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How does ocean farming empower the fishery economy? A policy impact evaluation of marine ranch demonstration zones

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Introduction: The construction of marine ranches, as a crucial component of implementing the "Big Food Concept" and the "Strengthening the Ocean" strategy, provides new solutions for the sustainable development of marine resources and the growth of the fishery economy.

Methods: This study centers on investigating the impact mechanisms of marine ranch demonstration zones on fishery output value, employing a multi-period difference-in-differences (DID) model with panel data from 43 coastal prefecture-level and above cities in China from 2007 to 2022 to empirically evaluate policy effects at municipal level.

Results: Key findings reveal that marine ranch demonstration zone construction significantly drives fishery output growth by improving marine ecosystems, extending industrial chains, and conserving biological resources, thereby enhancing fisheries' stability and sustainability while upgrading economic quality and efficiency; policy effects exhibit spatial and typological heterogeneity, with enhancement-oriented and recreation-oriented marine ranches demonstrating more pronounced impacts, while cities in the East and South China Sea regions capitalize more effectively on the economic benefits.

Discussion: These findings position marine ranch as a critical pathway transforming ecological benefits into economic gains. We propose accelerating sustainable "blue granary" development through three strategic priorities: refining modern marine ranch policy frameworks, implementing regionally differentiated strategies, and fostering diversified synergistic development approaches.

KEYWORDS

marine ranch demonstration zone, policy evaluation, marine resources, fishery output value, difference-in-differences model

1 Introduction

Fisheries constitute a vital component in developing the marine economy and advancing marine ecological civilization, serving as a critical pillar for socioeconomic development in coastal regions. However, since the 20th century, overfishing, environmental pollution, and habitat degradation have led to the decline of global marine fishery resources, rendering traditional capture fisheries and aquaculture increasingly incompatible with the requirements of healthy economic development and marine ecosystem carrying capacity. As an innovative mode of marine fishery production, marine ranch has emerged as an effective solution to transform fishery development models, improve marine ecosystems, and ensure the sustainable utilization of marine biological resources. It represents a significant practice in implementing the Two Mountains" theory and a strategic approach to achieving the "Dual Carbon" goals. President Xi Jinping explicitly emphasized: "We must adopt a Big Food Concept, seeking food supplies from both land and sea—cultivating the ocean through 'farming the seas and nurturing fisheries', establishing offshore ranches and 'blue granaries'." To construct a diversified food supply system and realize the grand vision of "harvesting food from the sea and strengthening fisheries through marine ranch", a series of long-term initiatives have been deployed. The establishment of national marine ranch demonstration zones has become a focal point and key driver of ecological civilization construction in the new era.

With the rapid expansion of the marine economy and emerging ocean industries, China's marine fisheries account for a relatively diminishing share of GDP, reflecting a declining contribution to the broader marine economy. As a high-potential sector within marine fisheries, marine ranch not only revitalizes traditional fisheries but also expands their multifunctional value by integrating stock enhancement, ecological restoration, recreational activities, and eco-tourism. This integrated approach effectively stimulates secondary and tertiary marine industries, creating new growth engines for marine fisheries while contributing to sustainable ocean economy development and maritime power construction. Pursuant to the Guidelines on Strengthening Aquatic Biological Resource Conservation, China has established a nationwide network of marine ranches—from northern to southern coasts—featuring artificial reefs deployment, seagrass transplantation, and stock enhancement of fish, crustaceans, and cephalopods. While progress has been steady in optimizing nearshore green aquaculture layouts and advancing demonstration zones. However, achieving the trinity of species proliferation, habitat improvement, and economic benefits remains a long-term endeavor, persistent challenges include fragmented spatial planning, regional development disparities, and institutional mechanism gaps. Resolving the dichotomy between sustainable utilization of marine fishery resources and ecological conservation remains a critical challenge for coastal regions. This necessitates a fundamental transformation of fishery development paradigms—through effective industrial chain extension and the transition toward green, coordinated, and sustainable marine fisheries.

This study investigates the impact mechanisms of marine ranch construction on marine fishery output value by treating China's

national marine ranch demonstration zones as a quasi-natural experiment. Using a multi-period difference-in-differences (DID) model and coastal city panel data in China from 2007 to 2022, we quantitatively evaluate the policy effects of these demonstration zones to address two fundamental questions: whether marine ranch construction enhances fishery output value, and the underlying mechanisms driving this relationship. By conducting granular analysis at the prefecture-level city scale and incorporating region-specific characteristics of demonstration zones. By assessing marine ranch performance through the lens of fishery economic output, this study offers robust empirical evidence and policy recommendations for achieving the synergistic integration of economic benefit enhancement, marine habitat improvement, industrial chain extension, and fish stock conservation.

2 Literature review

Against the backdrop of increasing global overexploitation of fishery resources and ecosystem imbalance, marine ranch has emerged as an innovative fisheries management approach. This paradigm seeks to achieve sustainable fisheries development through marine ecosystem restoration and optimized resource utilization structures (Wang and Zhang, 2024). Consequently, scholars have conducted extensive research aligned with the strategic objectives of marine ranch development and the practical needs of establishing 'blue granaries', particularly focusing on the establishment of national marine ranch demonstration zones and marine fisheries productivity enhancement. Through systematic literature review, this paper synthesizes existing research progress and identifies knowledge gaps, aiming to elucidate the mechanistic pathways through which marine ranch demonstration zones influence marine fishery economic output. Our findings contribute to advancing research in marine ranch development and its economic implications.

First, regarding research on the effectiveness of marine ranch demonstration zones. Current literature primarily focuses on policy interpretation, construction objectives, and implementation models of marine ranch. As Qin and Sun (2021) noted, the concept of marine ranch refers to a fisheries model that establishes habitats for marine organisms' reproduction, growth, feeding, and predator avoidance through artificial reefs and stock enhancement, thereby conserving and augmenting fishery resources while improving marine ecosystems for sustainable utilization. Through comparative analysis of strategic objectives between marine ranching and traditional mariculture, Que et al. (2016) emphasized that marine ranch places greater emphasis on adopting scientific production technologies and refined management approaches, which not only restore marine ecosystems but also facilitate the transition of fisheries from quantity-oriented to quality-driven development. Several scholars have evaluated the benefits of demonstration zones from various perspectives, including land-sea coordination and maritime power strategies, employing both qualitative discussions and empirical analyses. For instance, Wan et al. (2022), from a land-sea coordination perspective, revealed long-term governance paradigms of marine ranch through core leadership and multi-stakeholder participation, examining value co-

creation mechanisms driven by collaborative innovation and diversified financing. Liu et al. (2024) employed the entropy weight method to construct a comprehensive evaluation index system, quantifying the ecological benefits of marine ranch through biological resource and environmental factor surveys. Yuan et al. (2024) developed an integrated assessment framework spanning ecological, economic, and social dimensions to evaluate construction benefits, specifically measuring marine ranch's contributions to ecosystem services, biodiversity, and fishery resources through analysis of artificial reef and stock enhancement effects.

Second, concerning research on existing challenges in marine ranch demonstration zone development. Current marine ranch initiatives remain imperfect, with scholars identifying persistent issues in comprehensive benefits, technological systems, and integrated development models under rigid constraints of resource scarcity and industrial limitations. As demonstrated in Ru et al. (2023)'s comparative analysis of marine ranch approaches, China's program faces significantly greater challenges than benchmark models like the UK's North Sea fisheries or Japan's Hokkaido fisheries, particularly regarding near-shore fishery resource depletion and marine ecological degradation. From an institutional supply perspective, Wang (2019) highlight excessive pressure on coastal aquaculture, resulting in low modernization levels of marine ranch and underdeveloped deep-sea fishing capabilities^[8]. From a fisheries modernization perspective, Ni and Han (2009) identified three systemic constraints in traditional production models – structural homogeneity, low productivity, and weak industrial resilience, which necessitate both managerial transformation and industrial convergence in marine ranch demonstration zones. Li et al. (2022b)'s research identified a critical deficiency in contemporary marine ranch development: the absence of an integrated high-quality development model that effectively combines whole-industry-chain synergy, coordinated land-sea spatial planning, and cross-sector industrial convergence. Yang et al. (2019)'s operational analysis of marine ranching demonstration zones revealed two critical systemic deficiencies: imbalanced trophic structures within the marine food web, and the absence of standardized scientific evaluation frameworks. These shortcomings collectively undermine both production efficiency and long-term sustainability, lead to negative impacts on both production efficiency and sustainable utilization capacity.

Third, researches on the impacts of marine ranch development on fisheries. Since the 18th National Congress of the Communist Party of China, China's marine fishery economy has demonstrated a positive trend of simultaneous growth in both scale and quality. However, challenges such as disconnected industrial chains, fishery resource depletion, and extensive aquaculture practices have become increasingly apparent during this development phase (Hu and Ma, 2025). In response, scholars have examined the performance of marine ranch pilot projects from multiple perspectives, including aquaculture models, ecological restoration, and industrial optimization. Ding and Suo (2022) characterized marine ranch as an artificially constructed and managed ecosystem within natural marine waters, demonstrating its capacity to achieve synergistic coupling of habitat optimization, fish stock

enhancement, and production efficiency improvement. This integrated approach enabled both effective conservation and sustainable yield of fishery resources. Pan et al. (2024) systematically examined the sea-use classification framework for marine ranch, analyzing distinct production-enhancement models and value-added pathways for marine products across different ranch types. Cao and Shen (2022) identified marine ranch development as an effective strategy for enhancing blue carbon sequestration, while simultaneously promoting marine habitat restoration and fish stock conservation. Complementing this ecological perspective, Hu and Sun (2024) analyzed marine ranch through a legal-institutional lens, demonstrating how scientifically defined maritime boundary standards for different zone types can clarify stakeholder rights and responsibilities, thereby facilitating systematic fishery resource development. Zhang et al. (2023) extended the research scope to fishery supply chain integration, demonstrating that marine ranch facilitates the establishment of a coordinated land-sea industrial support system, this integrated approach effectively enhances marine fishery output value. Concurrently, numerous scholars have investigated the regional feature of marine ranch's economic impacts through comparative studies across coastal zones. Wang et al. (2024) examined the mechanism of action of the multiple networks of marine ranch industry innovation, taking Yantai City as an example, and points out that policy guidance and innovation environment play an important role in increasing fishery output value. Du et al. (2021) developed an ecological security index for Rongcheng's national marine ranch demonstration zone by applying the mean utility-entropy weight method. Suo et al (2025)'s empirical study of the Miaowan marine ranch in the Pearl river estuary quantitatively evaluates two core ecological functions: fishery resource conservation and stock enhancement effectiveness. While substantial literature documents the positive outcomes of marine ranching pilot programs, dissenting scholarly perspectives highlight unresolved challenges. Liu et al (2024)'s production mode analysis revealed that enhancement-oriented marine ranches show negligible improvements in nutritional quality and food safety standards compared to conventional aquaculture. Yu and Wang (2015) pointed out that the current conservation-oriented marine ranch fail to transcend the conventional “release-then-harvest” fishery model, resulting in a large amount of investment fail to achieve expected goals, these shortcomings may have a negative impact on fishery production capacity.

By reviewing existing literature, it can be seen that the academic community has closely focused on the forefront hotspots of marine ranch construction, and has conducted a lot of beneficial explorations from multiple perspectives such as yield optimization, ecological restoration, and legislative confirmation of rights. The rich theoretical analysis and empirical testing not only solidify the foundation for subsequent discussions, but also point out the direction for further expansion. However, critical gaps persist in current research, as evidenced by three systemic limitations: First, existing research on marine ranch development has been predominantly theoretical or case-based, with limited empirical validation. Moreover, most studies focus on ecological performance

metrics, while economic impact assessments of demonstration zones remain scarce. Second, while existing studies have gradually incorporated environmental impacts and social benefits into their analyses, they predominantly focus on localized assessments of marine ranch development. Crucially, researchers have yet to treat China's national marine ranch demonstration zones as a quasi-natural experiment to rigorously examine their economic effects through empirical models. Third, current studies predominantly rely on provincial-level panel data, which employs an excessively coarse analytical scale. This approach not only overlooks inter-city disparities among coastal cities, including variations in resource endowments, economic foundations, and human capital, but also fails to account for distinct developmental characteristics between coastal and inland cities within the same province. Consequently, the resulting evaluations lack both precision and contextual relevance, ultimately limiting their capacity to generate actionable policy recommendations.

The marginal contributions of this study are threefold: First, by treating the national marine ranch demonstration zones as a quasi-natural experiment, we quantitatively identify the policy effects of these demonstration zones and systematically examine the intrinsic relationships between marine ranch development and fishery output value through three key pathways: improving marine ecological environments, extending fishery industry chains, and conserving marine biological resources. Second, utilizing prefecture-level city data from coastal areas provides more granular and objective insights into inter-city disparities and regional characteristics compared to previous studies relying on provincial-level panel data. Third, by focusing on diverse marine geographical locations and various types of marine ranch demonstration zones, we investigate the heterogeneous impacts of demonstration zone construction from both geographical and functional perspectives, offering nuanced understanding of how policy effects vary across different spatial contexts and development objectives.

3 Policy background and research hypotheses

3.1 Policy background

In 2006, China's State Council issued the Notice on the Action Plan for the Conservation of Aquatic Biological Resources in China, which called for the protection and sustainable utilization of aquatic biological resources to promote sustainable fisheries development. Against this backdrop, coastal cities across the country gradually began establishing marine ranches and actively engaged in activities such as artificial reef construction and stock enhancement. In March 2013, the State Council issued the Several Opinions on Promoting the Sustainable and Healthy Development of Marine Fisheries, advocating for the scientific advancement of mariculture, enhanced protection of aquatic germplasm resources and improved breeding of superior varieties. The document called for establishing standardized, large-scale breeding bases to increase the adoption rate of high-quality aquatic varieties. In 2015, the State Council's

Action Plan for Water Pollution Prevention and Control and the Ministry of Agriculture's Notice on Establishing National Marine Ranch Demonstration Zones jointly launched the official initiative to develop national marine ranch demonstration zones. Under this program, 20 coastal cities, districts and counties across seven pilot provinces—Tianjin, Hebei, Liaoning, Shandong, Jiangsu, Zhejiang, and Guangdong—were designated as the first batch of national marine ranch demonstration zones. In December 2016, China announced the second batch of national marine ranch demonstration zones. The following year, the government issued the National Marine Ranch Demonstration Zone Construction Plan (2017-2025), which outlined key development priorities for these zones, including the design, construction, and deployment of artificial reefs, transplantation and restoration of seaweed fields and seagrass meadows, supporting facilities such as boats, management platforms, monitoring and management systems. The plan also proposed establishing a new spatial framework for the "one belt, three zones" marine ranch network including the coastal zone, the Yellow Sea and Bohai Sea region, the East China Sea region, and the South China Sea region. In 2021, the first national standard for marine ranch, the "Technical Guidelines for Marine ranch Construction" was released, which standardized the main habitat types of marine ranching in China's coastal areas and the technical elements of the entire process of marine ranching construction, including pre construction planning and layout, habitat creation and breeding release during construction, and post construction engineering acceptance. As of December 2022, China had approved eight batches of national marine ranch demonstration zones, totaling 153 sites nationwide. These include 42 conservation-oriented demonstration zones, 87 enhancement-oriented demonstration zones and 24 recreational demonstration zones, and a sea area of over 2500 hectares.

3.2 Research hypotheses

As the pilot policies for national marine ranching demonstration zones continue to advance, coastal local governments have implemented a series of measures, including the artificial enhancement of key economically valuable fish species, restoration of marine ecosystem structures, and optimization of maritime spatial utilization to establish fundamental conditions for augmenting fishery resources and elevating their economic value (Qin and Yue, 2020). These efforts not only ensure the precise implementation of marine resource optimization and ecological restoration initiatives but also drive steady improvements in both the quality and output of the marine fishery economy. The impacts are manifested in three key dimensions: First, the national marine ranch demonstration zones aim to achieve faster fry growth and higher reproductive efficiency under limited resource constraints by introducing fish species with high survival rates, short growth cycles, and significant economic value. This approach enables accelerated production growth in a shorter timeframe. Simultaneously, marine ranching emphasizes scientifically planned maritime spatial utilization to avoid overcrowding of fishing vessels and reduce resource wastage, thereby mitigating marine

ecological degradation. This dual effect of resource optimization and ecological restoration enhances the productivity and stability of marine ecosystems, creating favorable conditions for subsequent fishery resource enhancement and economic output (Bai et al., 2022). Second, these demonstration zones leverage advanced aquaculture technologies such as the internet of things, big data, and cloud computing to optimize farming practices. By adjusting stocking densities, feeding frequencies, and feed utilization rates, they reduce production costs (Sun et al., 2023). Additionally, data-driven analysis enables accurate prediction of fish reproduction cycles and market demand, allowing for well-timed and appropriately scaled harvesting. Third, the establishment of national marine ranch demonstration zones provides clearly defined maritime spatial rights, offering a transparent framework for policy implementation and resource allocation. Delineating maritime boundaries not only minimizes disputes but also establishes a spatial foundation for enforcing relevant policies. This ensures the sustainable utilization of marine resources, supports ecological conservation, and institutionalizes long-term fishery resource sustainability (Du and Cao, 2021). Based on this, we propose Hypothesis 1.

H1: The establishment of national marine ranch demonstration zones contributes to increased output value in marine fisheries.

Due to variations in geographic location, resource endowments, industrial foundations, and ecosystem characteristics among coastal cities across China's four major sea areas—the Yellow Sea, Bohai Sea, East China Sea, and South China Sea—the impact of national marine ranch demonstration zones on marine fishery output exhibits significant regional heterogeneity (Shen and Hu, 2017). Specifically, in terms of geographic location and marine habitats, the four major sea areas exhibit distinct ecosystem characteristics due to variations in water temperature, sunlight exposure, and climate. The South China Sea, located in low latitudes with a tropical climate, features year-round high temperatures, abundant rainfall, and sufficient sunlight, resulting in relatively shorter growth cycles and faster reproduction rates for marine organisms. The Yellow Sea and Bohai Sea, situated in mid-latitudes with a temperate monsoon climate, experience lower winter seawater temperatures and pronounced seasonal variations, leading to more seasonal impacts on marine life growth and reproduction. In terms of fishery resource endowments, coastal cities across different marine areas exhibit distinct patterns of resource distribution and reserves: coastal cities in the East China Sea region concentrate their fishery resources in nearshore waters, where abundant marine biological resources support annual catch volumes and aquaculture yields that rank among the highest nationwide; meanwhile, coastal cities along the South China Sea possess fishery resources primarily distributed in offshore waters, where economically valuable large pelagic fish species such as tuna and skipjack are relatively abundant, though these face significant harvesting challenges and high operational costs (Li et al., 2018); in contrast, the Yellow Sea and Bohai Sea regions, due to overfishing and environmental pollution, demonstrate relatively depleted fishery resource reserves, with marine capture resources showing a year-on-year declining trend, leading to a predominance of mariculture in their fishery production systems (Du and Gao,

2020). In terms of industrial infrastructure, coastal cities along the Yellow Sea and Bohai Sea possess mature modern urban clusters, developed urban ecosystems, and relatively advanced industrial foundations, which enable them to secure financial and technical support for marine ranch development while simultaneously facing challenges in marine habitat restoration; benefiting from deepening openness policies, coastal cities in the East China Sea and South China Sea regions are equipped with large-scale deep-water ports and highly efficient logistics industrial chains, providing solid guarantees for policy implementation and market expansion (Xu et al., 2025a). Based on this, we propose Hypothesis 2.

H2: The impact of national marine ranching demonstration zones on marine fishery output exhibits heterogeneous characteristics.

To advance the development of modern marine ranching and support high-quality growth in marine fisheries, pilot regions have adopted a three-pronged approach focusing on integrated planning, three-dimensional development, and policy support. Guided by strategic planning principles that emphasize industrial integration and coordinated land-sea development, these regions have implemented targeted measures in “optimal site selection and layout,” “efficient resource allocation,” and “promoting industrial upgrading” (Qin and Tao, 2021). During the implementation of supporting policies, design plans, and construction schemes for the “blue granary” initiative, these efforts have not only enhanced the stability of fishery resources through improved marine ecosystems but also expanded the development potential of the fishery economy by extending industrial chains. Additionally, they have strengthened the sustainability of fishery production through marine biodiversity conservation (Geng et al., 2023). This paper will analyze these effects based on the characteristics of different impact pathways:

First, the pilot policy for national marine ranching demonstration zones primarily aims to establish marine ecological protection areas and implement marine biological restoration programs. By reducing land-based pollutant discharges into the sea, it effectively improves marine ecological conditions, protects marine biodiversity, and enhances the stability of marine ecosystems. These measures collectively ensure the steady growth of fishery resources and increase marine fishery yields (Wei and Wang, 2021). Additionally, reducing pollutant emissions helps improve seawater quality, alleviates issues of resource waste and ecological stress, and extends the stable production period of fisheries. This creates a favorable external environment for enhancing the economic benefits of marine fisheries (Du and Cao, 2021).

Second, the pilot policy for national marine ranching demonstration zones generates labor demand for marine-related industries in coastal regions and drives comprehensive development across all fishery production segments through industrial chain extension (Qin et al., 2022). On the one hand, marine fisheries have shifted from simple fishing operations and aquaculture production to a multi-level industrial chain including deep processing of aquatic products, logistics transportation, scientific research and development, and innovative services. By expanding emerging marine industries such as offshore fishing and

island tourism, the industrial chain has been extended, the added value of fishery production activities has been increased, and economic benefits have been enhanced (Wang et al., 2024). On the other hand, the construction of national level marine ranch demonstration zones can absorb more local residents and labor from other coastal areas, create more employment opportunities, promote local residents' employment and income growth, and further drive the economic benefits and modernization level of marine fisheries in the region (Sun et al., 2024).

Third, the conservation of marine biological resources serves as the foundation for enhancing the output value of marine fisheries in coastal regions. With the progressive advancement of national marine ranching demonstration zones, the establishment of marine biological monitoring and restoration systems has enabled the optimization of resource distribution structures and the rational regulation of fishery resource distribution and utilization intensity (Zheng and Zhang, 2024). Building upon this foundation, marine ranching development strengthens regulations for maritime enterprises and fishing operations by adopting scientific harvesting models, especially through the promotion of integrated benthic-pelagic co-culture systems and rotational aquaculture strategies—which effectively curb overfishing practices. This approach not only transforms traditional fishing methods by shifting the operational focus from merely increasing marine capture yields to developing high-value-added seafood products, thereby enhancing market competitiveness (Zhang and Sun, 2001), but also establishes a sustainable marine fishery resource management system. By ensuring the sustainable utilization of marine fishery resources, this strategy improves the economic efficiency per unit of catch, ultimately leading to a significant increase in the output value of coastal marine fisheries. The impact path is shown in Figure 1. Based on this, we propose Hypothesis 3.

H3: National marine ranch demonstration zones enhance marine fishery output in pilot cities through three synergistic mechanisms, including improving marine ecological conditions,

extending fishery industry chains, and conserving marine biological resources.

4 Methodology and data

4.1 Method selection and model construction

This study treats the pilot policy of national marine ranch demonstration zones as a "quasi-natural experiment" and employs a Difference-in-Differences (DID) model to evaluate its effects. Given that the policy was implemented in multiple batches across different years and regions, resulting in asynchronous policy shocks, traditional single-time-point evaluation methods are inadequate. Therefore, a multi-period DID approach is adopted for empirical analysis, with the baseline model specified as Equation 1:

$$MFOV_{it} = \alpha + \beta did_{it} + \omega X_{it} + \delta_i + \mu_t + \varepsilon_{it} \quad (1)$$

In this model, the dependent variable $MFOV_{it}$ represents the marine fishery output value of coastal region i in year t . The core explanatory variable did_{it} is the interaction term between a time dummy variable and a policy dummy variable. The set of control variables X_{it} includes per capita GDP ($pgdp$), gross ocean product (gop), the proportion of fishery industry ($industry$), fiscal deficit ($fiscal$), the share of agricultural share ($agriculture$), and consumer price index (cpi). City fixed effects δ_i and time fixed effects μ_t are incorporated to account for unobserved heterogeneity, while ε_{it} denotes the random error term. The primary focus of this empirical analysis is whether the coefficient β of the explanatory variable did_{it} is positive and statistically significant, as it directly reflects the impact of the national marine ranch demonstration zones on marine fishery output value. A significantly positive β indicates that the establishment of marine ranch demonstration zones effectively promotes the growth of marine fishery output, while a negative coefficient suggests an inhibitory effect.

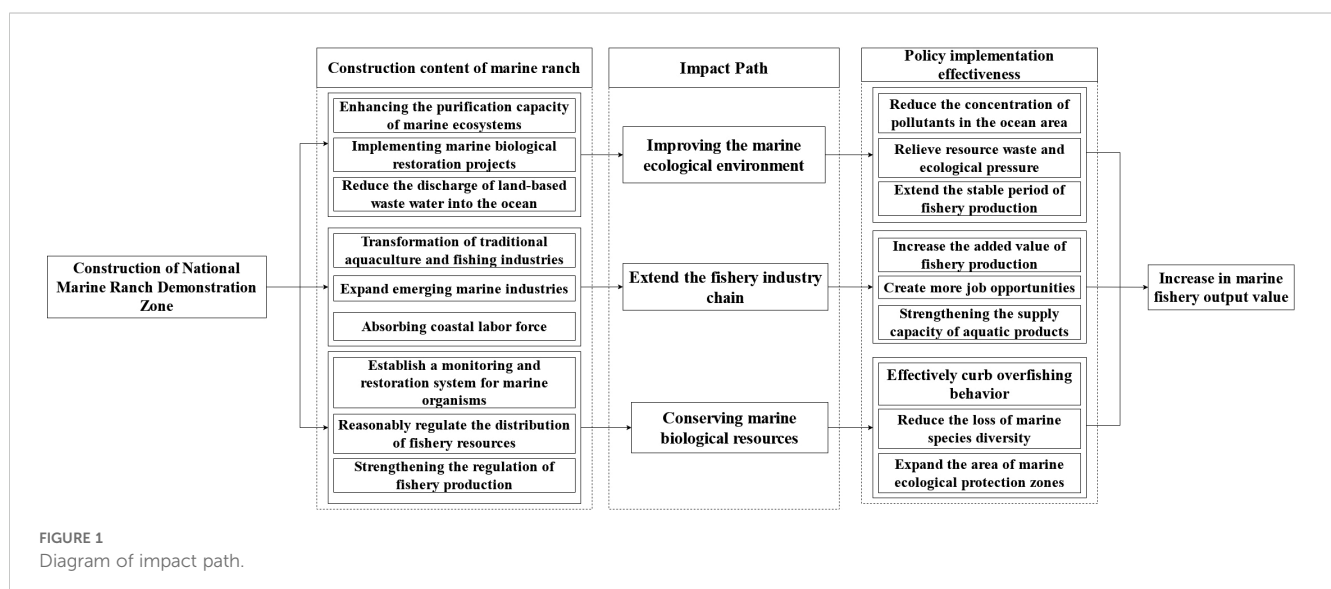


FIGURE 1
Diagram of impact path.

4.2 Indicator selection and data explanation

4.2.1 Explained variable

Marine fishery output value, as a key metric for assessing both fishery resource utilization efficiency and economic performance, not only reflects the scale and economic worth of regional fishery production but also directly indicates the productive potential of coastal fishery resources. However, existing studies predominantly rely on provincial-level fishery output data, which, while useful for capturing macro-level regional trends, often overlook inter-city spatial disparities. This limitation can lead to imprecise conclusions and subsequently compromise the effectiveness of policy formulation and implementation. To address this gap, this study shifts the analytical focus from the provincial to the prefectural level by compiling and analyzing 2007 to 2022 statistical yearbooks from coastal prefecture-level cities across China. This refined approach enables a more granular examination of the spatial distribution patterns and temporal evolution of marine fishery output values.

4.2.2 Explanatory variable

In November 2015, with the approval of the State Council, the Ministry of Agriculture issued the Notice on the Establishment of National Marine Ranch Demonstration Zones, designating 20 cities, counties and districts across Liaoning, Tianjin, Hebei, Shandong, Zhejiang, and Guangdong as China's first batch of national marine ranch demonstration zones. In December 2016, the second batch of 22 demonstration zones was announced, marking a new phase in the development of marine ranch. Afterwards, the Ministry of Agriculture successively announced the list of 111 national marine ranch demonstration zones in the third to eighth batches in December 2017, December 2018, December 2019, December 2020, January 2022, and January 2023. Based on the official lists published by the Ministry of Agriculture, this study constructs a policy group dummy variable $treat_{it}$ to indicate whether coastal city i is designated as a national marine ranching demonstration zone (assigned a value of 1 if included in the list of national marine ranch demonstration zones, otherwise 0), and a time dummy variable $post_{it}$ to reflect policy implementation status (assigned a value of 1 for the approval year and subsequent years, otherwise 0). The core explanatory variable did_{it} is the interaction term of these two dummy variables. A statistically significant positive coefficient of this interaction term in the regression analysis of marine fishery output value demonstrates that the national marine ranching demonstration zone policy significantly enhances the economic development level of marine fisheries in coastal regions.

4.2.3 Control variable

To mitigate omitted variable bias, this study controls for the following time-varying factors influencing marine fishery output value: (1) Per capita GDP ($pgdp$), calculated as the ratio of regional GDP to year-end population, reflecting regional affluence, consumption potential, and economic vitality; (2) Gross ocean product (gop), representing the foundation and performance of marine industries—as only provincial-level data are available, city-

level gop is estimated using marine GDP per unit coastline length multiplied by municipal coastline length; (3) Fishery industry share ($industry$), measured as the proportion of fishery-related manufacturing and construction in GDP. Among them, the fishery industry involves industries such as aquaculture processing, fishing equipment manufacturing, fishing feed, and fishing drugs. The construction industry includes industries such as fishing port and dock construction, artificial reef deployment, offshore and land-based aquaculture facility construction, and production auxiliary facility construction, where higher values indicate more robust industrial infrastructure; (4) Fiscal deficit ($fiscal$), expressed as the ratio of fiscal expenditure to revenue (values >1 indicate deficit); (5) Agricultural share ($agriculture$), measured as the primary industry's contribution to GDP; and (6) Consumer price index (cpi), capturing regional price levels and household purchasing power.

The summary statistics of the main variables are shown in Table 1.

4.3 Data description

This study conducts empirical analysis using data from 43 coastal cities in China spanning 2007 to 2022. The definitions, symbols, and calculation methods of key variables are presented in Table 2.

The marine fishery output data primarily originate from provincial and municipal statistical yearbooks, while data for control variables were collected from the China City Statistical Yearbook, China Marine Statistical Yearbook, China Fishery Statistical Yearbook, and China Urban-Rural Development Statistical Yearbook. Although China has 55 coastal cities (excluding Hong Kong, Macao, and Taiwan), severe data gaps in key metrics for some regions necessitated the exclusion of certain locations. To ensure data availability, completeness, and accuracy, the study ultimately utilizes data from 43 coastal cities spanning 2007 to 2022 as the final sample.

TABLE 1 Summary statistics of the main variables.

Variables	N	Mean	SD	Min	Max
<i>MFOV</i>	645	7.501	8.851	0.006	57.679
<i>did</i>	645	0.178	0.383	0	1
<i>pgdp</i>	645	59.132	38.672	50.802	203.489
<i>gop</i>	645	982.099	1080.347	589.361	5842.306
<i>industry</i>	645	23.417	9.655	21.163	43.487
<i>fiscal</i>	645	6.111	3.333	5.317	23.548
<i>agriculture</i>	645	0.099	0.077	0.086	0.610
<i>cpi</i>	645	102.275	1.548	102.180	106.900

TABLE 2 Definition and measurement methods of main variables.

Variable category	Symbol	Variable definition
Explained variable	<i>MFOV</i>	Compiled and obtained from statistical yearbooks of various provinces and cities
Explanatory variable	<i>did</i>	Multiplying virtual variables of time grouping and policy grouping
	<i>pgdp</i>	GDP/year-end total population
	<i>gop</i>	Gross ocean product
	<i>industry</i>	Output value of fishery industry and construction industry/GDP
Control variable	<i>fiscal</i>	Fiscal expenditure/fiscal revenue
	<i>agriculture</i>	Output value of primary industry/GDP
	<i>cpi</i>	Consumer price index

5 Empirical analysis

5.1 Benchmark analysis

Based on the benchmark model, this section quantitatively analyzes the impact of the national marine ranch demonstration zone pilot policy on marine fishery output value. The results are presented in Table 3, where column (1) shows regression results without control variables, while columns (2) to (4) display results

TABLE 3 Benchmark regression results.

Variables	(1)	(2)	(3)	(4)
	<i>MFOV</i>	<i>MFOV</i>	<i>MFOV</i>	<i>MFOV</i>
<i>did</i>	7.225***	2.973*	2.008***	1.574***
	(1.881)	(1.516)	(0.628)	(0.775)
<i>pgdp</i>		0.027	0.041*	0.029
		(0.030)	(0.022)	(0.026)
<i>gop</i>		0.005***	0.005***	0.005***
		(0.001)	(0.001)	(0.001)
<i>industry</i>		0.350***	0.217*	0.229**
		(0.001)	(0.109)	(0.111)
<i>fiscal</i>		0.193	-0.223**	-0.192
		(0.237)	(0.101)	(0.121)
<i>agriculture</i>		17.530*	0.622	0.108
		(9.092)	(7.283)	(7.012)
<i>cpi</i>		-0.056	-0.057**	-0.309**
		(0.066)	(0.022)	(0.151)
N	645	645	645	645
Time fixed effect	No	No	Yes	Yes
Urban fixed effect	No	No	No	Yes
R ²	0.101	0.646	0.943	0.946

The standard deviation is in parentheses; *, ** and *** represent significant at the 10%, 5%, and 1% levels, respectively.

with sequential inclusion of control variables, time fixed effects, and city fixed effects. The findings demonstrate that the estimated coefficient of the core explanatory variable *did* remains significantly positive regardless of control variable inclusion, indicating that the national marine ranch demonstration zone policy effectively promotes marine fishery output growth even after accounting for control variables, temporal effects, and regional effects, thereby validating Hypothesis H1. On the one hand, the construction for marine ranches helps optimize the structure and production efficiency of local marine fishery resources, promote the promotion of ecological aquaculture models in the fishery industry, and further empower precise management of the marine fishery industry through new technologies such as intelligent monitoring systems, breeding of high-quality seeds, and vaccine research and development; On the other hand, the implementation of the national level marine ranch demonstration zone policy has brought new development opportunities for local marine related enterprises. Through policy subsidies, enterprises can upgrade their aquatic product processing equipment, improve processing efficiency and product quality, thereby extending the industrial chain and developing high value-added products. In addition, the company actively develops the marine tourism industry by constructing fishing platforms, underwater sightseeing facilities, and other facilities. While fully developing local marine tourism resources, it promotes the coordinated development of marine fisheries, processing industries, and tourism, forming a virtuous cycle and jointly promoting the increase of marine fisheries output value.

5.2 Robust test

5.2.1 Parallel trend test

A fundamental prerequisite for applying the multi-period difference-in-differences (DID) model is satisfying the parallel trends assumption. This study employs an event study approach to test this assumption, with the validation results presented in Figure 2. Using the 7th year before policy implementation as the baseline, regression analysis was conducted for coefficients covering 7 pre-treatment years and 6 post-treatment years. The horizontal

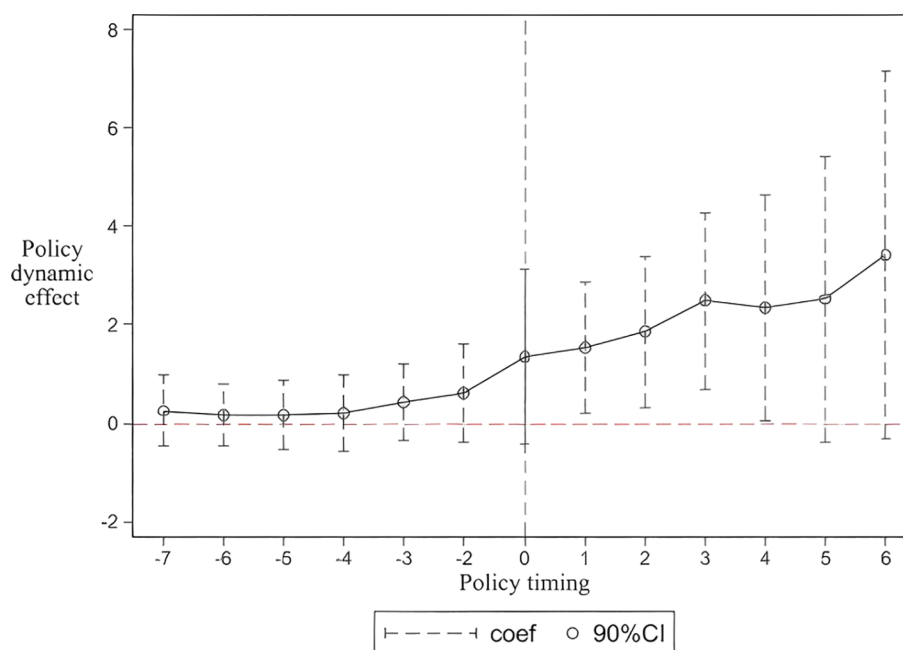


FIGURE 2
Parallel trend test.

axis represents policy timing, while the vertical axis shows dynamic policy effects (estimated coefficients β_k). Figure 2 demonstrates that all β_k estimates were statistically insignificant during the pre-policy period, confirming no systematic differences in marine fishery output between treatment and control groups prior to the intervention—thus validating the parallel trends assumption. However, the β_k coefficients became insignificant again in the 5th and 6th years after the first batch of demonstration zones were approved, likely attributable to the COVID-19 pandemic's substantial disruptions to aquatic product processing and marine tourism industries, which partially attenuated the policy effects of marine ranching development.

5.2.2 PSM-DID robustness test

The multi-period difference-in-differences approach may suffer from sample selection bias due to non-random designation of national marine ranch demonstration zones, potentially introducing endogeneity that could distort findings. To address this, we employ PSM-DID (Propensity Score Matching combined with DID) and conduct robustness checks using three matching methods: nearest-neighbor matching, kernel matching, and radius matching. Balance test results in Table 4 show that all matched covariates achieve standardized biases below 10%, failing to reject the null hypothesis of no systematic differences between treatment and control groups. PSM-DID robustness test results are shown in Table 5, the estimates consistently demonstrate statistically significant positive coefficients for the core explanatory variable *did* across all matching approaches, confirming that the marine ranch demonstration zone policy robustly enhances marine fishery output value—thereby validating the reliability of baseline regression results.

5.2.3 Placebo test

To further eliminate potential interference from random factors, this study conducts a placebo test by randomly assigning virtual treatment and control groups. Through 1000 regression simulations based on Equation 1 with randomly generated lists of pilot cities and policy implementation timelines, the distribution of parameter estimates and p-values is presented in Figure 3. The results demonstrate that the estimated coefficients of the pseudo-policy dummy variables are tightly clustered around zero, with the majority being statistically insignificant at the 10% level, and the parameter estimates align closely with the baseline regression results. These findings confirm the robustness of our empirical results, indicating that other policy changes or unobservable factors are unlikely to confound the impact of the national marine ranch demonstration zone policy on marine fishery output value.

5.2.4 Heterogeneity processing effect test

When treatment effects exhibit heterogeneity across groups and time periods, traditional multi-period difference-in-differences (DID) estimators under the two-way fixed effects (TWFE) framework may produce significant biases. To address this, our study adopts the Goodman-Bacon decomposition approach by categorizing treatment and control groups into three distinct pairwise comparisons including treated vs. never-treated groups, earlier-treated vs. later-treated groups and later-treated vs. earlier-treated groups. We separately calculate DID estimates for these subgroup combinations along with their respective weighting shares to assess the magnitude of TWFE estimator bias (Goodman-Bacon, 2021). The decomposition results are shown in Figure 4. The results reveal that potential temporal heterogeneity primarily stems from

TABLE 4 PSM-DID balance test results.

Variables		Mean		Bias/%	t-test	
		Experimental group	Control group		T	P> t
<i>pgdp</i>	U	91.356	63.697	75.0	8.38	0.000
	M	91.443	88.097	9.1	1.27	0.492
<i>gop</i>	U	1910.4	987.05	77.1	9.21	0.000
	M	1848.5	1828.2	1.7	-0.94	0.901
<i>industry</i>	U	20.874	23.918	-32.1	-3.44	0.001
	M	20.961	20.647	3.3	0.62	0.778
<i>fiscal</i>	U	5.801	5.705	3.1	0.34	0.731
	M	5.711	5.890	-6.2	-0.51	0.611
<i>agriculture</i>	U	0.085	0.088	-5.5	-0.56	0.574
	M	0.084	0.087	-4.9	-0.40	0.688
<i>cpi</i>	U	101.92	102.39	-35.0	-3.21	0.001
M	101.93	101.86	4.7	0.26	0.591	

U is before matching, M is after matching.

the “later-treated vs. earlier-treated” 2×2 DID category, which contributes relatively minor weight to the overall estimate—clustered near the zero baseline and substantially smaller than the other two comparison groups. This indicates that the “bad controls” constitute a negligible proportion and exert limited influence on the final DID results.

The Bacon decomposition results are shown in Table 6, indicate that differences attributable to “bad controls” account for only 7.9% of the total treatment effect. This minimal proportion of contaminating variation demonstrates that TWFE estimator produces limited bias when assessing the impact of national marine ranch demonstration zones on marine fishery output value, confirming the reliability of the estimated coefficients.

TABLE 5 PSM-DID robustness test.

Variables	(1)	(2)	(3)
	Neighbor matching	Kernel matching	Radius matching
<i>did</i>	1.755*** (0.743)	1.745*** (0.723)	1.718*** (0.712)
Control variable	Yes	Yes	Yes
N	509	509	495
Time fixed effect	Yes	Yes	Yes
Urban fixed effect	Yes	Yes	Yes
R ²	0.949	0.949	0.948

The standard deviation is in parentheses; *, ** and *** represent significant at the 10%, 5%, and 1% levels.

Although the Bacon decomposition confirms that baseline regression results remain largely unaffected by heterogeneous treatment effects, this study further validates their reliability by adopting the multi-period doubly robust estimator proposed by Callaway and Sant’Anna (2021). This methodology employs a doubly robust framework that: (1) stratifies samples into subgroups to estimate group-specific treatment effects, and (2) aggregates these effects using weighting strategies that reduce the influence of potentially biased subgroups. Specifically, we compute four distinct average treatment effect (ATT) metrics: equal-weighted subgroup average (*Simple ATT*), the dynamic average treatment effect of grouping weighted sum based on the time of first processing by distance (*Dynamic ATT*), the calendar average treatment effect of weighted sum based on normal year grouping (*CAverage*) and the average treatment effect of grouping weighted sum based on the time of first treatment (*GAverage*). As shown in Table 7, all four ATT measures demonstrate statistically significant positive effects at the 1% level, robustly confirming that national marine ranch demonstration zones significantly enhance marine fishery output value—thereby reinforcing the credibility of baseline findings.

5.2.5 Exclude interference from other policies

To mitigate potential confounding effects from concurrent national marine policies on the evaluation of marine ranch demonstration zones, this study employs an extended difference-in-differences (DID) model design by incorporating three categories of potentially competing national marine policies as covariates. These include national marine ecological civilization demonstration zones (established per the 2012 Indicator System for the Construction of Marine Ecological Civilization Demonstration Zones by the former State Oceanic Administration, Guohaifa [2012] No. 44), marine

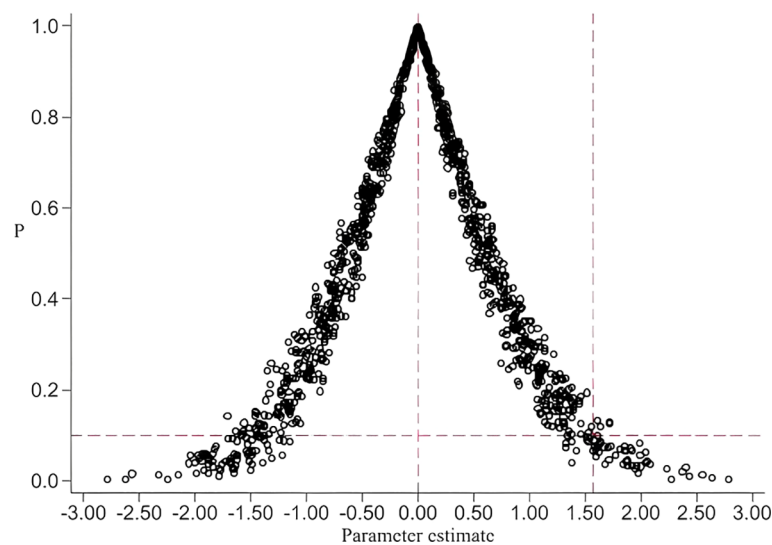


FIGURE 3
Placebo test results.

economic development demonstration zones (guided by the 2016 Directives on Promoting Marine Economic Development Demonstration Zones, Development and Reform Region [2016] No. 2702), and marine economic innovation and development demonstration cities (designated under the 2016 Notice on Central Financial Support for Marine Economic Innovation During the 13th Five-Year Plan, Caijian [2016] No. 659). As shown in Table 8, after controlling for these policy variables, the marine ranch demonstration zone policy maintains a statistically significant positive effect on marine fishery output—with coefficient directionality consistent with baseline estimates—while none of the three competing policies show significant coefficients. This confirms that no systematic relationship exists between these concurrent policies and marine fishery output, and the output enhancing effect of marine ranch zones operates independently of other national marine initiatives, with robustness tests revealing no evidence of material policy synergies or offset effects.

5.2.6 Other robustness tests

To further strengthen the credibility of our empirical findings, this study conducts multi-dimensional robustness checks and variable processing. First, to mitigate potential bias from outliers that may inflate standard errors and distort coefficient estimates, we trim the top and bottom 1% of sample data to enhance estimation stability. Simultaneously, we apply 1% winsorization to both tails to ensure data consistency and reinforce the parallel trends assumption. Second, accounting for potential time lags in policy impact realization (where positive effects on marine fishery output may emerge gradually), we implement one-period lags for both core explanatory and control variables. Third, recognizing that provincial capitals and specially designated cities often receive prioritized policy support and funding, with inherent advantages in technological capacity, industrial infrastructure, and resource endowments compared to ordinary cities, we exclude these

jurisdictions to test for sample selection bias. Finally, given the unique dynamics of marine ranch demonstrations where existing zones may amplify fishery output trends and influence new zone designation probabilities, we introduce interaction terms between original control variables and time trends using 2007 as the baseline year, then re-estimate the model. As Table 9 demonstrates, the core variable *did* maintains statistically significant positive coefficients across all specifications, with magnitude and significance levels consistent with baseline results—confirming that the marine ranch policy robustly enhances fishery output after addressing outliers, temporal lags, administrative hierarchy effects, and time-varying confounders.

5.3 Handling endogeneity issues

To address endogeneity concerns, this study employs an instrumental variable (IV) approach, selecting the coastline length of coastal prefecture-level cities (*Iv_coastline*) as the instrument. The selection rationale is twofold, on the one hand, coastline length directly determines the available marine area, providing essential spatial foundations for marine ranch demonstration zones—semi-enclosed bays and island-adjacent waters along coastlines offer logistical advantages for artificial reef deployment and ecological conservation, making them priority sites for marine ranch. On the other hand, coastline length is an inherent geographical feature formed over long-term natural processes, satisfying exogeneity requirements. Given that the endogenous explanatory variable *did* is binary, traditional two-stage least squares (2SLS) estimation is unsuitable. Instead, following Yu et al. (2024), we adopt an endogenous treatment effects model with Heckman two-stage estimation, a method particularly effective for policy evaluation with binary endogenous variables. The procedure involves: In the first stage, a Probit regression with “marine ranch demonstration

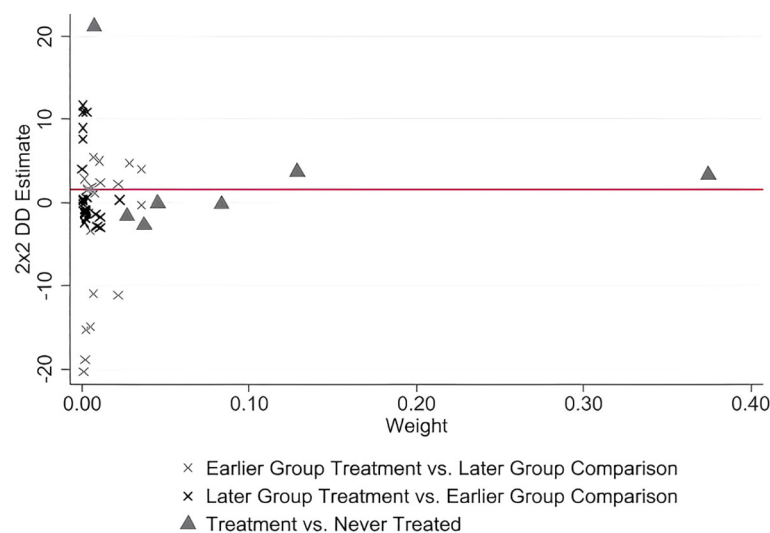


FIGURE 4
Goodman-Bacon decomposition test chart.

zone designation” as the dependent variable and the IV as the explanatory variable, yielding the inverse Mills ratio (λ). In the second stage, a regression of marine fishery output value incorporating λ as a control variable to assess the policy impact.

The instrumental variable estimation results are presented in Table 10. In the first-stage regression, a statistically significant positive correlation exists between the instrumental variable and the “marine ranch demonstration zone designation,” consistent with the theoretical justification for IV selection outlined earlier. The second-stage regression yields a significantly positive coefficient for the treatment variable (did), confirming that—after addressing endogeneity concerns—the estimated policy impact remains aligned with the baseline regression results.

5.4 Heterogeneity test

5.4.1 Regional heterogeneity test

Building on the research of Pan et al. (2024) and Zhang and Liu (2019), this study categorizes China’s coastal regions into three major maritime zones—the Yellow-Bohai Sea, East China Sea, and South China Sea for heterogeneous policy impact analysis. This zoning aligns with the Maritime Zoning Standards of the People’s Republic of China while accounting for geographical contiguity and marine ecological continuity. Specifically, the Yellow-Bohai zone integrates the Yellow Sea and Bohai Sea into a unified unit due to their shared temperate monsoon climate, semi-enclosed topography, and interconnected fishery ecosystems. The East China Sea zone encompasses the Yangtze River Delta and adjacent waters, characterized by high-intensity human activities and nearshore fishery dominance. The South China Sea zone covers tropical waters with distinct pelagic fishery resources and coral reef ecosystems. This tripartite division enables precise evaluation of how national marine ranch

demonstration zones differentially affect fishery output across regions with varying ecological-economic profiles.

The results of regional heterogeneity tests are shown in Table 11, and demonstrate that the implementation of national marine ranch demonstration zone policies has significantly increased marine fishery output in both the East China Sea and South China Sea regions, with a more pronounced effect observed in the East China Sea. However, no statistically significant impact was found for the Yellow-Bohai Sea region. From the perspective of fishery resource endowments, the East China Sea and South China Sea belong to tropical marine ecosystems characterized by abundant and diverse economically valuable fish species with wide distribution ranges. The establishment of national marine ranch demonstration zones in these regions facilitates more efficient utilization of fishery resources, not only maintaining stable supply for seafood market demand but also creating higher value-added products, thereby boosting marine fishery output. In contrast, the Yellow-Bohai Sea region features temperate marine conditions with relatively enclosed waters, lower temperatures, and more homogeneous resource endowments where economically valuable fish species are concentrated in specific areas. Comparatively, the East and South China Seas demonstrate clear advantages in terms of fish species diversity and resource potential, offering greater room for benefits when implementing national marine ranch demonstration zone policies. From an industrial upgrading and market competition standpoint, the East and South China Sea regions benefit from stable market demand and more predictable price trends for their economically valuable fish species, enabling greater capacity for optimizing the benefits of marine ranch demonstration zone development. Moreover, compared to the Yellow-Bohai Sea region which primarily relies on traditional aquaculture methods, the East and South China Sea regions - with their deeper adoption of modern fishery technologies - can further amplify their scientific innovation capabilities through national marine ranch demonstration zone

TABLE 6 Goodman-Bacon decomposition result.

Control group types	Weight	Estimate
Treated vs. never-treated groups	0.703	2.462
Earlier-treated vs. later-treated groups	0.218	0.115
Later-treated vs. earlier-treated groups	0.079	0.582
DID weighted estimation result	1.659	

construction, achieving the dual goals of quality improvement and efficiency gains in marine fishery production.

5.4.2 Heterogeneity test of marine ranch types

Given significant variations in coastal marine areas, climatic conditions, and ecological environments, the objectives, functional orientations, ecological impacts, and management approaches of marine ranch demonstration zones differ substantially across regions. In accordance with the 2019 National Marine Ranch Demonstration Zone Management Guidelines, this study categorizes marine ranches into three functional types including conservation-oriented, enhancement-oriented, and recreation-oriented. Introduce variables that represent differences in types to test this, where *yh*, *zz*, and *xx* respectively represent the number of coastal cities that approved the establishment of conservation-oriented, enhancement-oriented, and recreation-oriented marine ranches in the current year. By interacting these type-differentiated variables with the policy treatment indicator, we construct a triple-difference model to isolate the heterogeneous effects of marine ranch policies across functional categories.

The marine ranch type heterogeneity test results are showed in Table 12, they reveal differential impacts of demonstration zone policies on fishery output across functional categories: while enhancement-oriented and recreation-oriented marine ranches show statistically significant positive coefficients, conservation-oriented ranches exhibit a significantly negative coefficient—indicating output suppression effects. From an ecological economics perspective,

TABLE 7 Estimation of CSDID treatment effect.

Variables	(1)	(2)	(3)	(4)
Simple ATT	2.010***			
	(0.939)			
Pre_avg		0.187		
		(0.207)		
Post_avg		2.471***		
		(1.128)		
CAverage			1.841***	
			(0.874)	
GAverage				1.756***
				(0.775)

The standard deviation is in parentheses; *, ** and *** represent significant at the 10%, 5%, and 1% levels.

TABLE 8 Test after excluding interference from other policies.

Variables	Estimate
<i>did</i>	1.629**
	(0.753)
National marine ecological civilization demonstration zones	-1.169
	(0.989)
Marine economic development demonstration zones	-0.013
	(1.590)
Marine economic innovation and development demonstration cities	1.380
	(1.485)
Control variable	Yes
N	645
Time fixed effect	Yes
Urban fixed effect	Yes
R2	0.941

The standard deviation is in parentheses; *, ** and *** represent significant at the 10%, 5%, and 1% levels.

conservation-oriented marine ranching prioritizes marine environmental restoration and ecological conservation, aiming to safeguard marine biodiversity and protect endangered species through habitat reconstruction and preservation of natural spawning grounds. Its core rationale involves consciously sacrificing short-term economic gains for long-term ecological dividends via high-proportion environmental investments and rigorously designed fishing moratoriums. On one hand, conservation-oriented ranching allocates a higher share of total investment to ecological restoration. According to the 2023 Ministry of Agriculture and Rural Affairs Notice on Adjusting the Seasonal Fishing Moratorium System (Nongbanyu [2025] No. 13), at least 70% of project funds must be dedicated to artificial reef construction, directly crowding out productive investments and limiting short-term expansion of fishing and aquaculture capacity. On the other hand, to rebuild population resources, such ranching typically implements extended seasonal fishing bans—per the same notice (Ministry of Agriculture and Rural Affairs [2023] No. 1), conservation-oriented marine ranching requires moratorium periods of approximately 123 to 137 days. While effectively curbing overfishing, these prolonged bans also reduce fishing frequency and intensity, directly depressing short-term fishery output. In contrast, enhancement-oriented marine ranching, though also deploying artificial reefs, focuses investments on boosting resources and direct production of specific commercial fish species, while recreation-oriented models channel resources into cultural-tourism facilities to enhance service-based output. Both types prioritize economically returns-driven sectors, making their policies more likely to deliver short-term positive impacts on fishery output or related industry revenues, with demonstration zones exhibiting more pronounced production-boosting effects. This trade-off exemplifies the “delayed return” characteristic of ecological economics, where temporary suppression of economic activity is exchanged for enhanced ecosystem services, ultimately laying the foundation for

TABLE 9 Other robustness tests.

Variables	(1) Cut off by 1%	>(2) 1% winsorization	>(3) one-period lags	>(4) Exclude provincial capitals and separately planned cities	>(5) Consider the trend of time
<i>did</i>	1.457*** (0.753)	1.450* (0.767)	1.454* (0.857)	1.530* (0.788)	2.030** (0.859)
Control variable	Yes	Yes	Yes	Yes	Yes
N	632	645	645	525	645
Time fixed effect	Yes	Yes	Yes	Yes	Yes
Urban fixed effect	Yes	Yes	Yes	Yes	Yes
R2	0.943	0.946	0.941	0.932	0.930

The standard deviation is in parentheses; *, **, and *** represent significant at the 10%, 5%, and 1% levels.

sustainable long-term ecological benefits. These findings conclusively validate Hypothesis H2.

5.5 Analysis of mediating effect

Building upon the theoretical framework analyzing the mediating mechanisms between national marine ranch demonstration zone policies and marine fishery output value, this study demonstrates that the establishment of these demonstration zones enhances fishery production through three interconnected pathways: reducing marine pollution while restoring and protecting marine ecosystems, thereby increasing the availability of high-quality fishery resources; effectively curbing overfishing to maintain marine biodiversity and promote sustainable utilization of fishery resources; and expanding employment opportunities, developing tertiary industries, extending fishery industry chains, scaling up production, and advancing aquaculture technologies to optimize resource utilization patterns. Accordingly, this paper examines how national marine ranch demonstration zones improve marine fishery output by focusing on three key aspects including enhancing marine ecological environments, extending fishery industry chains, and conserving marine biological resources - and constructs a mediation effects model, as shown in Equations 2 and 3 by introducing mediating variables based on Equation 1. For mediator selection: following Li et al. (2018), five marine pollution indicators are used to assess ecological improvements: sewage discharge volume (*sdv*), dissolved inorganic nitrogen content (*din*), active phosphate content (*po*), chemical oxygen demand (*cod*), and petroleum content (*oil*); drawing on Jin and Quan (2023), fishery industry chain extension is measured through the number of fishery practitioners (*nofe*), the proportion of aquaculture extension funding (*appl*), and the share of fishery circulation services (*fcsi*), reflecting workforce absorption, promotion investment, and service sector expansion; based on Jiao et al. (2023) and Li et al. (2022a), marine fishing intensity is evaluated by marine fishery yield (*mfy*), while marine protected area ratio (*mpa*) with 2007 as the baseline represents protected area changes, and permitted sea use area ratio (*lpe*) serves as a proxy for marine biodiversity loss, as human maritime activities directly encroach upon marine species' habitats.

$$M_{it} = \alpha + \gamma_1 did_{it} + \omega_1 X_{it} + \delta_i + \mu_t + \varepsilon_{it} \tag{2}$$

$$MFOV_{it} = \alpha + \beta did_{it} + \gamma_2 M_{it} + \omega_2 X_{it} + \delta_i + \mu_t + \varepsilon_{it} \tag{3}$$

The regression results of the mediating effect on improving the marine ecological environment are shown in Table 13. The coefficient of influence of the core explanatory variable *did* on various marine pollutant indicators is significantly negative, indicating that the promotion of pilot policies for national marine ranch demonstration zones can improve the marine ecological environment and drive a significant increase in marine fishery output by reducing marine sewage discharge and lowering the concentration of marine pollutants. The construction of the marine ranch demonstration zones significantly reduce the concentration of pollutants in the sea area and strengthen the

TABLE 10 Estimation results using instrumental variable method.

Variables	(1)	(2)
	First stage (<i>did</i>)	Second stage:MFOV
<i>did</i>		2.645***
		(0.653)
<i>Iv_coastline</i>	0.043***	
	(0.007)	
λ		-20.955**
		(8.657)
Control variable	Yes	Yes
N	645	645
Time fixed effect	Yes	Yes
Urban fixed effect	Yes	Yes

The standard deviation is in parentheses; *, ** and *** represent significant at the 10%, 5%, and 1% levels.

purification capacity of the marine ecosystem through the implementation of strict marine environmental protection measures. The improved marine ecosystem not only optimizes the health status of fish species, but also enhances the quality of aquatic products, stimulates consumers' demand for fresh, healthy, and environmentally friendly aquatic products, thereby promoting product sales and economic benefits. High quality aquatic products can also attract more high-end markets and international customers, further promoting the growth of fishery output value.

The mediation effect regression results for extending fishery industry chains in Table 14 show statistically significant positive

TABLE 11 Regional heterogeneity test results.

Variables	(1)	(2)	(3)
	Yellow-Bohai	East China Sea	South China Sea
<i>did</i>	-0.039	4.054***	0.434*
	(0.363)	(1.501)	(0.230)
Control variable	Yes	Yes	Yes
N	195	195	255
Time fixed effect	Yes	Yes	Yes
Urban fixed effect	Yes	Yes	Yes
R^2	0.803	0.761	0.737

The standard deviation is in parentheses; *, ** and *** represent significant at the 10%, 5%, and 1% levels.

coefficients across all indicators of industrial chain expansion, demonstrating that the establishment of national marine ranch demonstration zones creates substantial employment opportunities for coastal fishery practitioners. The operation and management of these zones require a large number of skilled professionals, not only attracting local fishermen but also enhancing the overall expertise and competitiveness of the workforce through targeted training programs, thereby improving fishery production efficiency. Simultaneously, increased funding for aquaculture promotion reflects stronger governmental support for advanced mariculture techniques. By optimizing the allocation of these funds and disseminating high-efficiency aquaculture technologies, the zones

TABLE 12 Heterogeneity test results of marine ranch types.

Variables	(1)	(2)	(3)
	conservation-oriented	enhancement-oriented	recreation-oriented
<i>did</i>	1.259**	0.297	0.742***
	(0.511)	(0.658)	(0.643)
<i>did</i> × <i>yh</i>	-0.824**		
	(0.334)		
<i>did</i> × <i>zz</i>		1.108***	
		(0.189)	
<i>did</i> × <i>xx</i>			1.639***
			(0.583)
Control variable	Yes	Yes	Yes
N	645	645	645
Time fixed effect	Yes	Yes	Yes
Urban fixed effect	Yes	Yes	Yes
R^2	0.956	0.928	0.952

The standard deviation is in parentheses; *, ** and *** represent significant at the 10%, 5%, and 1% levels.

TABLE 13 Mediating effect analysis: improving the marine ecological environment.

Variables	(1)	>(2)	(3)	(4)	(5)
	sdv	din	po	cod	oil
<i>did</i>	-2.879*** (1.206)	-0.082*** (0.028)	-0.004*** (0.002)	-0.246** (0.121)	-0.006** (0.618)
Control variable	Yes	Yes	Yes	Yes	Yes
N	645	645	645	645	645
Time fixed effect	Yes	Yes	Yes	Yes	Yes
Urban fixed effect	Yes	Yes	Yes	Yes	Yes
R^2	0.704	0.932	0.668	0.697	0.792

The standard deviation is in parentheses; *, ** and *** represent significant at the 10%, 5%, and 1% levels.

significantly boost output-input ratios and shorten production cycles, ultimately enhancing economic returns. Furthermore, the growing proportion of fishery circulation services stabilizes and enhances product supply capacity while reducing logistics costs, thereby extending the entire production-to-consumption value chain. Emerging service sectors, such as marine tourism, recreational fishing, and fishery finance, not only generate additional output value but also stimulate complementary industries like catering, hospitality and transportation, fostering an integrated fishery economic ecosystem.

The regression results of the mediating effect on the conservation of marine biological resources are shown in Table 15. The coefficient of the core explanatory variable *did* has a positive and significant impact on the change in the area of marine protected areas, while the coefficient of the impact on the intensity of marine fishing and the loss of marine species diversity is negative and significant. This indicates that the construction of marine ranch demonstration zones can promote the expansion of marine protected areas, while curbing overfishing, reducing species diversity loss, and further conserving marine biological resources. On the one hand, the construction of national marine ranch demonstration zones includes planning for the protection and restoration of marine habitats. By establishing marine protected zones, the habitats and ecological networks of marine organisms can be effectively protected. The expansion of such protected zones not only limits the damage of human activities to the marine environment, but also provides a safer living space for marine organisms. On the other hand, strict fishing restrictions such as annual catch limits and specific area bans are usually implemented in national marine ranch demonstration zones, which can effectively curb overfishing, protect the population and ecological balance of marine organisms, reduce overexploitation of marine resources, and mitigate the negative impact on species diversity. Through scientific fishing strategies, excessive consumption of marine resources can be reduced, thereby extending the survival cycle of marine organisms and improving the efficiency and yield of fisheries production. In summary, hypothesis H3 is confirmed.

6 Discussion

The development of marine ranch worldwide has now transcended its original purpose of merely boosting fishery yields within individual nations, emerging as a pivotal vehicle for restructuring the blue economy value chain and tackling shared oceanic challenges. In the United States, marine ranch primarily serves as the implementation platform for the National Artificial Reef Program, catalyzing the expansion of marine tourism, recreational fishing industries, and simultaneously alleviating pressures on fisheries (Johnson et al., 2019). Norway has developed diversified aquaculture models within its marine ranch initiatives to address climate change threats, employing intelligent feeding systems and disease prevention technologies to reduce per-unit farming costs (Falconer et al., 2024). Japan executes its “cultivation fishery” projects through marine ranch, leveraging the synergy between artificial reefs and seedstock enhancement to amplify marine resource restoration efficiency and achieving a dual win of coastal environmental protection and increased income for fishing communities (Okumura et al., 2022). South Korea’s oyster reef ranch along its eastern coast utilizes multi-tiered hanging aquaculture frames to dramatically boost oyster yield per hectare compared to traditional methods, thereby mitigating shellfish resource crises caused by mangrove destruction (Kang et al., 2021). Australia, through government-led macro-regulation and policy pilots, drives iterative technological and methodological upgrades in marine ranch (Ruff et al., 2023). These nations’ practices in developing marine ranch to stimulate marine economies provide invaluable insights for China’s progressive establishment of marine ranch demonstration zones. Concurrently, the global trade network underpinned by maritime interconnectivity plays a crucial role in China’s national marine ranch development. On one front, China’s promotion of green port infrastructure, energy-efficient vessels, and intelligent navigation management has effectively minimized oil pollution, noise disturbances, and biofouling threats from shipping activities in core ranch areas, significantly improving marine environmental quality and laying the groundwork for coastal cities to secure approvals for demonstration zones (Xu and Chen, 2025; Wang et al., 2025). On another front, China’s diversified logistics channels for seafood exports enable marine ranch products to efficiently access emerging markets like Central Asia and Central-Eastern Europe. Through deep integration into global ocean governance collaboration networks, China systematically imports Nordic deep-sea intelligent cage technologies and industrialized recirculating aquaculture concepts, developing localized high-efficiency breeding and disease control solutions tailored to indigenous ecological characteristics (Xu et al., 2025b; Guo et al., 2025).

Against the backdrop of profound transformations in global ocean governance and China’s comprehensive advancement of its maritime power strategy, China has prioritized the development of modern “blue granaries” as a key initiative, vigorously expanding marine ranch and achieving remarkable phased outcomes. These achievements are

TABLE 14 Mediating effect analysis: extending the fishery industry chain.

Variables	(1)	(2)	(3)
	nofe	appl	fcsi
<i>did</i>	0.060***	0.157***	0.062***
	(0.015)	(0.065)	(0.013)
Control variable	Yes	Yes	Yes
N	645	645	645
Time fixed effect	Yes	Yes	Yes
Urban fixed effect	Yes	Yes	Yes
<i>R</i> ²	0.744	0.869	0.922

The standard deviation is in parentheses; *, ** and *** represent significant at the 10%, 5%, and 1% levels.

manifested in the systematic shift from nearshore to deep-sea operations, significant enhancements in ecological and intelligent capabilities, and large-scale improvements in marine biodiversity proliferation. However, challenges persist, including severe overfishing in certain waters, critical marine ecological degradation, and the lingering issues of extensive aquaculture practices and pollution displacement. To assess the implementation effectiveness and impact mechanisms of national marine ranch demonstration zone policies, our study employs panel data from 43 coastal prefecture-level cities in China to explore the influence of marine ranch development on fishery output through multidimensional analysis. Our research contributes to the literature in two significant dimensions:(1) Existing studies on marine ranch and fishery output primarily rely on case analyses, lacking empirical models to evaluate policy effectiveness, and most remain at the provincial level without accounting for coastal cities’ disparities in economic development, industrial structure, and innovation capacity. By shifting the analytical focus to coastal prefecture-level cities, we employ a difference-in-differences model to quantitatively assess how environmental regulations impact marine pollution in coastal areas (Tian et al., 2025; Xiao et al., 2025). Findings reveal that the development of marine ranch demonstration zones significantly boosts fishery output. Consequently, coastal cities should fully implement such demonstration projects, establishing integrated systems encompassing intelligent deep-sea cages, large-scale ranch platforms, artificial reef complexes, ecological monitoring networks, and land-based support facilities. This approach enhances both per-unit sea area productivity and ecological carrying capacity, transforming marine ranch into multifunctional hubs for ecological restoration, germplasm conservation, and disaster mitigation.(2) Research on marine ranch outcomes often narrowly focuses on direct marine habitat restoration, rarely examining how geographical contexts and ranch typologies shape fishery output across coastal cities. Using a triple-difference model, we identify heterogeneous policy impacts: The magnitude of fishery output enhancement varies across marine zones due to chain effects of climate change, fish species distribution, and seawater temperature fluctuations, while divergent development priorities among ranch types further diversify policy outcomes. Thus, regional customization and precision management are imperative in policy design. This requires comprehensively accounting for local environmental uniqueness and

TABLE 15 Mediating effect analysis: conserving marine biological resources.

Variables	(1)	(2)	(3)
	mfy	mpa	lpe
<i>did</i>	-1.449**	0.864***	-0.129***
	(0.618)	(0.414)	(0.035)
Control variable	Yes	Yes	Yes
N	645	645	645
Time fixed effect	Yes	Yes	Yes
Urban fixed effect	Yes	Yes	Yes
<i>R</i> ²	0.758	0.563	0.755

The standard deviation is in parentheses; *, ** and *** represent significant at the 10%, 5%, and 1% levels.

species adaptability, while enhancing research on climate resilience and establishing real-time monitoring systems. These measures are essential for optimizing resource allocation, strengthening policy robustness, ensuring long-term sustainability, and maximizing marine ranch’s contributions to fishery economies.

7 Conclusions

This study treats the implementation of national marine ranch demonstration zones as a quasi-natural experiment, utilizing panel data from 43 coastal prefecture-level and higher cities in China from 2007 to 2022 to examine the impact and mechanisms of marine ranch development on fishery output through a multi-period difference-in-differences model. Key findings include: First, the demonstration zone policy significantly promotes local marine fishery output growth, this conclusion that remains true across multiple robust tests. Second, the policy exhibits marked regional heterogeneity, with coastal cities in the East China Sea and South China Sea regions demonstrating stronger economic benefits due to their abundant fish species diversity, favorable climatic conditions, and advanced port infrastructure. In addition, the increase in output value of breeding type and leisure type marine ranches is more significant compared to maintenance type.Third, marine ranch zones enhance fishery output sustainability through three synergistic pathways: improving marine ecosystems, extending fishery industry chains, and conserving marine biodiversity, thereby driving high-quality development in the fishery economy.

Based on the aforementioned findings, this study proposes the following policy recommendations:

1. Improve the policy system of modern marine ranch demonstration zones. Firstly, we should strengthen the rigid constraints and incentive mechanisms for marine green development, establish a green development standard system with “ecological carrying capacity assessment ecological compensation accounting biodiversity restoration” as the core, promote the implementation of three-dimensional ecological projects such as seagrass bed restoration and artificial reef

optimization in marine ranch demonstration zones, incorporate the goal of improving carbon sequestration capacity into assessment indicators, establish a special fund for marine ranch ecological restoration, provide cost subsidies to enterprises and individuals that generate positive externalities, and simultaneously promote “ecological label certification”. We should also implement a policy of excessive purchase of aquatic products from standard ranches to guide market green consumption. Secondly, we should break through the institutional and technological bottlenecks in the large-scale development of deep-sea aquaculture, establish exclusive green channels for sea use approval in the Yellow Sea, Bohai Sea, East China Sea, and South China Sea, simplify the sea use process, and establish a national level deep-sea equipment research and development center. We will focus on tackling core technologies such as intelligent aquaculture platforms, AI monitoring systems based on satellite remote sensing, and deep-sea energy self supply devices. Thirdly, to build a diversified integrated industrial chain ecosystem of “ocean ranch+”, on the one hand, it is necessary to promote policy innovation for the integration of the tertiary industry and land use, allocate some land use in the marine ranch demonstration zones for the construction of aquatic product deep processing clusters and ocean ranch research, culture, tourism and business circles, and improve the profit sharing mechanism among the government, enterprises and fishermen; On the other hand, the “sea land relay aquaculture” and “integrated fishing, light and tourism” models (upper level photovoltaic power generation, middle level leisure fishing, and bottom level ecological aquaculture in demonstration zones) should be promoted, and a regional marine industry digital intelligence platform should be established to integrate aquaculture data, logistics traceability, and consumer demand information, achieving efficient coupling of resource supply, production logistics, and sales markets.

2. Tailored to local conditions, grasp the differences in coastal zones, and scientifically explore strategies for the construction of marine ranches that are suitable for regional characteristics. On the one hand, adaptation strategies should be formulated based on the sea zone, and a gradient regional development path should be established, for the East and South China Seas, priority should be given to establishing enhancement-oriented demonstration zones featuring deep-sea intelligent cage clusters and integrated tertiary industry complexes, with supporting policies including “National Deep-Sea Aquaculture Pilot Zone” designation accompanied by sea zone usage fee reductions and cold-chain logistics subsidies. The Yellow-Bohai Sea region requires distinct focus on conservation-oriented ranch complemented by shellfish-seaweed carbon sequestration projects and blue carbon financing instruments to offset lower output gains, alongside targeted high-value species (e.g., sea cucumbers, abalone) stock enhancement programs supported by land-based breeding centers to improve per-unit-zone productivity. Strategic optimization of demonstration zone typologies should expand enhancement and recreation-

oriented models, utilizing the former to rebuild baseline resources while the latter boosts value through recreational fishing infrastructure, while integrating conservation zones with premium species projects through eco-label premium mechanisms that translate ecological value into market returns. In terms of operation mode, we will promote the “community cooperative led+professional operator contracting” model, with the government providing composite sea area use rights confirmation, and using commercial profits to support ecological maintenance, ultimately forming a virtuous cycle system of maintenance with compensation, proliferation with market, and leisure with brand.

3. Actively explore the diversified development path of “ecological restoration industrial integration resource proliferation” as a trinity. For marine ecological improvement, multifunctional ranch zones should be prioritized in eutrophic estuaries and bays by establishing shellfish-seaweed symbiosis systems that leverage the synergistic water-purifying effects of filter-feeding bivalves and macroalgae, combined with deployment of multifunctional artificial reefs to optimize benthic habitats and create high-productivity grounds for commercial species. To extend fishery value chains, innovative land-sea integration models should be developed through port-side processing centers that transform raw marine ranch products into premium categories like ready-to-eat seafood and bioactive compounds, complemented by offshore recreational tourism and fishing experience programs to establish full-chain value enhancement from production to consumption. For marine resource conservation, a dynamic balance mechanism should be implemented by designating core protection zones in critical habitats, employing smart monitoring to quantify recovery outcomes, and exploring market-based compensation tools like eco-label certification and carbon credit trading with regulated ecological harvesting permitted only when target populations reach sustainable thresholds. In addition, we should strengthen policy coupling and institutional innovation, establish a three-dimensional layered development and management system for sea areas, allow for the spatial overlap of ecological restoration, proliferation production, and leisure tourism functions, form cross regional industrial consortia to integrate seedlings, equipment, logistics, and other elements, build an ecological origin product traceability system, and through quality premium feedback on maintenance investment, ultimately form a new pattern of improving the quality and efficiency of marine fishery production capacity through ecological optimization laying the resource foundation, processing and extending product value, and scientific maintenance ensuring sustainable output.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

ZW: Writing – original draft, Formal analysis. JM: Writing – original draft, Data curation. YZ: Writing – original draft, Software. QH: Writing – review & editing, Funding acquisition.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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