Evaluation of Ecological Capacity of Fishery Enhancement Species of the Mainstream of the Yellow River in Henan Province, China

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Abstract

In order to understand the ecosystem structure of the main stream of the Yellow River in Henan province, carry out scientific enhancement, and realize the effective conservation and restoration of the fishery resources of the Yellow River, according to the investigative data of fishery resources and ecological environment in the main stream of the Yellow River in Henan province from 2013 to 2016, Ecopath with Ecosim 6.5 software is used to establish the Ecopath model of the main stream of the Yellow River in Henan province, including 22 functional groups including Silver carp(*Hypophthalmichthys molitrix*), Bighead carp(*Aristichthys nobilis*), carp(*Cyprinus carpio*), crucian carp(*Carassius auratus*), Black carp(*Mylopharyngodon piceus*) and grass carp(*Ctenopharyngodon idella*).The results of the model were used to systematically analyze the overall characteristics of ecosystem functions; combined with the analysis results of food web structure and energy flow, the ecological capacity of typical enhancement species such as Silver carp(*Hypophthalmichthys molitrix*), Bighead carp(*Aristichthys nobilis*), carp(*Cyprinus carpio*), crucian carp(*Carassius auratus*), grass carp(*Ctenopharyngodon idella*), Black carp(*Mylopharyngodon piceus*) and bream(*Pseudobrama simoni*) was estimated. The results show that the ecosystem nutrition relationship in the main stream of the Yellow River in Henan province is relatively simple, the ecosystem's maturity and stability are low, and it is easily disturbed by external factors; the service and output functions of fishery resources are degraded.Without significantly changing the main energy flow and food web structure of the existing fishery ecosystem, this study estimates that the ecological capacity of Silver carp(*Hypophthalmichthys molitrix*),Bighead carp(*Aristichthys nobilis*), carp(*Cyprinus carpio*), crucian carp(*Carassius auratus*), grass carp(*Ctenopharyngodon idella*),Black carp(*Mylopharyngodon piceus*) and bream(*Pseudobrama simoni*) is respectively 12.76t/km^2, 4.25t/km^2, 0.478t/km^2, 0.342t/km^2, 9.31t/km^2, 0.005t/km^{2}and 0.283t /km^2. Compared with the existing biomass in the ecosystem,Silver carp(*Hypophthalmichthys molitrix*), Bighead carp(*Aristichthys nobilis*), and grass carp(*Ctenopharyngodon idella*) all have a larger breeding space.

Keywords: the main stream of the Yellow River in Henan province; enhancement; Ecopath model; ecological capacity
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Introduction

The main stream of the Yellow River in Henan province, belonging to the lower Yellow River, is dominated by Cyprinidae resources[1].Since the 1970s, due to changes in the hydrological environment and unscientific management, fish production in the Yellow River except for the Qinghai section has dropped sharply. By the 1980s (at this time, there were 79 species of fish in the mainstream of the Yellow River), the output was only 15%-20% in the 1950s[2]; and since the 1980s, the amount of indigenous fish species resources in the Yellow River basins has continued to decline rapidly. In recent years, there are only 48 species in the same basin, and the decline rate is as high as 39%[3]. The restoration and protection of fishery resources is urgently needed.Enhancement and release is one of the important fishery resource restoration methods adopted by countries all over the world [4], but there are not many cases of successful enhancement and release in my country [5].Among the several important factors that affect the effect of multiplication and release, excluding human intervention, it is more that there is no certain understanding of environmental factors such as the ecology of the waters around the drainage basin [6].The main stream of the Yellow River in Henan Province, as a well-known outflow sedimentary river at home and abroad, has huge sand content, turbid water body, and single biological population structure. This will not only restrict the reproduction of its indigenous aquatic organisms [7], but also affect the successful development of multiplication and release. In addition, the lack of understanding of the energy flow relationship and typical populations of the river section will also have a huge impact on the work of multiplication and release [4]. Based on the field biological survey data of the Henan section of the main stream of the Yellow River from 2013 to 2015 and the China Fisheries Yearbook, this study uses Ecopath with Ecosim 6.5 (EwE6.5) software to construct an Ecopath model of the ecosystem of the main stream of the Yellow River in Henan, and analyzes its ecosystem structure and Energy flow characteristics, calculated the ecological capacity of the target species, hoping to optimize the enhancement and release, and realize the sustainable development of the main stream of the Yellow River in Henan.

Materials and Methods

Data source

The data of this study comes from the biological survey data of the main stream of the Yellow River in Henan province from 2013 to 2015 (including Xixiayuan Reservoir, Sanmenxia Reservoir, Fanxian, Taohuayu, Natural Wenyan Canal, Kaifeng, Yiluo River and Qin River and other sections of the Yellow River) and China Fisheries Yearbook (2013-2015).The survey content includes the biomass of Phytoplankton,zooplankton, large seaweeds,swimming organisms and benthic organisms. The experimental protocols were approved by the Animal Care and Protection Committee of Dalian Ocean University.

Ecopath model establishment

Division of functional groups

The ecosystem defined by the Ecopath model is composed of a series of ecologically related functional groups , all functional groups can basically cover the energy flow path of the ecosystem. In this study, the main organisms in the Henan section of the Yellow River are Silver carp(*Hypophthalmichthys molitrix*),Bighead carp(*Aristichthys nobilis*),carp(*Cyprinus carpio*),crucian carp(*Carassius auratus*), grass carp(*Ctenopharyngodon idella*), Black carp(*Mylopharyngodon piceus*), bream(*Pseudobrama simoni*), etc. Each of the 7 target organisms is divided into an independent functional group, and other organisms are divided into 15 functional groups according to their specifications, biology and feeding characteristics, totaling 22 functional groups (Table. 1). The functional groups basically cover the entire energy flow of the ecosystem process.

Table 1. Functional groups and main species check list based on Ecopath model.

No.	Group name	Species composition
1	Redfin culter(*Chanodichthys erythroterus*)	Alice-billed red tandoori(*Erythroculter illishaeformis,Bleeker,1871*),Mongolian red tandoori(*Culter mongolicus*)
2	Other piscivorous	fish Other piscivorous red fin (*Culter erthropterus*),wasselblad (*Pelteobagrus vachelli*),yellow catfish (*Pelteobagrus fulvidraco*),black snakehead (*Channaargus*),catfish (*Silurus asotus*),etc
3	sharpbelly(*Hemiculter leucisculus*)	Channel fish (*Hemiculter Leucisclus*) ,meal stick (*Hemiculter bleekeri bleekeri warpachowsky*)
4	barbel chub(*Squaliobarbus curriculus*)	barbel chub(*Squaliobarbus curriculus*)
5	Black carp(*Mylopharyngodon piceus*)	Black carp(*Mylopharyngodon piceus*)
6	Common carp(*Cyprinus carpio*)	Common carp(*Cyprinus carpio*)
7	crucian carp(*Carassius auratus*)	crucian carp(*Carassius auratus*)
8	Bighead carp(*Aristichthys nobilis*)	Bighead carp(*Aristichthys nobilis*)
9	Bream fishes(*Parabramis pekinensis*)	bream fishes(*Parabramis pekinensis*),bream(*Pseudobrama simoni*),etc
10	Wild miscellaneous fish Other fishes	oligo-scale floating fish(*Pseudolaubuca engraulis,Nichols,1925*),pointed finfish(*CYPRINFORMES*),snake gargoyle(*Saurogobio,Bleeker,1870*),rod flower gargoyle(*Gobio rivuloides,1925*),silver-jaw-bearded gargoyle(*Gnathopogon argentatus,Sauvage et Darby,1874*),horsemouth(*Opsariicjthys bidens*),goby(*Ctenogobiusgiurinus*),etc
11	Silver carp(*Hypophthalmichthys molitrix*)	Silver carp(*Hypophthalmichthys molitrix*)
12	grass carp(*Ctenopharyngodon idella*)	grass carp(*Ctenopharyngodon idella*)
13	Shrimp and crabs Macrocvostaceall	Procambarus clarkii(*Procambarus clarkia*),beautiful white shrimp(*Chinese white prawn*),Macrobrachium nipponensis(*Macrobrachium nipponense*),etc
14	Molluscs(*Granulifusus kiranus*)	river clams(*Corbicula fluminea*),snails(*Gastropod*),etc
15	Other benthos	Sandworms(*Nereis succinea*),etc
16	Mierozooplankton	Protozoa and Wheel animalcule(*Rotifers*)
17	Cladocera	reticulate(*Ceriodaphnia comuta*), long spines and prickly bodies(*Diaphanosoma sarsiRichard*), etc
18	Copepoda(*Calanoida*)	Copepoda(*Calanoida*),Chinese sclerotia(*CYCLOPOIDA*), etc
19	Submerged macrophyte(*Submerged plant*)	Microtoothed Pond(*Potamogeton maackianus A.Bennett*),Bitter grass(*Vallisneria natans,Lour.Hara*), Malayan(*Potamogeton wrightii Morong*), etc
20	Other vascular plants	Other macrophyte Reeds(*Phragmites australis,Cav.Trin.ex Steud*), etc
21	Phytoplankton(*Phytoplankton*)	diatoms, green algae(*Chlorophyta*), cyanobacteria(*Cyanobacteria*), cryptophytes, euglena(*Euglena*), golden algae(*Chrysophyta*), xanthellae(*Yellow-green algae*) and dinoflagellate, etc

22	Detritus Corpses	feces of animals and plants, and organic matter imported by rivers, etc

Model debugging and ecological capacity estimation

The form of energy flow is expressed in wet weight (t/km^2). Time is defined as 1a. The biomass of fish and macroinvertebrates is estimated by the sea sweeping area method.The wet weight of Phytoplankton(*Phytoplankton*) is converted by the concentration of Chla measured in the survey [10-11].The calculation of the P/B and C/B values of single primary productivity refers to the instantaneous total mortality and empirical formula [12-13].The amount of debris is calculated using the empirical formula of debris and primary production carbon [14]. The food composition matrix data of the functional group is derived from the gastric content analysis of the sample.

This study defines the ecological capacity as the maximum carrying level of the target speciesthat does not significantly change the main energy flow and food web structure of the ecosystem after a large number of target species are introduced [16]. In order to estimate the ecological capacity of the main economic species, based on the Ecopath model that reflects the current energy flow status of the main stream of the Yellow River in Henan, the biomass of the target species in the model is gradually increased to represent the enhancement scale of the target species in actual production.Expansion (*corresponding to the increase in fishing output*), if the biomass of a target species is greatly increased, it will inevitably affect the closely related species in the system, and cause changes in the energy flow of the system. The Ecopath model must be adjusted. The parameters rebalance the system and determine the ecological capacity of the target species in the iterative process. Therefore, if the biomass of the target species is increased until the EE>1 of another functional group in the system is found, it means that the biomass allowed by the system at this time is the ecological capacity of the target species.

Results and analysis

Model output

Table. 2 shows the basic input and output of the Ecopath model of the ecosystem of the Henan section of the Yellow River. Since the data source belongs to the field survey, the result of the biomass data is true and reliable. It can be seen from Table. 2 that the trophic level of the ecosystem of the entire Henan section of the Yellow River can be divided into 4 levels. Among them, the trophic levels of red fish, grass carp(*Ctenopharyngodon idella*), and herring were 3.812, 2.001, and 3.025, respectively, which belonged to medium and high nutrient organisms in this ecosystem. The conversion efficiency of ecological nutrition of all functional groups is between 0.000 and 0.998. Among them, the conversion efficiency of ecological nutrition of grass carp(*Ctenopharyngodon idella*) and red fish is low, only 0.073 and 0.127; while herring can reach 0.253.

Model quality evaluation

The Pedigree index can be used to quantify the parameter quality of the Ecopath model. Morissette et al. [17]analyzed the input parameters of 150 Ecopath models worldwide and found that the range of the pedigree index was 0.16-0.68. In this study, the Pedigree index before and after the enhancement of the main stream of the Yellow River in Henan was 0.571 and 0.592, respectively, and the model quality was high.

Table2. Input and output (in italic) parameters of Ecopath model in in Yellow River of Henan Province.

No.	Group name	Trophic level	Biomass (t/km²)	Production / biomass (year⁻¹)	Consumption / biomass (/year⁻¹)	Ecotrophic efficiency	Production / consumption
1	Redfin culter(*Chanodichthys erythroterus*)	***3.812***	0.0475	0.974	3.200	***0.127***	***0.304***
2	Other piscivorous	***3.709***	0.095	1.665	6.100	***0.097***	***0.273***
3	sharpbelly(*Hemiculter leuciscului*s)	***3.866***	0.169	1.862	16.650	***0.615***	***0.112***
4	barbel chub(*Squaliobarbus curriculus*)	***2.981***	0.895	1.283	11.350	***0.998***	***0.113***
5	Black carp(*Mylopharyngodon piceus*)	***3.025***	0.005	0.912	11.544	***0.253***	***0.079***
6	Common carp(*Cyprinus carpio*)	***2.918***	0.338	0.960	10.693	***0.475***	***0.090***
7	crucian carp(*Carassius auratus*)	***2.260***	0.296	1.130	12.300	***0.659***	***0.092***
8	Bighead carp(*Aristichthys nobilis*)	***2.811***	0.008	0.990	6.900	***0.628***	***0.143***
9	Bream fishes(*Parabramis pekinensis*)	***3.016***	0.283	2.373	27.200	***0.956***	***0.087***
10	Other fishes	***2.788***	0.895	2.155	11.000	***0.476***	***0.196***
11	Silver carp(*Hypophthalmichthys molitrix*)	***2.203***	0.002	1.100	8.000	***0.755***	***0.138***
12	grass carp(*Ctenopharyngodon idella*)	***2.001***	0.009	0.987	7.100	***0.073***	***0.139***
13	Macrocvostaceall	***2.993***	0.928	3.092	41.223	***0.369***	***0.075***
14	Molluscs(*Granulifusus kiranus*)	***2.000***	3.148	1.326	10.605	***0.693***	***0.125***
15	Other benthos	***2.001***	1.099	4.130	201.500	***0.803***	***0.020***
16	Mierozooplankton	***2.000***	0.78	49.301	597.934	***0.506***	***0.082***
17	Cladocera	***2.016***	1.0396	62.863	457.252	***0.407***	***0.137***
18	Copepoda(*Calanoida*)	***2.016***	1.043	48.903	378.053	***0.564***	***0.129***
19	Submerged macrophyte(*Submerged plant*)	***1.000***	72.292	2.253	0.000	***0.014***	-
20	Other macrophyte	***1.000***	65.36	1.000	0.000	***0.000***	-
21	Phytoplankton(*Phytoplankton*)	***1.000***	8.893	185.000	0.000	***0.376***	-
22	Detritus	***1.000***	211.62	-	-	***0.576***	-

Notes: Bold italic number is estimated value by model.

Evaluation of enhancement capacity

The traditional collocation ratio of Silver carp(*Hypophthalmichthys molitrix*) and Bighead carp(*Aristichthys nobilis*) is

3:1, which is 75% and 25% respectively [18]. Without significantly changing the main energy flow and food web structure of the existing fishery ecosystem, the ecological capacity of Silver carp(*Hypophthalmichthys molitrix*) is 12.76t/km², and the ecological capacity of Bighead carp(*Aristichthys nobilis*) is 4.25t/km²; at this time, the ecological capacity of carp(*Cyprinus carpio*) is 0.52t/km² ; The ecological capacity of crucian carp(*Carassius auratus*) is 0.385t/km²; the ecological capacity of grass carp(*Ctenopharyngodon idella*) is 22.551t/km²; the ecological capacity of herring is 0.015t/km²; the ecological capacity of bream(*Pseudobrama simoni*) is 0.283t/km²; The investigation found that the resources of Silver carp(*Hypophthalmichthys molitrix*),Bighead carp(*Aristichthys nobilis*), carp(*Cyprinus carpio*), crucian carp(*Carassius auratus*), grass carp(*Ctenopharyngodon idella*), herring, and bream(*Pseudobrama simoni*) of the main stream of the Yellow River in Henan were approximately 13.348t/km², 4.442t/km², 0.182t/km², 0.089t/km², 22.541t/km²,0.01t/km² and 0.0001t/km². Adhering to the above principles, based on the Ecopath model, it is concluded that natural water bodies can be fully utilized, and seedlings are required to increase biomass of Silver carp(*Hypophthalmichthys molitrix*), Bighead carp(*Aristichthys nobilis*), carp(*Cyprinus carpio*), crucian carp(*Carassius auratus*), and grass carp(*Ctenopharyngodon idella*) by 13.348t/km², 4.442t/km², and 0.182t/km², 0.089t/km², 22.541t/km². See Table. 3 for the system parameters and evaluation values when it proliferates to the ecological capacity.

Table3. Input and output (in italic) parameters of Ecopath model at carrying capacity by enhancement in Yellow River of Henan Province.

No.	Group name	Trophic level	Biomass (t/km²)	Production / biomass (year⁻¹)	Consumption / biomass (year⁻¹)	Ecotrophic efficiency	Production / consumption
1	Redfin culter(Chanodichthys erythroterus)	***3.812***	0.048	0.974	3.200	***0.127***	***0.304***
2	Other piscivorous	***3.709***	0.095	1.665	6.100	***0.097***	***0.273***
3	sharpbelly(Hemiculter leucisculus)	***3.866***	0.169	1.862	16.650	***0.615***	***0.112***
4	barbel chub(Squaliobarbus curriculus)	***2.981***	0.895	1.283	11.350	***0.998***	***0.113***
5	Black carp(Mylopharyngodon piceus)	***3.025***	0.015	0.912	11.544	***0.084***	***0.079***
6	Common carp(Cyprinus carpio)	***2.918***	0.520	0.960	10.693	***0.309***	***0.090***
7	crucian carp(Carassius auratus)	***2.260***	0.385	0.296	12.300	***0.506***	***0.092***
8	Bighead carp(Aristichthys nobilis)	***2.811***	4.450	0.990	6.900	***0.001***	***0.143***
9	bream fishes(Parabramis	***3.016***	0.283	2.373	27.200	***0.956***	***0.087***

	pekinensis)						
10	Other fishes	***2.788***	0.895	2.155	11.000	***0.476***	***0.196***
11	Silver carp(Hypophthalmichthys molitrix)	***2.203***	13.350	1.100	8.000	***0.000***	***0.138***
12	grass carp(Ctenopharyngodon idella)	***2.001***	22.550	0.987	7.100	***0.000***	***0.139***
13	Macrocvostaceall	***2.993***	0.928	3.092	41.223	***0.425***	***0.075***
14	Molluscs(Granulifusus kiranus)	***2.000***	3.148	1.326	10.605	***0.999***	***0.125***
15	Other benthos	***2.001***	1.099	4.130	201.500	***0.909***	***0.020***
16	Mierozooplankton	***2.000***	0.780	49.301	597.934	***0.611***	***0.082***
17	Cladocera	***2.016***	1.040	62.863	457.252	***0.712***	***0.137***
18	Copepoda(Calanoida)	***2.016***	1.043	48.903	378.053	***1.000***	***0.129***
19	Submerged macrophyte(Submerged plant)	***1.000***	72.292	2.253	0.000	***0.998***	-
20	Other macrophyte	***1.000***	65.360	1.000	0.000	***0.002***	-
21	Phytoplankton(Phytoplankt on)	***1.000***	8.893	185.000	0.000	***0.431***	-
22	Detritus	***1.000***	211.620	-	-	***0.654***	-

Notes: Bold italic number is estimated value by model.

Ecosystem characteristics before and after enhancement

At present, the ecosystem of the main stream of the Yellow River in Henan and the ecologicalenergy flow parameter table (Table. 4) and the ecological energy flow diagram (Fig. 1 and Fig. 2) when the ecological capacity reaches the maximum ecological capacity after enhancement show that the total output of the system and the flow of debris energy are reduced , The total flow and total production of the system increase, indicating that the energy utilization efficiency of the system is greatly improved after multiplication, and the energy loss of the system is reduced. In addition, the total output of the system/net system productivity decreased by 25.48%. It can be seen from Fig. 1 and Fig. 2 that Silver carp(*Hypophthalmichthys molitrix*), Bighead carp(*Aristichthys nobilis*), and grass carp(*Ctenopharyngodon idella*) all have a larger breeding space compared with the existing biomass in the current ecosystem.

Table 4. Comparison of energy characteristic parameters in ecosystem before and after enhancement.

Parameter	At present	After enhancement
Sum of all consumption(t·km^{-1}·year^{-1})	1624.98	1910.570
Sum of all exports(t·km^{-1}·year^{-1})	738.34	550.106
Sum of all respiratory flows(t·km^{-1}·year^{-1})	1135.10	1323.333

Sum of all flows into detritus(t·km^{-1}·year^{-1})	1682.50	1493.858
Total system throughput(t·km^{-1}·year^{-1})	5180.92	5277.866
Sum of all production(t·km^{-1}·year^{-1})	2038.33	2078.562
Calculated total net primary production(t·km^{-1}·year^{-1})	1873.44	1873.439
Total primary production/total respiration	1.65	1.416
Net system production(t·km^{-1}·year^{-1})	738.34	550.106
Total primary production/total biomass	11.94	9.562
Total biomass/total throughput	0.03	0.037
Total biomass (*excluding detritus*)(t·km^{-1}·year^{-1})	156.93	195.917
Conectance Idex	0.312	0.313
Omnivory index	0.176	0.178

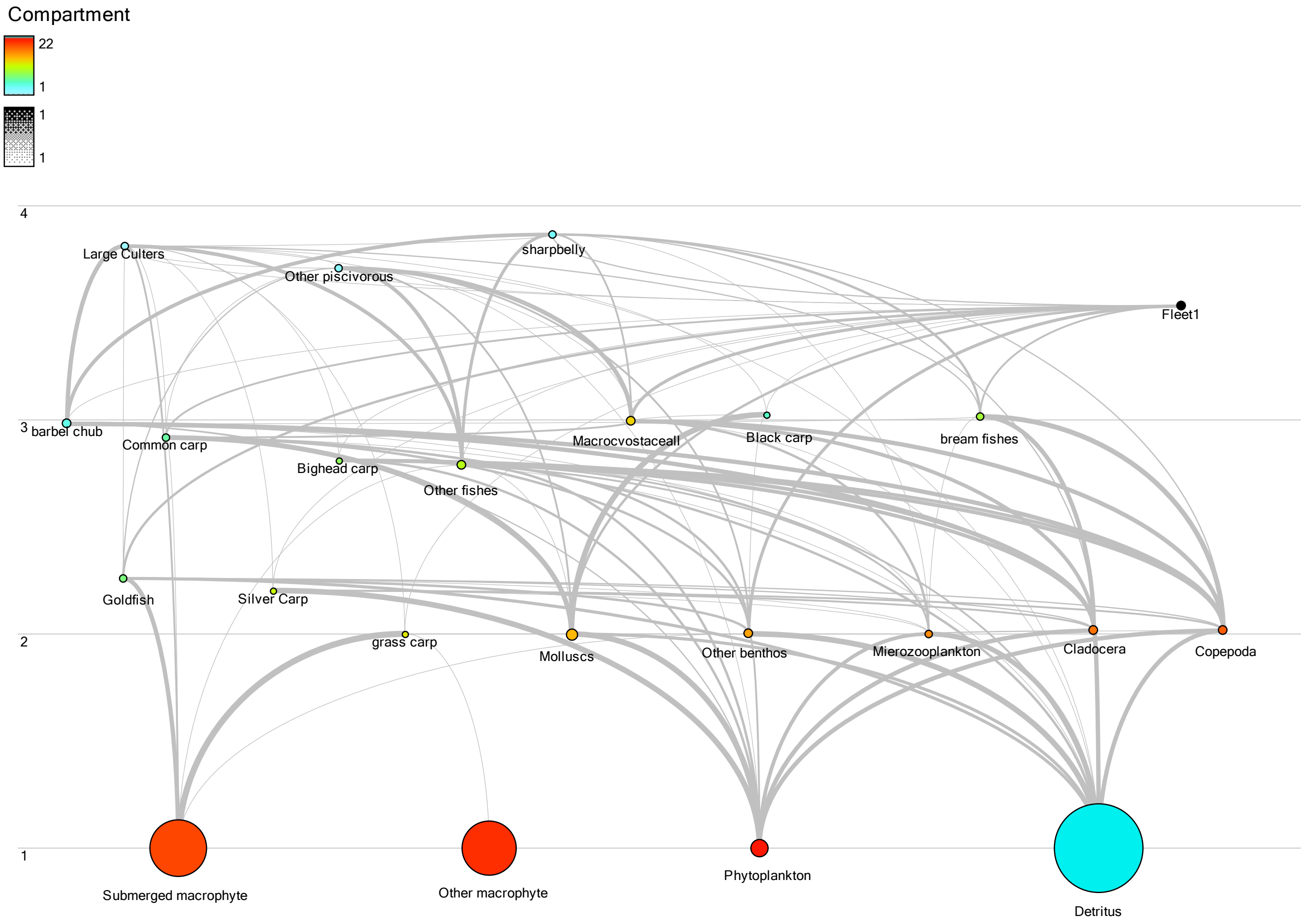

Fig. 1. Energy flow of ecosystem at present.

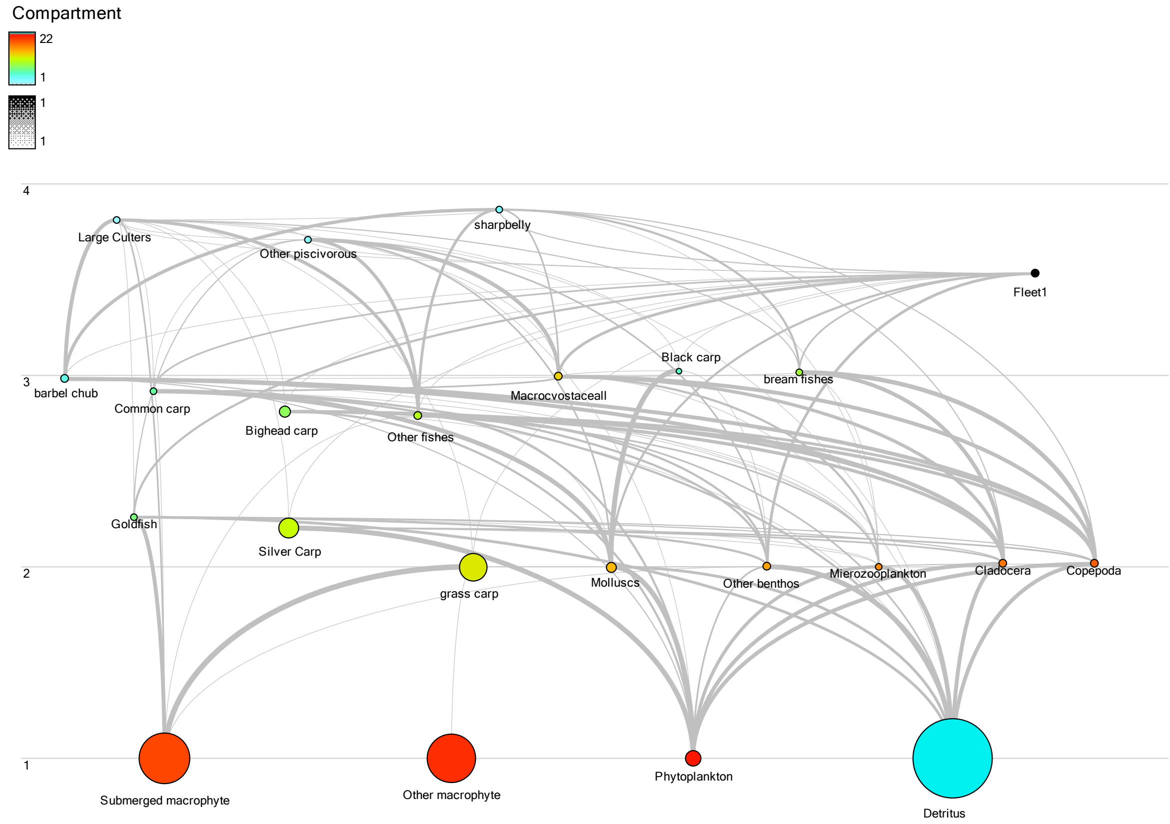

Fig. 2. Energy flow of ecosystem at carrying capacity by enhancement.

Discussion

In recent years, pollution in the surrounding areas of Henan Basin on the mainstream of the Yellow River has been relatively serious, with pollution occurring in several months, ranging from mild to moderate [18]. This will have a great impact on the ecological environment around the basin. The data shows that the total conversion rate of the ecosystem in the Henan section of the Yellow River is 4.2%, which is far from the Lindemann efficiency of 10-20% [19]. At the same time, the secondary productivity is also excessive, the nutrient flow of the ecosystem is blocked, the energy transfer between the various nutrient levels is limited, and the conversion efficiency is low.In addition, the TPP/TR, CI, and SOI values of the ecosystem in the Henan section of the mainstream of the Yellow River are all low, indicating that the ecosystem is not stable and vulnerable to external stress; the nutritional relationship is relatively simple, the biodiversity is low, and the food web is simplified. The above shows that under the interference and stress of multiple factors such as environmental degradation and overfishing, the ecosystem of the Henan section of the mainstream of the Yellow River has poor material and energy cycles, and the species tends to be single. The ecosystem, especially fishery resources, has served and output functions Seriously degraded.

At present, enhancement and release have become the main means of fishery resource restoration [20], but disorderly release will be difficult to achieve the desired effect. However, based on the current more mature Ecopath model, it has been successful in a number of domestic studies [4]. Studies have shown that: in the ecosystem of the Henan section of the Yellow River, the target biological output is low. It is recommended to use multiplication and release methods to achieve the purpose of making full use of water bodies. When calculating the ecological capacity, it can be known that restricting the ecological capacity of the above-mentioned main economic fishes are mainly two types of bait organisms, mollusks and other benthic animals such as Sandworms(*Nereis succinea*), etc. It is recommended to put mollusks and benthic animals such as Sandworms(*Nereis succinea*) into the water body to expand the ecological capacity of the main economic fish.

The ecological capacity determined in this study takes into account the correlation between enhancement species and predators, food organisms, and food competitors, as well as the impact of enhancement and release activities on the entire ecosystem, in order to determine the Silver carp(*Hypophthalmichthys molitrix*), Bighead carp(*Aristichthys nobilis*), carp(*Cyprinus carpio*), and crucian carp(*Carassius auratus*) in the Henan section of the mainstream of the Yellow River. The reasonable release of grass carp(*Ctenopharyngodon idella*), herring and bream(*Pseudobrama simoni*) provides a scientific basis, which is conducive to optimizing reproduction and release strategies, scientifically formulating reproduction and release plans, and preventing and controlling ecological risks of reproduction and release. However, the ecological capacity of the enhancement species obtained by the research is only the theoretical upper limit, and the actual enhancement and release work should be determined after comprehensively considering the ecological benefits, economic benefits and social benefits.

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