ESTIMATING ECOLOGICAL CARRYING CAPACITY AND MANAGEMENT OF ENHANCEMENT SPECIES IN TANGSHAN MARINE ECOSYTEM (BOHAI SEA, CHINA) BASED ON ECOSYSTEM MODEL

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ABSTRACT

The Tangshan marine ecosystem is one of the areas in Bohai Sea that are gazetted for marine farming through stock enhancement. The sea cucumber, shellfish, black rockfish and yellow rockfish are the main target species for enhancement, but there is limited information of the ecological carrying capacity of these species. In this study, a food web model of Tangshan marine ecosystem is developed using Ecopath with Ecosim (EwE) modelling framework and used to estimate the potential biomass of selected species that can be released without destabilising the ecosystem. The model, which is not spatially resolved, consists of 19 functional groups chosen on the basis of functional role in the ecosystem and availability of data. The pedigree index, reflecting the overall quality of the input parameters, is within the intermediate range of the global Ecopath models. The model shows that Tangshan marine ecosystem is a relatively immature system, phytoplankton-based, and less resilient to ecosystem disturbances. Nevertheless, the ecosystem has the capacity to support more than 200% increase in biomass of blackfish, yellow croaker, sea cucumber and shellfish relative to the present level. The main conclusion from this study is that the Tangshan marine ecosystem can support stock enhancement for multiple species within the limits of the ecological capacity assessed by the model. It is important to note, however, that the ecological capacity in this study is based on the principle of mass balances, with limited consideration of spatial effects and changes in species life history. The parameter-combination used to achieve mass balances, from which the ecological carrying capacity is determined, is one of the possible parameter-combinations that can achieve similar results. This implies the present model should be considered as a best working hypothesis rather than a definitive representation of the Tangshan marine ecosystem.

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1 INTRODUCTION

1.1 Background

The world population faces the enormous challenge of having to provide food and livelihoods to more than 9 billion people by the middle of the 21st century, while addressing the disproportionate impacts of climate change and environmental degradation on the resource base. The United Nations' 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs) offer a unique, transformative and integrative approach to shift the world on to a sustainable and resilient path that leaves no one behind. Food and agriculture are key to achieving the entire set of SDGs, not least SDG 14 (Conserve and sustainably use the oceans, seas and marine resources for sustainable development) (FAO, 2018). With capture fishery production relatively static since the mid-1980s, aquaculture has been responsible for the continuing growth in the supply of fish for human consumption (Figure 1) (FAO, 2018). However, in recent years, frequent disease outbreaks in the aquaculture industry have resulted in the abuse of medicine, which has led to a decline in the quality of aquatic products (Yang H. , 2016). The demand for green, healthy and safe aquatic products is growing. Marine ranching is an important way to address this need.

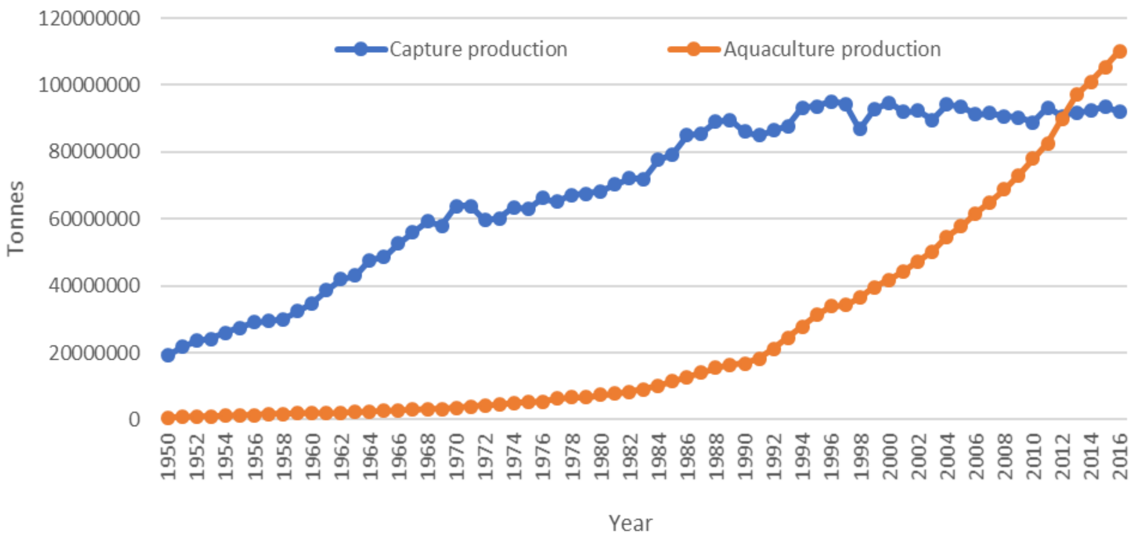

Figure 1. World capture fisheries and aquaculture production.

Since the 1980s, the demersal fish resources of almost all coastal and offshore waters in China have been severely depleted because of overfishing. About 70-80% of the demersal fish production is composed of juvenile fish (Chen, 2014). Due to overfishing, most of the traditional fishing species in China have little or far less than expected yield during the fishing season, and some species, such as the large yellow croaker (*Larimichthys crocea*) and cuttlefish (*Sepiella maindroni*), have declined or even collapsed. Yield of other species such as the largehead hairtail (*Trichiurus lepturus*) and the small yellow croaker (*Pseudosciaena polyactis*) has remained high, but age and size at sexual maturity has decreased. At the same time lower trophic level species and smaller individuals are being targeted, which formerly were used for bait in traditional fisheries (Chen, 2014).

About 40% of China's marine fishing production comes from trawl fisheries (Fisheries and Fisheries Administration, 2017). The bottom trawl fishery has caused damage to the seabed environment and changed the physical structure and living conditions of fish, reducing the heterogeneity of substrate (Shen, 2010). Restoration of the impact of bottom trawling on the substrate takes at least 10-15 years for gorgonian and soft coral communities (Shen, 2010). Trawling operations also cause the suspension of sediments and its pollutants, causing secondary pollution of the water column.

In response to the severe decline in fishery resources and the degradation of marine biological habitats, the government of China has implemented a series of management measures since the mid-1990s, such as the zero increase and even reduction of fishing output based on 1999 annual marine fishing catch, strict control of the total number and total power of fishing boats, based on *China's action plan for the conservation of aquatic living resources* and *the national plan for the construction of marine ranching demonstration areas* (Gao & Gao, 2008); (Shi, 2007); (Yang H. , 2016). One part of these plans, the establishment of marine ranches is of particular interest. By the end of 2016, 5.58 billion CNY had been invested in more than 200 marine ranches, including 42 national demonstration ranches covering more than 850 square kilometers of sea area and the construction of over 60 million m^3 of artificial reefs (Ministry of Agriculture and Rural Affairs of China, 2017). At present, the design of marine ranches in the country has begun to take shape, and economic, ecological and social benefits have become increasingly apparent. However, due to lack of experience and scientific planning for construction and management, some ranches have not achieved the intended purpose and even caused damage to the local environment. Therefore, the Ministry of Agriculture and Rural Affairs of China issued *Technical Specifications for Artificial Reef Construction*. These oblige companies establishing marine ranches to investigate and evaluate marine biological resources when constructing artificial reefs and to adopt scientific management methods to continuously optimize management plans to achieve better use of sea areas. This study will provide scientific management advice for a marine ranch in Tangshan, Bohai Sea

1.2 Overview of the development of Ocean Ranching and Ocean Ranches

The distinction between ocean ranching and ocean ranches is not always clear as the latter has in part developed from the former. Ranching is when hatchery produced juveniles are released into nature to forage and grow in areas that are not controlled by the party releasing them. This can be compared to livestock grazing in a commons among livestock from other farmers and even wild animals. In fisheries such releases are used to increase the harvestable biomass of a species. The best-known example is the ranching of salmon which started before the middle of last century in Europe and the US to compensate for reduced smolt production in rivers harnessed for hydroelectric development (Thorpe, 1980).

Marine ranches on the other hand have defined boundaries and are more like large farms in that the owner has exclusive rights to manage and harvest living marine resources within the boundaries of the ranch. Enhancement of the production and harvest of desired species can be achieved by habitat improvement, increased feed production, improved spawning grounds and the artificial culture and release of target species. Harvesting may depend on domestication or training fish to recognize sound and aggregate near the source of the sound

Marine ranches have become increasingly popular in Japan and China, while marine ranching is more important in Europe and the US.

Marine ranches are most commonly in coastal areas but can also be in offshore waters. It involves both the construction and maintenance of facilities for the production, release and harvest of target species, and the construction of artificial reefs and other habitat improvement measures (Huang, 1979). China's marine ranch construction originated from the release of shrimp spawn (*Fenneropenaeus chinensis*) and construction of artificial reefs in the late 1970s. After more than 30 years of construction, a series of marine ranches, which included artificial reefs, transplanting seagrass and algae, enhancement of economically important species of fish, shrimps, crabs and cephalopods, have been built along the coast of China.

In China, in the late 1970s and early 1980s, in order to increase the quality product and increase the production and quality of aquatic products, marine ranches were established to address the problem of declining fish stocks. The focus was on releasing high-yielding economic species, transforming shallow sea bio-communities and shortening the food chain to achieve the goal of increasing fishery resources (Zeng, 1985). However, the process of changing the relative composition of marine ecological bio-communities will affect the marine ecosystem. The concept of “marine farming and animal husbandry” is based on the principle of giving priority to economic benefits.

In the 2010s, China has been developing national marine ranching demonstration areas. The purpose of marine ranching construction is to improve the coastal ecological environment and restore fishery resources. Professor Chen Yong, a Chinese marine ranching expert, believes that marine ranches is a modern marine fishery production mode that is supported by science and technology and managed by scientific theories and methods to achieve ecological health, resource richness and product safety. It is a marine fishery production system that combines various technical elements such as habitat restoration and optimization, seed production and release, fish behavior conditioning, ecological and environmental monitoring, and harvest management (Hu & Tong, 2012).

China's marine ranches can be divided into three types based on their purpose, i.e. fishery resource conservation, fishery enhancement and recreational fishery. The establishment of marine ranches in China has brought about economic, ecological and social benefits. Marine ranches in China have been estimated to produce direct economic benefits of 31.9 billion CNY/year, ecological benefits of 60.4 billion CNY/year, annual carbon sequestration of 190,000 tons, nitrogen reduction of 16,844 tons and phosphorus of 1,684 tons. More than 16 million tourists experience sightseeing at sea and recreational fishing each year (Ministry of Agriculture and Rural Affairs of China, 2017).

1.3 The construction of artificial reefs

As early as 1952, the construction of artificial reefs began to be implemented in national plans in Japan and was included in the coastal fishery revitalization policy. In 1958, large-scale artificial reefs were built to create suitable marine habitats for target species to improve production of desired species. Japan established the first marine ranch in the world in 1977. The large-scale development of marine ranches with artificial reefs as the main characteristic has also led to the development and research of artificial reef technology in Japan (Liu, 2001).

The construction of artificial reefs in the US has a history of more than 150 years. In 1860, coastal fishermen in South Carolina discovered that fish aggregated around trees that had been washed into the sea by floods. Therefore, they tried to sink trees and stones into the seabed to build artificial reefs. Fish aggregated around these structures, but unlike Japan's main goal of fishery enhancement and mariculture the main purpose of US marine ranching construction is to develop recreational fisheries (Wang & Han, 2015).

1.4 Ecological carrying capacity and ecological enhancement capacity

The concept of carrying capacity is derived from the logistic equation of population growth, which was first used by Errington in 1934 (Tang, 1996; Kashiwai, 1995). Kaiser and Beadman (2002) defined carrying capacity as the potential maximum biomass a species or population can maintain in relation to available resources. The ecological capacity model has been applied to marine ranch management (Yin & Zhang, 2011; Wang, Zhang, Zhang, & Zhang, 2016) (Wang, Zhang, Zhang, & Zhang, 2016). When the ecological capacity is applied to an active fishery, ecological enhancement capacity can be estimated as the maximum increase in a population that can be supported for specific period in a specific sea area, and will not lead populations, biological communities nor the structure and function of the ecosystem to change markedly (Lin, Li, & Li, 2013). The Ecopath model provides theoretical guidance for the study of ecological enhancement capacity (Jiang & Gibbs, 2005).

1.5 Rationale

The Tangshan marine ranch was established to enhance fisheries. When designing and managing constructing the marine ranch, estimates of ecological carrying capacity are important to decide on the amount of target species to be released (Jin & Deng, 2000; Zhang, Wang, & Tu, 2009). At present, the determination of the amount of economically important fish species and other high-value animals released in the reef area is mainly based on the experience of fishermen. However, the amount released directly affects the results. If the density of the released fish is too small the production potential of the area will not be fully utilized. If the density if too high exceeding the ecological capacity, the competition for food and habitat will be intensified, resulting in species occupying a similar niche as the enhancement species are replaced, and even in the decline of ecosystem function (Deng, 1998; Li, Wang, & Yang, 2009). The cultivation of Japanese scallops (*Patinopecten yesoensis*) grew to a considerable scale in the 1970s (Wu, Zhang, Zhang, Tong, & Liu, 2013). However, due to the high density of seed released, the ecological balance was disrupted resulting in high mortalities. Therefore, researchers have developed the environmental capacity assessment to control the stocking density and solve the problem of high mortality. Rational and effective assessment of the ecological carrying capacity of economically important marine species such as reef fishes and other species in the reef ecosystem is of great significance for regulating the density of seedlings in the reef area. In the past, the determination of ecological capacity was mainly based on the biological data of the target species. The interaction between species in the biome is not considered, resulting in a large deviation between the calculated results and the actual situation. This study uses the Ecopath model to simulate the energy flow of the marine pasture ecosystem to estimate the ecological carrying capacity of target species.

1.6 Research objectives

To propose a scientific management strategy of enhancement species in Tangshan marine ecosystem in Bohai Sea in China.

1.6.1. Specific objectives

- To analyze the energy utilization efficiency in the Tangshan marine ecosystem based on a food web model.
- To assess the ecological capacity for stock enhancement in the Tangshan marine ecosystem.
- To determine optimum harvest rates for the enhancement species in Tangshan Marine ecosystem.

2. MATERIAL AND METHODS

2.1.Study area

The study was conducted in the Tangshan Marine farming area, which is located in Luanhekou, Bohai Sea, China (Figure 2.1). The seabed has a flat bottom with the slope of less than 2%, the water depth is 7~15m, and the substrate is gravel, sand and mud. The total sea area is $132km^2$, of which the artificial reef area is $2km^2$. At present, artificial reefs of 201,977 m^3, including cement component reefs, granite reefs, and ship reefs, have been deployed in the planned marine area, which consists of cement member reef 50,652 m^3, granite reef 149,050 m^3, and boat reef 2,275 m^3.

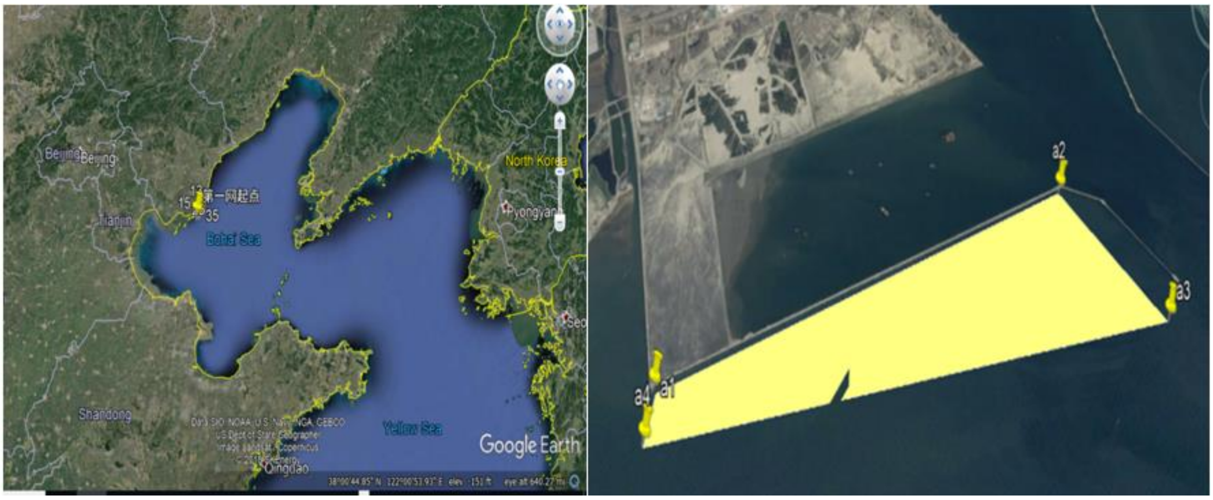

Figure 2. The location of Tangshan marine farming area in Bohao Sea, China.

The study employed Ecopath with Ecosim (EwE) modelling framework to develop a model of Tangshan marine ecosystem, which was used to estimate the ecological carrying capacity of enhancement species.

1.1 Basic principle of Ecopath model

Ecopath partitions an ecosystem into a series of ecologically related functional groups, all of which basically cover the energy flow paths in the ecosystem. Functional groups can include species with the same ecological habits, important species, or species of different body lengths/age groups, as well as organic detritus, plankton and benthic organisms. According to the principle of nutritional dynamics, the energy input and output of each functional group must be balanced.

The Ecopath model is based on two main equations: one describing the material balance and the other considering the energy balance.

$$P_i = Y_i + B_i \cdot M_{2i} + E_i + BA_i + M_{0i} \qquad (2.2.1)$$

$$Q_i = P_i + R_i + U_i \qquad (2.2.2)$$

Where: for every functional group i, P is the total production; Y is the total catch; B is the biomass per unit of habitat area; M_2 is the predation mortality; E is the net migration (emigration-immigration); BA is the biomass accumulation; $M_0 = P_i \times (1 - EE_i)$ is other deaths; EE_i is the ecological nutrition efficiency, which refers to the utilization ratio of the production in the system; Q is the consumption; R is respiration; U_i is the amount of unassimilated food.

Assuming that the diet composition of each organism remains unchanged during the study period, formula (2.2.1) can be formally re-expressed as:

$$B_i \cdot \left(\frac{P}{B}\right)_i - B_i \cdot \left(\frac{P}{B}\right)_i \cdot (1 - EE_i) - \sum_{j=1}^{n} B_j \times \left(\frac{Q}{B}\right)_j \cdot DC_{ji} - Y_i - E_i - BA_i = 0 \quad (2.2.3)$$

Where: DC_{ji} is the proportion of prey j in the diet of predator i.

Three out of the four parameters, including biomass (t/km^2), P/B (/year), Q/B (/year) and EE, for every defined functional group, are required to initialise the Ecopath mass balance model. In addition, mandatory data are required on exports (catches, t/km^2), diet composition (% volume), proportion of unassimilated food, biomass accumulation, and net migration rates (year^{-1}).

1.2 Construction of the Ecopath model of Tangshan marine ecosystem

1.2.1 Defining functional groups

The model was constructed with 19 functional groups, which were defined according to the species ecological or bio-taxonomic status. Groups with high economic value or ecological function in the model area, and for which data were available, were modelled as separate species. These included black rockfish (*Sebastes schlegelii*), yellow rockfish (*Hexagrammos otakii*), Sea cucumber, Shellfish. Groups that were merged include Type I fishes, Type II fishes, Type III fishes, small demersal fishes, small pelagic fishes, Crustacean, Cephalopod, Mollusca, Echinoderm, Other benthos, Sea bird, Zooplankton, Phytoplankton, Benthic algae and seaweed, and Detritus (Table 1). Type I fishes inhabit the fish reef or the reef gap and rely on the skin and the lateral line for direct contact with solids. Type II fish swim around the reef, their habit of contacting the reef is not as strong as that of the type I fish. Type III fish are migratory pelagic fish that prefer to stay above the reef (Table 1).

Table 1. Description of components in functional groups used in Tangshan marine ranching Ecopath model

No.	Functional group	Composition
1	Black rockfish	Black rockfish (*Sebastes schlegelii*)
2	Yellow rockfish	Yellow rockfish (*Hexagrammos otakii*)
3	Sea cucumber	Sea cucumber (*Apostichopus japonicus*)
4	Shellfish	Scallop (*Patinopecten yessoensis*), abalone (*Haliotis discus hannai*)
5	Type I fishes	*Zoarces elongates, Ernogrammus hexagrammus, Acanthopagrus schlegelii, Blenniidae, Agrammus agrammus*
6	Type II fishes	*Pleuronectiformes*, *Cleisthenes herzensteini*, *Platichthys bicoloratus, Paralichthys olivaceus, Raja porosa, Cynoglossus joyneri*
7	Type III fishes	*Scomberomorus niphonius*

8	small demersal fishes	*Synechogobius hasta, Enedrias fangi, Tridentiger trigonocephalus, Tridentiger barbatus，Tridentiger bifasciatus, Ernogrammus hexagrammus，Ctenotrypauchen microcephalus, Platycephalus indicus, Okamejei kenojei*
9	small pelagic fishes	*Engraulis japonicus, Sardinella zunasi, Thryssa kammalensis*
10	Crustacean	*Charybdis japonica, Oratosquilla oratoria, Palaemon gravieri, Alpheus distinguendus, Alpheus japonicus, Tachypenaeus curvirostris, Crangon affinis, Leptochela aculeocaudata, Callianass japonica, Dorippe japonica, Diogenes edward-sii, alcocki Fenneropenaeus chinensis, Carcinoplax vestita, Amphipoda, Isopoda, Pugettia nipponensis Rathbun, Xenophthalmus pinnotheroides, Acanthomysis sp. Leptochela aculeocaudata, Parapenaeopsis a cultrirostris,* Portunus trituberculatus*, Tritodynamia japonica,*
11	Cephalopod	*Octopus variabilis, Octopusocellatus, Loliolus japonica*
12	Mollusca	*Crassostrea gigas, Chlorostoma rustica, Glossaulax didyma, Nassarius siquijorensis, Nassarius succinctus, Nassarius variciferus, Polinices fortune, Rapana venosa, Solen strictus, Scapharca broughtonii*
13	Echinoderm	*Asterias amurensis, Asierias rollestoni Bell, Strongylocentrotus nudus, Hemicenlrotus Pulcherrimus, Asterina pectinifera, Ophiuroidea. sp. Temnopleurus hardwickii*
14	Other benthos	*Lumbrineridae. spp, polychaete. spp, Bryozoa, Sphyraenus, Brachiopoda*
15	Sea birds	Seagull
16	Zooplankton	*Copepods, Chaetognath,Tunicata, 0ther planktonic larva, Megalopa larva, Rhopilema esculenta, Acetes chinensis,* Fish eggs
17	Phytoplankton	diatom, dinoflagellate
18	Benthic algae and seaweed	*Sargassum thunbergii, Cladophora sp, Ulva pertusa, Gelidium amansii, Sargassum Pallidum, Chondrus ocellatus, Laminaria japonica, Gracilaria lemaeiformis, Lomentaria sp,Sargassum horneri, Plocamium telfairiae, Grateloupia turuturu, Phyllospadixi watensis Makino, Codium fragile, Enteromorpha intestinalis, Undaria plnnatifida, Zostera marina*
19	Detritus	

1.2.2 Model parameterisation

(1) Biomass (B)

Biomass data were derived mainly from the trap survey data from 10 stations of six voyages conducted from July 2016 to June 2017. These were supplemented by data from from small-scale trawling surveys (around reef areas) and diving surveys. The size of trap is 6.6m* 0.28m*0.18m and mesh size is 0.015m. The parameters of trawl net are as follows: the width of net mouth is 5m, towing speed is about 4 kn., and towing time is about 20 minutes.

The calculation formula of density was as follows:

a. trap sampling method: Density = biomass in the trap/the trap impact range, where the trap’s impact range = the area of the circle whose trap length is the diameter.
b. Trawling method: The biomass was calculated according to the swept area method (Zhan, 1995).
c. Diving method: The biomasses of Bethic algae and seaweed, Sea cucumber, Shellfish, Echinoderm (sea urchin)) were calculated according to quadrat sampling method (Sun, 1992).
d. phytoplankton biomass is converted by chlorophyll a (Su & Tang, 2002).

e. Organic debris biomass is estimated using a linear model proposed by Pauly et al. (1993). That is as follows:

$$\log_{10} D = -2.41 + 0.954 \log_{10} PP + 0.863 \log_{10} E$$

where *D* is the detritus standing stock in $g \cdot C \cdot m^{-2}$, *PP* is the primary production in $g \cdot C \cdot m^{-2} \cdot year^{-1}$ and *E* is the euphotic depth, in m.

(2) P/B ratio and Q/B ratio

The P/B ratio for each of the fish functional group was assumed to be equivalent to instantaneous rate of total annual mortality (Z) (Allen, 1971).

The Z value for each of the fish group was calculated by using length-converted catch curve analysis method using body length frequency data collected during the 2016-2017 surveys. Using a variety of methods for estimating fish and another aquatic animals' P/B proposed by Gulland (1983) and Pauly (1980). The Q/B ratio for each of the fish functional group was estimated using an empirical formula (Palomares & Pauly, 1998) that relates Q/B with one parameter of the VBGF, habitat temperature, morphological variables, and food type.

$$\log(\frac{Q}{B}) = 5.847 + 0.28 \log Z - 0.152 \log W_{\infty} - 1.36T^{'} + 0.062A + 0.510h + 0.390d$$

where W_{∞} is the asymptotic weight (g) that is analogous to L_{∞} (and calculated, for this study, as $W_{\infty} = qL_{\infty}^{3}$, where q is a constant of condition factor (g/cm^3). (Sparre & Venema, 1998), T' is an expression for the mean annual temperature of the water body, expressed using $T^{'} = 1000 / Kelvin$ (where *Kelvin*=°C+273.15), *A* is the aspect ratio of caudal fin (approximately equal to 1.32 and 1.9 for fish with round and forked tails, respectively; (Froese & Pauly, 2018), *h* is a dummy variable expressing food type (i.e. 1 for herbivores, and 0 for detritivores and carnivores), and *d* is a dummy variable also expressing food type (i.e. 1 for detritivores, and 0 for herbivores and carnivores).

(3) Diet composition matrix

The diet composition matrix is derived from the analysis of stomach contents of sampled fish (group 1, 2, 5 and 6) and from literatures: group 3 (Zhang, Sun, & Wu, 1995), group 4 (Guzman , Serviere-Zaragoza, & Siqueiros-Beltrones, 2003), group 7 and 8 (Yang J. , 2001a), group 10 (Yang J. , 2001b), group 9 and 12 (Tong, Tang, & Pauly, 2000), group 13 (Tsehaye & Nagelkerke, 2008), group 14 (Christian & Luczkovich, 1999), group 15 (Xu, Chen, Tian, Liu, & Yin, 2016), group 16 (Jiang, et al., 2008) .(Table 2.2)

(4) The catch

The catch statistics data comes from Tangshan marine ranching company.

1.2.3 Model debugging and balancing

Ecopath model debugging is to maintain the balance between the input and output of the ecosystem. The basic condition for the balance of the model is: 0<EE≤1. First, check whether

the EE value of each functional group is less than or equal to 1. After the first run of the model parameterization estimate, it is inevitable that some functional groups have an EE value greater than 1 (unbalanced functional group), mainly because the intake or catch exceeds the biological production value. Then, the Ecopath model automatic mass-balance function was used to set the confidence interval (10% change of input parameters) and adjust the food group of the unbalanced functional group (Kavanagh, Newlands, Christensen, & Pauly, 2004). At the same time, check the food conversion efficiency GE (ratio of production to consumption, P /Q) to meet the requirements of 0.1~0.3 (Christensen, Walters, & Pauly, 2004a), and the P /Q value of each functional group should be less than the net efficiency value (production/food digestion). Repeat debugging until $0 < EE < 1$.

In Ecopath model, Pedigree index (Christensenb & Walters, 2004) is used to analyze the data source and quality of the model and quantify the uncertainty of input parameters of the model. Pedigree index range: 0~1.0; 1.0 index data is of high quality and can be obtained through accurate sampling. 0 index data source is fuzzy, data refer to guestimates. Designating parameters, the index of model quality is shown in Table 2 and 3

Table 2. Diet composition (proportion) of groups in Tangshan Ecopath model after adjustment to achieve a mass balanced model, but whose values are still in the range reported in literature

	Prey \ predator	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1	Black rockfish															0.050	
2	Yellow rockfish	0.030	0.010			0.050	0.050									0.050	
3	Sea cucumber	0.050	0.050			0.001								0.02			
4	Shellfish	0.030				0.001						0.005	0.001	0.03			
5	Type I fishes					0.020										0.200	
6	Type II fishes					0.010	0.030										
7	Type III fishes																
8	small demersal fishes	0.160	0.105			0.330	0.250		0.010			0.100					
9	small pelagic fishes	0.040	0.005			0.052	0.150	0.865	0.004	0.100		0.100				0.650	
10	Crustacean	0.620	0.620			0.101	0.120	0.083	0.200	0.250	0.150	0.300		0.05			
11	Cephalopod	0.005				0.030	0.050	0.052									
12	Mollusca	0.005	0.060	0.055	0.010	0.162	0.060		0.065	0.200	0.175	0.295	0.050	0.05		0.050	
13	Echinoderm	0.005	0.030			0.115	0.020				0.020	0.020		0.01			
14	Other benthos	0.050	0.115	0.010	0.010	0.100	0.170		0.100		0.200	0.040		0.17			
15	Sea birds																
16	Zooplankton	0.005	0.005	0.016	0.021	0.028	0.100		0.564	0.450	0.050	0.100	0.050		0.110		
17	Phytoplankton									0.030	0.080		0.200		0.040		0.800
18	Benthic algae and seaweed			0.158	0.957				0.057				0.180	0.300	0.250		
19	Detritus			0.761	0.002						0.325	0.040	0.519	0.370	0.600		0.200
	Import	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	(1 - Sum)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 3. Designation of data pedigree index to different functional groups

classifications (B)	**Group**	**classifications (P/B ,Q/B)**	**Group (P/B)**	**Group (Q/B)**	**classifications (DC)**	**Group**	**classifications (Catch)**	**Group**
Estimated by Ecopath		Estimated by Ecopath			General knowledge of related group /species		Guesstimate	
From other models		Guesstimate			From other models	11,12,13,14	From other models	
Guesstimated		From other models	3,4,10,11,12, 13,14,15,16,17	3,4,10,11,12, 13,14,15,16	General knowledge for same group /species	3,4,5,6,7,9, 10,15,16	FAO statistics	
Approximate or indirect method	3,4,5,6,7, 11,12,14,19	Empirical relationship	1,2, 5,6,7,8,9	1,2, 5,6,7,8,9	Qualitative diet composition study	8	National statistics	
Sampling/locally, low precision	2,8,9,10, 13,16,17,18,	Similar group/ species, similar system, low precision			Quantitative but limited diet composition study	1,2	Local study, low precision/incomplete	5,6,7,8,9,10
Sampling/locally, high precision	1	Similar group/ species, same system, low precision			Quantitative, detailed, diet composition study		Local study, high precision/complete	1,2,3,4, 13
		Same group/ species, similar system, high precision						
		Same group/ species, same system, high precision						

Notes：B-Biomass in habitat area, P/B-Production/Biomass, Q/B- Consumption/Biomass, DC-Diet Composition

1.3 Estimation of ecological capacity and release biomass for enhancement species

The calculation of the ecological enhancement capacity follows the method of shellfish culture capacity (Jiang & Gibbs, 2005). According to the construction principle of the Ecopath model, by continuously increasing the biomass of a certain released species (the catch is also proportionally increased), the changes in other functional groups such as bait organisms in the system are observed, and when EE > 1 of any other functional group in the model at the time, the ecosystem (model) is disrupted. The biomass value of the released species, therefore, is the ecological capacity before the model is about to be unbalanced. When the ecosystem reaches the ecological capacity, the robustness test of the biomass parameters is tested by changing the biomass value of each functional group in the status of the ecological enhancement capacity balance, and the biomass is multiplied by the factor 0. 01, 0.1.1, 0.5, 2, 10 and 100. Only one biomass value of one functional group is changed at a time, and the biomass of other functional groups remains unchanged. Under the condition of maintaining the balance of the Ecopath model, the degree of change in the biomass value of a functional group is used to test the degree of disturbance of the biomass of this functional group when the system reaches the ecological capacity (Byron, Link, Costa-Pierce, & Bengtson, 2011).

Management strategy in this study mainly refers to the determination of the catchable size and the annual catch of the main enhancement species.

According to the theory of maximum sustainable yield (Figure 3), to achieve MSY, the optimal releasing biomass is the difference between half the ecological capacity and the current biomass without taking into account factors such as fish growth, death and the environment, only the theoretical value. When the biomass is equal to half the ecological carrying capacity, the growth rate of the enhancement species will be the highest, and MSY can be obtained at this time (Zhan, 1995; Mace, 2001). Therefore, to achieve maximum sustained yield, the optimal releasing amount is the difference value between half the ecological capacity and the current biomass.

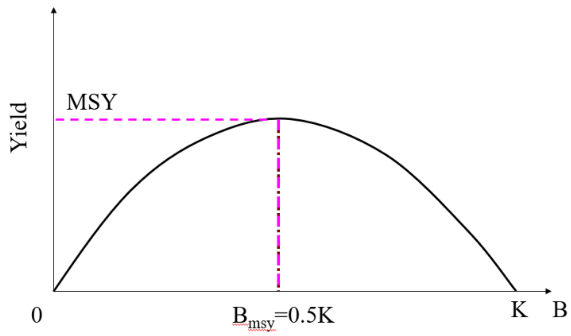

Figure 3. The curve of the relationship between yield and biomass

According to the literature (Lin & Cheng, 2004), the catchable age is scientific between the age of the weight growth inflection point and the critical age. The age of weight inflection point can be obtained according to the formula (2.3.4.1 and 2.3.4.2) as followed.

$$\frac{d^2W_t}{dt^2} = 0 \qquad (2.2.3)$$

$$\mathrm{W}_t = W_\infty(1 - e^{-k(t-t0)})^b \qquad (2.2.4)$$

where W_t is Weight at age t, W_∞ is the theoretical maximum weight the species can reach, k is growth coefficient that measures the rate at which the W_∞ is reached, t is the age , t_0 is theoretical age at zero weight and b is power exponent.

The critical age refers to the age at which the biomass of a generation of fishery resource populations reaches maximum when there is no fishing, or the relative growth rate of weight equals instantaneous natural mortality. It can be obtained according to the formula as followed.

$$\frac{dB_t}{B_t \cdot dt} = \frac{dW_t}{W_t \cdot dt} = M \qquad (2.2.5)$$

Where B_t is the biomass of the stock at age t, W_t is Weight at age t, M is instantaneous natural mortality of the stock. M=0.8*Exp(-0.0066-0.279lnL$_\infty$+0.6543lnK+0.4634lnT) (Zhan, 1995), T was the average annual temperature of habitat sea area.

The catchable body length and the catchable body weight can be obtained by substituting the catchable age into the body length Von Bertalanffy Growth Function (equation 2.3.6) and the body weight Von Bertalanffy Growth Function (2.2.4).

$$L_t = L_\infty(1 - e^{-k(t-t0)}) \qquad (2.2.6)$$

where L_t is length at age t, L_∞ is the theoretical maximum length the species can reach, k is growth coefficient that measures the rate at which the L is reached, t is the age , t_0 is theoretical age at zero length.

The annual catch is determined by the MSY of the enhancement species (Lin & Cheng, 2004). The MSY is calculated using the equation of Gulland (1979) as:

$$MSY = 0.5ZB \qquad (2.2.7)$$

where Z was the total mortality and B was the biomass. The current biomass (B) was from survey data, and the ecological carrying capacity was from calculated result of the model.

3. RESULTS

3.1. Mass balances and output of the Ecopath model

A balanced model was successfully constructed for the Tangshan marine ecosystem with 19 functional groups. The basic inputs such as biomass, P/B, Q/B, and key outputs such as TLs, P/Q and EE are summarized in Table 4. Two top predators are identified: Type III fishes and Sea birds (TLs of 4.089 and 4.217, respectively). Other high-level consumers are fish and Cephalopod such as black rockfish, Yellow rockfish, Type I fishes, Type II fishes, small pelagic fishes and small demersal fishes (TLs between 3.0 and 3.7). Primary consumers are Sea cucumber, Shellfish, Crustacean, Mollusca, Echinoderm and Other benthos (TLs between 2.0 and 3.0). The sea cucumber and Shellfish are the biggest representatives of primary consumers, while the black rockfish is the biggest representative of second consumers (Table 4).

Table 4. Input and output (in italic) parameters of Ecopath model in Tangshan marine ecosystem.

No.	Group name	Trophic level	Biomass (t/km²)	P/B (/year)	Q/B (/year)	EE	P/Q
1	Black rockfish (*Sebastes schlegelii*)	*3.404*	1.043	1.300	7.469	*0.272*	*0.174*
2	Yellow rockfish (*Hexagrammos otakii*)	*3.296*	0.492	1.240	5.487	*0.607*	*0.226*
3	Sea cucumber (*Apostichopus japonicus*)	*2.033*	72.00	4.500[a]	20.20[a]	*0.124*	*0.223*
4	Shellfish	*2.043*	55.00	4.470[b]	15.12[b]	*0.110*	*0.296*
5	Type I fishes	*3.602*	0.120	1.136	7.76	*0.699*	*0.146*
6	Type II fishes	*3.665*	0.060	1.054	5.82	*0.371*	*0.181*
7	Type III fishes	*4.089*	0.300	3.54	11.1	*0.040*	*0.319*
8	small demersal fishes	*3.020*	6.360	1.93	14.73	*0.240*	*0.131*
9	small pelagic fishes	*3.163*	5.800	1.56	15.93	*0.845*	*0.184*
10	Crustacean	*2.223*	32.80	4.500[c]	16.50[c]	*0.635*	*0.273*
11	Cephalopod	*3.231*	0.460	3.300[c]	8.800[c]	*0.170*	*0.375*
12	Mollusca	*2.106*	36.41	5.850[d]	19.20[d]	*0.611*	*0.305*
13	Echinoderm	*2.371*	28.14	3.000[c]	11.70[c]	*0.194*	*0.256*
14	Other benthos	*2.110*	33.27	3.900[e]	22.00[e]	*0.771*	*0.177*
15	Sea birds	*4.217*	0.005	0.060[b]	61.28[b]	*0.000*	*0.001*
16	Zooplankton	*2.000*	42.29	17.000[f]	57.70[f]	*0.370*	*0.300*
17	Phytoplankton	*1.000*	65.75	56.200		*0.586*	
18	Benthic algae and seaweed	*1.000*	257.3	15.000		*0.390*	
19	Detritus	*1.000*	130.0			*0.446*	

Notes: Missing input parameters (e.g. P/B and Q/B ratios) were taken from the literature (a (Bundy, Fanning, & Zwanenburg, 2005), b (Xu, Chen, Tian, Liu, & Yin, 2016), c (Lin, Li, & Li, 2013), d (Tong, Tang, & Pauly, 2000) , e (Froese & Pauly, 2018) and f (Thomas, et al., 2004) and adjusted proportionally as weighted estimates for all species in a functional group whenever possible.

3.2.Trophic relationship and keystone species

The trophic relationship between functional groups was studied by mixed trophic impact (MTI) analysis (Figure 4). The diagonal direction was a significant negative effect exerted by the functional group itself, which was the effect of food competition within the functional group. Most functional groups exert a direct negative impact on their primary food by predation. Conversely, an increase in the biomass of the bait has a direct positive effect on the predator. Phytoplankton, Benthic algae and seaweed and Detritus have a positive impact on most functional groups; Mollusca, Crustacean, Echinoderm, other benthos and Zooplankton are affected by primary producers and upper predators, which play a key role in the effective energy transfer and have a stronger influence on the system. The effects of target species' predator organisms, food competitors, and main bait organisms on target species can be directly reflected. Fishing has a significant negative impact on most of the catchable fishery functional groups, but has has a significant positive impact on Mollusca due to the trophic cascade effect.

Based on mixed trophic impact analysis (MTI) (Figure 4), the Ecopath model provides a means to identify keystone species. The keystone species of ecosystems are biological species that are relatively low in biomass and play an important role in the ecosystem and the food web by mapping the relationship between the relative overall impact (εi) and the keystone index (KSi) can identify key species (Libralato, Christensen, & Pauly, 2006). The functional groups of the Tangshan marine ecosystem are arranged according to descending order of key index values (Figure 5). The keystone species correspond to functional groups with higher εi and higher KSi (values close to or greater than 0). There are no obvious keystone species in the Tangshan marine ecosystem. According to the keystone index and the relative overall impact value, small pelagic fishes and crustacean can be included in Group 1. Black rockfish can be classified into Group 2. The energy flow of the Tangshan marine ranch ecosystem is shown in Figure 6, which shows the energy flow relationship between the adjacent trophic levels in the marine ranch, as well as the biomass, respiration and consumption of each trophic level and the input and output of energy between adjacent trophic levels.

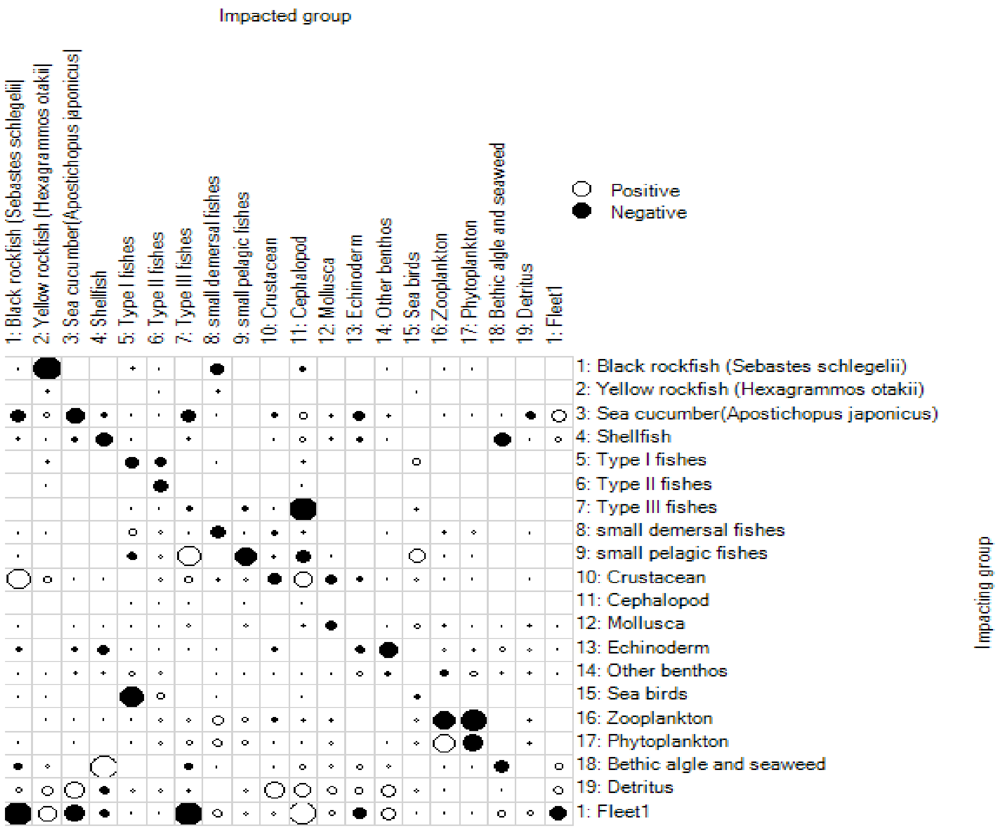

Figure 4. Trophic relations of functional groups in Tangshan marine ranching ecosystem

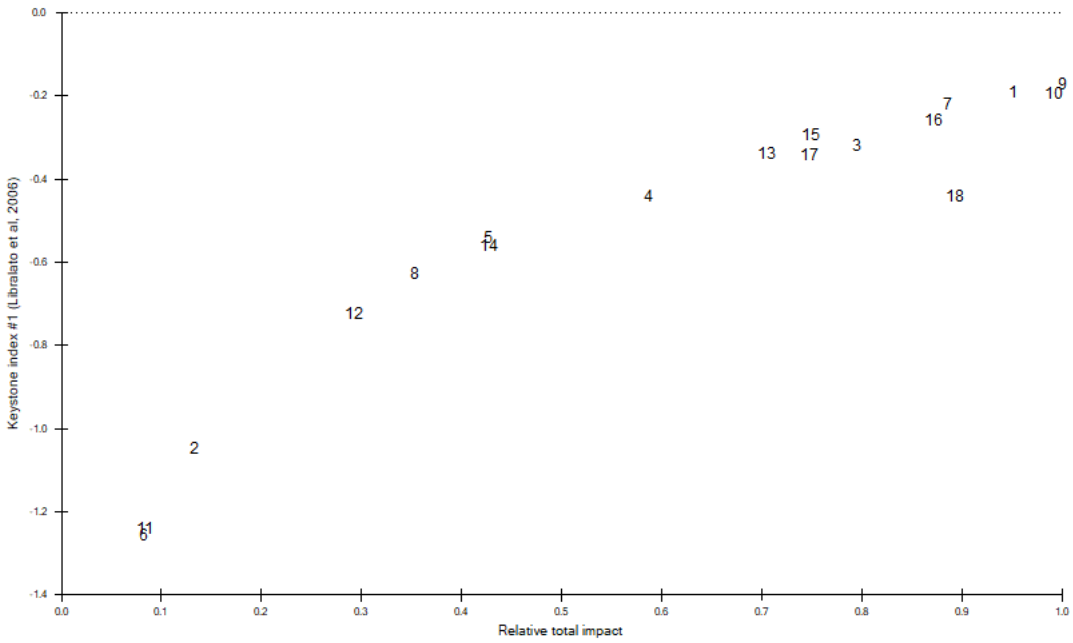

Figure 5. Relative total impact (εi) and keystoneness index (KSi)values in the functional groups

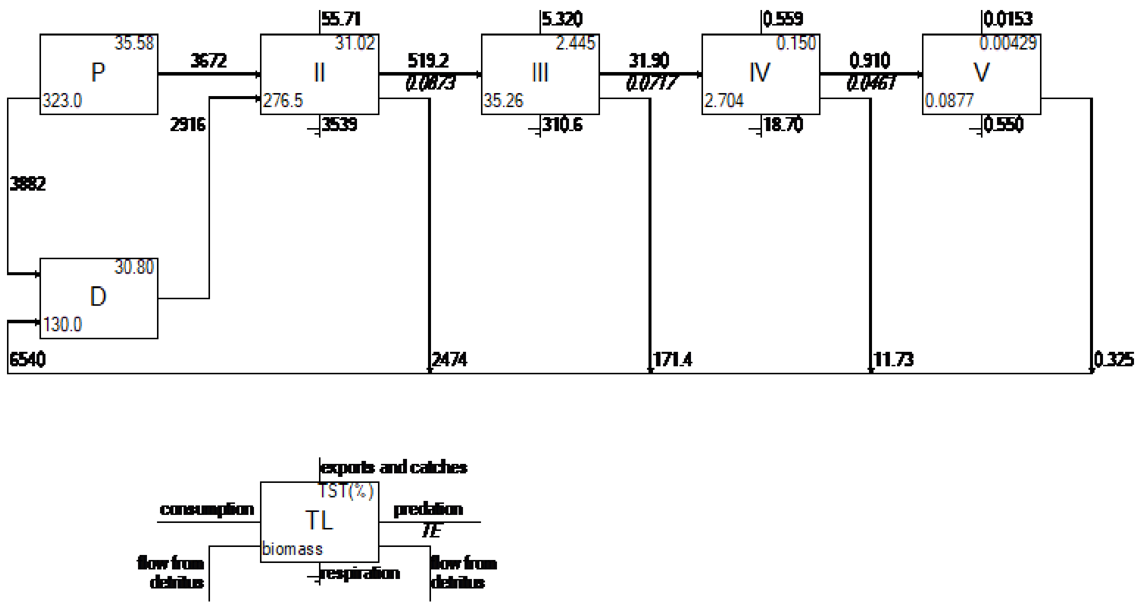

Figure 6. The ecosystem energy flow diagram of Tangshan marine ecosystem.

3.3. General characteristics of the ecosystem

According to the network analysis function of the Ecopath model, the calculated parameters describing the energy flow, stability, and food network characteristics of the ecosystem are shown in Table 5. The Ecopath flow diagram in Tangshan marine ecosystem is shown in Figure 7. Total system throughput (TST), which quantifies the total consumption, total export, total respiration and total flow into detritus, reflects the size of the system. The total system flow is 21317.7t/km^2/year. The total consumption is 7221.5 t/km^2/year, accounting for 33.8% of the total energy flow; 18.1% is the total respiratory flow (3869.1 t/km^2/year), 30.6 % is the total flow into detritus (6540.6 t/km^2/year), and 17.2% is the total export (3686.3 t/km^2/year). The transfer efficiency from primary producers is 6.9%, and the transfer efficiency from detritus is 6.1%. The net system production is 3685.5t/km^2/year, and the total primary production is 7554.6 t/km^2/year. The ratio of total primary production to total respiration (TPP /TR) was 1.95. The ratio of total primary production to total biomass (TPP /TB) was 11.85. The System Connectance Index (CI) and System Omnivory Index (SOI) are 0. 337 and 0. 108, Finn's cycling index (FCI) is 6.763. Biomass flows to detritus for different groups in Tangshan marine ecosystem is shown in Table 6.

Table 5. General characteristic parameters for Tangshan marine ranching ecosystem before and after enhancement of different target species

Parameter	V0	V1	V2	V3	V4	V5	Units
Sum of all consumption	7221.56	7229.54	7308.30	10186.92	9698.22	10102.30	t/km^2/year
Sum of all exports	3686.35	3681.35	3636.56	1974.66	2437.21	2097.91	t/km^2/year
Sum of all respiratory flows	3869.13	3874.12	3918.92	5580.82	5118.27	5457.56	t/km^2/year

Sum of all flows into detritus	6540.69	6535.34	6489.94	7018.36	5266.19	6298.37	$t/km^2/year$
Total system throughput	21317.73	21320.36	21353.72	24760.76	22519.89	23956.15	$t/km^2/year$
Sum of all production	9462.77	9464.16	9482.37	10123.37	10194.96	10178.92	$t/km^2/year$
Mean trophic level of the catch	2.11	2.120	2.13	2.0707	2.0821	2.0797	
Gross efficiency (catch/net p.p.)	0.00816	0.0082	0.00828	0.0171	0.0145	0.0164	
Calculated total net primary production	7554.65	7554.65	7554.65	7554.65	7554.65	7554.65	$t/km^2/year$
Total primary production/total respiration	1.95	1.95	1.93	1.354	1.476	1.384	
Net system production	3685.52	3680.53	3635.73	1973.83	2436.38	2097.09	$t/km^2/year$
Total primary production/total biomass	11.85	11.83	11.56	9.63	9.43	9.46	
Total biomass/total throughput	0.03	0.030	0.03060	0.03168	0.0356	0.0333	/year
Total biomass (excluding detritus)	637.6	638.67	653.41	784.40	801.40	798.71	$t/km^2/year$
Connectance Index (CI)	0.337	0.337	0.337	0.337	0.337	0.337	
System Omnivory Index (SOI)	0.108	0.108	0.107	0.107	0.107	0.107	
Finn’s cycling index (FCI) (%)	6.763	6.743	6.567	12.77	6.783	10.35	
Transfer efficiency from primary producers (%)	6.926	7.282	8.238	6.855	6.248	7.030	
Transfer efficiency from detritus (%)	6. 112	6.557	7.171	5.446	6.204	6.206	
Total transfer efficiency (%)	6.605	6.991	7.823	6.198	6.225	6.668	

Notes: V0-The current status of the system; V1-The status at ecological carrying capacity of the single target species(Black rockfish); V2-The status at ecological carrying capacity of the single target species(Yellow rockfish); V3-The status at ecological carrying capacity of the single target species(Sea cucumber); V4-The status at ecological carrying capacity of the single target species(Shellfish); V5-The status at ecological carrying capacity of the multiple target species(Sea cucumber, Shellfish, Black rockfish and Yellow rockfish).

Table 6. Biomass flows to detritus for different groups of Tangshan marine ranching under current status

	Name	Flow to Detritus ($t/km^2/year$)	Net efficiency	Omnivory index
1	Black rockfish (*Sebastes schlegelii*)	2.545	0.218	0.148
2	Yellow rockfish (*Hexagrammos otakii*)	0.780	0.282	0.082
3	Sea cucumber (*Apostichopus japonicus*)	574.7	0.278	0.033

4	Shellfish	385.2	0.370	0.044
5	Type I fishes	0.227	0.183	0.242
6	Type II fishes	0.110	0.226	0.275
7	Type III fishes	1.686	0.399	0.068
8	small demersal fishes	28.06	0.164	0.084
9	small pelagic fishes	18.46	0.230	0.153
10	Crustacean	162.07	0.341	0.201
11	Cephalopod	2.070	0.469	0.142
12	Mollusca	222.6	0.381	0.101
13	Echinoderm	133.88	0.321	0.281
14	Other benthos	176.07	0.222	0.098
15	Sea birds	0.062	0.001	0.095
16	Zooplankton	949.10	0.375	
17	Phytoplankton	1528.23		
18	Benthic algae and seaweed	2354.02		
19	Detritus			0.297

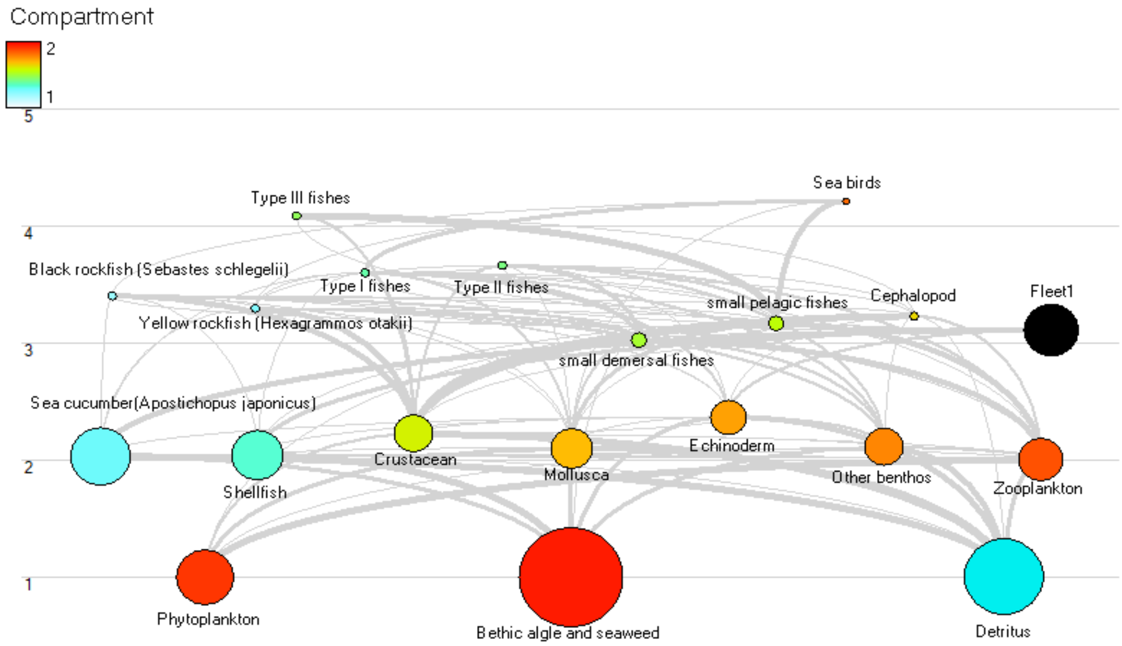

Figure 7. The Ecopath flow diagram of Tangshan marine ecosystem (The size of the circle is scaled to biomass).

3.4. The ecological capacity of enhancement species

3.4.1. The ecological capacity of single target species

The ecological capacity of black rockfish, yellow rockfish, sea cucumber and shellfish were estimated to be 2.111t/km^2, 16.3 t/km^2, 218.8 t/km^2 and 218.8 t/km^2, respectively. Comparing the current status and that of the current target species (V1, V2, V3 and V4) to the ecological capacity, the general characteristic parameters for Tangshan marine ecosystem (Table 5), most of the characteristic parameters show minimal/or no change. The calculated total net primary production is basically the same before and after. The other energy flow and ecosystem indices of the system have not changed basically, which does not affect the ecological stability of the water ecosystem.

3.4.2. The ecological capacity of multiple target species

If the four-target species are simultaneously released, considering the economic and ecological benefits, the ecological capacity is calculated according to the biomass proportion of the current target species, and that for the black rockfish, yellow rockfish, sea cucumber and shellfish are 2.47t/km^2, 1.17t/km^2, 163 t/km^2 and 123 t/km^2, respectively. Comparing the current status and that of the multiple target species (V5) to the ecological capacity, there is no substantial change to the general characteristic parameters for Tangshan marine ecosystem (Table 5). The calculated total net primary production is basically the same before and after. The other energy flow and ecosystem indices of the system have not changed basically, which does not affect the ecological stability of the water ecosystem.

3.5. Management strategy

In this report, I only present results for management enhancement strategy of two fish species, black rockfish and yellow rockfish.

3.5.1 Black rockfish

If only the black rockfish is released, the optimal releasing amount will be about 0.0145 t/km^2, according to the difference between half the ecological capacity (1.0575 t/km^2) and the current biomass (1.043t/km^2); if four-target species(black rockfish, yellow rockfish, sea cucumber and shellfish) are simultaneously released, the optimal releasing amount of black rockfish will be about 0.192 t/km^2, according to the difference between half the ecological carrying capacity (1.235 t/km^2) and the current biomass (1.043 t/km^2).

The relationship between length and weight is represented by the equation $W=0.0159L^{3.2255}$ ($R^2=0.9945$, n=322, Figure 8).

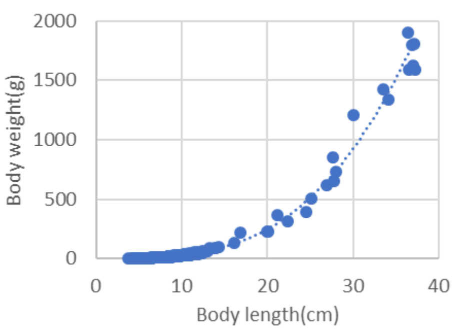

Figure 8. Length-weight relationship of black rockfish

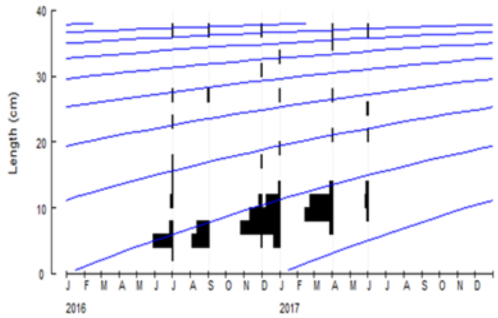

Figure 9. Length Frequency distribution data and growth curves estimated using Shepherd's method.

The estimated Von Bertalanffy growth function (VBGF) parameters of black rockfish using Shepherd's method in FISAT II were: L_∞= 41.0 cm and k = 0.33 year^{-1}, t_0 = -0.408 (Figure 9). W_∞=0.0159$L^{3.2255}$=2408.67g. Therefore, the VBGF of black rockfish in Tangshan marine ecosystem is represented as: $L_t = 41.0 \times (1 - e^{-0.33(t+0.408)})$; $W_t = 2408.67 \times (1 - e^{-0.33(t+0.408)})^{3.2255}$.

According to the body length VBGF, the body length growth rate function was $dL_t/dt = 135 \times e^{-0.33(t+0.408)}$. Following the body weight VBGF, the body length growth rate function was $dW_t/dt = 2563 \times e^{-0.33(t+0.408)} \times (1 - e^{-0.33(t+0.408)})^{2.2255}$.According to body length and weight growth rate functions, the curves between length and weight growth rate and age were drawn (Figure 10). The growth rate (in terms of length) gradually declined with the increasing age. In terms of weight, growth rate first increased to 348.02 g/a, then gradually decreased. The age that body weight growth rate became slower (i.e. the inflection age of body weight) could be calculated by $d^2w/dt^2 = 0$, t=3.14 years. The body length and body weight at inflection age of body weight of black rockfish were 28.3 cm and 727.3 g, respectively.

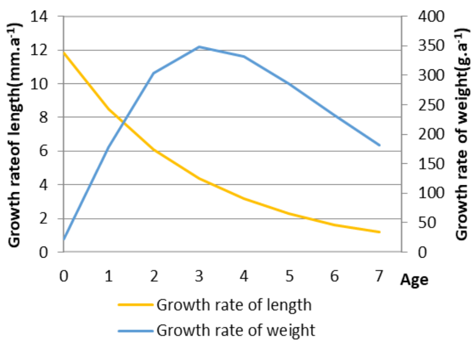

Figure 10. Growth rate curve of body length and body weight of black rockfish.

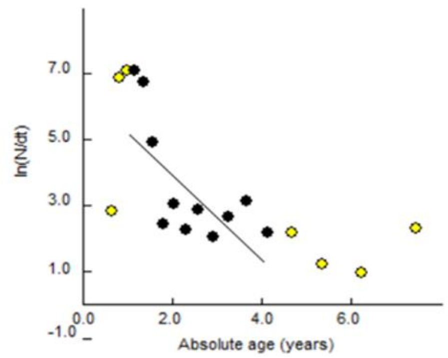

Figure 11. Length converted catch curve analysis

The estimated rate of total mortality (Z), applying the body length-converted catch curve analysis method for black rockfish, was 1.30 year^{-1} (Figure 11). Since the natural mortality, M, estimated using formulas in FishBase at an annual average sea surface temperature of 18°C was 0.475 year^{-1}, fishing mortality, F, would correspond to 0.855 year^{-1}.

The critical age refers to the age at which the biomass of a generation of fishery resource populations reaches maximum when there is no fishing, or the relative growth rate of weight equals instantaneous natural mortality. According to the formula $dB/Bdt = dW_t/W_t dt = M$, the critical age of black rockfish was about 3.18 years. The body length and body weight at critical age were 28.5 cm and 741.2 g, respectively.

Maximum sustainable yield of the black rockfish was estimated at 0.678 t/km^2, if only the black rockfish is released. However, MSY for black rockfish increases to 0.803 t/ km^2 if multiple target species (black rockfish, yellow rockfish, sea cucumber and shellfish) are simultaneously released.

According to the inflection age and the critical age, the catchable age of black rockfish is calculated as 3.14-3.18 years. To be operated more easily, it can be controlled by corresponding body length (or body weight) in practice, namely the catchable body length (or body weight) is controlled within 28.3-28.5 cm (or 727.3-741.2g).

3.5.2 Yellow rockfish

If only the yellow rockfish released, the optimal releasing amount will be about 7.658 t/km^2, according to the difference between half the ecological capacity (8.15 t/km^2) and the current biomass (0.492 t/km^2). If four-target species (black rockfish, yellow rockfish, sea cucumber and shellfish) are simultaneously released, the optimal releasing amount of yellow rockfish will be about 0.093 t/km^2, according to the difference between half the ecological carrying capacity (0.585 t/km^2) and the current biomass (0.492 t/km^2).

The relationship between length and weight for the yellow rockfish is represented by the formula $W=0.0048L^{3.4622}$ (R^2=0.9429, n=84, Figure 12).

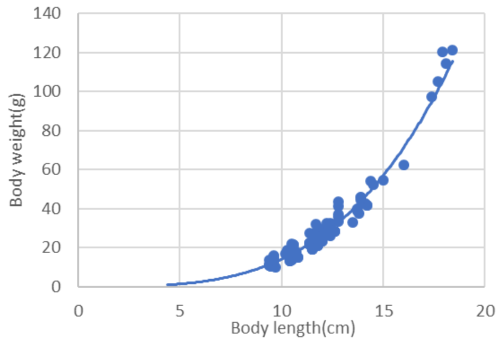

Figure 12. Length-weight relationship of yellow rockfish.

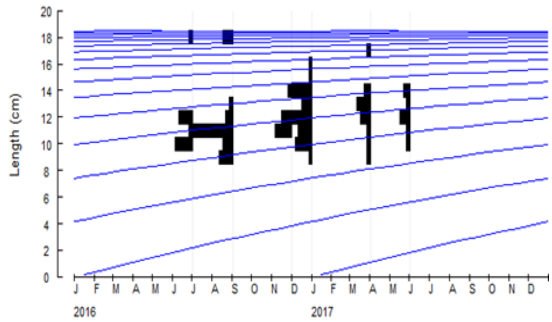

Figure 13. Length frequency distribution and growth curves estimated using Shepherd's method.

The estimated Von Bertalanffy growth function (VBGF) parameters of yellow rockfish using Shepherd's method in FISAT II were: L_∞= 32.0 cm, k = 0.24 year^{-1}, t_0 = -0.608 (Figure 13). $W=0.0048L^{3.4622}$ =942.67g. Therefore, the VBGF of yellow rockfish in Tangshan marine ecosystem is represented as $L_t = 32.0 \times (1 - e^{-0.24(t+0.608)})$; $W_t = 942.67 \times (1 - e^{-0.24(t+0.608)})^{3.4622}$. Growth rate in terms of length is therefore represented by the function $dL_t/dt = 7.68 \times e^{-0.24(t+0.608)}$, while body weight by function $dW_t/dt = 783.3 \times e^{-0.24(t+0.608)} \times (1 - e^{-0.24(t+0.608)})^{2.4622}$.

Figure 14 shows that growth rate in terms of length gradually declined with the increasing age, while growth rate in terms of weight first increased to 97.74 g/year, then gradually decreased. The age that body weight growth rate became slower (i.e. the inflection age of body weight) could be calculated by $d^2w/dt^2 = 0$, t=4.57 years. The body length and body weight at inflection age of body weight of yellow rockfish were 22.8 cm and 289.6 g, respectively.

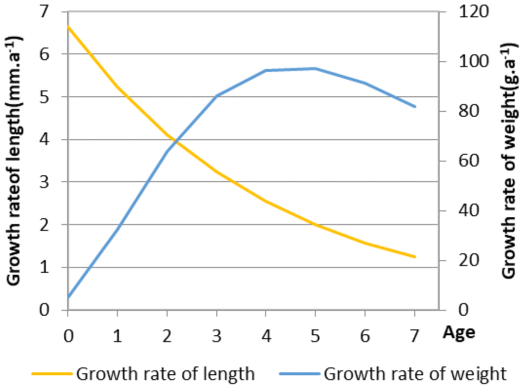

Figure 14. Growth rate curve of body length and body weight of yellow rockfish.

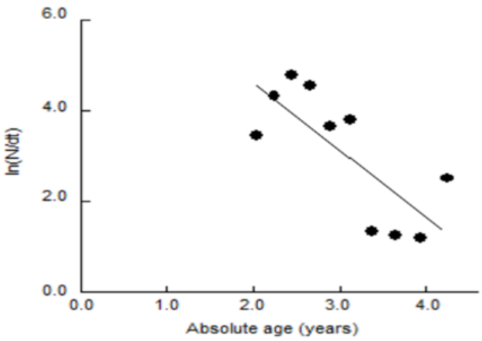

Figure 15. Length converted catch curve analysis

The estimated instantaneous rate of total mortality (Z), applying the body length-converted catch curve analysis method for yellow rockfish, was 1.24 year^{-1} (Figure 15). Since natural mortality, M, estimated using formulas in FishBase at an annual average sea surface temperature of 18°C was 0.298 year^{-1}, fishing mortality, F, would correspond to 1.142 year^{-1}.

According to the formula $dB/Bdt = dW_t/W_t dt = M$, the critical age of yellow rockfish was about 4.51 years. The body length and body weight at critical age were 22.6 cm and 284.1 g, respectively.

Maximum sustainable yield of the yellow rockfish is 5.053 t/km^2 if only the yellow rockfish is released, but decreases to about 0.363 t/ km^2 if four-target species (yellow rockfish, yellow rockfish, sea cucumber and shellfish) are simultaneously released.

According to the inflection age and the critical age, the catchable age of yellow rockfish is calculated as 4.51-4.57 years. To be operated more easily, it can be controlled by corresponding body length (or body weight) in practice, namely the catchable body length (or body weight) is controlled within 22.6-22.8 cm (or 284.1-289.6 g).

4. DISCUSSION

Based on data pedigree index, the reliability of the Ecopath model for Tangshan marine ecosystem can be evaluated. The pedigree index reflecting the overall quality of the input parameters of the model is about 0.329, which is within the intermediate range of the global 150 Ecopath model pedigree indices (0.16-0.68) analysed (Morissette & Hammill, 2006). There are still gaps in data for the modelled ecosystem. The input parameters of certain functional groups (such as diet composition, P/B, Q/B) are based on other models and this increases uncertainty in model inputs. All crustaceans were classified into a functional group. During the first parameterization of the model, the crustacean functional group showed an unbalanced EE (EE>1). However, the lack of these important biological information also points out the way for future research. Collecting more biological information in the study area will help improve the overall quality of the current model. The model was balanced with a set of parameter combinations, but this does not necessarily mean they are the best parameters for the model. The model could inevitably be balanced with a multiple set of different parameter combinations; therefore, this model is used as one of the best working hypotheses rather than a definitive representation of Tangshan marine ecosystem

4.1.Ecosystem energy flow characteristics · ·

The ecosystem biomass is concentrated in the first and second trophic levels (producers and herbivores and detritus consumers). Detritus-eating sea cucumbers, herbivorous shellfish (Scallop and abalone) and echinoderms constitute the main part of consumer biomass. This may be related to the high productivity and high current biomass of benthic algae and seaweed in the area (Zhang, 2012). The large algae and seaweed communities not only provide habitat for the main marine organisms that inhabit coastal waters, but also provide food sources through different types of trophic channels (Ortiz & Wolfs, 2002; Lozano-Montes, Loneragan , Babcock, & Jackson, 2011).

In addition, the detritus-eating sea cucumber, mollusca and other benthos functional groups also have higher biomass, which may be related to the abundant food (high biomass of detritus) in the system. The current high ecosystem detritus biomass is likely to be related to the carbon source input of large-scale cultivated seaweeds in marine ranch area.

At present, the three types of nutrient channels from the primary carbon source in Tangshan marine ecosystem include the energy channel of the herbivorous species, Shellfish (mainly abalone) and Echinoderm (mainly sea urchin), supported by large algae; classic grazing food chain nutrition channel connecting plankton, small pelagics and type III Fish; and detritus flow channel controlled primarily by sea cucumbers and other benthic organisms. The system D (detritus): H (herbivorous) ratio (0.79) shows that the nutrient channel supported by benthic macroalgae and phytoplankton in the current ecosystem exceeds the detritus flow channel and dominates the system. This is inconsistent with the traditional view that the reef ecosystem in temperate waters is dominated by the detritus flow channel (Krumhansl & Scheibling, 2012). This can be attributed to a series of artificial induction activities, such as artificial reefs, which are attached to fixed large algae. An attachment base is provided to enhance the nutritional utilization of algae in the benthic food web by the proliferation and release of herbivorous species such as abalone, which is similar to a low level of aquaculture activity (Spanier, 1989) .

4.2. Ecosystem maturity and stability

The TPP/TR value is an indicator reflecting the maturity of the system. The closer the value is to 1 the more mature the ecosystem is (Odum, Odum, & Andrews, 1971). The TPP/TR of 1.953 shows that system is still in the developmental stage. At the same time, system maturity can also be evaluated by the connection index (CI) and the system ominousness index (SOI). When the system is close to maturity, the food chain is transformed from linear to mesh, and the system is connected more closely (Odum, Odum, & Andrews, 1971). The low CI and SOI index values of the current system indicate that the nutritional effects between the functional groups are relatively weak and the system has not attained maturity. In addition, the FCI is an important indicator of stability of an ecosystem. Compared with the relatively high FCI of other mature ecosystems such as Tongoy Bay (10.1%) (Wolff, 1994), the Red Sea coast Eritrean (10.76%) (Tsehaye & Nagelkerke, 2008) and the Mediterranean coastal reef subtidal community (21.69%) (Pinnegar, 2000), the Tangshan marine ecosystem has a relatively low FCI (6.849%), which may suggest that system is less resilient in the face of fisheries and other external disturbances. However, the low FCI for the Tangshan marine ecosystem could also be related to fewer functional groups compared to other ecosystems (MF Freire, Christensen, & Pauly, 2008).

4.3.Ecological carrying capacity of target species

The assessment of ecological capacity before releasing target species is aimed at ensuring that the structure and function of the ecosystem are not destroyed and that the stability of the ecosystem in the released sea is not affected. The black rockfish and the yellow rockfish are typical reef fishes. They have similar feeding behaviour, and they both feed on crustacean, small demersal fish and other benthos. Although they are both piscivores, there are a few yellow rockfish in the stomach of the black rockfish but no black rockfish in the stomach of the yellow rockfish, which indicates that black rockfish may be in an advantage in the interspecies relationship with the yellow rockfish. As a typical sedimentary feeding animal, sea cucumber mainly feeds on sediment, organic matter, certain bacteria and protozoa in the bottom layer (Li, Song, & Hu, 2010); the shellfish (mainly abalone) is mainly used to ingest brown algae, red algae, and can also swallow small animals, such as foraminifera, polychaetes and copepods. The sea cucumber and the abalone are in different niches, which are nutritionally beneficial in terms of diet (Kang, Kwon, & Kim, 2003). Proliferation of sea cucumber and abalone can improve the utilization of organic detritus in the ecosystem and the energy cycle of the system.

According to the model estimation, the ecological carrying capacities for multi-target species were 2.3 t/km^2, 1.15 t/km^2, 182.1 t/km^2 and 121.4 t/km^2, respectively. This accounts for more than 200% increase in the biomass of each species. The blackfish, yellow croaker, sea cucumber and shellfish room for expansion. Therefore, while releasing the seed, it is necessary to increase the deployment of fish reefs and algae reefs to provide more habitats for the target species. The ecological carrying capacity simulated by the Ecopath model emphasizes the theoretical maximum limit, but in the actual fishery production management, the maximum sustainable yield (MSY) theory is widely used. When MSY is equal to half the ecological carrying capacity, the growth rate of the proliferated organism is highest (Mace, 2001).

The ecological capacity of target species in Tangshan marine ecosystem is determined from the perspective of energy balance. The Ecopath model itself does not take into account the changes in the growth of organisms in the ecosystem, taking only fixed parameter values, without considering spatial changes, and lacking sufficient biological variables, such as life history (ZHANG, FANG , & WANG , 2009) . The ecological capacity itself is in the dynamic process, and the spatial and temporal changes of the population and the changes in the coastal ecological environment have an impact on it. Therefore, when interpreting results of ecological carrying capacity from the current model, it is also necessary to consider the dynamic changes that the static model cannot describe. However, the ecological capacity assessment method used in this study can provide a reference method for calculating the ecological capacity of the current marine ranch area. With the expansion of sea treasures and the expansion of the scale of marine ranch area, the Ecopath model is used to evaluate the structure of artificial reef ecosystems, and the ecological capacity of target species is estimated. This is an analysis of fishery management strategies based on ecosystem model. The scientific development of the marine ranching construction can be guided from the perspective of ecological sustainable development.

5 CONCLUSIONS

In this study, a food web model of Tangshan marine ecosystem has been developed based on EwE modelling framework. The overall aim is to use the model estimate ecological carrying capacity of selected species for marine farming. The model shows that Tangshan marine ecosystem is relatively an immature system, which is phytoplankton-dominated and comparatively less resilient. Nevertheless, the ecosystem has capacity to support more than 200% increase in biomass of current biomass of blackfish, yellow croaker, sea cucumber and shellfish. The ecological capacity of target species in Tangshan marine ecosystem is determined on the basis of mass balance, without further consideration for spatial changes and life history. The set of parameters used to determine the ecological carrying capacity is one of the possible parameter combinations that can achieve similar results. This model is open for further improvement, and the current application should be considered as a best working hypothesis rather than definitive representation of the Tangshan marine ecosystem.

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6 LIST OF REFERENCES

Allen, R. (1971). Relation between production and biomass. *Journal of the Fisheries Research Board of Canada*, 1573-1581.

Bundy, A., Fanning, P., & Zwanenburg, K. (2005). Balancing exploitation and conservation of the eastern scotian shelf ecosystem: application of a 4d ecosystem exploitation index. *ICES Journal of Marine Science, 62*(3), 503-510.

Byron, C., Link, J., Costa-Pierce, B., & Bengtson, D. (2011). Calculating ecological carrying capacity of shellfish aquaculture using mass-balance modeling: Narragansett Bay, Rhode Island. *Ecological Modelling., 222*, 1743-1755.

ChenXinjun. (2014). Fisheries Resources and Fisheries Hydrography. Beijing in China: Ocean Press.

Christensen, V., Walters, C. J., & Pauly, D. (2004a). *Ecopath with Ecosim: A User's Guide.* Vancouver, Canada: Fisheries Centre of University of British Columbia.

Christensenb, V., & Walters, C. J. (2004). Ecopath with Ecosim: Methods, capabilities and limitations. *Ecological Modelling, 172*, 109-139.

Christian, R., & Luczkovich, J. (1999). Organizing and understanding a winter's seagrass foodweb network through effective trophic levels. *Ecological Modelling, 117*(1), 99-124.

Deng, J. (1998). Study on fishery biology of Chinese shrimp. Chinese Bulletin of Life Sciences. *10*(4), 191-194,197.

FAO. (2018). *The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable development goals.* Rome: FAO Licence: CC BY-NC-SA 3.0 IGO.

Fisheries and Fisheries Administration. (2017). *Fisheries Statistical Yearbook.* Beijing, China: China Agriculture Press.

Froese, R., & Pauly, D. (2018, Dec.). *Tilapia walteri Thys van den Audenaerde, 1968.* . Retrieved from http://www.fishbase.org/

Gao, M., & Gao, J. (2008). Research on Optimization of China's Marine Fisheries Management System. *Journal of Pacific*(2), 81-85.

Gulland, J. A. (1999). *Report of the FAO/ UNDP workshop on the fishery resources of the Western Indian Ocean.* South equator.

Guzman , d., Serviere-Zaragoza, E., & Siqueiros-Beltrones, D. (2003). Natural diet of juvenile abalone haliotis fulgens and h. corrugata (mollusca: gastropoda) in bahia tortugas, mexico. *Pacific Science, 57*(3), 319-324.

HuangWenzhao. (1979 年 01 月). Theory and Practice of Cultivated Fisheries. Fujian Fisheries Science and Technology, 6-21.

HuQifeng, & TongShujuan. (2012). How to establish "marine ranching". Guangming Daily.

Jiang, H., Cheng, H., Xu, H., Francisco, A. S., Manuel J., Z. R., Pablo, D. M., & William J.F., L. Q. (2008). Trophic controls of jellyfish blooms and links with fisheries in the east china sea. *Ecological Modelling, 212*(3-4), 492-503.

Jiang, W., & Gibbs, M. (2005). Predicting the carrying capacity of bivalve shell-fish culture using a steady, linear food web model. *Aquaculture, 244*, 171-185.

Jin, X., & Deng, J. (2000). Variations in community structure of fishery resources and biodiversity in the Laizhou Bay，Shandong. *Chinese Biodiversity, 8*(1), 65-72.

Kang, K., Kwon, J., & Kim, Y. (2003). A beneficial coculture:charm abalone Haliotis discus hannai and sea cucumber Stichopus japonicus. *Aquaculture, 216*, 87-93.

Kashiwai, M. (1995). History of carrying capacity concept as an index of ecosystem productivity. *Bulletin of Hokkaido National Fisheries Research Institute*(59), 81-100.

Kavanagh, P., Newlands, N., Christensen, V., & Pauly, D. (2004). Automated parameter optimization for Ecopath ecosystem models. *Ecological Modelling, 172*, 141-150.

Krumhansl, K., & Scheibling, R. (2012). Production and fate of kelp detritus. *Marine Ecology Progress Series, 467*, 281-302.

Li, C., Song, A., & Hu, W. (2010). Analysis of current status and sustainable development strategies of aquaculture industry in Shandong Province . *Progress in fisheries science, 31*(4), 126−133.

Li, J., Wang, G., & Yang, W. (2009). Fish resource enhancement abroad. Chinese Fisheries Economies. *27*(3), 111-123.

Libralato, S., Christensen, V., & Pauly, D. (2006). A method for identifying keystone species in food web models. *Ecological Modelling, 195*(3-4), 153-171.

Lin , L., & Cheng, J. (2004). Analysis of the status of fishery biology of small yellow croaker in the East China Sea. *Journal of Ocean University of China : Natural Science Edition, 34*(4), 565-570.

Lin, Q., Li, X., & Li, Z. (2013). Based on the ecopath model, the ecological capacity of Chinese shrimp in Laizhou Bay. *Applied Ecology, 24*(4), 1131-1140.

LiuHuifei. (2001). Current Status of Artificial Reef Construction in Japan. Fisheries Information and Strategy, 16(12), 15-17.

Lozano-Montes, H., Loneragan , N., Babcock, R., & Jackson, K. (2011). Using trophic flows and ecosystem structure to model the effects of fishing in the Jurien Bay Marine Park, temperate Western Australia. *Marine and Freshwater Research, 62*(5), 421-431.

Mace, P. M. (2001). A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management. *Fish Fish, 2*(1), 2-32.

MF Freire, K., Christensen, V., & Pauly, D. (2008). Description of the East Brazil Large Marine Ecosystem using a trophic model. *Scientia Marina, 72*(3), 477-491.

Ministry of Agriculture and Rural Affairs of China. (2017). National Marine Ranch Demonstration Zone Construction Plan (2017-2025).

Morissette, L., & Hammill, M. O. (2006). The trophic role of marine mammals in the northern gulf of st. lawrence. *Marine Mammal Science, 22*(1), 74-103.

Odum, E., Odum, H., & Andrews, J. (1971). *Andrews J.Fundamentals of ecology. Edition 3rd 1971.* Saunders Philadelphia.

Ortiz , M., & Wolfs, M. (2002). Trophic models of four bethic communities in Tongoy Bay(Chile): comparative analysis and preliminary assessment of management strategies. *Journal of Experimental Marine Biology and Ecology, 268*, 205-235.

Palomares, M. L., & Pauly, D. (1998). Predicting food consumption of fish populations as functions of mortality, food type, morphometrics, temperature and salinity. *Marine & Freshwater Research, 49*(5), 447-453.

Pinnegar, J. (2000). *Planktivorous fishes:links between the Mediterranean littoral and pelagic(PhD thesis).* University of Newcastle.

Power, M. E., Tilman, D., Estes, J. A., Menge, B., & Bond, W. (1996). Challenges in the quest for keystones: Identifying keystone species is difficult-but essential to understanding how loss of species will affect ecosystems. *Bioscience, 46*(8), 609-620.

Seaman, W. (2000). *Artificial Reef Evaluation With Application to Natural Marine Habitats.* Taylor＆Francis,2000.

Shen, Z. Y. (2010). *Marine Ecology* . Beijing, China: Science Press.

Shi, J. (2007, 3). Reflections on the implementation of the “Outline for the Conservation of Aquatic Living Resources in China”. *Chinese Fisheries*(376), 74-75.

Spanier, E. (1989). *How to increase the fisheries yield in low productive marine environments.* New York: Institute of Electrical and Electronics Engineers.

Sparre, P., & Venema, S. (1998). *Introduction to tropical fish stock assessment, Part I: Manual. FAO Fisheries Technical Paper, 306, 1.* FAO. Rome: FAO.

SuLJ, & TangSQ. (2002). Study on Ecosystem Dynamics in Costal Ocean. Processes of the Bohai Sea Ecosystem Dynamics. Beijing: Science Press.

TangQ S. (1996). On the carrying capacity and its study. Marine Fisheries Research, 17(2), 1-5.

Thomas A., O., Stuart, B., Abraham, F. B., Rodrigo, H. B., Mónica, C., Graham, J. E., . . . Petra, W. (2004). A trophic model of a Galápagos subtidal rocky reef for evaluating fisheries and conservation strategies. *Ecological Modelling, 172*, 383-401.

Thorpe, J. E. (1980). *Salmon ranching.* London: .Academic Press Inc. (London) Ltd.

Tong, L., Tang, Q., & Pauly, D. (2000). A preliminary study on the ecological channel model of the Bohai Sea. *Chinese Journal of Applied Ecology, 11*(3), 435-440.

Tsehaye, I., & Nagelkerke, L. (2008). Exploring optimal fishing scenarios for the multispecies artisanal fisheries of Eritrea using a trophic model. *Ecological Modelling, 212*(3-4), 319-333.

Vianny, N. (2016). Improving fisheries management strategies for Lake Victoria by means of ecological modelling optimizaton. *United Nations University Fisheries Training Programme*, 15-21. Retrieved from http://www.unuftp.is/static/fellows/document/vianny15prf.pdf

Wang Enchen, & Han Limin. (2015). Analysis of the concept, characteristics and architecture of the intelligent marine ranching. China Fisheries Economy, 33(2), 11-15.

Wang, T., Zhang, H., Zhang, H., & Zhang, S. (2016). Ecological capacity of Chinese prawn in Haizhou Bay based on nutrient channel model. *Chinese Journal of Fisheries Science, 23*(4), 965-975.

Wolff, M. (1994). A trophic model for Tongoy Bay—a system exposed to suspended scallop culture (Northern Chile). *Journal of Experimental Marine Biology and Ecology, 182*(2), 149-168.

Wu, Z., Zhang, X., Zhang, L., Tong, F., & Liu, H. (2013). Estimating the ecological capacity of sea cucumber and C. sinensis in the artificial reef area of Rongcheng Island based on linear food web model. *Chinese Journal of Fisheries Science*, *20*(2), 327-337.

Xu, Z., Chen, Y., Tian, T., Liu, Y., & Yin, Z. (2016). Ecosystem structure and functional changes of artificial reefs in Zhangzidao based on ecopath model. *Journal of Dalian Ocean University, 31*(1), 85-94.

Yang, H. (2016). Review and prospect of marine pasture construction in China. *Journal of Fisheries, 40*(7), 1133-1140.

Yang, J. (2001a). Study on Dietary and Nutritional Levels of Fish in the Bohai Sea. *Fisheries Information and Strategy, 16*(10), 10-19.

Yang, J. (2001b). Dietary and trophic level studies of invertebrates in the Bohai Sea. *Fisheries Information and Strategy, 16*(9), 8-16.

Yin, Z., & Zhang, S. (2011). Study on the change of ecological capacity of fishery resources in Shengsi artificial reefs in Zhejiang Province. *Progress in Fisheries Science, 32*(5), 108-113.

ZengChengkui. (1985). Marine farming and animal husbandry is promising. Science and Technology Progress and Countermeasures., 9-10.

Zhan, B. (1995). *Fisheries Resource Assessment.* Beijing: China Agriculture Press.

Zhang, B., Sun, D., & Wu, Y. (1995). Preliminary analysis of the feeding habits of A. sinensis (Apothecium japonjcus) in the shallow sea reef area of Lingshan Island. *Marine Science*, *19*(3), 11-13.

ZHANG, J., FANG , J., & WANG , W. (2009). Research Progress on Ecological Capacity of Filter-feeding Shellfish in Shallow Sea. *Journal of Fisheries Science of China*, *16*(4), 626-632.

Zhang, X., Wang, X., & Tu, Z. (2009). Current status and prospect of fisheries resource enhancement in Shandong Province． Chinese Fisheries Economies. *27*(2), 51-58.

ZhaoR X, & QiuW H. (2010). Progress in Japanese Cultivated Fisheries. Fisheries Information and Strategy, 23-25.

7 APPENDIX

The biological parameters of some functional groups

Functional groups	Species	P/B(Z)	Q/B	a	b	k	Linf	t0
black rockfish	*Sebastes schlegelii*	1.3	7.469	0.0159	3.2255	0.33	41	-0.26
yellow rockfish	*Hexagrammos otakii*	1.24	5.487	0.00423	3.46	0.42	32.8	-0.37
Type I fishes	*Zoarces elongates*	1.14	4.9	0.0024	3.119	0.18	34.2	-0.91
	Ernogrammus hexagrammus	0.58	14.5	0.0126	2.865	0.28	15.9	-0.20
	Acanthopagrus schlegelii	0.87	4.8	0.0118	3.102	0.28	40.3	-0.55
	Blenniidae	1.66	6.3	-	-	0.4	18	-0.3
	Agrammus agrammus	1.43	8.3	0.0068	3.25	0.91	18.9	-0.2
		1.136	7.76					
Type II fishes	*Cleisthenes herzensteini*	2.63	4.9	0.012	3.01	0.22	46.5	-0.6
	Platichthys bicoloratus	0.34	3.6	0.0225	3	0.15	62.8	-0.93
	Raja porosa	0.49	4.7	0.0225	3.267	0.23	59.2	-0.52
	Cynoglossus joyneri	0.33	11.6	0.0021	3.24	0.19	29.1	-0.9
	Paralichthys olivaceus	1.48	4.3	0.008	3.154	0.15	54	-0.31
		1.054	5.82					
Type III fishes	*Scomberomorus niphonius*	3.54	11.1	0.0024	3.209	0.91	80.4	-0.13
small demersal fishes	*Synechogobius hasta*	0.71	3.9	0.0309	2.43	0.17	52	-0.23
	Enedrias fangi	4.65	18	0.0006	3.44	0.7	17.8	-0.27
	Tridentiger trigonocephalus	1.75	18	-	-	0.7	11.7(w_∞=16)	-0.3
	Tridentiger barbatus	1.94	17.5	0.0093	3.06	0.61	11.1	-0.25
	Tridentiger bifasciatus	3.52	24.3	0.00073	2.98	0.65	12.8	-0.31
	Ernogrammus hexagrammus	0.71	14.5	0.0126	2.865	0.28	15.9	-0.71
	Ctenotrypauchen microcephalus	2.7	25.7	0.0079	2.628	0.44	19	-0.42

	Platycephalus indicus	0.76	4.6	0.0067	2.999	0.36	64	-0.3
	Okamejei kenojei	0.67	6.1	0.0025	3.267	0.24	40	-0.54
		1.93	14.73					
small pelagic fishes	*Engraulis japonicus*	2.92	16.6	0.00465	3.12	1.56	18	-0.12
	Sardinella zunasi	2.76	14.6	0.0209	3.01	0.63	16	-0.52
	Thryssa kammalensis	1.99	10.6	0.0084	3.13	0.33	15	-0.62
		2.56	13.93					