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RESEARCH ARTICLE

What drives the growth of China's mariculture production? An empirical analysis of its coastal regions from 1983 to 2019

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Abstract
China's mariculture (i.e., seafood farming in the ocean) production has grown rapidly. It ranks the first in the world and has made a huge contribution to solving human food security and nutrition issues. This study aimed to examine the development process of China's mariculture since 1983, clarify the main driving factors for the growth of mariculture production, and analyze whether China's experience can help other major producers in the world. Using the data on China's 10 coastal regions, this study applied the Logarithmic Mean Divisia Index (LMDI) from both the national and regional perspectives to analyze the main driving factors for the growth of China's mariculture production from 1983 to 2019. The results indicate that China's total mariculture production showed an overall upward trend and the major driving factor for the increase changed from the initial labor force to unit production. The primary factor for the increase in the Circum-Bohai Sea was labor, whereas that in the South China Sea, Yellow Sea and East China Sea was unit production. China's mariculture production has expanded from resource-driven to efficiency-driven. This study has practical significance for policy formulation and the future development direction of mariculture. This study provides a universally applicable methodology, and has reference significance for the world's major mariculture producers to further study the sustainable growth of mariculture production.

Keywords Driving factor · Logarithmic Mean Divisia Index · Mariculture · Production growth · Unit production

Introduction

Mariculture is a promising activity with regard to working towards the United Nations Sustainable Development Goals, especially goal 2: zero hunger and goal 12: sustainable consumption and production (Skallerud and Armbrecht 2020). It is an important supplement to global capture fisheries and essential for solving global food security and nutrition issues (Campbell and Pauly 2013; Costello et al. 2020; Lester et al. 2022). Mariculture plays an important role in livelihoods, employment and local economic development in coastal areas of many developing countries (Food and Agriculture Organization of the United Nations [FAO] 2020). The "Global Aquaculture Production" database shows that mariculture production in major producing countries has been steadily increasing over the years, despite the current slowdown in global growth rates (Fig. 1). China's mariculture production has increased from 10,000 tons (10 kt) in 1950 to 36,403.631 kt in 2019, accounting for 3.17% and 62.9% of the world's mariculture production, respectively. According to the State of World Fisheries and Aquaculture, excluding the largest producer China, other major producers include Indonesia, Republic of Korea, Philippines, Norway, Chile and Japan. Among them, the Indonesia, Republic of Korea, Norway, Chile have seen significant increases in mariculture production, while in Japan and Philippines has declined since 2010. Moreover, the growth is expected to continue with population growth, increases in per capita seafood consumption, and decreases in other protein source consumption (Gutierrez-Wing and Malone 2006; Oyinlola et al. 2018).

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Although mariculture is almost all over the world, whether modern or traditional, its distribution is mainly concentrated in South Asia, Southeast Asia, East Asia and Latin America (Aslan et al. 2015; Ruff et al. 2019; Ismail et al. 2021), used for cultivate crustaceans, finfish, molluscs and relatively small amount of seaweed (Schwartz 2020). Many Asian countries, as well as Latin America, Europe and North America recently, have professional strength and related support institutions in mariculture (Landuci et al. 2021; Skallerud and Armbrecht 2020). However, most African countries have lagged far behind despite their grand regional and national goals (Probyn et al. 2001). To promote the development of mariculture in Africa, it is necessary to learn experiences from China, the largest producer, and clarify the driving factors of production increase, formulate reasonable policies and plans, supplemented by a favorable environment for infrastructure, technical expertise and investment (FAO 2020; Botes et al. 2003). Since the twenty-first century, with adjustments in the national dietary structure and the shortage of arable land and freshwater resources, China's mariculture industry has developed rapidly (Yu and Yin 2019; Yu et al. 2020a; Xu et al. 2022). The current mariculture production in China is ranked first in the world, and the rapid development in recent decades has met people's demand for seafood and contributed greatly to economic development (Liang et al. 2018; FAO 2022).

The rapid growth of China's mariculture production has aroused the interest of scholars, making the exploration of the driving factors of its growth a research hotspot. Considering the external factors, scholars believe that the support of national policy has effectively promoted the healthy and stable development of mariculture in China (Yu et al. 2020b; Ji et al. 2020), and the scientific marine spatial planning can cultivate real adaptive mariculture (Marin et al. 2019; Wu et al. 2021; Ji et al. 2022). Regarding the internal factors, the improvement and promotion of technology has become a key factor in the increase in mariculture production (Wang and Ji 2017; Wang et al. 2020; Zheng et al. 2019). The expansion of mariculture space and optimization of mariculture methods also have a positive impact on the sustainable development of mariculture (Chen 2018; Xu et al. 2020; Zhou et al. 2022).

Existing studies are relatively in-depth but mainly focus on a single factor, qualitative analysis. In this study, the Logarithmic Mean Divisia Index (LMDI) was used to conduct a relatively comprehensive and quantitative analysis of the growth of China's mariculture and identify the main direct driving factors. Due to the availability of data, this study takes China's mariculture production as the research object, and analyzes its driving factors in detail. The paper presents a review of the evolution of the mariculture production in China over the last forty years, and a descriptive analysis by regions is accompanied with the decomposition of the driving factors influencing production increase, obtained by applying the LMDI. China is by far the major seafood producer in the world and therefore the economic analysis of its production is interesting per se. However, in order to be useful for local and international readers, it is convenient that the study presents not only descriptive, but inference, explanatory or comparison analysis, which may serve as lessons for other regions in the world. Taking this as an example, other major producers can conduct research, so as to formulate policies for the sustainable development of domestic mariculture according to the results.

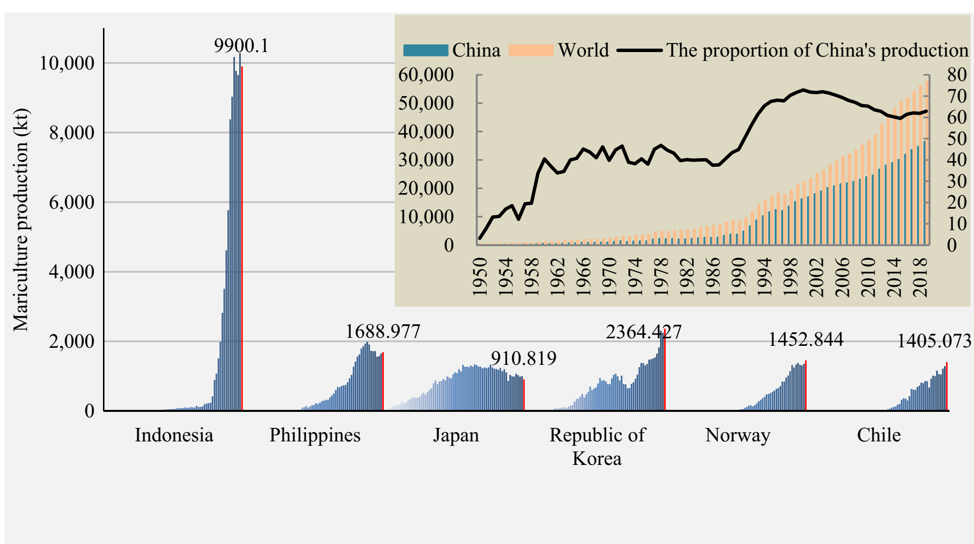

Fig. 1 Mariculture production in major producing countries in the world from 1950 to 2019. Note: Each set of bars is the production of each year from 1950 to 2019. Data Source: "Global Aquaculture Production" database from Food and Agriculture Organization

Materials and methods

Establishment of LMDI decomposition model

Ang's (2004) Logarithmic Mean Divisia Index (LMDI) method can achieve complete decomposition during the decomposition process, and no residual or residual value is generated. When performing time series comparison or spatial differentiation comparison analysis of the same index, the model can significantly improve the accuracy of results (Ang 2005). LMDI has been widely used in an international context, especially in CO_2 emission research. Using international comparisons and LMDI, scholars decompose the CO_2 emissions of Greece, Mexico, and South Korea, and examine the driving factors of CO_2 emissions changes related to energy use and production process (Hatzigeorgiou et al. 2008; Jung et al. 2012; Sheinbaum et al. 2010). A generalized logarithmic mean Divisia index (GLMDI) method is proposed to decompose the CO_2 emissions per value added gaps between China and USA (Zhao et al. 2017). Scholars have improved a number of approaches based on the LMDI methodology, to decompose changes in aggregate CO_2 emissions (González et al. 2014; Luo et al. 2021). Combining multi-regional input–output analysis and LMDI method, scholars have investigated the key drivers of the decline in UK's production-consumption-based coal consumptions from a global perspective (Wang and Song 2021). The LMDI decomposition method was employed to calculate the driving factors of agricultural water use in different stages in the middle reaches of the Heihe River basin (Zhang et al. 2018). This methodology has strong applicability and can be used to study the driving factors for the increasing mariculture production.

According to the actual situation of China's mariculture and characteristics of statistical data, this study examined 10 coastal regions and used the LMDI method to reveal the driving factors of China's mariculture industry. In this study, mariculture production is decomposed into four factors: unit production, mariculture structure, per capita area, and labor force. The model is as follows:

$$P = \sum_{i=1}^{10}\sum_{j=1}^{4} P_{ij} = \sum_{i=1}^{10}\sum_{j=1}^{4} \frac{P_{ij}}{S_{ij}} \times \frac{S_{ij}}{S_i} \times \frac{S_i}{L_i} \times L_i = \sum_{i=1}^{10}\sum_{j=1}^{4} Q_{ij} \times G_{ij} \times J_i \times L_i \quad (1)$$

where P represents the total mariculture production of China's 10 coastal regions (unit: ton); P_{ij} and S_{ij} represent the production (unit: ton) and area (unit: ha) of mariculture species j in coastal region i, respectively; S_i and L_i represent the mariculture area (unit: ha) and personnel (unit: person) of coastal region i (unit: ha), respectively; Q_{ij}, G_{ij}, J_i, L_i represent unit production (unit: ton/hectare), mariculture structure (unit: %), per capita area (unit: ha/person) and labor force (unit: person), respectively.

Based on the LMDI method, the change in mariculture production from 1983 (base year) to year T, ΔP, can be expressed as follows:

$$\Delta P = P^T - P^0 = \Delta P_{Q_{ij}} + \Delta P_{G_{ij}} + \Delta P_{J_{ij}} + \Delta P_{L_{ij}} \quad (2)$$

where ΔP represents the difference in mariculture production; P^T represents the total mariculture production in year T; and P^0 represents the total mariculture production in 1983. Moreover, $\Delta P_{Q_{ij}}$, $\Delta P_{G_{ij}}$, $\Delta P_{J_{ij}}$, $\Delta P_{L_{ij}}$ represent the effects of unit production, mariculture structure, per capita area, and labor force, respectively.

In this study, the LMDI model is used for the additive decomposition of mariculture production changes, and each term on the right-hand side of Eq. (2) can be formulated as follows:

$$\Delta P_{Q_{ij}} = \sum_{i=1}^{10}\sum_{j=1}^{4} w_{ij} \frac{Q_{ij}^T}{Q_{ij}^0} \quad (3)$$

$$\Delta P_{G_{ij}} = \sum_{i=1}^{10}\sum_{j=1}^{4} w_{ij} \frac{G_{ij}^T}{G_{ij}^0} \quad (4)$$

$$\Delta P_{J_{ij}} = \sum_{i=1}^{10}\sum_{j=1}^{4} w_{ij} \frac{J_i^T}{J_i^0} \quad (5)$$

$$\Delta P_{L_{ij}} = \sum_{i=1}^{10}\sum_{j=1}^{4} w_{ij} \frac{L_i^T}{L_i^0} \quad (6)$$

$$w_{ij} = \frac{P_{ij}^T - P_{ij}^0}{\ln P_{ij}^T - \ln P_{ij}^0} \quad (7)$$

where $\Delta P_{Q_{ij}}$, $\Delta P_{G_{ij}}$, $\Delta P_{J_{ij}}$, $\Delta P_{L_{ij}}$ represent the changes in total mariculture production caused by changes in unit production, mariculture structure, per capita area, and labor force, respectively; Q_{ij}^T, G_{ij}^T, J_i^T, L_i^T represent unit production, mariculture structure, per capita area and labor force in year T, respectively; Q_{ij}^0, G_{ij}^0, J_{ij}^0, L_{ij}^0 represent unit production, mariculture structure, per capita area and labor force in 1983, respectively; w_{ij} represents the weight of the model. A positive indicator indicates that this factor has a positive impact on the total production of mariculture; otherwise, it has a negative impact.

Among the four driving factors, the per capita area and labor force are resource-driven factors, indicating that the increase in mariculture production mainly depends on the resource input, which is unsustainable and cannot guarantee a continuous increase in mariculture production. The unit production and mariculture structure are not resource-driven factors. This reveals that the increase in mariculture production is mainly driven by efficiency improvement and structural adjustment, which are sustainable and can realize the stable development of mariculture in the future.

Data source and processing

This study selected 10 coastal regions engaged in mariculture as samples: Tianjin municipality (hereinafter referred to as Tianjin), Hebei province, Liaoning province, Jiangsu province, Zhejiang province, Fujian province, Shandong province, Guangdong province, Guangxi Zhuang autonomous region (hereinafter referred to as Guangxi), and Hainan province. Based on the availability and completeness of the data, the research content of this study does not include Shanghai, Taiwan, Macau, and Hong Kong. As the regions were engaged in mariculture for a long time, their activities can represent all the activities of China's mariculture production. Following Eq. (1), this study collected three indicators: mariculture production, area, and personnel. All relevant data were obtained from the China Fishery Statistical Yearbook (1983–2020), China Marine Statistical Yearbook (1993–2017), and China's Ocean Economic Development Report (2011–2020). It is worth noting that in 2018, the State Council of China abolished the Ministry of Agriculture and established the Ministry of Agriculture and Rural Affairs, so the editor-in-chief of the China Fishery Statistical Yearbook was changed from the Fisheries Administration of Ministry of Agriculture of the People's Republic of China [FAMA] to the Fisheries Administration of Ministry of Agriculture and Rural Affairs of the People's Republic of China [FAMAR].

With the global outbreak of the global novel coronavirus pneumonia (COVID-19) in 2020, China has adopted a phased closed management of this infectious disease and delayed the resumption of work, which has a great impact on the production of mariculture. The production data from 2020 to 2023 are greatly affected by the epidemic. In order to ensure the accuracy of the research results and exclude the influence of external uncertainties, this paper uses the data before 2020. In various statistical data, some indicators were missing at the provincial level across the country for years before 1983. Therefore, to ensure the accuracy of the results and to be able to examine the inter-provincial differences, the study period was defined as 1983–2019. Since Hainan province was separated from Guangdong province and formally established in 1988, the data of Guangdong province from 1983 to 1988 were separated, and then the relevant data of Hainan province's mariculture was estimated. The study period was long, and the statistical quality of China's mariculture production has changed. Therefore, the data for mariculture production was adjusted from 1983 to 2016 based on the adjustment coefficients published in 1996, 2006, and 2016 in the China Fishery Statistical Yearbook. The species of mariculture in the yearbook mainly included fish, crustaceans, shellfish, algae, and others, where others consisted of sea cucumbers, sea urchins, and jellyfish. The overall production was small, and the mariculture areas were mainly concentrated in certain typical areas; therefore, this study selected only the production and mariculture areas of fish, crustaceans, shellfish, and algae for research. Because of the lack of data in some years, this study used the geometric average method to calculate the annual growth rate and estimated the missing data to ensure data completeness.

Results and discussion

Analysis of the national mariculture production and related indicators over the years

China has a large population and since ancient times, agriculture has been its foundation (Han and Li 2015; Fukase and Martin 2015). The government has always attached great importance to the issues of food security and considered food self-sufficiency as a core policy (Feng et al. 2004). Because of long-term overfishing, China's offshore fishery resources have been seriously depleted (Su et al. 2020). Chinese fisheries have undergone a structural change, from a fishery-led to a mariculture-led sector (Han and Jiang 2019). As the main source of marine food growth, mariculture can effectively compensate for the shortage in terrestrial food resources while meeting the increase in residents' demand for high-quality protein (Kobayashi et al. 2015; Merino et al. 2012; Ruff et al. 2020). Large-scale mariculture in China began in the 1960s and involved mainly cultivating marine algae, represented by kelp (Li et al. 2005). After the 1980s, with the rise of prawn and bivalves culture, mariculture entered a 20-year period of rapid development (Liang et al. 2018). According to the China Fishery Statistical Yearbook, since 1983, the overall production of mariculture in China has shown a continuous growth, with an annual rate of 11.46% (FAMAR 2020). The scale of mariculture increased from 186,700 hectares (ha) in 1983 to 1,992,200 ha in 2019; the number of professional mariculturists increased from 174,900 in 1983 to 900,900 in 2019 (FAMAR 2020). China's mariculture has experienced five waves of kelp, prawn, bivalves, fish, and precious marine products. At present, a diversified development pattern has formed, with the main shellfish, fish, shrimp, crab, and other precious marine products being equally and regionally distributed (Han 2018).

The overall trend changes of China's mariculture production (including fish, crustaceans, shellfish, and algae), areas, and labor from 1983 to 2019 are shown in Fig. 2. As depicted in the figure, China's total mariculture production from 1983 to 2019 generally showed a continuous upward trend, increasing from the initial 937.831 kt (adjusted production) to 20,277.751 kt in 2019, with major changes around 1996 and 1997. Before 1996, the average growth rate of total mariculture production was 19.73%. In 1995, the total mariculture production greatly increased to 7,879.768 kt. However, it fell by 3.16% in 1996 and reached the lowest growth rate in 1997, with the production of 7,896.976 kt. The decline in total production was mainly due to the large reduction in shellfish and algae production caused by natural disasters (FAMA 1996, 1997). From 1998 to 2019, total mariculture production showed steady growth, with an average growth rate of 5.06%. The growth rates in 2018 and 2019 were less than 2%.

From 1983 to 2019, China's mariculture area showed a fluctuating trend of first increasing and then decreasing. The growth rate was the fastest before 1992, with an average of 15.97%, and reached the maximum of 34.72% in 1991, with a mariculture area of 575,660 ha. In 1992, the mariculture area decreased by 13.73%, mainly because of the sharp decrease in the area occupied by shellfish and algae. However, the mariculture area increased steadily from 1993 to 2006, with an average growth rate of 9.01%. The largest area reduction in 2007 was mainly due to the larger reduction in fish area. From 2008 to 2014, the growth rate of mariculture areas slowed down year by year, but the average growth rate was still higher than 9%. From 2015 to 2019, there was a trend of declining fluctuations. The mariculture area reached its maximum of 2,055,474 ha in 2015 and then decreased year by year, with an average annual decrease of 4.49%.

The average growth rate of China's mariculture labor force was 4.76% in 37 years. The overall decreasing trend occurred after a fluctuating growth, which is the same as the trend changes of the mariculture area. The labor force in 1983 was 174,867. Until 1995, the mariculture labor force increased steadily, with an average growth rate of 7.12%. From 1996 to 2003, the labor force grew rapidly, with an average of 7.58%. In 1993, the growth rate was the largest, with an increase of 17.66%. From 2004 to 2013, there was a slow fluctuating increase, with an average labor force growth rate of 2.23%, reaching a peak of 925,374 in 2013. From 2014 to 2019, there was a slow downward trend, and the labor force decreased by 0.44% a year on average.

Decomposition of the influencing factors of national mariculture production

Figure 2 shows the trend changes of China's total mariculture production and related indicators; however, it does not reveal the magnitude and extent of the impact of various driving factors on total mariculture production. Therefore, based on formulas (1)–(7), the driving factors of China's total mariculture production changes from 1983 to 2019 were decomposed to reveal the magnitude and extent of the impact of the four driving factors at different stages during the study period. The results are presented in Fig. 3. According to the fluctuation characteristics of the time series of mariculture production, area, and labor, the time series from 1983 to 2019 was divided into four stages: 1983–1991, 1992–2000, 2001–2009, and 2010–2019.

In the first stage, total mariculture production increased slowly (1983–1991). Except for unit production, all other factors increased the productivity. The effect of factors on

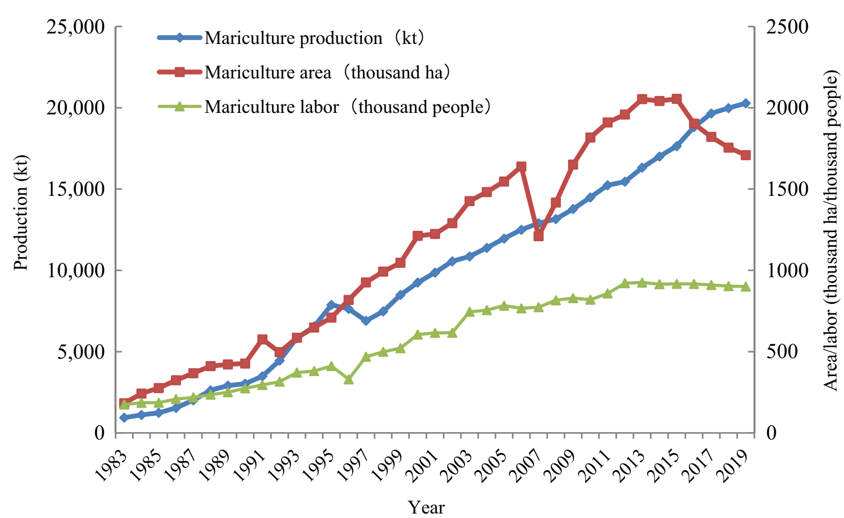

Fig. 2 Changes in mariculture production, areas, labor from 1983 to 2019. Date source: China Fisheries Statistical Yearbook (1984–2020) and China Marine Statistical Yearbook (1993–2017)

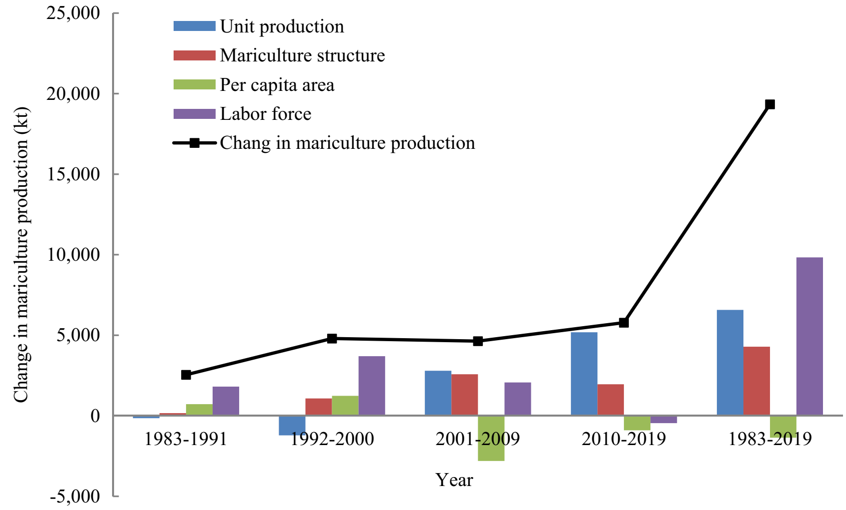

Fig. 3 Changes of the driving factors' contribution to national mariculture production

the increased production was in the following order: labor force > per capita area > mariculture structure. At this stage, the Chinese government issued Document No. 5 in 1985, which formulated the guiding ideology, development policy, and basic path for the development of fishery production (Yu and Han 2020). It declared that all coastal areas attach importance to the development and utilization of waters in the same way they do to cultivated land (FAMA 1990). Mariculture extends from Liaoning in the north to Guangdong and Guangxi, increasing the development and utilization of shallow coastal beaches. The coastline stretches over several thousand kilometers, and millions of acres of tidal flats are led by shrimp farming (FAMA 1987). With the development of rural commodity production and adjustment of the agricultural industry structure, farmers turned to fish farming; consequently, fish farming by professional families developed rapidly (FAMA 1988). At the same time, most areas of China's mariculture production suffered natural disasters of varying degrees; the technical level was relatively backward; and the mariculture structure was gradually adjusted (FAMA 1991). China's labor force advantage was very significant; therefore, the factor was mainly labor resource-driven in the first stage.

In the second stage, total mariculture production increased rapidly (1992–2000). As in the first stage, all the factors increased the productivity, except for unit production. The driving factor for the increasing production was still labor-based, and its influence was much higher than that of the mariculture structure and per capita area. At this stage, the Chinese government issued the "Ninth Five-Year" fishery development policy, the Ministry of Agriculture released an opinion on further accelerating fishery development (No.3 Document of the State Council in 1997), and various coastal areas issued a series of policies to further support the development of shallow beaches (FAMA 1996, 1998). Due to the continuous increase in disease prevention and control and the active promotion of high-production and high-efficiency pond and shallow beach aquaculture technologies, the mariculture model in various places was continuously improved, and the structure of mariculture species was optimized (FAMA 1995). Adding to the activities of the "Agricultural Science and Technology Extension Year" in 1997, coastal areas strengthened their leadership in the promotion of mariculture technology. A series of scientific and technological achievements that helped promote the development of the mariculture industry were popularized and applied (FAMA 1997). Therefore, at this stage, China's mariculture production rose rapidly. Although the main influencing factor was still the labor force, the contribution of mariculture structure and per capita area increased. At the same time, the severe mariculture disease situation and the shortage of famous, special, high-quality, and new aquatic fingerlings were still the two major "bottlenecks" restricting the sustainable and healthy development of the mariculture industry. Therefore, low unit production was still a problem that needs to be solved (FAMA 1993).

In the third stage, the growth rate of total mariculture production slowed down (2001–2009). Except for the negative effect of per capita area, other factors worked together to promote production, and the contribution of unit production jumped to the first place. The gap in the contribution of unit production, labor force, and mariculture structure to total mariculture production was reduced. At this stage, the Chinese government formulated the "Fisheries Development Action Plan" and "Development Plan for Competitive Export Aquatic Products Cultivation Areas" in 2002. It also increased its policy support and investment in mariculture. The mariculture method had changed gradually from traditional to modern. It had become factory-based, intensified, and profitable. Moreover, the unit production had actively improved. The sea area of mariculture has developed from a 10-m isobaths to nearly 30-m isobaths; coastal areas focused on the development of large deep-water anti-wave cages, increased their capital investment, and effectively enlarged the scale of mariculture (FAMA 2003). Farming in the sea became the main method, accounting for 52.7% of the national mariculture production; farming in the intertidal mudflat ponds was the second largest production method of mariculture (FAMA 2006). The increasing requirements of the international and domestic markets for quality mariculture products and China's imperfect seafood quality supervision and inspection system had an adverse impact on seafood export (FAMA 2002). In 2008, mariculture in China continuously suffered adverse effects and huge impacts, such as rising prices of production materials, global financial crisis, freezing rain and snow, typhoons, and other major natural disasters. At the same time, the Chinese government's policy on supporting fisheries significantly increased, which effectively mobilized the enthusiasm of fishermen in production and effectively guaranteed the slow growth of total mariculture production.

In the fourth stage, total mariculture production steadily increased (2010–2019). In addition to the negative effect of per capita area, the contribution of the labor force also became negative, leading to a decrease in production. However, the negative impact of per capita area was the most significant. Unit production and mariculture structure helped in increasing mariculture production. The contribution of unit production still ranked first, followed by the mariculture structure; the difference between the two was relatively small. At this stage, "Twelfth Five-Year Plan for National Fisheries Development" was issued in 2011. This plan emphasized that the development of mariculture has gradually shifted from focusing on production to quality. The Chinese government implemented the "Twelfth Five-Year Plan for National Marine Economic Development" and the "National Marine Functional Zoning (2011–2020)" in 2012, and created the "Construction Plan of National Marine Ranching Demonstration Zone Construction Plan (2017–2025)" in 2017. The implementation of these plans further reduced the scale of mariculture, and the development of mariculture changed its priority from production to sustainable development (Yu et al. 2020a). The "Thirteenth Five-Year Plan for National Fisheries Development" was implemented in 2017 and proposed the completion of the spatial planning of aquaculture waters. It also changed the development model of mariculture and developed modern marine ranching to promote high-quality growth of mariculture. At present, China continues to deepen the supply-side structural reform of the fishery industry, insisting on improving its quality and efficiency, reducing volume and increasing income, developing green mariculture, and enriching fishermen to ensure the high-quality and stable development of China's mariculture industry (FAMAR 2018). "Opinions on Accelerating the Green Development of Aquaculture" issued by ten Ministries of China in 2019, this document proposes to "optimize the production layout of aquaculture, change the farming method, improve the farming environment, strengthen production supervision, broaden the development space" in order to achieve the sustainable development of aquaculture, and guide the mariculture development in the future.

It can be concluded that mariculture production showed an overall increasing trend during the study period, but the effects of influencing factors at different stages were different. From 1983 to 2019, unit production, mariculture structure, and labor force collectively acted as production-increasing factors, and the per capita area had a decreasing effect. Consistent with the first and second stages, the positive impact of the labor force on mariculture production was the most significant, indicating that resource-driven is the main driver of mariculture production increase. Unit production played a negative role in the first and second stages, but it jumped to the first place and played a positive role in the third and fourth stages, ranking second in the contribution rate of the increase in mariculture during the research phase. This indicated that the main factor for the increase in mariculture production was efficiency-driven. The mariculture structure was always a positive factor in production changes. Its contribution to the increase in mariculture production changed from a rapid increase to a slow decrease. Judging from the cumulative effect of the four stages, the total production increased slowly from the initial stage to a rapid increase, and then to a steady increase in the later stage. Among them, the slow growth rate in the first stage was mainly due to the backward mariculture technology, poor ability of farmers to resist pests and natural disasters, and the low level of unit production. The rapid increase in the second stage was mainly due to the increase in mariculture area, adjustment of the mariculture structure, and increase in the number of mariculture personnel. The slow increase in the third stage was mainly due to the sharp decrease in per capita area, as well as the impact of major domestic disasters and the global financial crisis. The steady increase in the fourth stage was mainly due to the fact that China has begun to increase the per unit area yield level, pay attention to the quality of seafood, and reduce the mariculture area to protect the marine environment.

Analysis of the regional mariculture production over the years

From 1983 to 2019, the changes in mariculture production in the 10 coastal regions are shown in Fig. 4. The mariculture production of the 10 coastal regions greatly changed during the last 37 years. There were also large differences between regions. In the first stage, the production changes in the 10 coastal regions were not obvious. In the second stage,

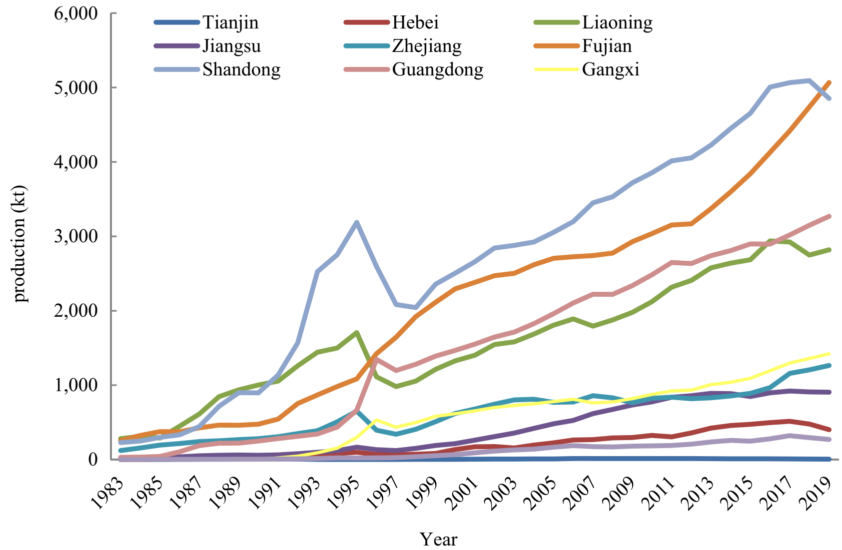

Fig. 4 Changes in mariculture production of 10 coastal regions from 1983 to 2019. Date source: China Fisheries Statistical Yearbook (1984–2020) and China Marine Statistical Yearbook (1993–2017)

the production of all regions showed a fluctuating upward trend, and the fluctuation range was relatively large. In the third stage, the production of the 10 coastal regions began to diverge, and the regional differences in the fourth stage were quite significant. In 1983, the 10 coastal regions for mariculture production were in Liaoning, Fujian, Shandong, Zhejiang, Guangdong, Jiangsu, Guangxi, Hebei, Hainan, and Tianjin municipalities, in the order from largest to smallest, with a difference of 281.15 kt between the maximum and minimum production. In 1995, the 10 coastal regions' overall growth of mariculture production was relatively large; Shandong province ranked first in production, followed by Liaoning, Fujian, Guangdong, Zhejiang, Guangxi, Jiangsu, Hebei, and Tianjin, respectively. Subsequently, Fujian's production grew rapidly and leaped to first place in 2019, whereas Shandong, ranking second, slowed its growth rate in the past four years. Mariculture production in the first two provinces was much higher than in other regions, followed by Guangdong and Liaoning. The last six regions, namely, Guangxi, Zhejiang, Jiangsu, Hebei, Hainan, and Tianjin, had relatively small differences in mariculture production. The maximum production was less than 1,500 kt. Overall, Liaoning, Shandong, and Fujian have always been strong provinces in mariculture, and the mariculture production of the three provinces has always ranked among the top four coastal regions.

According to the sea area where mariculture production is located, 10 coastal regions were divided. Since individual provinces are close to two sea areas, they were fine-tuned. For example, Shandong relies on the Bohai Sea and the Yellow Sea for mariculture. Since the government classified Shandong in the statistical category of the Circum-Bohai economic circle, this study divided Shandong's area into the Circum-Bohai Sea for research. Finally, this study formed three mariculture areas, namely, the Circum-Bohai Sea (including Tianjin, Hebei, Liaoning, and Shandong), Yellow Sea and the East China Sea (including Jiangsu, Zhejiang, Fujian), and the South China Sea (including Guangdong, Guangxi, and Hainan). Changes in the proportion of mariculture production in the three areas of China's total production are shown in Fig. 5. In terms of changes in total production, the Circum-Bohai Sea has always been the area with the highest proportion of mariculture production in China, followed by the Yellow Sea, East China Sea, and South China Sea has the least proportion. For the subregions, the proportion of the Circum-Bohai Sea to China's total mariculture production first expanded and then gradually decreased. The proportion reached the largest in 1995, accounting for 63.39%, and then decreased to 39.84% in 2019. The Yellow Sea and the East China Sea had the largest proportion in 1983; such proportion dropped sharply in 1995 and then gradually expanded to 35.7% in 2019. The proportion of mariculture production in the South China Sea has continued to expand from 3.37% in 1983 to 24.46% in 2019. Overall, the pattern of mariculture production in China has not changed greatly, and the Circum-Bohai Sea still bears the main pressure on mariculture production in China. From 1983 to 2019, the Circum-Bohai Sea, Yellow Sea and East China Sea reduced their contribution to China's total mariculture production, and the South China Sea increased its contribution. The gap in mariculture production of the three seas decreased, and the distribution of China's mariculture production tended to be more average.

Decomposition of the influencing factors of regional mariculture production

The decomposition results of the factors influencing regional mariculture production from 1983 to 2019 are shown in

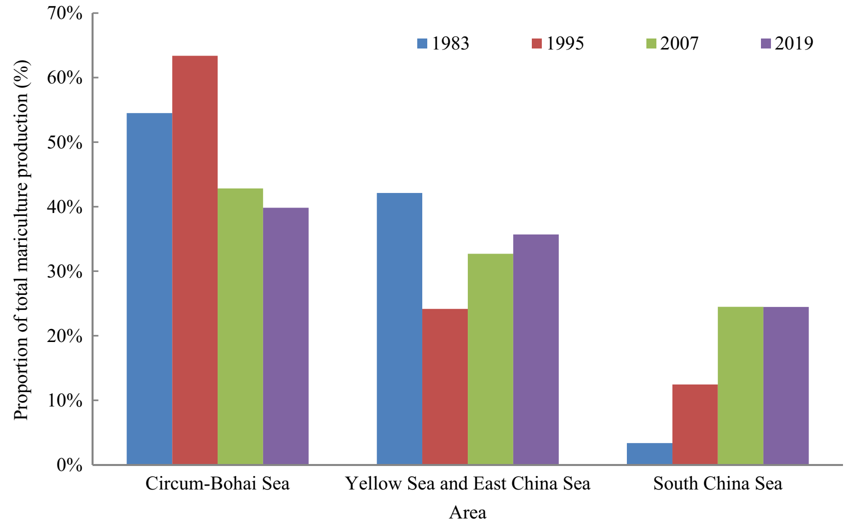

Fig. 5 Changes in mariculture production of 3 areas from 1983 to 2019

Table 1. This study visualized the results on a map, as shown in Fig. 5. The total production of the Circum-Bohai Sea increased significantly, and the factors that promote production were labor force, mariculture structure, and per capita area. Labor force was the primary factor causing an increase in mariculture production. The mariculture structure and labor force in Tianjin had the effect of reducing production, but the increase in unit production and per capita area completely compensated for this reduction. The per capita area in Hebei had a negative effect on the production of mariculture, but the impact was relatively small, and the primary driving factor for the increase was unit production. Liaoning and Shandong are the main provinces for mariculture production in the Circum-Bohai Sea, and the increase in mariculture production contributed 94.65% to the increase in mariculture production in the Circum-Bohai Sea. The results of the decomposition of the driving factors for mariculture in these two provinces were similar. The negative impact of unit production was far less than the positive impact of mariculture structure, per capita area, and labor force. Therefore, the results of the comprehensive comparison were all increases in production. Labor force was the primary driving factor for the increase in mariculture production in these two provinces.

In the Yellow Sea and the East China Sea, the contribution of mariculture structure and per capita area to

Table 1 Decomposition of the driving factors for regional mariculture production from 1983 to 2019 (Unit: kt)

Area	Region	ΔP Chang in mariculture production	$\Delta P_{Q_{ij}}$ Effect of unit production	$\Delta P_{G_{ij}}$ Effect of mariculture structure	$\Delta P_{J_{ij}}$ Effect of per capita area	$\Delta P_{L_{ij}}$ Effect of the labor force
Circum-Bohai Sea	Tianjin	4.86	18.98*	-11.68	11.04	-13.48
	Hebei	399.95	273.63*	24.04	-54.45	156.73
	Liaoning	2,536.77	-937.10	439.37	911.66	2,122.84*
	Shandong	4624.69	-2,609.87	1,309.80	2,091.96	3,832.80*
Yellow Sea and East China Sea	Jiangsu	8,87.43	759.08*	-65.39	-62.00	255.74
	Zhejiang	1,143.18	898.62*	-230.10	64.84	409.82
	Fujian	4,812.66	3,077.23*	-30.83	-162.64	1,928.90
South China Sea	Guangdong	3,238.94	3,912.16*	717.60	-1,582.26	191.44
	Guangxi	1,420.01	1,600.92	574.41	-1,620.67*	865.35
	Hainan	270.43	181.69*	-9.12	-17.88	115.74
Area						
Circum-Bohai Sea		7,566.27	-3254.36	1761.53	2960.21	6,098.89*
Yellow Sea and East China Sea		6,843.27	4734.93*	-326.32	-159.8	2,594.46
South China Sea		4,929.38	5694.77*	1282.89	-3220.81	1,172.53

* is the primary factor affecting mariculture production

production was negative; that of unit production and labor force was positive; and unit production was the main driving factor for the increase in mariculture production. In terms of the contribution of coastal regions to the increase in mariculture production, Fujian contributed 70.33%, followed by Zhejiang 16.71%, and Jiangsu. The results of the decomposition of driving factors for mariculture in Jiangsu and Fujian were similar, in which mariculture structure and per capita area had a negative effect on increasing production. However, the overall effect was small, although the unit production and labor force had a positive effect. Unit production was the main driving factor for increased mariculture production. The mariculture structure of Zhejiang caused a reduction in production, but the reduction effect was far smaller than the increasing effect of the other three factors, in which the unit production was the main driving factor.

The South China Sea was similar to the Yellow Sea and the East China Sea. Unit production was the main driving factor for the increase in mariculture production in this area. However, the mariculture structure had a positive impact on the increase in production, and the per capita area had a relatively strong negative impact. Comparing the three sea areas, the increase in mariculture production in the South China Sea was the smallest. In terms of the contribution of coastal regions to mariculture, Guangdong contributed the most, accounting for 65.71%, followed by Guangxi and Hainan. The negative effect of per capita area was more significant in Guangdong, but the increased effect of unit production, mariculture structure, and labor force compensated for the decrease. Unit production was the primary driving factor for the increase. The negative impact of per capita area was most significant on Guangxi, and it was also the only major influencing factor among the 10 coastal regions that had a negative value. However, the positive impact of unit production, mariculture structure, and labor force offset the negative impact. The production-promoting factors of Hainan were unit production and labor force, while production-reducing factors were mariculture structure and per capita area.

From Table 1, it can be seen that among the 10 coastal regions, the primary driving factor for the development of mariculture in the seven coastal regions was unit production, followed by labor force in two coastal regions. The Circum-Bohai Sea has always been a key area for the development of mariculture, with abundant population resources and low labor costs. In the early stages of the development, mariculture development was mainly driven by an increase in the labor force. In the past 10 years, the industrial structure has been adjusted; the ecological environment of the sea area has improved; the level of aquaculture technology has improved; and the contribution of unit production and mariculture structure has increased. However, it still cannot replace the status of the labor force. The South China Sea, Yellow Sea and East China Sea were areas with the rapid development of mariculture technology. The initial development was relatively slow, but mariculture technology innovation was rapid; the mariculture mode was advanced; and its unit production contributed the most to the increase in mariculture production.

Conclusions

Using data on China's 10 coastal regions, from 1983 to 2019, this study analyzed and summarized the history of the mariculture industry. It applied the LMDI model to incorporate unit production, mariculture structure, per capita area, and labor force into the growth factors of mariculture production and explored the main factors. This study also analyzed the driving factors of China's mariculture production growth from national and regional perspectives, to provide a more comprehensive approach to increase mariculture production. It is of great practical significance to understand the development status of mariculture in China, analyze the driving factors for the increase in mariculture production, and realize the sustainable development of mariculture.

The results indicate that from 1983 to 2019, the total mariculture production in China showed an overall upward trend. The decrease in production in 1996 and 1997 was mainly due to the large reduction in the production of shellfish and algae caused by natural disasters. The mariculture area and labor force showed a trend of first increasing and then decreasing. From the decomposition of the influencing factors of national mariculture production, the total production in the first (1983–1991) and second stage (1992–2000) increased slowly to rapidly, and the main driving factor was the increase in labor. The total production in the third (2001–2009) and fourth stage (2010–2019) increased and then slowed down to a steady level; the main driving factor was the increase in unit production. Mariculture has transitioned from rapid to stable development. At the same time, the primary reason for the increase in production was the shift from labor to unit production. This means that China's focus has shifted from quantity to quality of mariculture, from being resource-driven to becoming efficiency-driven.

From 1983 to 2019, the mariculture production of the 10 coastal regions changed significantly. There were also large differences between regions. Liaoning, Shandong, and Fujian provinces had always been strong provinces in mariculture. The Circum-Bohai Sea was the area with the highest proportion of mariculture production in China, followed by the Yellow Sea, East China Sea, and South China Sea. The gap in mariculture production in the three sea areas decreased, hence the distribution of mariculture production in China became more balanced. The decomposition of the influencing factors of regional mariculture production revealed labor as the primary factor in Liaoning and

Shandong and unit production in the remaining seven coastal areas. The primary factor leading to an increase in mariculture production in the Circum-Bohai Sea was labor, whereas that in the South China Sea, Yellow Sea and East China Sea was unit production. Therefore, the empirical results have some practical implications for policymaking. The future development trend of China's mariculture pertains to adjusting the industrial structure, improving mariculture methods, innovating mariculture technology, and promoting production efficiency. For other major mariculture producers in the world, the mariculture production can be decomposed according to the LMDI method, to further analyze the driving factors for the increase or decrease. Drawing lessons from China's development experience and combining the sea area conditions to formulate mariculture development policies that conform to the concept of sustainable development is of vital importance to these countries, especially coastal countries in Africa. In the future, China's mariculture development can comprehensively enhance its global competitiveness and achieve sustainable and healthy development from the following aspects: rational layout and efficient utilization of the developed mariculture sea area, promoting far-reaching mariculture to expand the production space, promoting the construction of Marine Ranch, and strengthening the protection of mariculture sea area resources under environmental regulations.

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Data availability All data generated or analyzed during this study are included in this article.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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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