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# The evolution of food and nutrition supply patterns of marine capture and mariculture in China and its transformation coping strategies

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This study examines the shift in China's seafood production, revealing that mariculture has surpassed marine capture as the primary source of marine food. The research aims to assess the roles of marine capture and mariculture in meeting rising food demand and ensuring nutrition security, given the limitations of land-based food production. Using data from 2003 to 2021, the study highlights several key trends: mariculture, focused on shellfish and algae, now outpaces marine capture, which remains centered on fish and crustaceans. Significant regional disparities are observed, with mariculture expanding rapidly in several coastal provinces as marine capture declines. Nutrient supply from marine capture has followed a three-phase pattern of growth, stagnation, and decline, while mariculture's nutrient output has steadily increased, particularly in protein. By 2019-2020, mariculture surpassed marine capture in energy and protein supply, though fat supply remains lower. Regional differences in nutrient supply show mariculture leading in multiple provinces. The study concludes by recommending strategies to promote sustainable, diverse, and environmentally friendly practices for China's marine food systems.

KEYWORDS

**marine fishery, marine capture, mariculture, transformation strategy, China, seafood**

## 1 Introduction

Seafood is a critical component of the global food system (Farmery et al., 2022), providing essential animal protein and micronutrients such as fatty acids and vitamins, which play a vital role in ensuring regional food and nutrition security (FAO, 2018). Despite this, global food security policies have predominantly focused on terrestrial agriculture systems, with limited attention to seafood production. Consequently, many countries have not fully integrated seafood into their national or regional food security frameworks (FAO, 2022; Koehn et al., 2017). The prolonged intensive use of terrestrial cropland systems, coupled with rapid population growth, has exacerbated land degradation and strained water and soil resources, making further expansion of land-based food systems increasingly challenging (Costello et al., 2020). The ocean, as a crucial resource for human survival and development, offers not only a sustainable source of food but also more environmentally friendly production methods compared to terrestrial animal-source foods (Gephart et al., 2021; Tigchelaar et al., 2022) Marine capture and mariculture represent the two primary methods of seafood production and are core components of marine fisheries. As the world leader in both marine capture and mariculture, China's evolving marine fisheries have substantial global implications (Shao and Dong, 2020).

Existing research on China's marine capture industry primarily addresses resource assessment, biodiversity, governance, policy evaluation, and the socioeconomic impacts on retired fishermen (Chen et al., 2020; Gao et al., 2021; Hang, 2018, 2018; Huang et al., 2022; Liang et al., 2020; Mallory, 2013; Wang et al., 2022; Zhang et al., 2022), Studies on mariculture focused on spatial utilization, green aquaculture efficiency, and the economic value of carbon sequestration (Feng et al., 2020; Hou et al., 2020; Liu et al., 2023; Qiu et al., 2022; Wang and Ji, 2017; Xu et al., 2022; Zhang et al., 2017), While this research has significantly contributed to the conservation and management of fisheries resources, it often overlooks the broader food security implications of seafood and the nutritional differences between marine capture and mariculture products. Given the growing pressures of climate change, ecological degradation, and shifting food consumption patterns, China's marine capture and mariculture industries are at a critical juncture, requiring a transformation towards greater sustainability, diversity, and ecological balance (Dong et al., 2022; FAO, 2022; Fu et al., 2022; Melnychuk et al., 2021; Xu et al., 2020). However, current studies remain fragmented, lacking a comprehensive analysis of how these industries can adapt to future challenges., and the existing results are scattered and lack systematic research on the coping strategy of transformation.

In this study, we position seafood as a fundamental component of the broader agri-food system and analyze the supply patterns of marine capture and mariculture in China from 2003 to 2021. By examining the differences in food composition, nutritional value, and regional distribution, we propose strategies for transforming China's marine fisheries to enhance their contribution to national and regional food and nutrition security. Our findings aim to provide scientific guidance for optimizing seafood production, improving its nutritional value, and ensuring a sustainable role for marine fisheries in the future.

The following sections outline the content of this study: Section 2 presents the research methods and data, Section 3 presents the results, Section 4 discusses the findings, and Section 5 concludes with recommendations.

# 2 Materials and data

## 2.1 Food nutrient transformation model

The diversity of seafood species, along with the comparison of regional differences in marine capture and mariculture food supply, is critical for understanding the spatial distribution and production structure of seafood supply. This understanding provides essential guidance for policy formulation and adjustment. However, the nutritional composition of different food types varies significantly. Simply aggregating the output weight of different foods to represent the food supply disregards the nutritional differences between them (Yin et al., 2022a). Which deviates from the current trend in China's dietary structure transitioning from "eating enough" to "eating well," "eating healthily," and "eating nutritiously" (Shi et al., 2022). For this reason, this paper converts a variety of seafood products into nutrients with the same efficiency and uniform units by means of the food nutrition transformation model, which has the advantage of differentiating food nutrient differences and comparable properties (Yin et al., 2022b). Since there are many nutrients in food and it is impossible to count them all, based on their importance and availability and with reference to relevant research results (Liu et al., 2021; Yin et al., 2022c), this paper selects three major nutrients of food, namely energy, protein, and fat. The calculation formula is as follows:

$$NS_{i,j} = \sum FY_{i,k} \times EP_k \times NPUF_{k,j}$$

where *NS* represents the nutrient supply; *FY* represents the food yield; *EP* represents the edible proportion; *NPUF* represents the nutrient per unit of food; *i* represents 11 provinces in China's coastal areas; *j* represents the nutrients, i.e., energy, protein, and fat; *k* represents the food type.

## 2.2 Data

Data on seafood yields were taken from the China Fisheries Statistical Yearbook, where there are 45 types of marine capture foods and 42 types of mariculture foods. Data on seafood nutrition composition comes from China Food Composition Tables: Standard Edition (6th Edition), Vol. 1 and Vol. 2, compiled by the National Institute for Nutrition and Health, Chinese Center for Disease Control and Prevention. According to the results of the second and third agricultural data census in China, adjustments to national aquatic product production data were made by the relevant government departments from 1997—2005 and 2012—2015, and the data of marine capture and mariculture production were corrected in this paper using the method of equal proportional distribution.

# 3 Result

## 3.1 Evolutionary characteristics of food supply patterns for marine capture and mariculture

### 3.1.1 Temporal changes in food supply for marine capture and mariculture in China

The total supply from China's marine capture fisheries has shown a trend of initial growth followed by a decline, with fish and crustaceans being the major contributor (Figure 1). From the change of total supply, the supply of marine capture food in China from 2003 to 2015 is growing slowly, with an average

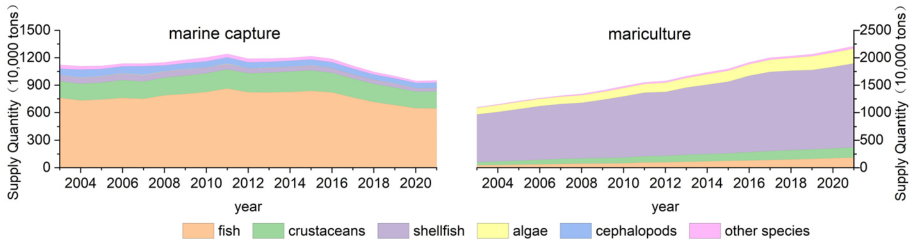


FIGURE 1
Changes of food supply in marine capture and mariculture in China from 2003 to 2021.

annual growth rate of 0.68%, and the peak in 2011 at 12.42 million tons. However, from 2016 to 2021, the supply exhibited a significant decline, dropping from 11.87 million tons in 2016 to 9.51 million tons in 2021, with an average annual decrease of 4.53%. of 4.53%. These trends indicates that China's marine capture fisheries have passed the rapid growth phase and entered a stage of stable production. With the implementation of resource protection policies such as reducing production and limiting quantity, the intensity of marine capture is gradually restricted, and the resources of offshore fishery stocks are beginning to recover. In terms of specific species, fish is the most important species of marine capture, supplying between 6.45 million and 8.64 million tons, followed by crustaceans, supplying between 1.81 million and 2.25 million tons. Fish and crustaceans accounted for 66.09%~69.57% and 16.19%~19.56% of the total catch respectively, both of which showed a trend of first rising (2003—2015) and then falling (2016—2021), precisely so that the changes in the supply of fish and crustacean catch dominates the change trend of total marine capture supply first increases and then decreases. Other species such as cephalopods, shellfish and algae species made relatively smaller contributions, with none exceeding 1 million tons.

The total supply of mariculture-produced food in China has shown a steadily increasing trend. Among the categories, shellfish and algae represent the largest supply volumes, while the growth rate of fish production has been particularly rapid. From the total supply changes, the supply of mariculture food grew from 10.96 million tons in 2003 to 22.11 million tons in 2021, with an average annual growth rate of 3.98%, doubling the supply, which shows the rapid development of China's mariculture industry from 2003 to 2021, and the amount of food supplied continues to grow. In terms of specific species, shellfish is the most dominant species of mariculture, the average annual growth rate is 3.23%, the supply accounts for 69.02%~78.62% of the total amount of mariculture food, but the proportion is gradually declining, a total decrease of 9.6 percentage points in 19 years. The second is algae, the supply of which is also gradually growing, with an average annual growth rate of 4.59%, and the supply proportion is stable at about 11%. Compared with marine capture, fish mariculture is smaller, but the growth rate is relatively fast, with an average annual growth rate of 8.10%, and the ratio of fish aquaculture to catch has increased from 5.96% in 2003 to 28.58% in 2021. The supply of crustaceans and other species of mariculture is small, but the growth is relatively fast, with an average annual growth rate of 6.69% and 8.47%, respectively.

In terms of total volume, the food supply from mariculture in China has surpassed that of marine capture, making it the primary source of marine-derived food. Comparing the changes in food supply of the two production methods, we can find the transformation characteristics of China's marine fisheries at this stage, that is, the gradual decline of marine capture food supply and the continuous growth of mariculture food supply. On the one hand, the decline in marine fishery catch aligns with increasing calls for the sustainable development of marine fishery resources. Overfishing has made it difficult to maintain a high supply of marine fishery resources, and the reduction in catch reflects the limits of the ocean's ecological carrying capacity (Su et al., 2020). On the other hand, the increase in mariculture production is related to advancements in aquaculture technology and management practices. In recent years, China's mariculture industry has benefited from significant improvements in these areas, particularly with the rapid adoption of deep-sea intelligent cages and the active promotion of the "mariculture + offshore wind power" integrated model. This industry has received strong support from both the government and private enterprises, leading to rapid growth. This is not only in line with the strategic adjustment direction of China's fishery industry, which is "Aquaculture is the main supply of aquatic products, supplemented by fishing", but also conducive to reversing the declining trend of fishery resources, relieving the pressure of terrestrial food production, enhancing the resilience of marine fishery development, and restoring offshore fish habitats and diversity. At the same time, marine capture food is mainly fish and crustaceans, while mariculture food is mainly shellfish and algae, and this complementary food production structure is also helpful to meet the diversified needs of residents' food diets.

### 3.1.2 Spatial-temporal evolution of food supply for marine capture and mariculture in coastal areas of China

In terms of temporal trends, the marine capture food supply in many coastal regions of China has shown a declining pattern, while the supply from mariculture has exhibited an upward trend (Figure 2). Using the linear trend analysis tool of Origin software, it is found that the provinces with significant (confidence level of 95%, same below) decreasing supply of marine capture food are Liaoning (-4.02, slope, same below), Shandong (-2.92), Guangdong (-0.98), Guangxi (-0.81), Shanghai (-0.66), and Hebei (-0.32). Liaoning, for example, where the supply fell the most, from 1.16

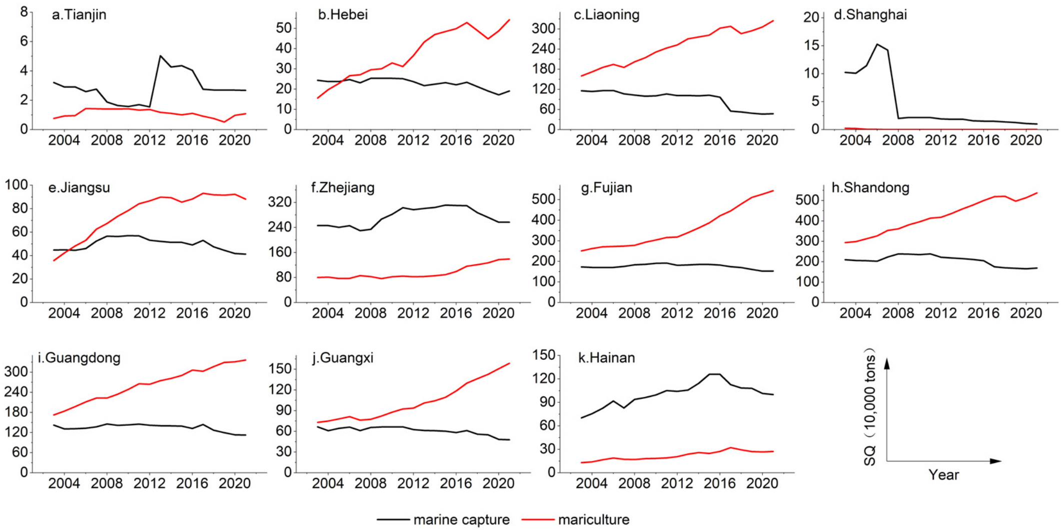


FIGURE 2
**(A–K)** Changes of food supply in marine capture and mariculture in coastal areas of China from 2003 to 2021.

million tons in 2003 to 0.48 million tons in 2021, representing a 58.96% drop. The overall trend of marine capture supply is significantly increasing in Zhejiang and Hainan, but its supply has been decreasing in recent years (2016-2021). The change trend of marine capture food supply in Fujian, Tianjin and Jiangsu is not significant and shows fluctuations. In the change of mariculture food supply, except for Tianjin and Shanghai, other provinces showed a significant upward trend. The slope of increase from largest to smallest being Fujian (16.71), Shandong (14.37), Liaoning (9.14), Guangdong (9.08), Guangxi (4.76), Zhejiang (3.24), Jiangsu (2.99), Hebei (2.06), and Hainan (0.91), while the provinces with larger amounts of growth are Fujian and Shandong, from 2.51 million tons and 2.94 million tons in 2003 to 5.44 million tons and 5.37 million tons in 2021, an increase of 116.91% and 82.88%, respectively. By comparing the changes in marine capture and mariculture, it can be seen that the supply of marine capture in many coastal areas of China is slowly declining, while the supply of mariculture is growing rapidly.

In terms of spatial distribution, significant regional differences exist in the supply of seafood along China's coastal areas. The highest average annual supply of marine capture is found in Zhejiang and Shandong, while Shandong and Fujian lead in mariculture production. In marine capture, Zhejiang and Shandong are 2.74 tons and 2.06 tons respectively, followed by Fujian, Guangdong and Hainan, with an average annual supply of 1 million tons to 1.8 million tons, then Liaoning, Guangxi and Jiangsu, with an average annual supply of 0.4 million tons to 1 million tons, and finally Hebei, Shanghai and Tianjin, with an average annual supply of less than 0.3 million tons. In mariculture, Shandong and Fujian are 4.22 million tons and million 3.61 tons respectively, followed by Guangdong (2.63 million tons), Liaoning (2.47 million tons), Guangxi (1.04 million tons) and Zhejiang (0.95 million tons), while the average annual supply of Jiangsu, Hebei, Hainan, Tianjin, Shanghai and other provinces is less than 0.8 million tons. These findings indicate that the spatial supply patterns of marine capture and aquaculture are not consistent across coastal regions. Overall, Shandong and Fujian are the top provinces in terms of total marine food supply, whereas Hebei, Shanghai, and Tianjin have the lowest marine food supply levels.

By comparing the spatiotemporal patterns of food supply under two production methods, the 11 coastal provinces can be classified three types. The first type includes where marine capture fisheries provide a higher food supply than mariculture, such as Zhejiang, Hainan, Shanghai, and Tianjin. Zhejiang, with its abundant fisheries resources, early modernization of the marine capture industry, and well-established industrial system, has maintained the highest marine capture output in the country over the long term (Lü et al., 2008); Hainan is adjacent to the South China Sea, rich resources of marine species (Zhang et al., 2023), convenient fishing operations, and a long historical record. As a result, the marine capture food supply in both provinces has been much greater than mariculture. But in recent years, Zhejiang and Hainan's marine capture and mariculture food supply gap has been narrowing. Shanghai and Tianjin have a very low level of marine capture and mariculture food supply, and there has been no expansion of the marine capture and mariculture industry. In the second category, there are provinces with a higher supply of mariculture food than marine capture, including Shandong, Fujian, Liaoning, Guangdong, and Guangxi, and the supply gap is gradually expanding, which has a high coincidence with the overall development trend of marine fisheries in China. The third category is Jiangsu and Hebei, where the supply of marine capture food was higher than that of mariculture at the beginning, but the supply reversed and widened the gap in 2005 and 2006 respectively. Across all three province types, the trends in food supply from marine capture and mariculture demonstrate that, under the pressure of rigid demand for biological resource conservation and food consumption structure upgrades, most provinces are gradually reducing the scale of marine capture while increasing support for marine aquaculture. As a result, the role of marine aquaculture in providing marine food has become increasingly prominent.

## 3.2 Evolutionary characteristics of nutrient supply patterns for marine capture and mariculture

### 3.2.1 Temporal changes in nutrient supply for marine capture and mariculture in China

The total nutritional supply from China's marine capture fisheries has exhibited a three-phase pattern of change, initially rising and then declining. Fish remain the dominant species in the nutritional supply, while crustaceans and cephalopods contribute significantly to calorie and protein supply (Figure 3). In terms of total nutritional output, marine capture fisheries experienced a slow increase from 2004 to 2011, stagnation from 2012 to 2015 and rapid decline from 2016 to 2021, with the average growth rates of energy in the three stages being 2.04%, 0.40% and -3.68%, protein at 1.90%, 0.56% and -3.74%, and fat at 2.41%, 0.26% and -3.58%, respectively. In terms of specific species, fish is the most dominant species in the nutrient supply of marine capture, and its average proportions in the total supply of energy, protein and fat is 76.91%, 74.47% and 89.94% respectively, indicating that fish has a greater comparative advantage in the supply of fat, and the change trend of the three nutrients of fish supply is highly consistent with the total nutrient supply of marine capture. Subsequently, crustaceans and cephalopods account for a high proportion of energy and protein supply, for example, the average proportions of crustaceans were 12.02% and 14.37%, and cephalopods were 7.01% and 8.15%, respectively. The nutrient supply of other species was extremely small, with an average share of no more than 2%.

Overall, the total nutritional supply from mariculture in China has shown a continuous upward trend, with shellfish being the largest contributor, followed by algae and crustaceans, while fish have exhibited the fastest growth rate. In terms of total supply, energy, protein and fat increased from 3422 billion kcal, 0.47 million tons and 51.10 thousand tons in 2003 to 7166 billion kcal, 1.14 million tons and 113.30 thousand tons in 2021, with average annual growth rates of 4.66%, 5.03% and 4.52%, respectively, which was higher than that of mariculture food supply (3.98%). This indicates that the structure of marine aquaculture is gradually shifting toward high-nutrition foods, particularly high-protein food. Shellfish is the largest contributor to the nutritional supply from mariculture, and its average proportion of energy, protein and fat is 46.44%, 45.64% and 59.13%, and its total supply of three nutrients is gradually increasing but the proportion is decreasing, indicating that the nutritional supply of shellfish is not growing at a high rate. Algae and crustaceans account for a large proportion of the total energy and protein supply and grow rapidly, for example, the average share of algae in energy and protein is 26.00% and 19.03%, with an average annual growth rate of 4.28% and 4.51% respectively; the share of crustaceans is 12.22% and 16.33%, with an average annual growth rate of 6.99% and 7.00% respectively. Fish have shown the fastest growth in the supply of energy, protein and fat, with average annual growth rates of 8.29%, 8.42% and 7.84%, respectively, with the most rapid increase observed in protein. Other species have contributed less to the nutritional supply, though their growth rates remain relatively fast.

In terms of total nutrient supply, China's marine capture has long been higher than mariculture, with the total energy and protein supply of mariculture just exceeding that of marine capture in 2019 and 2020, respectively, and the fat supply has been much lower than that of marine capture. This is different from the fact that seafood is

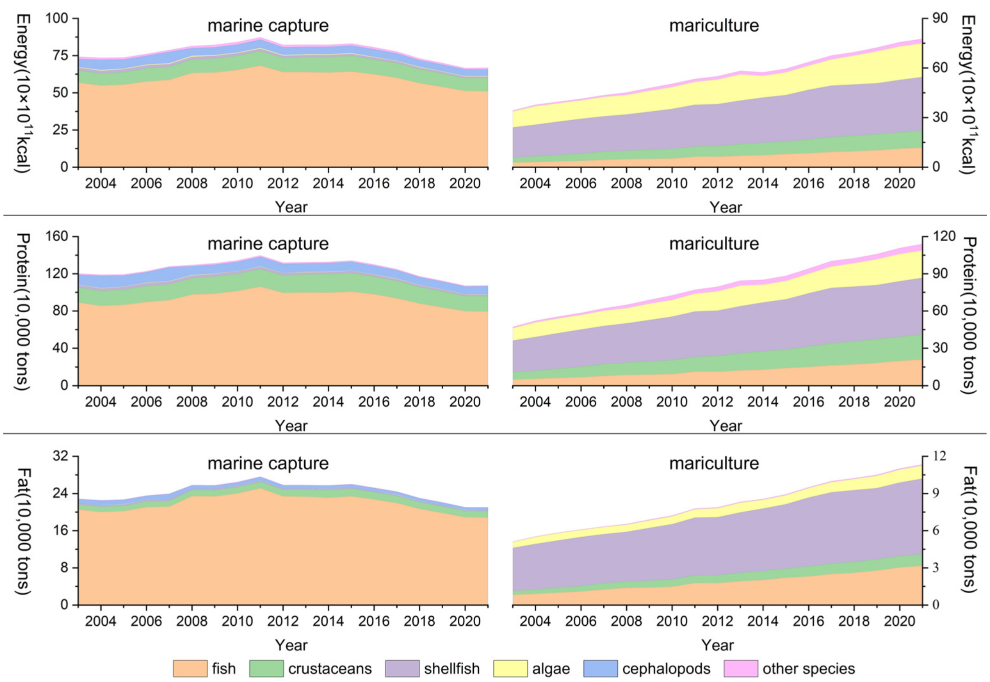


FIGURE 3
Changes in nutrient supply of marine capture and mariculture in China from 2003 to 2021.

obtained mainly through mariculture. Although aquaculture surpasses marine fisheries in terms of food supply quantity, it does not hold a significant advantage in terms of total nutritional yield. This is primarily due to the lower nutrient content per unit of aquaculture products compared to wild-caught fish, with fat content being particularly notable. Fish caught through marine fisheries typically consume natural foods such as algae, small crustaceans, and plankton, which are rich in long-chain fatty acids, proteins, and minerals. As a result, wild-caught fish generally have higher nutritional content, especially beneficial fats, compared to aquaculture products. Additionally, wild-caught fish often have longer growth cycles, allowing them to accumulate more nutrients and fats over time by feeding on natural food sources. Although the supply of mariculture fish is much lower than that of marine capture, the resultant fat supply from marine capture has been much greater than that from mariculture. On the one hand, the nutritional value and consumption habits of the captured marine fish have a certain substitution relationship with the shellfish and crustaceans of mariculture. On the other hand, under pressure to maintain biodiversity and sustainable resource use, there has been a significant decrease in the intensity of marine fish capture, and under the background of growing demand, decreasing nutrient supply for marine capture and increasing nutrient supply for mariculture will become a trend in the long term (Bouwman et al., 2013).

### 3.2.2 Spatial-temporal evolution of nutrient supply for marine capture and mariculture in coastal areas of China

In terms of temporal changes, the nutritional supply of marine capture has shown a declining trend in many coastal regions of China, while the supply from mariculture has exhibited a rising trend, with significant variation (Figure 4). Specifically, the energy supply of marine capture was significantly decreasing in Liaoning (-0.23, slope, same below), Shandong (-0.16), Shanghai (-0.05), Guangxi (-0.05) and Hebei (-0.01), significantly increasing in Zhejiang (0.14) and Hainan (0.19), and insignificant in other provinces. The energy supply of mariculture was significantly increased in Fujian (0.79), Guangdong (0.45), Shandong (0.30), Liaoning (0.24), Guangxi (0.17), Zhejiang (0.16), Jiangsu (0.15), Hebei (0.06) and Hainan (0.04), and only Tianjin and Shanghai had insignificant changes. In coastal areas, the order of protein supply from marine capture and mariculture was in line with energy. Shanghai, Guangxi, and Liaoning showed a significant decrease in the supply of fat from marine capture and Zhejiang and Hainan showed a significant increase; the change of fat supply of mariculture was consistent with the change of energy of mariculture. Overall, these results suggest that, compared to the declining trend in nutritional supply from marine capture, a larger number of coastal provinces have shown significant increases in marine aquaculture nutritional supply, with a more pronounced magnitude of growth.

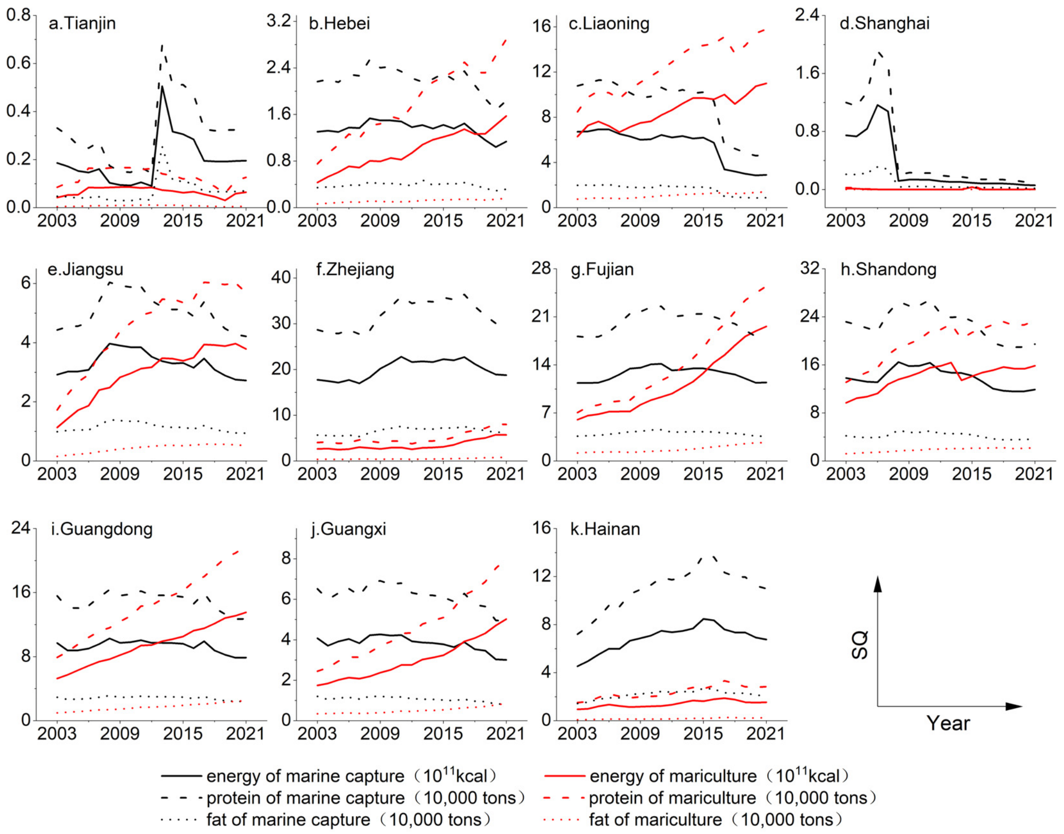


FIGURE 4
**(A–K)** Changes of nutrient supply in marine capture and mariculture in coastal areas of China from 2003 to 2021.

In terms of spatial distribution, the nutritional supply from marine capture in China's coastal regions is primarily concentrated in Zhejiang, Shandong and Fujian, while the nutritional supply from mariculture is mainly sourced from Shandong, Guangdong and Fujian. For marine capture, the average annual supply of energy, protein and fat in Zhejiang, Shandong and Fujian ranged from 1268 ~ 2003 billion kcal, 0.20 ~ 0.32 million tons and 40.50 ~ 65.50 thousand tons, respectively, and the ratio of the supply of energy, protein and fat to the total supply in the three provinces was 60.34%, 60.38% and 61.26%, respectively. Other provinces in descending order are Guangdong, Hainan, Liaoning, Guangxi, and Jiangsu, while Hebei, Shanghai, and Tianjin are the provinces with the lowest supply. For mariculture, the average annual supply of energy, protein and fat in Shandong, Guangdong and Fujian were 947 ~ 1393 billion kcal, 0.14 ~ 0.20 million tons and 17.10~ 18.50 thousand tons respectively, and the ratio of the supply of energy, protein and fat to the total supply of the three provinces were 62.93%, 61.07% and 65.56%, respectively. Liaoning, Zhejiang, Guangxi, Jiangsu, and Hainan are the other provinces in descending order of supply, while Hebei, Shanghai, and Tianjin are still the smallest provinces in terms of supply.

Comparing the spatiotemporal evolution of nutritional supply from both production methods, it was found that seven coastal provinces (Hebei, Liaoning, Jiangsu, Fujian, Shandong, Guangdong and Guangxi) have achieved multiple nutrients supply in mariculture exceeding marine capture, and only 4 provinces Zhejiang, Hainan, Shanghai and Tianjin have not exceeded. Energy and protein supplies from mariculture exceeded marine capture between 2004 and 2019 in the above 7 provinces, but the fat supply of mariculture in Shandong, Fujian, Jiangsu and Hebei has not exceeded marine capture. Moreover, in the transcendence order, it basically follows that energy faster than protein faster than fat (except Hebei), which was mainly related to the food structure of mariculture and marine capture. Compared to the dominant species in marine capture (fish and crustaceans), the dominant species in mariculture (shellfish and algae) have lower nutritional content per unit, with fat showing the largest disparity, followed by protein and energy. As a result, the rapid increase in mariculture supply has led to energy being the quickest to catch up, followed by protein, and finally fat. In Zhejiang, Hainan, Shanghai, and Tianjin, the supply from marine capture remains significantly higher than mariaculture, and thus, nutritional supply from capture continues to dominate in these regions.

# 4 Discussion

As the analysis above indicates, aquaculture and marine fisheries each have distinct comparative advantages in ensuring national food and nutrition security, with aquaculture providing greater food supply and marine fisheries offering superior nutritional content. With the gradual decline in the scale of marine fishery and the rapid expansion of mariculture in China, mariculture is poised to play a larger role in the future food system, with marine-derived foods taking an increasingly significant place in the daily diets and nutritional intake of the population. However, at this stage, China's marine fisheries are still facing the pressures of climate change, ecological environment deterioration, production space squeeze and upgrading of residents' food consumption structure, forcing the seafood supply system to transform deep blue (Deep blue is the most promising area for the development of marine fishery, which is specifically manifested in the modern fishery industry system with three basic forms, namely, deep-sea aquaculture, distant-water fishery and polar fishery.), diversified and green (FAO, 2022; Xu et al., 2020; Melnychuk et al., 2021; Fu et al., 2022; Dong et al., 2022). Enhance the resilience and food supply security of modern marine fisheries by developing concrete and feasible coping strategies.

## 4.1 Coping strategies for the deep blue transformation of marine food and nutrient supply

China's marine fisheries have long relied on offshore resources (Zhang and Wu, 2017), and overfishing and intensive aquaculture in offshore waters have caused severe depletion of fishery resources and the carrying capacity of resources has reached the limit, marine fisheries are expanding into deep blue (deep sea) space (Zheng and Zhang, 2024), and the use of natural water bodies in the deep sea for food production has become an inevitable trend. For marine capture, the space for food and nutrient supply expands to the deep sea, which can be carried out by relying on three ways: pelagic fisheries, transoceanic fisheries and polar capture fisheries. Although the above methods are restricted by international regulations and conventions like the United Nations Convention on the Law of the Sea, they can still improve the capacity to supply food nutrition by strengthening international fisheries cooperation, changing fishing operation methods, upgrading shipboard intelligent equipment, etc. For mariculture, the food and nutrient supply space expands to the deep sea, and can rely on deep sea aquaculture. In recent years, many areas in China have made progress in exploring deep-sea aquaculture, and the coastal provinces have actively promoted the use of new equipment and new farming mode, such as a number of large-scale aquaculture facilities such as “Deep Blue No. 1” “Guoxin No. 1” and “Puwang No. 1”, and are also promoting the launch of new models such as large-scale deep-water cage culture, purse seine aquaculture and breeding workers' vessels. At present, China's deep-sea aquaculture is still in its infancy, and practical problems such as more investment, high risk, and less technology integration have become obstacles to its development, but the high economic return, high nutritional quality, huge domestic consumption potential and successful foreign aquaculture experience (Norway and other countries) all provide assistant for the rapid development of China's deep-sea aquaculture.

## 4.2 Coping strategies for the diversity transformation of marine food and nutrient supply

With the improvement of China's residents' economic income and living standards, the food consumption structure of residents has gradually transformed and upgraded from "eating enough" to "eating well" "eating healthy" and "eating nutritiously" transformation and upgrading. There is also a growing demand for diversity in marine aquatic product types and nutrients. There are many types of seafood available for human consumption, and they are rich in animal protein and extremely valuable micronutrients such as Omega-3 (ω-3) polyunsaturated fatty acids, seafood is important for the enhancement of food consumption diversity and dietary nutrition. For marine capture, on the one hand, China should continue to strictly control the total amount of capture and fishing intensity, control the number of fishing vessels and accelerate the upgrading of fishing vessel equipment, refine fishing practices for fish stocks, gradually reverse the trend of decline of offshore fishery resources, and restore fish biodiversity. China, on the other hand, is expected to adjust the capture structure, reduce the overfished fish stocks, appropriately increase the capture diversity of crustaceans and cephalopods, pay attention to the assessment of fishery stock and available quantity, and increase the development and utilization of underutilized fishery stocks. For mariculture, first of all, China needs to actively support the large-scale development of fish farming, which is an effective way to improve the level of protein and fat supply, and it is also an effective way to relieve the pressure of meat production in terrestrial areas. Secondly, China should accelerate the diversification of fish farming species, increase the selectivity of food consumption, and avoid the domination of farming production by a few major species. At the same time, China should also actively promote the development of special mariculture, cultivate new species and new brands of shellfish, crustaceans and cephalopods, which can not only meet the diversified food consumption needs, but also help to adjust the farming structure, avoid farming risks and expand fishers' income channels, etc.

## 4.3 Coping strategies for the green transformation of marine food and nutrient supply

Due to the lag of development planning and management concepts (Su et al., 2020), China's marine fishery has experienced a long period of extensive development, and the phenomenon of "double utilization" in the capture industry and aquaculture industry has occurred, resulting in the decline of offshore fishery resources and the destruction of the aquaculture ecological environment, so promoting the green transformation of marine fishery has become an important issue facing the Chinese government. Green development is the basic requirement for the development of modern aquatic industry, aiming to promote the ecology and sustainability of aquatic products in the supply process. In terms of marine capture, China needs to scientifically assess the reasonable catch of fishery stocks, continue to release excess fishing capacity, reduce non-target catches through technical control, administrative supervision and economic intervention, control resource loss and waste, guide fishing vessels to improve their operational methods, and strengthen data statistics on landed catches. In terms of mariculture, China needs to scientifically plan the aquaculture area and breeding density, strengthen technological innovation in the digitalization of genetically improved fish fingerlings, feeds, diseases and equipment, promote advanced technologies of multi-trophic level integrated aquaculture and deep-sea intelligent equipment aquaculture, and supporting the major coastal aquaculture provinces to conduct extensive intensive and environmentally friendly mariculture experiments. At the same time, China needs to strengthen the management of the marine fishery industry chain, by comprehensively coordinating the optimization of ecological, social, and economic benefits of marine fisheries, optimizing production operation methods, expanding the fine processing of aquatic products, building a cold-chain logistics system for aquatic products, and guiding consumers in reducing food waste.

# 5 Conclusions

This study utilizes marine fishery production from China from 2003 to 2021. Employing a food and nutrition conversion model, the analysis was conducted at both regional and provincial scales to evaluate the food and nutrient supply provided by marine capture fisheries and mariculture. The key findings are as follows: First, in terms of food supply, the total supply of marine capture food in China shows an initial increase followed by a decline, while mariculture exhibits a steady growth trend. Fish and crustaceans are the major catch species, whereas shellfish and seaweeds dominate the aquaculture sector, with aquaculture fish exhibiting the fastest growth rate. The food supply from mariculture has significantly surpassed that from marine capture fisheries, establishing aquaculture as the primary source of seafood. Second, regarding nutrient supply, the total nutritional supply from marine capture fisheries exhibits an initial increase followed by a decline, while mariculture shows a continuous growth trend. Fish and shellfish are the major contributors to nutritional supply from both marine capture and mariculture. Crustaceans and cephalopods from capture fisheries, as well as seaweeds and crustaceans from aquaculture, account for substantial proportions of nutritional supply, with aquaculture fish showing the fastest growth in nutritional supply. Historically, marine capture fisheries have provided a higher nutritional supply compared to mariculture, which contrasts with the dependence on mariculture for food supply, indicating a comparative advantage of marine capture fisheries in total nutritional supply.

Finally, in terms of transformation response strategies, the first approach is a shift towards deep-sea operations. Marine fishery can expand into distant-water fishing, trans-oceanic fisheries, and polar capture fisheries to make efficient use of international resources. For aquaculture, this requires accelerating the development and innovation of farming equipment and models. The second strategy is diversification. Marine fisheries should focus on adjusting the structure of fishing activities while controlling total catch volumes and fishing intensity. For aquaculture, efforts should support the scaling-up of fish farming while promoting diversification in aquaculture species. Additionally, there should be an active push for the development of specialized marine products. The third strategy is a shift towards sustainability. Marine fisheries should conduct scientific assessments of sustainable catch limits to minimize resource depletion and waste. Aquaculture, on the other hand, should focus on scientifically planning farming zones and densities, promoting sustainable farming technologies, and strengthening the management of the marine fisheries value chain.

## Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

## Author contributions

SQ: Conceptualization, Data curation, Formal analysis, Methodology, Software, Writing – original draft, Writing – review & editing. WY: Conceptualization, Methodology, Visualization, Writing – original draft, Writing – review & editing. YL: Formal analysis, Writing – review & editing. DL: Supervision, Visualization, Writing – review & editing.

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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.

## Publisher's note



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