Ecosystem structure and energy flow analysis of the adjacent waters around Miaodao Islands based on Ecopath model

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Abstract. Based on the survey data of fishery resources and ecological environment in the Bohai Sea and the Yellow Sea in 1998, an Ecopath model of the adjacent waters around Miaodao Islands was constructed to analyze the trophic structure, energy flow and ecosystem characters. The results showed that the model in the adjacent waters around Miaodao Islands could be divided into 18 functional groups, and the trophic levels of each functional group ranged from 1 to 4.180, of which the highest trophic level was Scomberomorus niphonius. The energy transfer efficiency of the ecosystem was 8.53%, and the flow from primary producers accounted for 53% of the total, while the flow from detritus accounts for 47%. The energy flow was mainly dominated by grazing food chain. The ratio of total primary production/total respiration was 2.47, the Connectance index was 0.438, and the Finn’s cycling index the Finn’s mean path length were respectively 6.336% and 2.636, indicating the low stability and maturity of the ecosystem.

1. Introduction
In recent years, due to the impact of intensive human fishing, the ecosystem around Miaodao Islands has deteriorated, fishery resources have declined sharply, and many economic fish species are even close to exhaustion. However, the traditional single-species fishery management strategy cannot prevent the decline of fishery resources and the deterioration of ecosystem[1]. Therefore, the research on the exploitation and management of fishery resources from the perspective of ecosystem is of great practical significance to restore the ecosystem function of the adjacent waters around Miaodao Islands and promote the sustainable development of marine fishery resources.

Based on the data of fishery resources and environment survey conducted in the Bohai sea and the Yellow Sea in 1998, Ecopath with Ecosim 6.5(EwE) software was used to construct the Ecopath model. Mainly analyzed the trophic structure, energy flow and ecosystem characters, and probed into the influence of human activities on the marine ecosystem. The aim of the paper is to restore the fishery resources and ecosystem function, to improve the relevant managements, and to lay the scientific foundation of the healthy ecological growth.

2. Study of sea areas and research methods

2.1 The study sea areas
Miaodao Islands are located in the Yellow Sea, Bohai Sea intersection, the surrounding sea fish is
mainly composed of migratory species, with the change of temperature and seasonal changes to carry out a wide range of migration. For example, Pseudosciaenapolyactis and Setipinnataty spend the overwintering period in the yellow sea. After march, they migrate to the north with the rising temperature and arrive at the bohai sea to spawn. After spawning, the school of fish dispersed to forage for food and then migrate to the wintering ground after October. Considering the fluidity of seawater and the migration of fish, the study scope of this paper is the Bohai Sea and the Northern Yellow Sea, with a longitude of 117°56´-125°44´ E, and a latitude of 37°07´-41°0´ N.

![Figure 1. Sketch map of study area of the adjacent waters around Miaodao Islands](image)

2.2 Functional groups division
According to the species, biological characteristics and feeding characteristics of the ecosystem around miaodao islands, the model was divided into 18 functional groups, which basically covered the energy flow process of the ecosystem.

2.3 Function group parameters and data sources
The survey data for this study were taken from the quarterly (May, August, October and February) survey data conducted by the Beidou fishery science survey vessel from 1998 to 1999. The biomass data of fish, crustaceans and cephalopods were based on the survey data of bottom trawl, and B values of Bohai Sea and Northern Yellow Sea were calculated by sweeping sea area method[2] respectively, and then the weighted average of biomass was calculated based on the area of Bohai sea and northern yellow sea. The biomass of Echinodermatas, Polychsetes and Meiobenthos can be obtained from the literature[3-5]. The biomass of phytoplankton is converted from the carbon unit of phytoplankton to the wet unit mass, and its ratio is 1:10[6]. The carbon mass of phytoplankton is converted from the water column integral of chlorophyll a, and its ratio is 50[7]. The detrital biomass was calculated using Christensen and Pauly's empirical formula[8]. EE value is difficult to obtain directly and is generally estimated by the model.

3. Results and analysis
3.1 Running results of the Ecopath model
The basic parameters of the Ecopath model for the ecosystem around Miaodao Islands are shown in Table 1. From the model balance results, it can be seen that the trophic levels of each functional group of the ecosystem in the waters around Miaodao Islands range from 1.000 to 4.180, in which Scomberomorusniphonius and liparistanakae occupied the top of the food web, and their trophic levels were 4.180 and 4.119 respectively. Engraulis japonicus and Setipinnataty, as plankton-feeding fish, have relatively low trophic levels (3.153 and 3.178). The trophic level of each functional group of benthos was between 2 and 3, among which the trophic level of crustaceans was relatively high at 2.726. The ecological trophic efficiency (EE) of most functional groups of the ecosystem is relatively high, most of which are between 0.512 and 0.984, among which the EE value of fish, crustaceans and cephalopods is above 0.9 due to the double pressure of predation and fishing.
Scomberomorusniphonius and liparis tanakae were at the top of the food chain and suffered less predation pressure, with an EE value of 0.765 and 0.598, respectively.

### Table 1. Input and output parameters of Ecopath model

| Functional group               | Trophic level | Biomass (t·km⁻²) | P/B  | Q/B  | EE   |
|--------------------------------|---------------|------------------|------|------|------|
| Engraulis japonicus            | 3.153         | 0.196            | 3.004| 10.60| 0.977|
| Setipinnataty                  | 3.178         | 0.0258           | 1.697| 8.580| 0.962|
| Pseudosciaenapolyactis         | 3.736         | 0.0132           | 1.358| 5.910| 0.933|
| Clupanodompunchtatus           | 2.516         | 0.0373           | 7.800| 28.90| 0.292|
| Scomberomorusniphonius         | 4.180         | 0.0107           | 0.790| 5.020| 0.765|
| Liparis tanakae                | 4.119         | 0.0326           | 0.800| 3.600| 0.598|
| Other pelagic fishes           | 3.497         | 0.099            | 1.030| 9.300| 0.950|
| Other demersal fishes          | 3.519         | 0.065            | 1.050| 4.950| 0.950|
| Benthic fishes                 | 3.631         | 0.014            | 1.600| 6.900| 0.950|
| Oratosquillaoratoria           | 3.574         | 0.00420          | 7.600| 30.20| 0.916|
| Crustaceans                    | 2.726         | 3.108            | 1.500| 11.60| 0.984|
| Cephalopods                    | 3.216         | 0.0944           | 5.100| 17.50| 0.902|
| Echinodermatias                | 2.526         | 17.28            | 1.300| 4.800| 0.293|
| Polychsetes                    | 2.086         | 7.183            | 5.680| 20.60| 0.512|
| Meiobenthos                    | 2.021         | 9.882            | 3.000| 15.00| 0.607|
| Zooplankton                    | 2.053         | 4.702            | 27.00| 100.00| 0.426|
| Phytoplankton                  | 1.000         | 12.03            | 100.00| 1203  | 0.354|
| Detritus                       | 1.000         | 47.71            |      |      | 0.335|

### 3.2 Trophic level energy conversion efficiency

Through trophic-level polymerization, the ecosystem in the adjacent waters around Miaodao Island can be merged into 6 integrated trophic levels, and the energy flow distribution of each trophic level is shown in Table 2. Among them, the data of total flow, captured food amount and flow debris amount of trophic grade V and VI were very low and can be ignored. In terms of the overall distribution of energy flow, the energy flow of trophic-grade I and trophic-grade II were 1203 t·km⁻² and 425.7 t·km⁻² per year, respectively, and the sum of them accounted for 97.76% of the total flow of the system, indicating that the energy flows of low trophic level accounted for a relatively large proportion in the system, while the energy flow of high trophic level accounted for less.

### Table 2. Distribution of energy flow in the ecosystem around Miaodao Islands (t·km⁻²·a⁻¹)

| Trophic level | Consumption by Predators | Export  | Flow to Detritus | Respiration | Throughput |
|---------------|--------------------------|---------|-----------------|-------------|------------|
| VI            | 0.000311                 | 0.000177| 0.000946        | 0.00271     | 0.00414    |
| V             | 0.0174                   | 0.00458 | 0.0653          | 0.132       | 0.219      |
| IV            | 0.218                    | 0.0285  | 0.812           | 1.664       | 2.721      |
| III           | 2.705                    | 0.130   | 11.54           | 20.41       | 34.79      |
| II            | 34.71                    | 0.0133  | 153.5           | 237.4       | 425.7      |
| I             | 425.7                    | 0.000   | 777.3           | 0.000       | 1203       |
| Sum           | 463.3                    | 0.177   | 943.3           | 259.7       | 1666       |

### 3.3 trophic structure characteristics of ecosystem

In terms of the trophic structure of ecosystem, phytoplankton and detritus occupied trophic level I, they provided a material and energy base for the entire ecosystem. Zooplankton, Crustaceans and Meiobenthos fed on primary producers and detritus, at trophic level II, and itself was fish feeding, for
the material energy transfer played an important role. In the fish functional group, all fish were at the trophic level III and above except Clupanodompunctatus, which had relatively low trophic level.

In the Ecopath model, the interrelationship of each functional group is represented by the mixed trophic relationship (Figure 2). Hollow dots indicate that the increase of biomass in the functional group has a positive effect on the increase of biomass in other functional groups and plays a promoting role, while solid dots indicate that the increase of biomass in the functional group has an inhibitory effect on other functional groups, and the size of the dots indicates the strength of the influence. The functional groups of benthic organisms interacted with each other as negative effects. Due to their high niche overlap and fierce competition, the growth of biomass of benthic organisms was restricted by each other. Among swimming animals, other pelagic fishes, other demersal fishes and benthic fishes had negative effects on most fish functional groups, mainly because of competition for bait. In contrast, Scomberomorusniphonius and Liparis tanakae had a negative effect on them by preying on other fish.

![Figure 2](image)

**Figure 2.** Mixed trophic impact in the adjacent waters around Miaodao Islands

### 3.4 Characteristics of ecosystem energy flow

Table 3 shows the energy conversion efficiency of different trophic levels from different sources. It can be seen that the energy conversion efficiency of each trophic level was close to 10% lindermans' efficiency, including low trophic level I and II of the conversion efficiency of 8.629% and 8.330% respectively, and the efficiency of peak occurred between trophic level V -VI, that was, the conversion efficiency of 11.34% was derived from the producer. The conversion efficiency from primary producers was 8.439%, slightly lower than that from detritus (8.632%). The average conversion efficiency of the whole ecosystem was 8.528%, not far different from the 10% linderman efficiency. The conversion efficiency of other ecosystems in nearby waters was 6.2% in Laizhou Bay[9], 8.1% in South yellow Sea[7], and 16.35% in Jiaozhou Bay[10]. In comparison, the order from large to small was Jiaozhou Bay, Miaodao Islands, Southern Yellow Sea, Laizhou Bay. Therefore, the conversion efficiency of Miaodao Islands was higher than that of Laizhou Bay, slightly higher than that of Southern Yellow Sea, and lower than that of Jiaozhou Bay.
### Table 3. Transfer efficiency of discrete trophic levels in the adjacent waters around Miaodao Islands

| Source    | Trophic Level | II   | III  | IV   | V    | VI   |
|-----------|---------------|------|------|------|------|------|
| Producer  |               | 8.158| 8.148| 9.042| 10.03| 11.34|
| Detritus  |               | 9.183| 8.520| 8.219| 10.51| 11.04|
| All flow  |               | 8.629| 8.330| 8.628| 10.26| 11.19|

Proportion of total flow originating from detritus: 0.47
Transfer efficiency from primary producers: 8.439%
Transfer efficiency from detritus: 8.632%
Total transfer efficiency: 8.528%

### 3.5 Ecosystem development characteristics

Total primary production/total respiration (TPP/TR) is an important indicator of ecosystem maturity. It is generally believed that the closer the ratio is to 1, the higher the ecosystem maturity will be. The TPP/TR value of the waters around Miaodao Islands was 2.468, indicating that the ecosystem development in the adjacent waters around Miaodao Islands was not mature. In addition, the connectance index (CI) and the system omnivory index (SOI) were indicators to represent the complexity of the internal connections of the system. The stronger the connection between its functional groups, the more mature and stable the system. CI and SOI of the waters around miaodao islands were 0.437 and 0.202 respectively, both of which were higher than Laizhou Bay and South Yellow Sea, indicating that the internal structure of the ecosystem around Miaodao Islands was more complex and the system was more stable. Finn’s cycling index (FCI) represents the degree to which the production capacity of the system is recycled. Finn’s mean path length (MPL) is the average length of each circular flow through the food chain. In general, the more mature the ecosystem, the higher the proportion of matter recycled and the longer the food chain through which the energy flows. The FCI and MPL of the adjacent waters around Miaodao Islands were 6.336 and 2.636, which were much lower than that of the South Catalan sea with more mature ecosystem[1][25.19, 4.27]. Based on the comparison results of the above parameters, the ecosystem in the adjacent waters around Miaodao Islands was in a fragile period of development and unstable, with more surplus production unused and the food web tending to a linear structure.

### Table 4. Summary statistics for the adjacent waters around Miaodao Islands Ecopath model

| Parameter                                      | Value  |
|------------------------------------------------|--------|
| Total system throughput (t·km⁻²·a⁻¹)           | 3171.752|
| Sum of all consumption (t·km⁻²·a⁻¹)            | 892.147|
| Sum of all exports (t·km⁻²·a⁻¹)                | 715.666|
| Sum of all respiratory flows (t·km⁻²·a⁻¹)      | 487.508|
| Sum of all flows into detritus (t·km⁻²·a⁻¹)    | 1076.431|
| Sum of all production (t·km⁻²·a⁻¹)             | 3171.752|
| Calculated total net primary production (t·km⁻²·a⁻¹) | 1429.210|
| Net system production (t·km⁻²·a⁻¹)             | 715.492|
| Total biomass (t·km⁻²·a⁻¹)                     | 54.788 |
| Mean trophic level of the catch                | 3.092  |
| Total primary production/total respiration (TPP/TR) | 2.468  |
| Total primary production/total biomass (TPP/TB) | 21.961 |
| Connectance index (CI)                         | 0.438  |
| System omnivory index (SOI)                    | 0.202  |
| Finn's cycling index (FCI)                     | 6.336  |
| Finn’s mean path length (MPL)                  | 2.636  |
4. Conclusion

Through the analysis of the ecosystem structure, energy flow and development characteristics of the adjacent waters around Miaodao Islands, we need to take multiple measures to strengthen the management in order to repair its ecosystem functions. First, establish and improve the investigation and evaluation system of fishery resources, strengthen resource monitoring, strengthen the research on the maximum sustainable yield and the research on the optimal catch quantity, and provide scientific basis for the implementation of the catch quota system. Secondly, the summer fishing moratorium system should be strictly implemented, and law enforcement inspection should be strengthened during the fishing moratorium period, so as to facilitate the recovery of fishery resources. In addition, while strengthening various protection and management measures, natural fishery resources should be augmented through release and other measures to increase the production capacity of fishery resources and improve the population structure and quality of fishery resources.

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