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Research Paper

Assessing the resource dynamics of economic fishes in the Dachen Island Marine Ranch in the East China Sea based on size spectrum model*

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Abstract Marine ranch is a novel paradigm in the transformation of traditional fisheries, which embodies a modern and high-tech approach to increasing marine fishery production and enables the sustainable and efficient exploitation of marine resources. After several decades of development, the industrial model of marine ranch has matured. However, in several developing countries, subsequent management and evaluation remain inadequate. In this study, the Dachen Island Marine Ranch in the East China Sea was used as a case to explore two fishery management strategies. A multi-species size spectrum model (MSSM) was established for the Dachen Island Marine Ranch to simulate fish community dynamics. While considering interspecific interactions, the effectiveness of two management strategies was assessed: (1) altering fishing mortality; and (2) increasing cod-end mesh size. The findings indicate that the change in the fishing mortality of large predators can induce trophic cascade effects, and the large predators have the greatest impact on community structure. In scenarios that simulate fishing mortality for multiple species, competition is shown between two species occupying similar ecological niches. An increase in cod-end mesh size can be observed to decrease bycatch while positively impacting community structure. Our findings suggest that fisheries management reforms should consider the effects of management changes on the entire ecosystem (including environment and biodiversity), rather than concentrating solely on the long-term yield of fish harvests. A stable ecosystem can yield more products, and long-term sustainable fishery yields are one of them.

Keyword: marine ranch; size spectrum model; fishing mortality; cod-end mesh size

1 INTRODUCTION

Marine ranch is a fishery model based on the principle of ecosystem to build or repair the places needed by marine organisms for reproduction, growth, foraging or predator avoidance in a specific sea area through measures such as artificial reefs and stocking (Chen et al., 2019; Tang, 2019; Yang et al., 2019; Ding et al., 2022; Yang, 2023). This ecological engineering strategy aims to cultivate and conserve fishery resources, improve the ecological environment of the marine area and achieve sustainable utilization of marine resources (Ministry of Agriculture of the People's Republic of China, 2017). In a global context, despite the varying philosophies underpinning the development of ocean ranch across different nations, the overarching goal is fundamentally aligned: to satisfy the demand for fishery resources (Ru et al., 2023).

As one of the earliest countries to adopt the

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concept of marine ranch, China has undergone a developmental journey from pilot exploration to large-scale expansion, with the functions of marine ranch has continuously evolved (Wang, 2010, 2015). Since 2017, the annual No. 1 Documents of China's Central Government have emphasized consistently the construction of modern marine ranch, providing policy impetus for standardization (Yang and Ding, 2022). In November 2021, China released its first national standard, The Technical Guidelines for Marine Ranch Construction, marking a milestone in systematic development (Yang and Ding, 2022). To date, by integrating advanced international technologies, China has established diverse marine ranch systems in the Yellow Sea, East China Sea, and South China Sea, including breeding-oriented, recreational fishery-based, and resource conservation-based models, demonstrating significant ecological and economic benefits (She, 2008; Ling, 2012; Yu et al., 2023). However, the construction of marine ranch in China was mainly focused on individuals of stock enhancement, scales of artificial reef construction and financial investment, while fishing management and comprehensive evaluation in later stages were seriously lacking (Yang, 2016). In contrast, Japan, the United States, and several European countries have developed proven comprehensive industrial models for marine ranch. To propose appropriate management measures, it is crucial to understand the interactions among species within the fisheries. Generally, the exploitation of a species will inevitably exert a profound impact on the population dynamics of other species (Smith et al., 2015). This impact is manifested in two aspects: (1) in the case of predation and competition, when the target species is the prey or predator of that species, fishing may indirectly affect the biomass of non-target species (Hilborn et al., 2015); (2) in trawl fisheries, there is often bycatch, which directly impacts the biomass of non-target species (Thrush and Dayton, 2002). Therefore, when multiple target species with varying trophic levels and body sizes are simultaneously harvested, achieving a balance in the fishing catch becomes a complex challenge (Hall and Mainprize, 2004; Pikitch et al., 2004).

Based on an ecosystem approach, this study proposes two management strategies for the later stages of marine ranch development in China and their long-term sustainability was assessed. In addition, our approach rigorously considers interspecific interactions and ensures that all species share a limited pool of resources (Gaichas et al., 2012). A Multi-species Size Spectrum Model (MSSM) for the fish community was developed, using the Dachen Island Marine Ranch in the East China Sea as the case study. By designing two scenarios to simulate the long-term benefits associated with the implementation of management measures, with particular emphasis on six economically significant species (*Trichiurus lepturus* (largehead hairtail), *Muraenesox cinereus* (daggertooth pike conger), *Pampus argenteus* (silver pomfret), *Harpadon nehereus* (Bombay duck or bummalo), *Larimichthys polyactis* (small yellow croaker), and *Larimichthys crocea* (large yellow croaker)). We explored (1) the mechanisms that lead to trophic cascades; *M. cinereus* and *H. nehereus* were chosen as the managed species and different fishing scenarios were designed for them. The former is the top predator in this marine ecosystem, occupying the top of the food chain, while the latter is the dominant species throughout the year, using a large amount of resources in the ecosystem (Zou et al., 2024). (2) whether an increase in cod-end mesh size in trawl fisheries can lead to a reduction in bycatch; Trawling is a cruel method of catching fish, as it tends to indiscriminately catch a wide range of sizes, often including small and younger fishes (Tsagarakis et al., 2014). We attempted to increase the cod-end mesh size to optimize the selectivity of the trawl. We assessed the effects of these two management strategies on the entire fish community, as well as their direct and indirect ecological impacts. It is important to note that this study is an effort to model ecosystems in data-scarce regions, without implying the necessity of these measures. Using small-scale marine ranches as a case study, the research seeks to elucidate the significance of fisheries management and provide theoretical frameworks for policymakers.

2 MATERIAL AND METHOD

2.1 Study area and data source

Located in the southeastern part of the outer sea area of Taizhou Bay, Zhejiang Province, Dachen Island is influenced by the coastal current, the Taiwan Warm Current and freshwater from river mouths. It used to be the second-largest fishing ground in the East China Sea and is an important habitat for species such as large yellow croaker and small yellow croaker to grow, feed and reproduce (Rui et al., 2022). Prolonged overfishing has led to a

decline in the capacity for reproduction and recovery, and catches have become younger, smaller, and lower value (Zou et al., 2024). Therefore, the Fisheries Management Department of China is proactively advancing the development of marine ranch projects to maintain the health of the island-reef complex ecosystem and ensure its long-term resource production capacity.

The catch data in this study were obtained from a series of four quarterly trawl surveys conducted at 21 stations in this sea area from 2020 to 2021 (Fig.1). The trawl had a net length of 46 m, a net width of 5 m and a cod-end mesh size of 25 mm, hauling for 20 min at a speed of 3 knots in each sampling station. All the catches were brought back to the laboratory and identified to species, and biological parameters such as individual body length and weight were measured and recorded. Stomach content analysis and age identification were performed when samples were sufficient. A total of 99 species of fish were collected in this year's trawl survey. Species identification was mainly based on *Fauna of Marine Fishes in Zhejiang* (Zhao, 2016).

2.2 Size-spectrum model

The MSSM used in this study was developed by Andersen and Beyer (2006) and implemented by Hartvig et al. (2011). The model rests on two main assumptions: (1) fish devour other fish that are smaller than themselves; and (2) individual fish can be described exclusively by their individual and asymptotic body weights (Andersen et al., 2016). The biological processes of the fish community are formulated by sub-models, including community, food consumption, somatic growth and reproduction, mortality, and resource spectrum models (Table 1). MSSM allow prey switching, interspecific and intraspecific predator-prey interactions, and size-selective fishing practices, all while using relatively fewer parameters compared with other ecosystem models (an advantage in data-poor contexts) (Zhang et al., 2016b). MSSM have become a critical tool in ecosystem-based fisheries management, with applications demonstrated across diverse marine ecosystems. In the coastal waters of northern Yellow Sea, China, species-based spatial management approaches incorporating total allowable catch (TAC) methods have been effectively implemented for mixed fishery regulation (Wo et al., 2022). Analytical applications of MSSM have revealed significant trophic dynamics, particularly how predator population declines from fishing pressure can paradoxically increase overall catch biomass through ecosystem-level interactions (Szuwalski et al., 2017). Recent methodological advancements have expanded MSSM frameworks to incorporate vessel competition dynamics, enabling simultaneous evaluation of ecological sustainability and socioeconomic outcomes in mixed fisheries (Novaglio et al., 2022). These applications collectively demonstrate the versatility of MSSMs in addressing complex fishery management challenges through integrated ecological and operational modeling approaches.

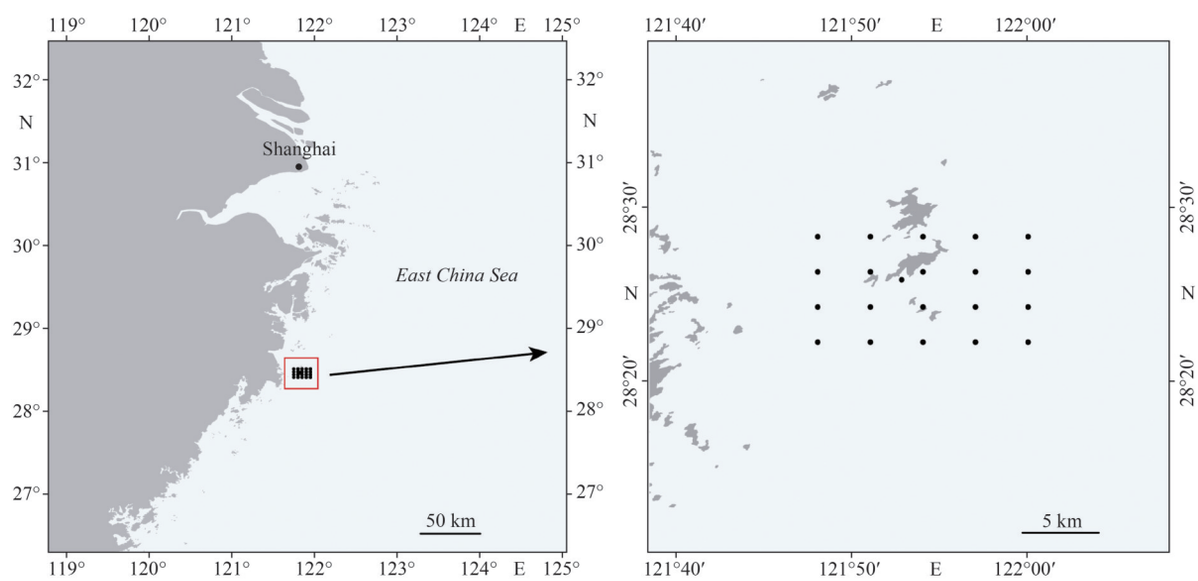

Fig.1 The Dachen Island Marine Ranch and the sampling points for fishery surveys

Table 1 Equations governing the model

Description	Equation
Community	
Conservation equation	$\frac{\partial N_i(w)}{\partial t}+\frac{\partial g_1\cdot(w)N_i(w)}{\partial w}=-\mu(w)N_i(w)$
Community spectrum	$N_c(w)=\sum_i N_i(w)+N_R(w)$
Food consumption	
Lognormal food preference curve	$\phi\left(\frac{w_p}{w}\right)=\exp\left[\frac{-\left(\ln\left(\frac{w}{w_P\beta}\right)\right)^2}{2\sigma^2}\right]$
Encounter rate	$E(w)=\gamma w^q\int_0^{\max(w_\infty)}N_c(\omega)\phi\left(\frac{w_p}{w}\right)w\mathrm{d}w_p$
Consumption	$f(w)hw^n=\frac{E(w)}{E(w)+hw^n}hw^n$
Somatic growth and reproduction	
Available energy	$E_a(w)=af(w)hw^n-k_sw^p$
Allocation of energy	$\psi\left(\frac{w}{w_\infty}\right)=H\left(\frac{\eta_m w_\infty}{\omega}\right)\left(\frac{w}{w_\infty}\right)^{1-n}$
Somatic growth	$g_i(w)=E_a(w)\left(1-\psi\left(\frac{w}{w_{\infty,i}}\right)\right)$
Egg production	$R_{P,i}=\frac{\varepsilon}{2w_0}\int_{\omega_0}^{w_{\infty,i}}E_a(w)\psi\left(\frac{w}{w_{\infty,i}}\right)N_i(w)\mathrm{d}w$
Density dependence	$R=R_{\max,i}\frac{R_{P,i}}{R_{P,i}+R_{\max,i}}$
Max recruitment	$R_{\max,i}=k_r\left(\alpha f_0hw_0^n-kw_0^p\right)w_{\infty,1}^{2n-q-3+a}\left(w_{\infty,i}-w_{\infty,i-1}\right)$
Mortality	
Predation mortality	$\mu_p\left(w_p\right)=\int_{w_0}^{\max(w_\infty)}\phi\left(\frac{w_p}{w}\right)(11-f(w))\gamma w^q\sum_i N_i(w)\mathrm{d}w$
Background mortality	$\mu_b=\mu_0w_\infty^{n-1}$
Starvation mortality	$\mu_s(w)=\begin{cases}0 & \alpha f(w)hq^n>k_s\omega^p\\ \frac{k_s-\alpha f(w)hw^n}{\xi_T-w_\infty} & \alpha f(w)hq^1\le k_s\omega^p\end{cases}$
Selective unbalanced fishing	$F\left(w_3w_\infty\right)=F_0H\left(\frac{w}{\eta_Fw_\infty}\right)$
Resource spectrum	
Resource production	$\frac{\mathrm{d}N_R(w)}{\mathrm{d}t}=r_0w^{p-1}\left[kw^{-\lambda}-N_R(w)\right]-\mu_p(w)N_R(w)$

$N_i(w)$: the abundance density of individual fish with weight w from species i with asymptotic size $W_{\infty i}$ (from Jacobsen et al. (2014)).

2.3 Model parameterization and calibration

The 17 species that account for more than 90% of the total catch were selected from the annual survey sample data. Their growth, predation, mortality and reproduction parameters were collected as the basic output for the model (Table 2). The species selection rules are as follows: (1) one or more species from each ecological position are uniformly selected from a food web perspective, thereby projecting the ecosystem's structural complexity and functional diversity; (2) the dominant species and those with high biomass are selected on the

Table 2 Summary of species-specific parameters

Species	K_{vb}	W_{max} (g)	W_{mat} (g)	β	σ	R_{max}	L_{25} (cm)	L_{50} (cm)	a	b
Trichiurus lepturus	0.25	1 066	159	35	1.3	1.00e+05	6.6	8.4	0.000 40	3.17
Muraenesox cinereus	0.20	1 594	312	27	1.3	1.00e+05	6.6	8.5	0.001 50	3.14
Collichthys niveatus	0.88	100	6	218	1.3	1.00e+05	1.9	3.7	0.008 51	3.02
Pampus echinogaster	0.32	686	93	43	1.3	1.00e+04	6.1	7.8	0.032 40	3.00
Harpadon nehereus	0.98	357	21	18	1.3	1.00e+04	2.8	4.7	0.001 90	3.37
Larimichthys polyactis	0.45	379	31	312	1.3	1.00e+05	2.5	4.3	0.023 60	2.86
Larimichthys crocea	0.35	2 038	144	142	1.3	1.00e+04	4.9	6.8	0.013 80	3.02
Amblychaeturichthys hexanema	0.36	52	9	14	1.3	1.00e+07	2.4	4.1	0.006 00	3.01
Lophius litulon	0.22	3 496	460	25	1.3	1.00e+03	7.2	10.5	0.017 40	3.01
Thryssa kammalensis	1.00	30	6	2 409	1.3	7.00e+06	1.7	3.6	0.014 13	3.21
Setipinna taty	0.40	454	26	290	1.3	1.00e+05	2.5	4.2	0.014 13	2.87
Miichthys miiuy	0.30	2 753	342	43	1.3	1.00e+03	10.5	14.3	0.014 13	3.02
Wak tingi	0.73	213	23	52	1.3	1.00e+05	2.6	4.3	0.030 00	2.82
Collichthys lucidus	0.66	78	8	154	1.3	1.00e+06	1.8	3.5	0.014 10	2.99
Pennahia argentata	0.46	523	38	31	1.3	2.00e+04	2.4	4.1	0.016 21	2.98
Dasyatis laevigata	0.14	2 337	312	83	1.3	7.90e+02	11.5	15.3	0.280 00	3.24
Coilia mystus	0.89	19	5	2 232	1.3	8.50e+06	1.7	3.2	0.000 01	3.26

basis of the results of data processing and analysis to reflect the ecosystem's stability and resilience, and to ensure the authenticity of the model; (3) economically important species are selected from an economic perspective.

The body shape parameters a and b were obtained by least-squares fitting of weight and length. The W_{max} (progressive weight) and K_{vb} (growth rate) were estimated using the von Bertalanffy growth equation when age and length data were available. The β (predator-prey mass ratio) was obtained through stomach content analysis and published literature. The W_{mat} (mature size) was estimated on the basis of observations of the species' maturity or reference to published literature, and for species lacking maturity information, it was estimated using an empirical formula $0.25\times W_{max}$ (Andersen and Pedersen, 2010; Houle et al., 2012). The catch mortality is determined by the fishing effort, gear selectivity, and catchability coefficient. The Dachen Island Marine Ranch is a protected marine area and lacks data on these three factors. The fishing gear used in this investigation was single trawl (which has similar selectivity for most fish species), the catchability coefficient was set to 0.5 and the initial fishing effort was set to 1 to enable the model to run (Zhang et al., 2016a). The selectivity function was used as an S-shaped function. Thus, the selectivity parameters used in this study were L_{50} (the length at which 50% of the selection is retained) and L_{25} (the length at which 25% of the selection is retained), with values inferred from Huang et al. (2005) for each species.

R_{max} (maximum recruitment) refers to the maximum number of recruits entering the population. The kappa (background resource) provides food for the smallest fish, and its upper limit determines the upper limit of R_{max}. To improve the model's realism, we employed the collected data to estimate species biomass observations, which enabled us to infer the maximum value of R_{max} and subsequent calibration of the kappa. The model was then optimized using the L-BFGS-B optimization algorithm in the R package optimParallel, minimizing the sum of squared errors between predicted and observed biomass values in logarithmic scale (Byrd et al., 1995; Gerber and Furrer, 2018). The model was run for 50 years (assuming from 1973 to 2023) and reached a stable state, and the predicted and observed biomass were fitted (Figs.2–3).

2.4 Simulation scenario

The calibrated model was used to simulate two scenarios: (1) change in fishing mortality and (2)

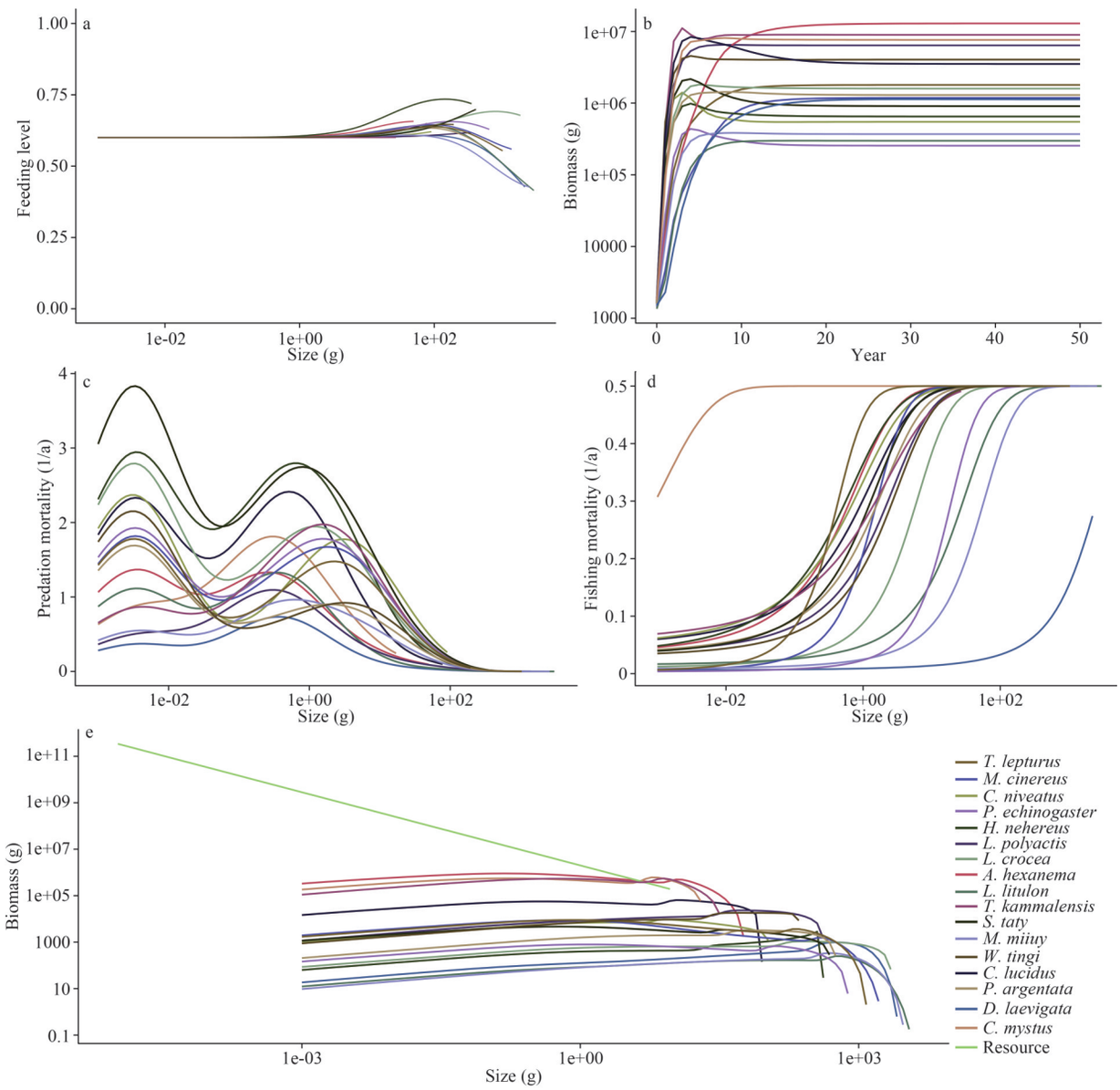

Fig.2 Model dynamics over 50 years under initial fishing mortality to reach steady state

a. feeding level of various species under the steady-state model; b. biomass of various species under the steady-state model; c. predation mortality of various species under the steady-state model; d. fishing mortality of various species; e. biomass density of various species under the steady-state model.

change in selectivity of trawl, thereby providing a scientific foundation for the optimized management of marine ranch operations. Finally, the process of scene design is summarized in a flowchart (Fig.4).

(1) Change in fishing mortality. In this scenario, *M. cinereus* and *H. nehereus* were selected as simulated species. This resulted in the simulation being divided into two sub-scenarios: single-species management and multi-species management. In single-species management, four sub-scenarios were identified: (i) decreased fishing mortality for *M. cinereus*; (ii) increased fishing mortality for *M. cinereus*; (iii) decreased fishing mortality for *H. nehereus*; and (iv) increased fishing mortality for *H. nehereus*. In multi-species management, four sub-scenarios were also identified: (i) decreased fishing mortality for *M. cinereus* and *H. nehereus*; (ii) increased fishing mortality for *M. cinereus* and decreased for *H. nehereus*; (iii) increased fishing mortality for *M. cinereus* and *H. nehereus*; and (iv) decreased fishing mortality for *M. cinereus* and increased for *H. nehereus*. In all scenarios, the magnitude of the change in mortality is set to increase or decrease by 75% (Qiao et al., 2024). The

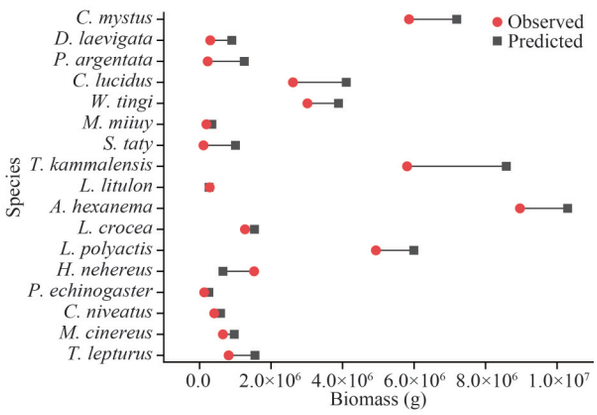

Fig.3 Predicted and observed biomass under the steady state

fishing mortality (inds./a) is calculated as the product of fishing effort, selectivity and catchability coefficient, with the latter being set as a constant of 0.5. The fishing effort can thus be directly used to measure the total mortality rate, and its simulation can subsequently reflect changes in the latter. We tracked species biomass through time and examined community size structure pre- and post-change. Changes in community biomass and size structure were assessed through a comparison of the mean community biomass and size spectrum slope in the decade preceding the change in fishing mortality to the mean community biomass and size spectrum slope in the final decade of the simulation.

(2) Change in selectivity of trawl. Under the initial fishing mortality, a simulation of three sub-scenarios with cod-end mesh sizes of 45, 54, and 65 mm, respectively, was conducted to reflect the changes in selectivity. According to Huang et al. (2005), mesh sizes of 45, 54, and 65 mm were selected for simulation so that the selection parameters L_{50} and L_{25} could be calibrated more accurately. In addition, the 54-mm mesh size was established as the standard under the fishery agreement with neighboring countries. By simulating mesh sizes both larger and smaller than this regulated value, the impacts of mesh size variation on fisheries were objectively demonstrated. The corresponding L_{50} and L_{25} values were matched with each scenario. Changes in community biomass and size structure were assessed through a comparison of the mean community biomass, size spectrum slope, mean weight (MW) and large fish index (LFI) in the decade preceding the change in the selectivity of trawl to the mean community biomass, size spectrum slope, MW and LFI in the final decade of the simulation.

The model is based on an initial fishing mortality of 50 years to reach a steady state and then changes the fishing mortality and selectivity to continue projecting forward until a new steady state appears, up to 2123 and 2070. We finally focused on six economic fish species (*T. lepturus*, *M. cinereus*, *P.*

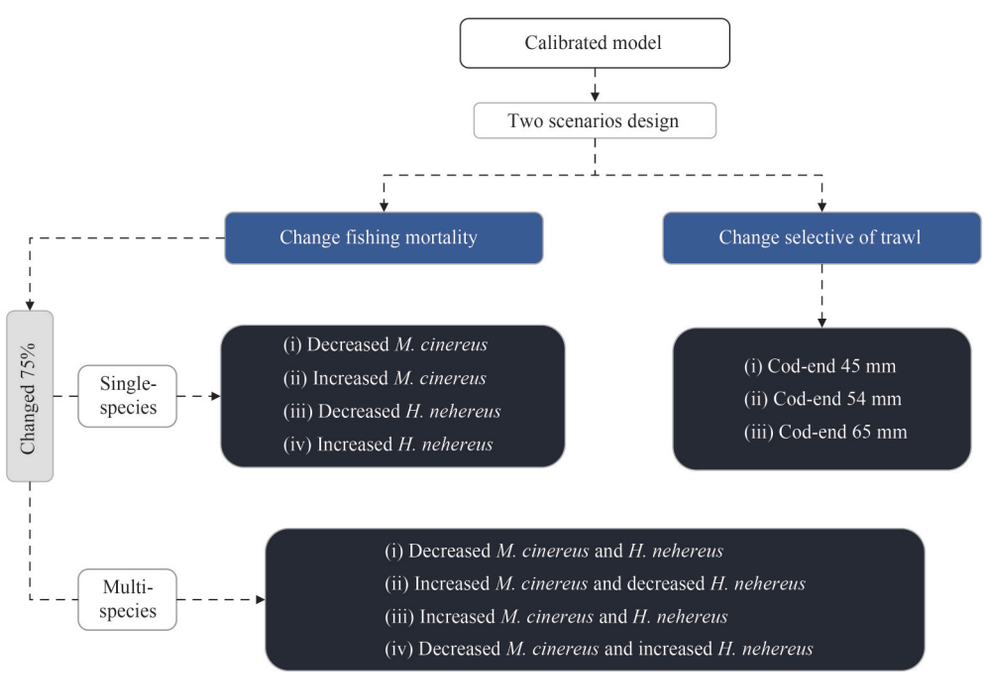

Fig.4 Flowchart of the sub-scenarios simulation in the calibrated model

argenteus, *H. nehereus*, *L. polyactis*, and *L. crocea*) and their maximum sustainable yield (MSY) were assessed.

3 RESULT

3.1 Single-species management

The MSSM output showed that in each of the species-specific simulations, an increase in fishing mortality led to a decrease in the biomass of the focal species, and vice versa. However, the direction and magnitude of changes in biomass of non-focal species varied across simulations. When the fishing mortality of *M. cinereus* decreased, its biomass eventually increased by one order of magnitude compared with the original value (Fig.5a), while the biomass of other target species decreased, with a greater decrease in *T. lepturus*. When the fishing mortality of *M. cinereus* increased, the biomass of all species in the community showed no significant temporal fluctuations, with only a slight increase in *T. lepturus* and *P. echinogaster* (Fig.5b). A decrease in the fishing mortality of *H. nehereus* led to an increase in the biomass of *T. lepturus* and *M. cinereus*. In contrast, the biomass of *P. echinogaster*, *L. polyactis*, and *L. crocea* decreased slightly (Fig.5c). The impact on other target species was relatively minor when the fishing mortality of the *H. nehereus* increased (Fig.5d).

In the scenario where the fishing mortality of *M. cinereus* decreased, the biomass of the community exhibits an upward trend, primarily driven by the rapid growth of the biomass of itself. Conversely, the biomass of other target species decreased to varying degrees. Relative to the scenario where the fishing mortality of *M. cinereus* decreased, the changes in the biomass of community and size spectrum slope in the other three scenarios (the fishing mortality of *M. cinereus* increased, the fishing mortality of *H. nehereus* increased and the

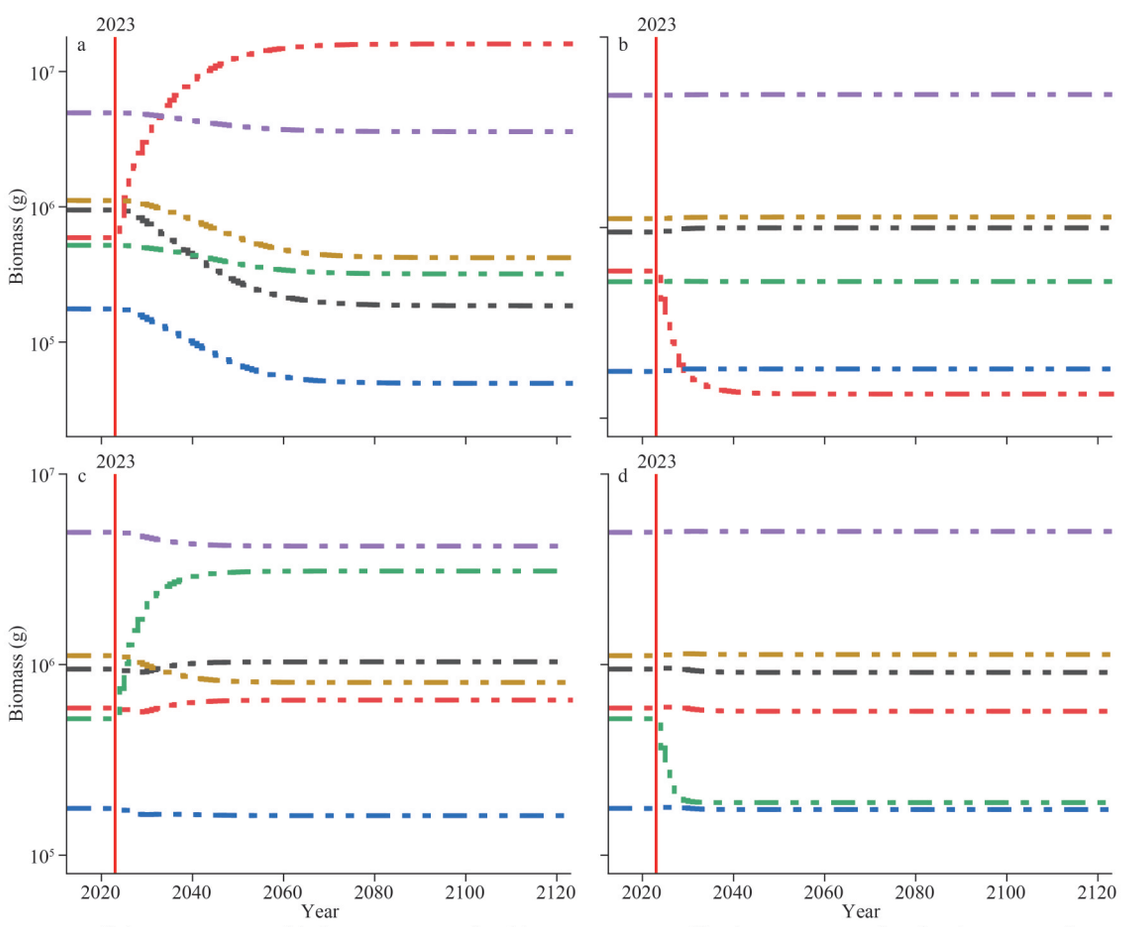

Fig.5 Changes in biomass under single-species management in 2023

a. 75% decrease in fishing mortality of *Muraenesox cinereus*; b. 75% increase in fishing mortality of *Muraenesox cinereus*; c. 75% decrease in fishing mortality of *Harpadon nehereus*; d. 75% increase in fishing mortality of *Harpadon nehereus*.

fishing mortality of *H. nehereus* decreased) were relatively minor (Table 3).

3.2 Multi-species management

In simulations of multi-species management, when the fishing mortality of both *M. cinereus* and *H. nehereus* decreased, the biomass of these two species increased significantly, while the biomass of the other four target species decreased to varying degrees, with the decrease ranging from large to small in the order *T. lepturus*, *P. echinogaster*, *L. crocea*, and *L. polyactis* (Fig.6a). On the contrary, when the fishing mortality of these two species increased, their biomass decreased, and the impact of this decrease on the biomass of the other four target species was relatively small (Fig.6c). When the fishing mortality of *M. cinereus* increased while the fishing mortality of *H. nehereus* decreased, the model output showed that the biomass of *L. crocea* and *L. polyactis* decreased, while the biomass of *T. lepturus* and *P. echinogaster* increased, with the biomass of *T. lepturus* increasing most significantly (Fig.6b). Decreased *M. cinereus* and increased *H. nehereus* fishing mortality led to a simultaneous decrease in the biomass of the four other target fish species, with *T. lepturus* biomass decreasing the most (Fig.6d).

Table 3 Change in community biomass and the size spectrum slope in single-species management

Species	Fishing mortality	Community biomass	Size spectrum slope
M. cinereus	Decrease	+30.7%	+6.8%
M. cinereus	Increase	-4.0%	-0.35%
H. nehereus	Decrease	-0.15%	-4.5%
H. nehereus	Increase	+0.15%	-0.2%

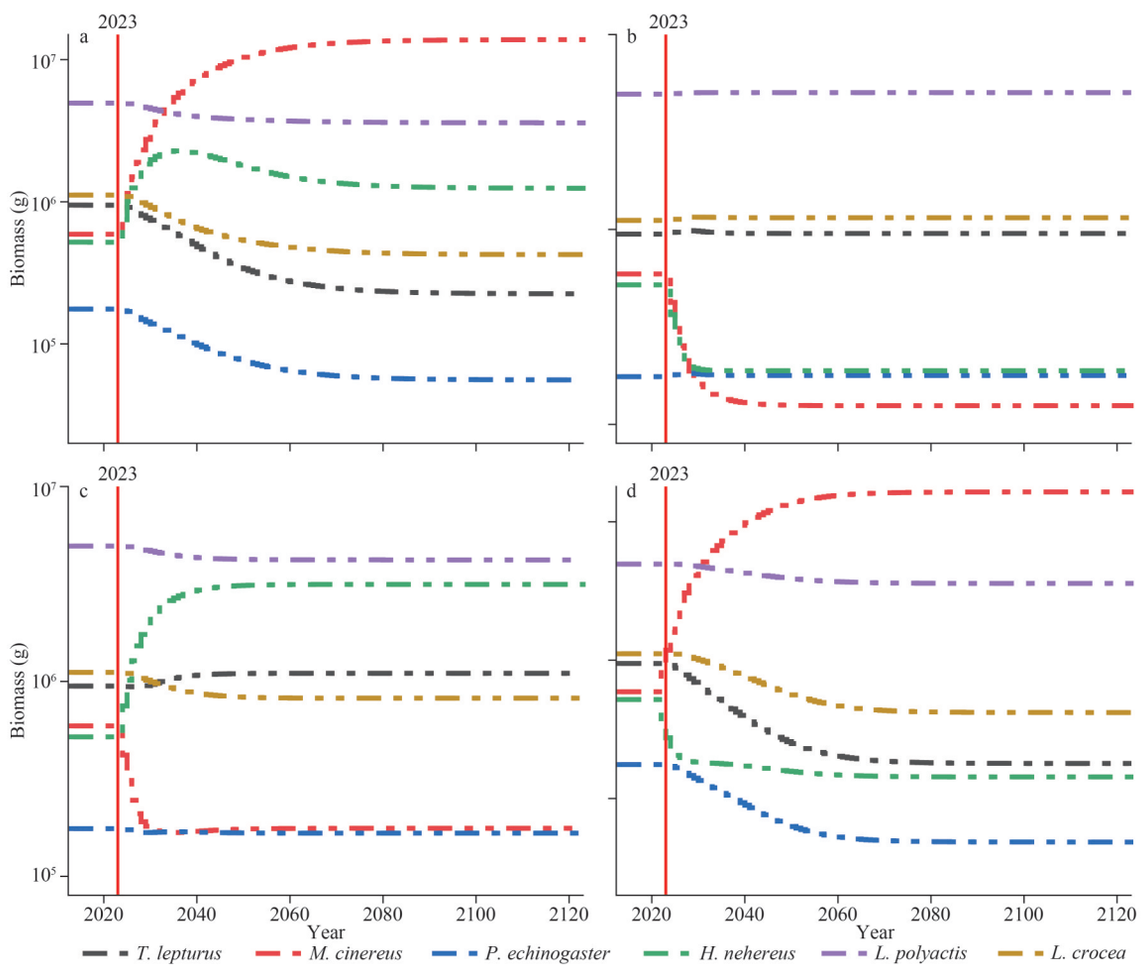

Fig.6 Changes in biomass under multi-species management in 2023

a. 75% decrease in fishing mortality of *Muraenesox cinereus* and *Harpadon nehereus*; b. 75% increase in fishing mortality of *Muraenesox cinereus* and *Harpadon nehereus*; c. 75% decrease in fishing mortality of *Harpadon nehereus* and 75% increase in fishing mortality of *Muraenesox cinereus*; d. 75% increase in fishing mortality of *Harpadon nehereus* and 75% decrease in fishing mortality of *Muraenesox cinereus*.

In the context of concurrent fluctuations in the fishing mortality of coupled *M. cinereus* and *H. nehereus* populations, effects on community biomass and the slope of the particle size spectrum can be reasonably ignored only if fishing mortality increases for both species simultaneously. In contrast, the other three scenarios will result in significant impacts on the biomass of community and size spectrum slope (Table 4).

3.3 Selectivity management

The biomass of the target species, including *L. crocea*, *L. polyactis*, and *P. argenteus*, exhibits a positive correlation with the cod-end mesh size. As cod-end mesh size increased, the biomass of these species undergoes a rapid and sustained increase over a period of several years. In contrast, the biomass of species such as *T. lepturus*, *M. cinereus*, and *H. nehereus* exhibits an initial rapid increase in response to the increased cod-end mesh size, followed by a decrease to levels below the pre-treatment baseline (Fig.7). The size spectrum slope, community MW and LFI all increased with the cod-end mesh size (Fig.8).

Table 4 Change in community biomass and size spectrum slope in multi-species management

Species	Fishing mortality	Community biomass	Size spectrum slope
M. cinereus *H. nehereus*	Decrease Decrease	+25%	+4.9%
M. cinereus *H. nehereus*	Increase Decrease	-0.9%	-0.02%
M. cinereus *H. nehereus*	Increase Increase	-1.8%	-4.7%
M. cinereus *H. nehereus*	Decrease Increase	+32%	+7.2%

3.4 MSY of each scenario

Under single-species management, the MSY of the target species exhibits a positive correlation with the fishing mortality of *M. cinereus*, with *L. crocea*, *L. polyactis*, and *T. lepturus* exhibiting the most pronounced responses to these changes. However, for *M. cinereus*, it will remain in a low-production state year-round (Fig.9a). The increase in the MSY of each target species in the scenario when the fishing mortality of *H. nehereus* was similar to the scenario where the fishing mortality of *M. cinereus* increased, but *M. cinereus* is more sensitive to fishing (Fig.9b).

In simulations of multi-species management, when the fishing mortality of *M. cinereus* increased while the fishing mortality of *H. nehereus* decreased to an appropriate extent, the trend of increase in the MSY of *T. lepturus* was significantly higher than that of the increase in only the fishing mortality of *M. cinereus* (Fig.10a). Within a specific range of the fishing mortality of *M. cinereus*, an increase in the fishing mortality of *H. nehereus* was predicted to positively impact the MSY of *M. cinereus* (Fig.10b). Within a specific range of the fishing mortality of *H. nehereus*, when the fishing mortality of *M. cinereus* increased, the MSY of *H. nehereus* increased (Fig.10d). Compared with the single-species scenario, increasing the fishing mortality for *M. cinereus* and *H. nehereus* led to an increase in the MSY of *P. argenteus*, *L. crocea*, and *L. polyactis* (Fig.10c, e, and f). In the case of increasing cod-end mesh size, the MSY of

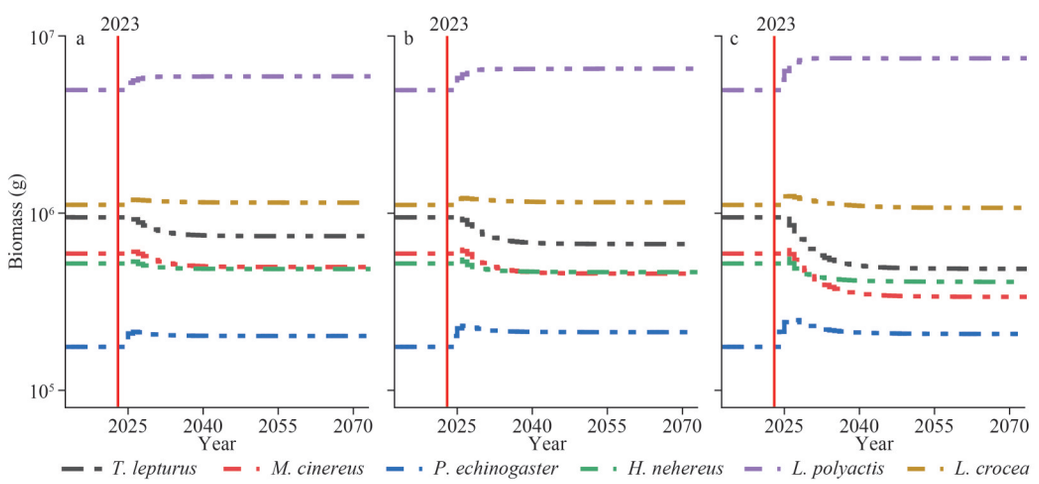

Fig.7 Changes in biomass under selectivity management in 2023

a. cod-end mesh of 45 mm; b. cod-end mesh of 54 mm; c. cod-end mesh of 65 mm.

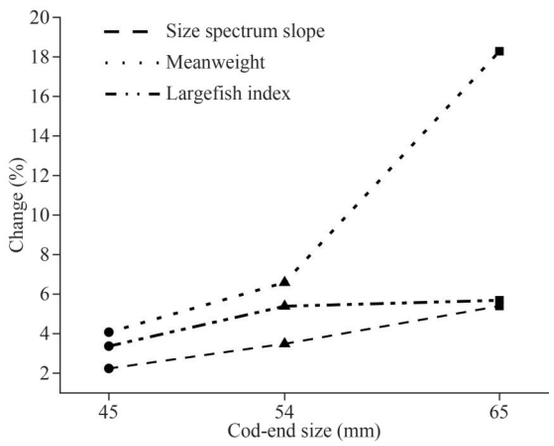

Fig.8 Changes in size spectrum slope, community MW and LFI when the cod-end mesh size increased compared with 25 mm

T. lepturus, *M. cinereus*, *P. argenteus*, *H. nehereus*, and *L. crocea* decreased, whereas the MSY of *L. polyactis* increased (Fig.11).

4 DISCUSSION

We had explored the dynamic responses of fish communities in the Dachen Island Marine Ranch to various management scenarios, revealing how fishing activities affect community dynamics, including direct and indirect effects on nutrient availability.

4.1 Trophic interaction under changed fishing mortality

In this study, the results indicate that a decrease in the fishing mortality of *M. cinereus* could increase its biological quantity by one order. Meanwhile, the biomass of many species, including all the target species decreased. Reductions in fishing mortality for top predators had a negative impact on the community. Population declines of a large number of species have been observed in a study on restoring F_{MSY} for predator populations (Zhang et al., 2025). The decline in a large number of species may lead to food web instability. Furthermore, restoring these declining populations may prove challenging because small populations, driven by predation, are prone to the Allee effect (per capita rate of population growth declining as abundance decreases) (Neuenhoff et al., 2019). When the fishing mortality of *M. cinereus* increased, total biomass of community decreased by only 0.31%. Although the biomass of all target species remained almost unchanged, their MSY improved. In a study of the East China Sea, the removal of top predators has been shown to increase community productivity (Szuwalski et al., 2017). Furthermore, Matsuda and Abrams (2006) demonstrated that changing the fishing mortality of top predators can have a trophic cascading effect. Changing the fishing mortality of *H. nehereus* exhibits no significant impact on the biomass of community and size spectrum slope. Notably, decreasing the fishing mortality of *H. nehereus* causes a decrease in the biomass and MSY of *L. crocea* and *L. polyactis*. An analysis of stomach contents showed that *H. nehereus* not only engages in intraspecific predation but also predominantly feeds on the juvenile stages of *L. crocea* and *L. polyactis* (Pan, 2011; Shi, 2018). *L. crocea* is one of the primary species for stocking in the Dachen

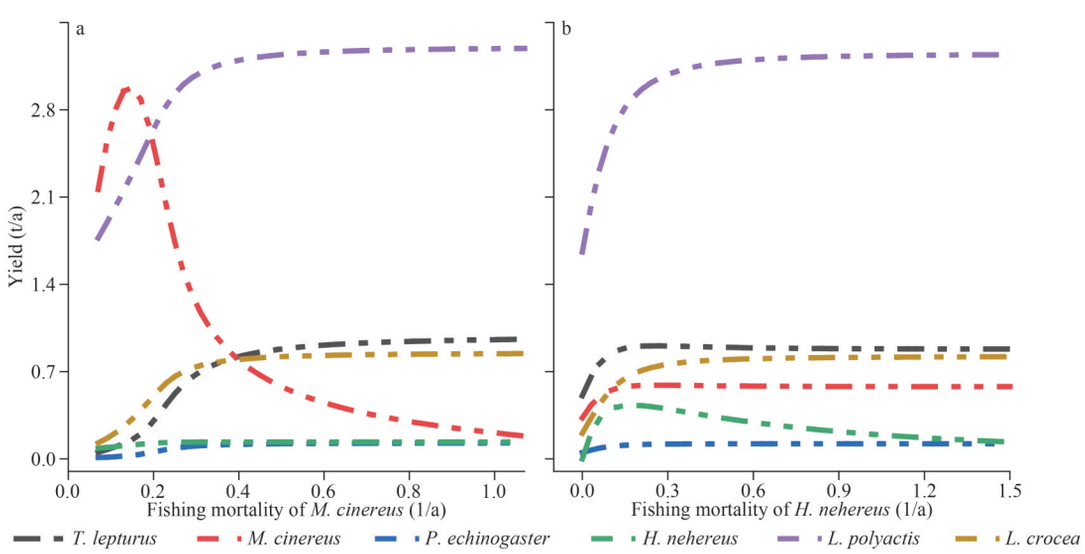

Fig.9 Changes in MSY under single-species management

a. change the fishing mortality of *M. cinereus*; b. change the fishing mortality of *H. nehereus*.

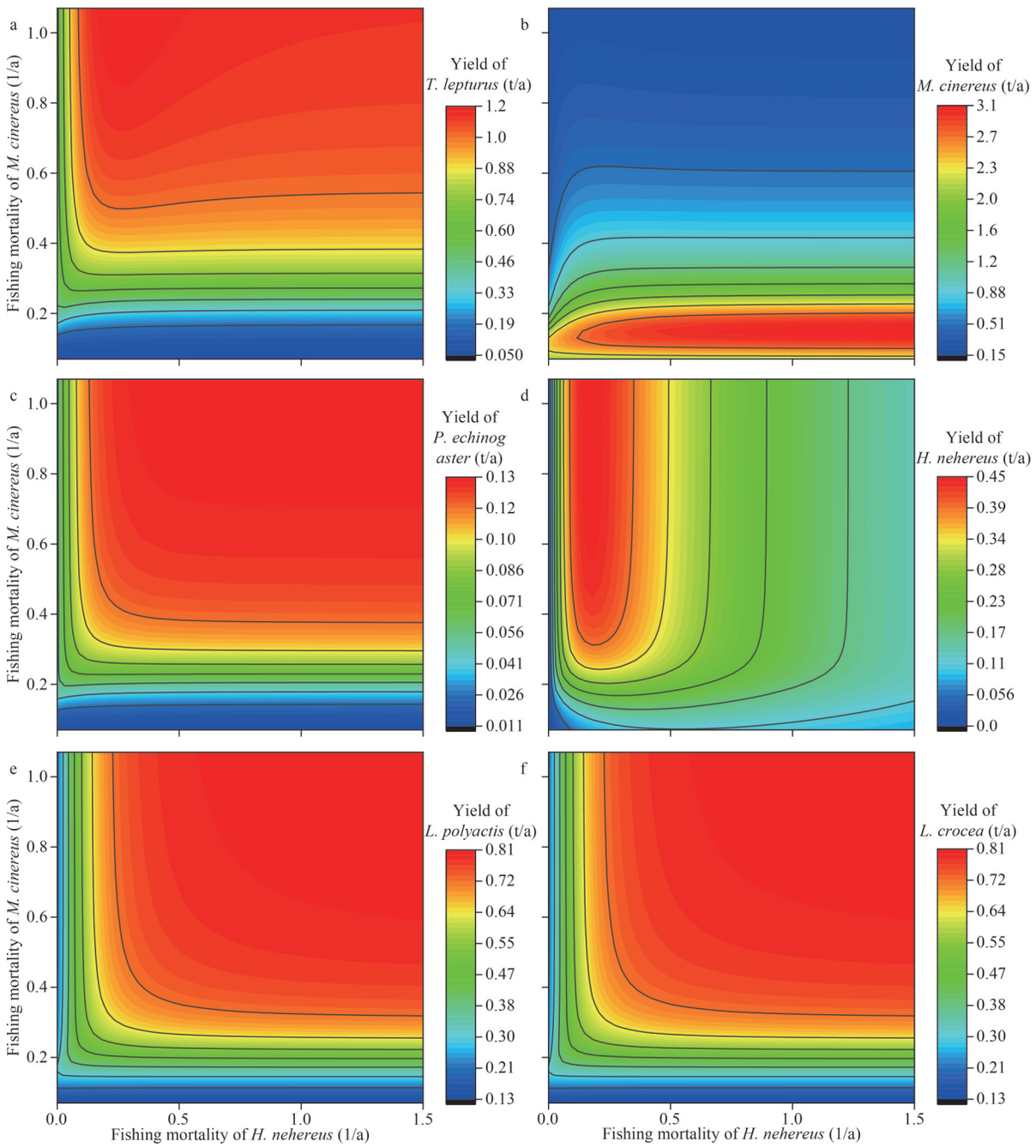

Fig.10 Changes in MSY under multi-species management, contour map of MSY when the fishing mortality of *Muraenesox cinereus* and *Harpadon nehereus* changes

a. MSY of *Trichiurus lepturus*; b. MSY of *Muraenesox cinereus*; c. MSY of *Pampus echinogaster*; d. MSY of *Harpadon nehereus*; e. MSY of *Larimichthys polyactis*; f. MSY of *Larimichthys crocea*.

Island Marine Ranch, and increasing the fishing mortality of *H. nehereus* may potentially contribute to the sustained growth of *L. crocea* populations.

In our multi-species management scenarios, simultaneous alterations in the fishing mortality of both *M. cinereus* and *H. nehereus* can either suppress or enhance the results of a single-species simulation. For example, compared with the scenario in which only the fishing mortality of *M. cinereus* decreased, a decrease in fishing mortality for both *M. cinereus* and *H. nehereus* can lead to a decrease in the biomass of *M. cinereus* and an increase in the biomass of other target species. As both *M. cinereus* and *H. nehereus* are bottom-dwelling fish species

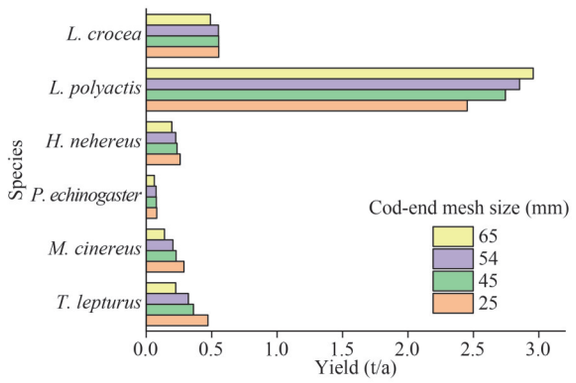

Fig.11 MSY of six main economic species at cod-end mesh sizes of 25, 45, 54 and 65 mm

that occupy similar habitats, their spatial overlap can be expected to increase under decreased fishing mortality. According to Grinnell's hypothesis (Grinnell, 1917), this decrease in fishing mortality can exacerbate the competitive pressure for survival space between the two species. Simultaneous increases in the fishing mortality of *M. cinereus* and *H. nehereus* did not exhibit a significant difference compared with individual increases in the fishing mortality of each species, with the biomass of community decreasing by only 1.8%. And the biomass of other species remains basically unchanged. This observation appears to contravene the expectation of the predator release effect, which posits that predation pressure can be alleviated by the removal of predators, thereby enhancing prey populations and biomass (Law et al., 2016). Notably, the predator release effect is not universally applicable, as marine ecosystems are complex and unstable. The intricate food webs in these ecosystems can, to some extent, mitigate the predator release effect. When a predator is removed from the system, other species can assume similar functional roles, thereby compensating for the loss; this phenomenon is known as functional redundancy (Pauly et al., 2002). Furthermore, the removed predator may also exert indirect effects on the competitors of the target species, thereby influencing the dynamics of target species.

4.2 Specific selection of cod-end size

A trawl is a widely used fishing gear in the marine fishing industry and is highly non-selective. When the cod-end mesh size increased, the biomass and MSY of *L. polyactis* and *P. argenteus* grew rapidly within a few years. According to previous studies, a larger cod-end mesh size demonstrated filter out smaller fish, which will escape and grow into catchable fish populations in the future, thereby increasing their MSY (Maynou et al., 2021). An increase in the cod-end mesh size resulted in a significant decrease in the biomass of larger fish species, including *M. cinereus*, *T. lepturus*, and *L. crocea*. In general, the selective properties of trawls and other active gears were adapted by altering the size selection in the cod-end (Glass, 2000). This strategy assumes that most fish entering the gear drift towards the cod-end, where a simple size selection process occurs: smaller fish with specific morphological characteristics have a greater probability of passing through the meshes and escaping, whereas larger fish have a greater probability of being retained in the cod-end. Thus, the retention probability increases with the size of fish (Elliott, 1984; Reeves et al., 1992; Dickson et al., 1995; MacLennan, 1995; Wileman, 1996; Millar and Fryer, 1999; Huse et al., 2000). In addition, the limitations of survey techniques have led to an underestimation of the biomass of certain species. The marine ranch area of Dachen Island is a paradigmatic example of an island reef ecosystem. Barros et al. (2001) suggest that the abundance of certain fish species exhibits a gradient distribution with increasing distance from the island reef environment. The survey points were strategically selected to be located at a considerable distance from the island reef to ensure the success of the trawl survey in this area. Consequently, this sampling approach may have resulted in the underestimation of certain species that are strongly affiliated with the reef habitat (e.g., *M. cinereus*).

4.3 Limitation of ecological indicator in management scenario

We used the size spectrum slope, LFI and MW, to assess the ecological status of the community. The MSY of economically important species is employed to evaluate the efficacy of marine ranch management strategies. An analysis revealed that in scenarios where the mortality of *M. cinereus* increased, the size spectrum slope decreased, resulting in steep spectrum lines. In contrast, when the mortality of *M. cinereus* decreased, the size spectrum slope increased, resulting in a flattening of the spectrum lines. Many studies proved that increased fishing mortality leads to a steepening of the spectrum slope as more desirable large-bodied individuals are removed (Rice and Gislason, 1996; Bianchi et al., 2000). Furthermore, our simulations

revealed that changes in the fishing mortality had minimal effects on the slope of the quality spectrum in other scenarios. The importance of large predators in influencing the slope of the community size spectrum was previously demonstrated in sensitivity analyses of a similar model (Benoit et al., 2021). Thus, caution should be taken when using size spectrum slopes as indicators of community status because changes in the community size spectrum slope driven by the largest predators may not reflect changes in the size distributions of other target species (Benoit et al., 2022).

Trawls have low species selectivity and size selectivity, and therefore also generate significant amounts of bycatch, including low-value and prohibited size ranges. Both types of bycatch are issues of growing concern in the public and scientific spheres (Lewison et al., 2004). Increasing the cod-end mesh size can effectively mitigate the adverse impacts of fishing on the fishery industry. Our study reveals that increasing the cod-end mesh size leads to a significant increase in the LFI and a corresponding rise in the MW of the fish community. Concomitantly, the mitigation of predation pressure on smaller fish species has also been achieved, thereby increasing their MSY and promoting a more balanced ecosystem. While improved selectivity can help balance exploitation rates with the productivity and abundance of component populations in mixed fisheries, improved selectivity can also lead to greater contrasts in production or biomass among components of the food web (Rochet et al., 2011). In this study, it has been found that the biomass of larger species is in a state of decline. Over time, the decline in larger species may disrupt food web balance. Moreover, the LFI and MW of community are two metrics that fail to adequately capture the community's biodiversity and size diversity (Rochet et al., 2009). Consequently, if the management objective is to preserve the ecological integrity and functional resilience of the ecosystem, then increasing selective fishing pressure may not be an effective strategy to achieve this goal (Hall, 1996).

In conclusion, the two strategies of predator-targeted fishing and increasing cod-end mesh size appear to improve overall status of the community. However, their potential negative impacts should not be overlooked. For instance, the consideration of biodiversity is neglected in terms of ecological functions, and climate factors were not incorporated into the modeling process. Therefore, we underscore that trade-offs exist among management strategies (For example, there are opposite adaptations of large fish and small fish when increasing cod-end mesh size). When trade-offs exist, there is no simple answer to the 'best' management scenario. Each management scenario has priorities and faces different trade-offs. We shall endeavor to develop strategies that will achieve multiple wins.

5 DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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