]. Phytoplankton is estimated from the Bohai Sea primary productivity of 112 $gC \cdot m^{-2} \cdot yr^{-1}$, which were converted to g wet weight phytoplankton $m^{-2} \cdot yr^{-1}$ by a wet weight: carbon ratio of 10:1. The ratio is used by several papers on Ecopath model, like Alaska gyre Ecopath model[10].

To balance import to and out from every box, the EE values are leading check parameters for equilibration

Table 1 Main species checklist of function groups in the Bohai Sea ecopath model

Microzooplankton

Copepoda (*Labidocera euchaeta*, *Calanus sinicus*, *Paracalanus parvus*), Mysidacea, *Sagitta* sp., Fish eggs

Macrozooplankton

Acetes chinensis, Jellyfish

Small mollusca

Arca subcrenata, *Philine kinglipini*, *Chlamys farreri*

Large mollusca

Sepiella maindroni, *Octopus ocellatus*, *Octopus variabilis*, *Loligo japonica*, *Loligo beka*

Small crustacea

Trachypenaeus curvirostris, *Alpheus japoncus*, *Oratosquilla oratoria*, *Palaemon gravieri*, *Crangon* sp.

Large crustacea

Penaeus chinensis, *Portunus trituberculatus*, *Charybdis japonica*

Herbivorous feeders

Mugil cephalus, *Liza haematocheila*

Small pelagic fish

Engraulis japonicus, *Setipinna taty*, *Coilia mystus*, *Harengula zunasi*, *Thrissa kammalensis*, *Clupanodon punctatus*

Demersal fish

Pseudosciaena polyactic, *Lateolabrax japonicus*, *Collichthys lucidus*, *Collichthys niveatus*, *Stromateoides argenteus*, *Argyrosomus Argentatus*, *Nibea albiflora*, *Johnius belengeri*, *Apogonichthys lineatus*

Benthic feeders

Raja porsa, *Raja pulchra*, *Cynoglossua joyneri*, *Enchelyopus elongatus*, *Pseudopleuronectes yokohamae*, *Cynoglossus semilaevis*, *Chaeturichthys stigmatias*, *Chaeturichthys hexanema*

Top pelagic feeders

Scomberomorus niphonius, *Paralichthys olivaceus*, *Pagrosomus major*, *Platycephalus indicus*, *Sphyraena pinguis*, *Saurida elongata*, *Miichthys miiuy*

Table 2 Parameter estimation for the group from the mass-balance model of the Bohai Sea*

Group	Catches ($t \cdot km^{-2}$)	Biomass ($t \cdot km^{-2}$)	P/B (yr)	Q/B (yr)	EE
Microzooplankton	–	4.40	36.0	186.0	(0.961)
Macrozooplankton	1.40	2.80	3.00	12.0	(0.964)
Small mollusca	0.78	(2.76)	6.85	27.4	0.950
Large mollusca	1.50	0.24	2.00	7.0	(0.890)
Small crustacea	0.20	(2.01)	8.00	30.0	0.950
Large crustacea	0.20	0.37	1.50	11.60	(0.823)
Herbivorous feeders	0.10	0.56	3.00	15.0	(0.903)
Small pelagic fish	0.50	2.14	2.37	7.9	(0.927)
Demersal fish	0.22	0.62	2.10	8.7	(0.808)
Benthic feeders	0.10	0.68	0.80	4.6	(0.902)
Top pelagic feeders	0.15	0.59	0.46	4.1	(0.553)
Phytoplankton	–	15.70	71.20	–	(0.457)
Detritus	–	43.00	–	–	(0.386)

* Values in brackets were calculated by the Ecopath program and dashes mean no entry.

of a model when running the ECOPATH software. The EE value should be between 0 and 1. Here, a value of zero indicates that the group is not consumed by any other groups in the system, nor is it exported. Conversely, a value near or equal to 1 indicates that the group is being heavily preyed or fished, leaving no individuals to die of old age[2]. Part of the original biomass data from the Bohai Sea trawling survey in 1982～1983 are considered too low, which leads to make no equilibrium of the model with the high value of EE. This results from the survey data mainly connected with com-

Table 3 Diet matrix for interacting groups in the Bohai Sea ecopath model

Prey	Predator										
	1	2	3	4	5	6	7	8	9	10	11
1. Microzooplankton	0.10	0.40	0.35	0.30	0.40	–	0.15	0.30	–	–	–
2. Macrozooplankton	–	–	0.05	0.05	–	0.10	–	0.15	–	–	–
3. Small mollusca	–	–	–	0.30	0.15	0.40	–	0.20	0.35	0.20	0.20
4. Large mollusca	–	–	–	–	–	–	–	–	–	0.05	0.05
5. Small crustacea	–	–	0.05	0.20	0.05	0.20	–	0.25	0.35	0.40	–
6. Large crustacea	–	–	–	–	–	–	–	–	–	–	0.05
7. Herbivorous feeders	–	–	–	–	–	–	–	–	0.10	–	0.15
8. Small pelagic fish	–	–	–	0.05	–	0.10	–	0.10	0.15	0.15	0.35
9. Demersal fish	–	–	–	–	–	–	–	–	–	0.15	0.15
10. Benthic feeders	–	–	–	–	–	–	–	–	0.05	–	0.05
11. Top pelagic feeders	–	–	–	–	–	–	–	–	–	–	–
12. Phytoplankton	0.60	0.20	0.15	–	–	0.10	0.30	–	–	–	–
13. Detritus	0.30	0.40	0.40	0.10	0.40	0.10	0.55	–	–	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

mercial species from bottom trawling, but the function groups in the model cover more living marine species. According to the result obtained by different resource assessment methods[8], biomass value estimated by bottom trawling survey is much lower than one from other stock assessment methods. It is necessary to modify thebiomass data to equilibrate the model. The biomass of small pelagic fish group in the model is estimated to $2.14\ t \cdot km^{-2}$ instead of $1.2\ t \cdot km^{-2}$ in the Bohai Sea survey. The biomass of benthic fish group is set to $0.68\ t \cdot km^{-2}$ instead of $0.32\ t \cdot km^{-2}$ in the survey.

4 Discussion

A flow chart showing trophic interactions and energy flow in the Bohai Sea is seen in Fig. 2. It presents the estimated trophic level of the 13 functional groups, the biomass and production, and the relative amounts of energy that flow in and out of each box. The energy flow to detritus, respiration and catch are also seen in the chart. The chart shows the two food paths, plankton path and benthic community path. That is the food web characteristic in the Bohai Sea ecosystem. The model explores a matrix of direct and indirect impact of competition and predation on species in the Bohai Sea (Fig.3), which assesses how an increase in the biomass of one group affects the biomass of other groups. The figure shows the relative impacts but to be comparable between groups. It can also give some insight into the stability of the ecosystem in terms of its ability to withstand changes. The groups of lower trophic level impact strong to the Bohai Sea ecosystem. The great fishing effort in the sea leads to the decrease of high value living marine resources, which can be seen by the negative impacts to the ecosystem from fishery.

The model estimated the biomass density of the species commercially utilized is 12.33 $t\cdot km^{-2}$ and the density for all fish species only 4.4 $t\cdot km^{-2}$ in the Bohai Sea. We conclude that the total biomass of commercially fishing species in the sea is 950 thousand tons and 338 thousand tons are fish species in the value. The density in the Ecopath model is relatively lower compared with the density in other ecosystem, such as Caribbean coral reef ecosystem and the Southern B.C. shelf model, but it is higher than the result published by the papers on

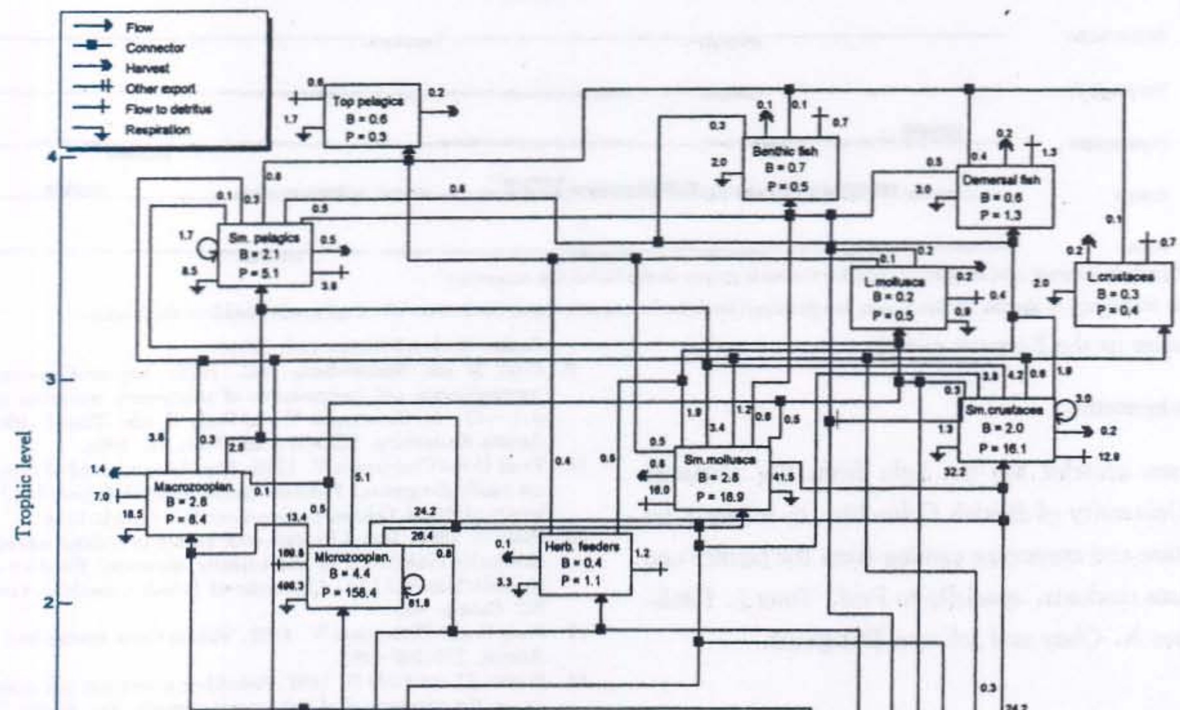

Fig.2 Flow chart of trophic interactions in the Bohai Sea ecopath model.
All flows are in $t\cdot km^{-2}yr^{-1}$. The size of each box is roughly proportional to the biomass therein (B: Biomass, P: Production).

the Bohai Sea. Considering the weakness of other assess methods depended mainly on the trawling data, the parameter estimation and energy flow from the Bohai Sea ecosystem model (1982 ~ 1983) could be reasonable even though they are only a preliminary assessment on the ecosystem.

It is the first Ecopath model in the sea, so some problems concerned with the input data have to be taken into account in future Ecopath model. Firstly the function group should be split further to make more precise input parameters of P/B and Q/B for each box. Secondly the diet data for some species is needed to be study further to let diet consumption matrix be more reasonable. Thirdly, it is better to consider the habitat for dif-

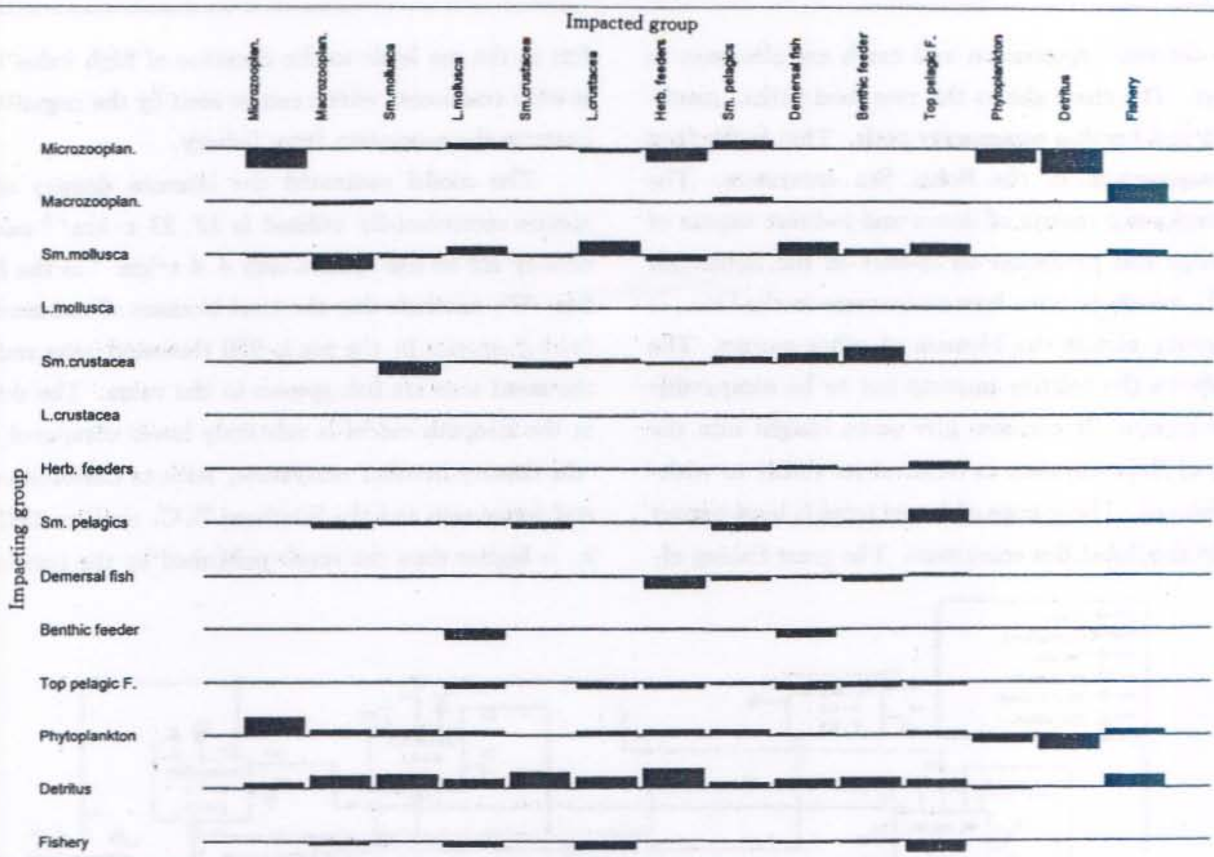

Fig.3 Mixed trophic showing mix trophic impacts for the each groups in the Bohai Sea ecosystem.
Increasing the abundance of species on the Y-axis has positive (black bar), negative (grey bar) or no effect on species listed on the X-axis.

ferent species in the Ecopath model.

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