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A study on the agglomeration characteristics of the scallop aquaculture industry in China

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Abstract

Scallops are economically important shellfish widely cultured in China. In this study, the agglomeration characteristics of the scallop aquaculture industry in Chinese coastal provinces were explored based on data from the China Fishery Statistical Yearbook from 2012 to 2020 and the comparative advantage and concentration level of the scallop breeding industry. The data were analyzed using the comprehensive relative advantage index, location entropy, and industrial concentration degree method. Two main results revealed that Hebei Province had the highest comparative advantage in terms of efficiency, followed by Fujian, Guangdong, Shandong, Guangxi, Liaoning, and Zhejiang Provinces. Hebei Province had the highest comparative advantage in scale, followed by Liaoning, Shandong, Hainan, Guangdong, Guangxi, Fujian, and Zhejiang Provinces. Additionally, the scallop cultivation industry in Hebei, Shandong, and Liaoning Provinces showed a high concentration, and the proportion of scallop production in the national production (CR_4) in the three provinces, as well as in Guangdong, accounted for more than 99% year-round. Overall, Hebei, Shandong, and Liaoning Provinces had a comparative advantage in scale, comprehensive comparative advantage, and industrial agglomeration.

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Introduction

Industrial agglomeration refers to an industrial development phenomenon in which a large number of certain types of enterprises or related enterprises in a particular region optimize industrial allocation, which can improve production efficiency and enhance industrial competitiveness through centralized distribution and aggregation of industrial capital elements in the area (Wang et al., 2021; Zhu et al., 2003). Therefore, to a certain extent, the degree of industrial agglomeration reflects the competitiveness of specific industries in specific regions. The degree of industrial agglomeration may differ due to differences in the economic and social development levels of different industries and regions. Analysis and research on the characteristics of industrial agglomeration play an essential role in understanding the industry's formation mechanism, clarifying the industry's competitive advantages, grasping the market's development and changes, and formulating industrial upgrading policies (Xiang et al., 2006). Currently, research methods for industrial agglomeration primarily include the industrial concentration rate, location entropy, spatial Gini coefficient, H index, and EG index. Elilsion and Glaeser (1997) proposed a new agglomeration index to measure the degree of industrial agglomeration, DO index, and so on (Liu et al., 2008). The study of industrial agglomeration in scallop aquaculture in China is of theoretical value and practical significance.

In terms of theoretical value, many studies on industrial agglomeration have been conducted in aquaculture, including fish (Miao et al., 2018; Cao et al., 2017; Zhang et al., 2018) and shrimp (Yuan et al., 2008). However, the research on shellfish remains very limited, particularly regarding scallops. The degree of industrial agglomeration has been studied through comprehensive comparative advantage, location entropy, industrial concentration rate, spatial Gini coefficient (Liu et al., 2015; Zhao et al., 2018), and so on. Currently, there remains a lack of research on scallop aquaculture industrial agglomeration in China. This study combined a comprehensive comparative advantage index, location entropy, industrial concentration rate, and other research methods with the development of the scallop farming industry in China to conduct an in-depth analysis and research on the agglomeration degree of this industry. The data and results can accumulate original material for studying the shellfish industry, enrich the theoretical study of the aquaculture industry to a certain extent, and promote and enrich the development of related disciplines.

Regarding practical significance, this article features targeted research on the Chinese scallop fishery agglomeration. It can help government management departments and related scientific researchers and practitioners grasp a broad picture of the scallop fishery of China and identify the problems existing in the Chinese scallop fishery, thus further promoting the healthy development of the scallop fishery in China. This has important practical significance.

The scallop culture in China originated in the 1970s and has experienced vigorous development over the past 50 years. It has become one of the pillar industries of shallow-sea farming since the first successful trial breeding in coastal Shandong Province. In China, there are four significant scallops cultured, including the zhikong scallop *Chlamys farreri*, primarily cultivated in the coastal areas of Shandong and Liaoning; the noble scallop *Chlamys nobilis*, primarily in Fujian; the bay scallop *Argopecten irradians*, primarily in Shandong, Hebei, and Liaoning; and the Yesso scallop *Patinopecten yessoensis*, primarily in Liaoning and Shandong. According to the China Fishery Statistics Yearbook, the aquaculture production and area comprising marine shellfish and scallops from 2012 to 2020 are outlined below (**Table 1**).

Table 1 Production and culture area of marine shellfish and scallop cultivation in China from 2012 to 2020

Year	Shellfish production (10^4 tons)	Shellfish farming area (10^4 Ha)	Scallop production (10^4 tons)	Scallop farming area (10^4 Ha)
2012	1208	147	142	54
2013	1273	156	161	64
2014	1317	153	165	64
2015	1358	153	179	65
2016	1421	136	186	47
2017	1437	129	201	46
2018	1444	124	192	44
2019	1439	120	183	41
2020	1480	119	175	38

Marine shellfish production in China has increased from 12.08 million tons in 2012 to 14.8 million tons in 2020, showing a steady increase overall. However, after reaching a peak of 1.56 million ha in 2013, the aquaculture area has slightly declined in recent years (**Figure 1**). The production and space of scallop cultivation in China initially increased and then decreased. The production of scallop cultivation increased from 1.42 to 2.01 million tons between 2012 and 2017 and then reduced to 1.75 million tons in 2020. The change in scallop cultivation area correlates with the difference in yield but is not completely synchronous. After increasing from 540,000 ha in 2012 to 650,000 ha in 2015, the annual scallop cultivation area showed a declining trend (**Figure 2**). The proportion of scallop cultivation production and space among the production and location of marine shellfish cultivation is consistent with the changing trend of scallop cultivation production and area, which reached their highest values of 13.97% and 42.64% in 2017 and 2015, respectively (**Figure 3**). From 2012 to 2020, the yield per unit of marine shellfish and scallop cultivation steadily rose. However, the yield per unit of marine shellfish cultivation was much higher than that of scallop cultivation, with the former being about three times that of the latter (**Figure 4**).

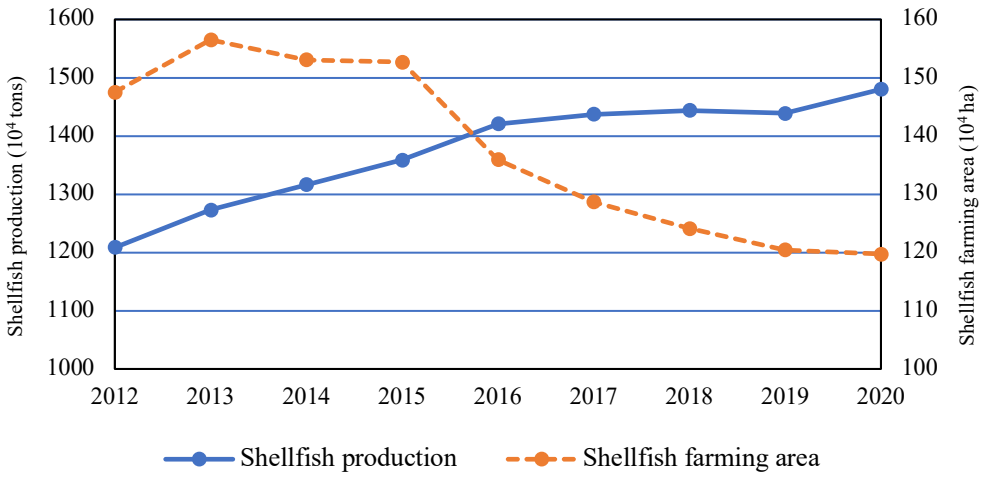

Figure 1 Trend of production and area of marine mollusk culture from 2012 to 2020

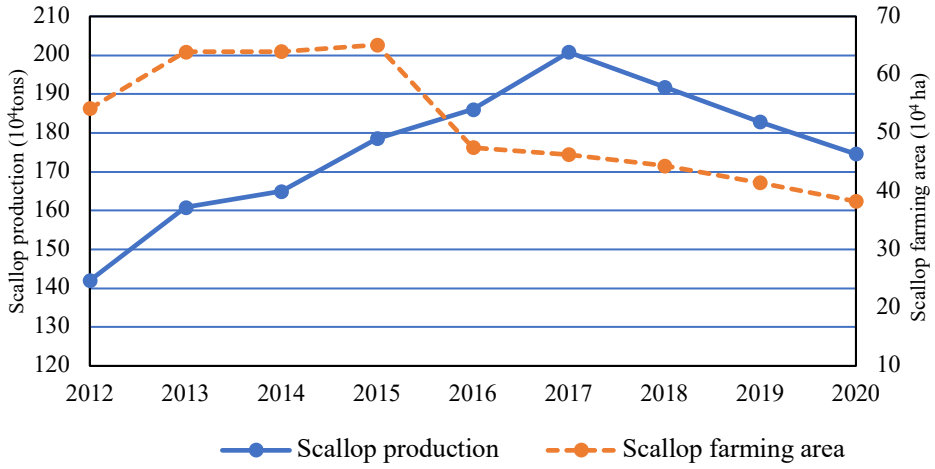

Figure 2 Yield and acreage trend of scallop culture from 2012 to 2020

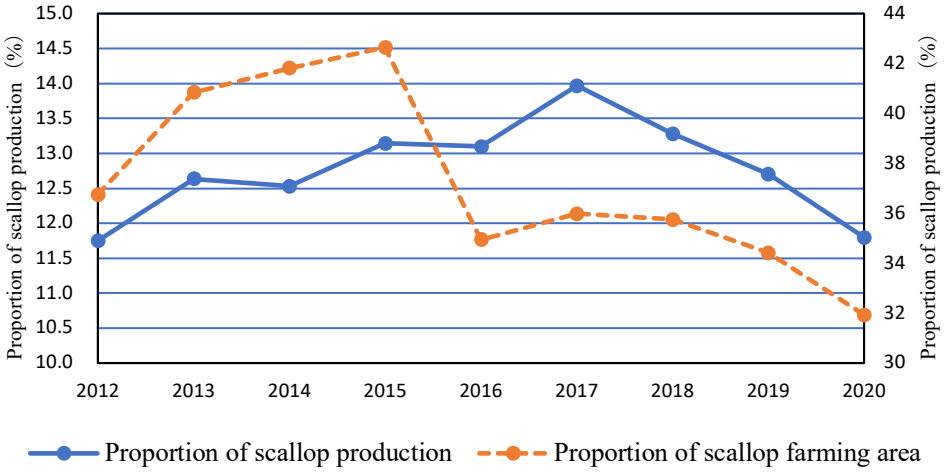

Figure 3 Trend chart of scallop cultivation yield and area proportion from 2012 to 2020

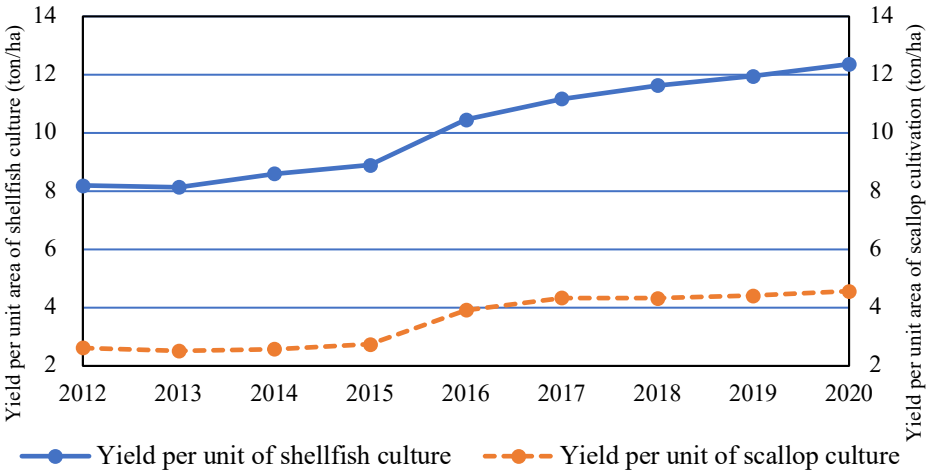

Figure 4 Trend chart of yield per unit area of marine shellfish and scallop culture from 2012 to 2022

Materials and methods

Data collection

In this study, the data reflecting the aquaculture production and area for marine shellfish and scallops in eight provinces from 2012 to 2020 were obtained from the China Fishery Statistics Yearbook, which can be downloaded from https://kns.cnki.net.

Methods

The comprehensive comparative advantage index method

For comprehensive measurements of scallop aquaculture industry advantages in different provinces, including the efficiency comparative advantage index efficiency (EAI), the scale relative advantage index (SAI), and the comprehensive comparative advantage index (AAI), index values >1 indicate that the scallop fishery province in question has an advantage in terms of the corresponding index value, and the greater the corresponding index value, the more precise the advantage (Pan et al., 2011).

Efficiency comparative advantage index (EAI)

The comparative advantage in efficiency in scallop cultivation among different provinces was reflected by comparing the relative level of scallop cultivation per unit yield in all eight provinces with that in the province in question and the ratio of scallop cultivation in China. The formula is as follows: $EAI_{ij}= \frac{AP_{ij}/AP_i}{AP_j/AP}$.

Where *i* represents province, *j* is scallop cultivation, AP_{ij} is the yield per unit of scallop cultivation in province *i*, AP_i is the yield per unit of marine scallop cultivation in province *i*, AP_j is the yield per unit of marine scallop cultivation in China, and AP is the yield per unit of marine scallop cultivation in China. $EAI_{ij}>1$ indicates that scallop cultivation efficiency in province *i* is higher than the national average and has a comparative advantage in terms of efficiency. In contrast, $EAI_{ij}<1$ indicates that scallop cultivation efficiency in province *i* is lower than the national average and is disadvantaged. The higher the EAI_{ij} value is, the more obvious the efficiency advantage of scallop culture.

Index of comparative advantage of size (SAI)

The scale comparative advantage of scallop cultivation in different provinces was reflected by comparing the scallop cultivation area in the eight provinces with the seawater mollusk cultivation area in the province in question and the ratio of scallop cultivation in China. The formula is as follows: $SAI_{ij}= \frac{GS_{ij}/GS_i}{GS_j/GS}$.

where *i* represents province, *j* is scallop cultivation, GS_{ij} is scallop cultivation area in province I, GS_i is marine scallop cultivation area in province *i*, GS_j is the national scallop cultivation area, and GS represents the national marine scallop cultivation area. $SAI_{ij}>1$ indicates that scallop cultivation in province *i* has a scale advantage and is more specialized than the national average. $SAI_{ij}<1$ indicates that the scallop cultivation scale effect in province *i* is not obvious, the degree of specialization is not high, and this province is at a disadvantage relative to the whole country. The larger the VALUE of SAI_{ij}, the more obvious the scale effect of scallop culture.

Comprehensive comparative advantage index (AAI)

The comparative advantages of scallop culture efficiency and scale in the eight provinces were comprehensively measured to reflect the dominance of scallop culture in these provinces. The formula is as follows: $AAI_{ij}= \sqrt{EAI_{ij} * SAI_{ij}}$.

$AAI_{ij}>1$ indicates that scallop cultivation in province *i* has a comparative advantage relative to the national average. An $AAI_{ij}<1$ indicates that scallop cultivation in the province *i* is at a disadvantage relative to the national average. The higher the AAI_{ij} value is, the more obvious the comprehensive comparative advantage of scallop culture.

Location entropy (LQ)

Location entropy reflects the industrial agglomeration level and specialization degree of scallop farming in different provinces by comparing the relative scallop farming level among the eight provinces and the scallop farming industry ratio in this province to the national scallop farming industry. The formula used for calculation is as follows: $LQ_{ij}= \frac{q_{ij}/q_j}{q_i/q}$.

In this formula, *i* represents province, *j* is scallop cultivation, q_{ij} is scallop cultivation production in the province *i*, q_j is scallop cultivation production in China, q_i is marine scallop cultivation production in the province *i*, and q is marine scallop cultivation area in China. $LQ_{ij}>1$ indicates that the concentration level and specialization degree of scallop aquaculture in province *i* are higher than the national average level. $LQ_{ij}<1$ indicates that the scallop breeding industry in province *i* has a low concentration level and a low degree of specialization. A higher LQ_{ij} value indicates a higher level of scallop aquaculture agglomeration.

Industrial concentration rate (CR)

The industrial concentration ratio is the sum of the proportion of scallop cultivation production in provinces that rank at the top in scallop cultivation among China's scallop cultivation production, reflecting the degree of spatial agglomeration of scallop cultivation (Chang et al., 2013) and measuring the competitiveness and monopoly of the industry.

Results

According to the methods mentioned above, the data on aquaculture production and area for marine shellfish and scallops in China overall and in eight provinces from 2012 to 2020 were calculated and analyzed. The scallop efficiency comparative advantage index, scale

comparative advantage index, comprehensive comparative advantage index, location entropy, and industry concentration rate of each province from 2012 to 2020 were obtained, as shown in **Table 2**.

Table 2 Efficiency, scale, comprehensive comparative advantage index and industrial agglomeration index of scallop breeding industry in various provinces from 2012 to 2020

Year	EAI							
	Hebei	Liaoning	Zhejiang	Fujian	Shandong	Guangdong	Guangxi	Hainan
2012	3.4728	0.9725	1.5182	3.0362	2.1504	2.3345	1.4762	2.2418
2013	3.8793	0.9476	0.9375	3.2259	2.3084	2.2206	1.5102	2.3493
2014	4.0488	0.9384	0.8394	3.2971	2.2334	2.0255	1.5193	2.3077
2015	4.2553	0.8993	0.8022	1.9015	2.1773	2.0796	1.4114	2.2579
2016	3.5831	0.8991	1.1211	2.7189	1.7878	1.7364	1.1742	1.8164
2017	3.3006	0.9244	0.9117	2.5019	1.7973	1.7326	1.0343	1.2816
2018	3.5665	0.9728	0.9361	2.3254	1.7117	1.8527	1.3929	0.1421
2019	3.4606	1.0209	0.8287	2.3015	1.8149	2.3296	1.3911	0.1533
2020	3.2245	0.8754	0.3032	2.4303	1.8195	2.2291	2.2703	30.5010
Year	SAI							
	Hebei	Liaoning	Zhejiang	Fujian	Shandong	Guangdong	Guangxi	Hainan
2012	2.0841	1.4702	0.0031	0.0077	0.7850	0.1731	0.0171	0.0079
2013	1.6872	1.4750	0.0038	0.0073	0.7356	0.1778	0.0152	0.0068
2014	1.6507	1.4837	0.0041	0.0076	0.7316	0.1981	0.0149	0.3398
2015	1.5204	1.4854	0.0050	0.0197	0.7684	0.1931	0.0145	0.3359
2016	1.8075	1.4804	0.0059	0.0091	0.9604	0.2319	0.0181	0.3940
2017	1.9381	1.4719	0.0063	0.0087	0.9469	0.2484	0.0197	0.3588
2018	1.8426	1.4544	0.0052	0.0094	1.0417	0.2430	0.0155	0.4534
2019	1.8792	1.4597	0.0058	0.0097	1.0764	0.2113	0.0158	0.3953
2020	2.1787	1.4184	0.0167	0.0106	1.0957	0.2278	0.0101	0.0162
Year	AAI							
	Hebei	Liaoning	Zhejiang	Fujian	Shandong	Guangdong	Guangxi	Hainan
2012	2.6903	1.1957	0.0690	0.1526	1.2993	0.6357	0.1590	0.1332
2013	2.5583	1.1822	0.0593	0.1530	1.3031	0.6283	0.1513	0.1263
2014	2.5852	1.1799	0.0586	0.1579	1.2783	0.6335	0.1505	0.8855

2015	2.5435	1.1558	0.0632	0.1935	1.2934	0.6338	0.1433	0.8709
2016	2.5449	1.1537	0.0816	0.1573	1.3103	0.6346	0.1459	0.8460
2017	2.5292	1.1664	0.0758	0.1477	1.3045	0.6560	0.1428	0.6781
2018	2.5635	1.1895	0.0695	0.1482	1.3353	0.6710	0.1470	0.2538
2019	2.5501	1.2207	0.0694	0.1492	1.3977	0.7016	0.1481	0.2462
2020	2.6505	1.1143	0.0711	0.1602	1.4119	0.7126	0.1513	0.7028

Year	LQ							
	Hebei	Liaoning	Zhejiang	Fujian	Shandong	Guangdong	Guangxi	Hainan
2012	7.2377	1.4297	0.0048	0.0233	1.6881	0.4041	0.0253	0.0177
2013	6.5451	1.3976	0.0035	0.0234	1.6980	0.3948	0.0229	0.0160
2014	6.6835	1.3923	0.0034	0.0249	1.6339	0.4013	0.0227	0.7841
2015	6.4696	1.3359	0.0040	0.0374	1.6730	0.4017	0.0205	0.7584
2016	6.4765	1.3311	0.0067	0.0247	1.7170	0.4027	0.0213	0.7157
2017	6.3970	1.3605	0.0057	0.0218	1.7018	0.4304	0.0204	0.4598
2018	6.5716	1.4148	0.0048	0.0219	1.7832	0.4503	0.0216	0.0644
2019	6.5032	1.4902	0.0048	0.0222	1.9535	0.4922	0.0219	0.0606
2020	7.0253	1.2416	0.0051	0.0257	1.9936	0.5077	0.0229	0.4939

Year	CR							
	Hebei	Liaoning	Zhejiang	Fujian	Shandong	Guangdong	Guangxi	Hainan
2012	20.47	24.84	0.02	0.43	47.47	6.23	0.15	0.00
2013	21.07	25.07	0.02	0.43	47.32	5.94	0.14	0.00
2014	22.78	24.61	0.02	0.47	45.88	5.92	0.14	0.18
2015	21.91	23.25	0.02	0.72	47.97	5.84	0.13	0.16
2016	20.94	23.60	0.04	0.48	48.97	5.68	0.13	0.16
2017	21.13	23.52	0.04	0.43	49.03	5.57	0.13	0.15
2018	19.71	22.48	0.03	0.46	51.24	5.92	0.15	0.01
2019	16.29	23.19	0.03	0.50	53.25	6.58	0.16	0.01
2020	18.28	19.57	0.04	0.57	54.92	6.39	0.16	0.07

Comprehensive comparative advantage analysis

From 2012 to 2020, the efficiency comparative advantage indexes for scallop cultivation efficiency in Hebei, Fujian, Guangdong, Shandong, and Guangxi were all greater than 1 (**Table 2** and **Figure 5**). Among these, Hebei had the highest comparative advantage in terms of efficiency in scallop cultivation, while Fujian, Guangdong, Shandong, and Guangxi had some advantages. The efficiency of scallop cultivation in Liaoning and Zhejiang was lower than the national average and was at a disadvantage. The scale of scallop cultivation in Hainan was small, and the efficiency comparative advantage index fluctuated sharply. In the last five

years, the efficiency comparative advantage of Hebei, Fujian, Zhejiang, and other regions showed a decreasing trend; the efficiency comparative advantage of Guangdong, Guangxi, and other regions showed an increasing trend; and the efficiency comparative advantage of Shandong, Liaoning, and other regions was stable.

From 2012 to 2020, the comparative advantage indices of the scallop cultivation scale for Hebei and Liaoning were both greater than 1 (**Table 2** and **Figure 6**), indicating that the proportion of the scallop cultivation area in the overall local shellfish cultivation area was higher than the national average, with a certain scale level and concentration advantage. The comparative advantage index for scallop cultivation scale in Hebei and Shandong has increased in recent years, particularly in Shandong, where it increased from 0.7850 in 2012 to 1.0957 in 2020, for a rate of nearly 40%. This implies that the scallop cultivation scale was rapidly developing toward a larger scale and being more professional. The scale effect of scallop cultivation in Zhejiang, Fujian, Guangdong, Guangxi, and Hainan was not apparent, and the degree of specialization was not high; thus, scallop cultivation in Zhejiang, Fujian, Guangdong, Guangxi, and Hainan was at a disadvantage.

From 2012 to 2020, the comprehensive comparative advantage indices of scallop cultivation in all regions except Hainan remained stable, with little change over the years (**Table 2** and **Figure 7**). The comprehensive comparative advantage index of scallop cultivation in Hebei was significantly higher than in other regions, indicating that Hebei had an obvious comparative advantage in China. Scallop cultivation in Shandong, Liaoning, and other locations had a comparative advantage. Scallop cultivation in Zhejiang, Fujian, Guangdong, Guangxi, and Hainan was disadvantaged.

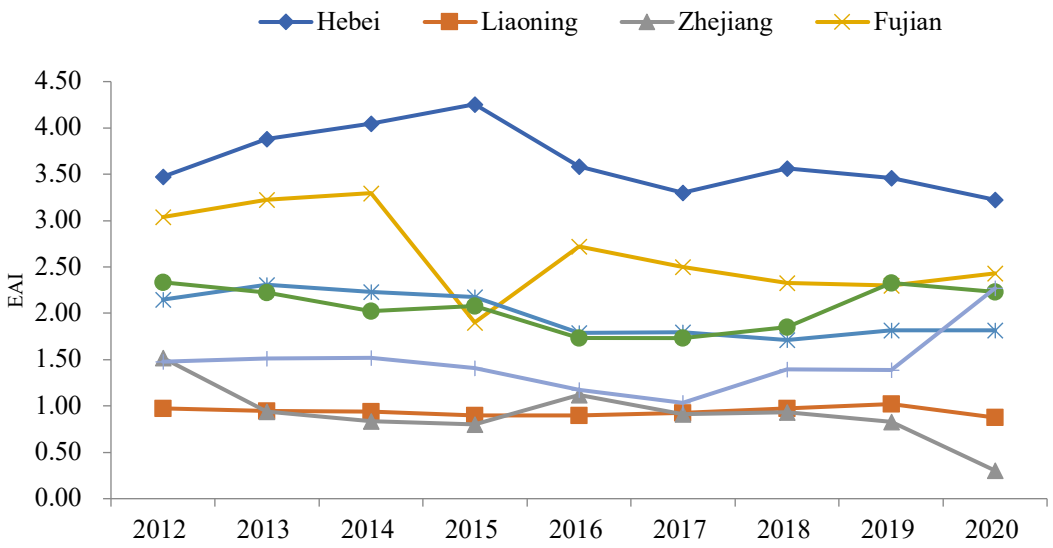

Figure 5 Trend of change in scallop cultivation efficiency comparative advantage in different provinces from 2012 to 2020

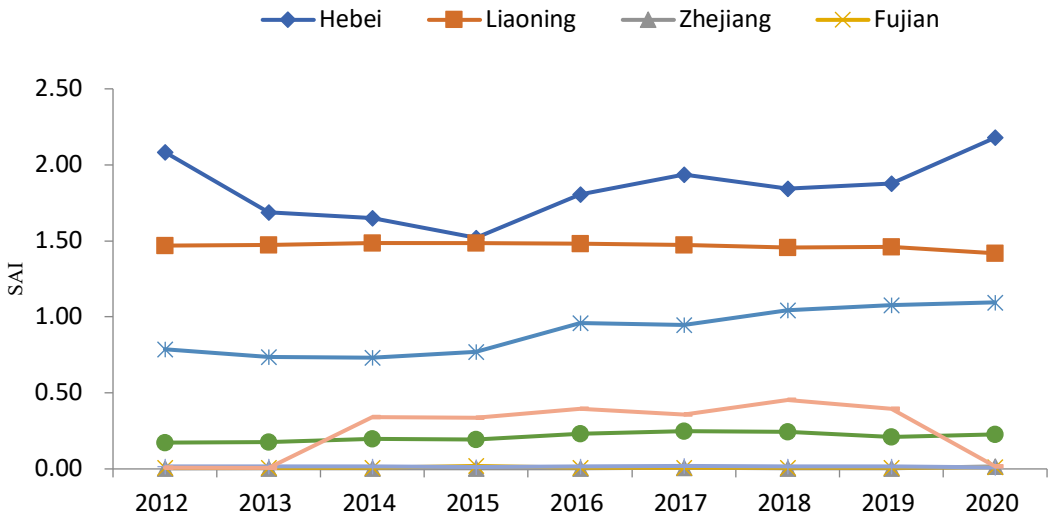

Figure 6 Trend of change in scallop cultivation scale comparative advantage in different provinces from 2012 to 2020

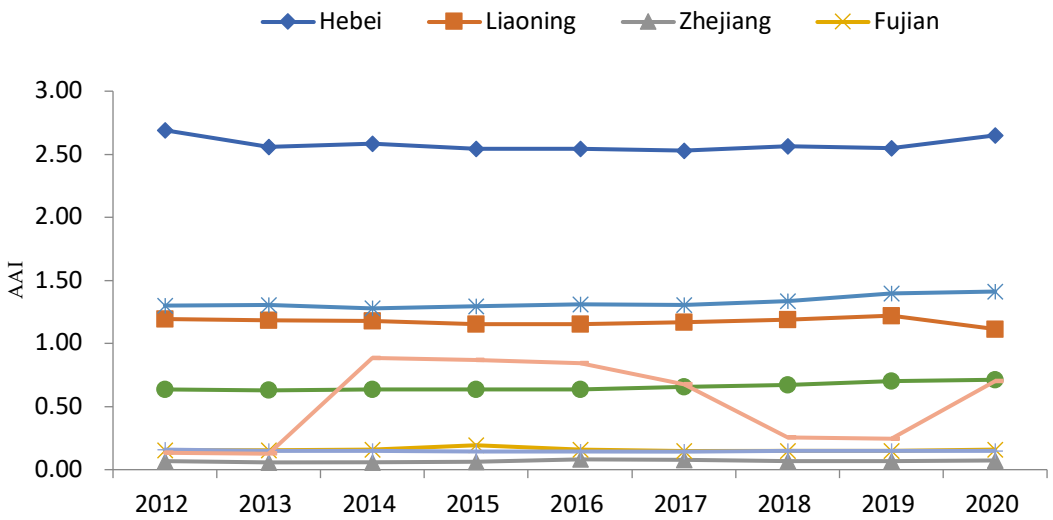

Figure 7 Trend of variation in scallop cultivation comprehensive comparative advantage in different provinces from 2012 to 2020

Analysis of LQ and CR

From 2012 to 2020, the location entropy of scallop cultivation in Hebei was much higher than the national average, indicating that its industrial agglomeration level was the highest (**Table 2** and **Figure 8**). The location entropy of scallop cultivation in Shandong and Liaoning was also greater than 1, indicating that the industrial agglomeration level was higher than the national average. Shandong's location entropy of scallop cultivation showed an upward trend (from 1.688 to 1.994), indicating that industrial agglomeration was in progress. The concentrations of scallop aquaculture in Zhejiang, Fujian, Guangdong, Guangxi, and Hainan were relatively low.

From 2012 to 2020, Shandong, Liaoning, Hebei, and Guangdong were the top four regions with the highest scallop production in China. The industrial concentration rate of scallop

production among the national production (CR_4) in these four provinces was above 99% throughout the year, indicating that the scallop breeding industry in China was essentially concentrated in Shandong, Liaoning, Hebei, and Guangdong Provinces (**Table 2** and **Figure 9**). The overall concentration rate of the scallop cultivation industry in Shandong showed a significant increasing trend, with an increase of 7.45%. The industrial concentration rate in Shandong Province exceeded that of other provinces in China, indicating that Shandong was the main production area of scallop cultivation, and the province had the most substantial concentration in terms of the scallop cultivation industry. Overall, the concentration rate of the scallop cultivation industry in Liaoning and Hebei showed a declining trend. In particular, the concentration rate of the scallop cultivation industry in Liaoning decreased from 24.84% in 2012 to 19.57% in 2020.

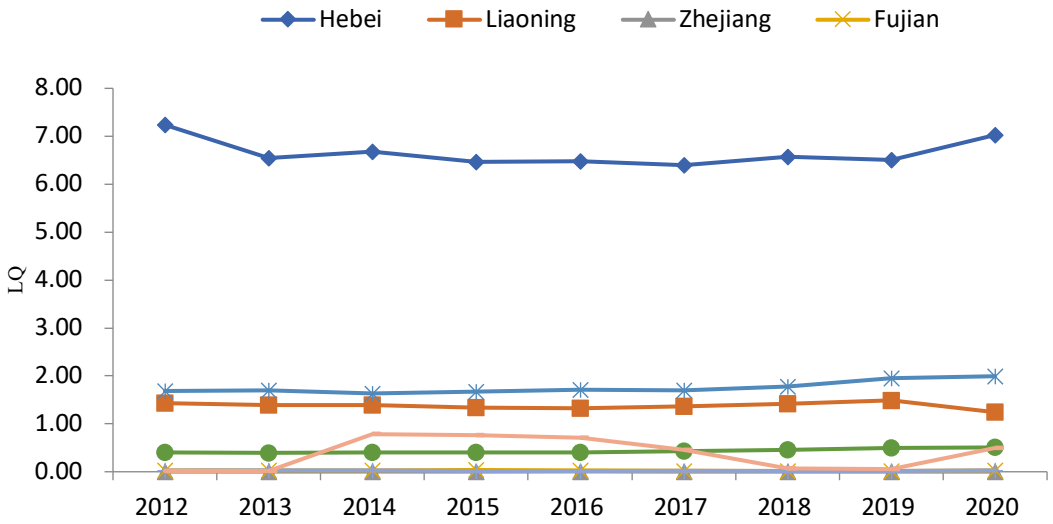

Figure 8 Trend of variation in location entropy of scallop cultivation in different provinces from 2012 to 2020

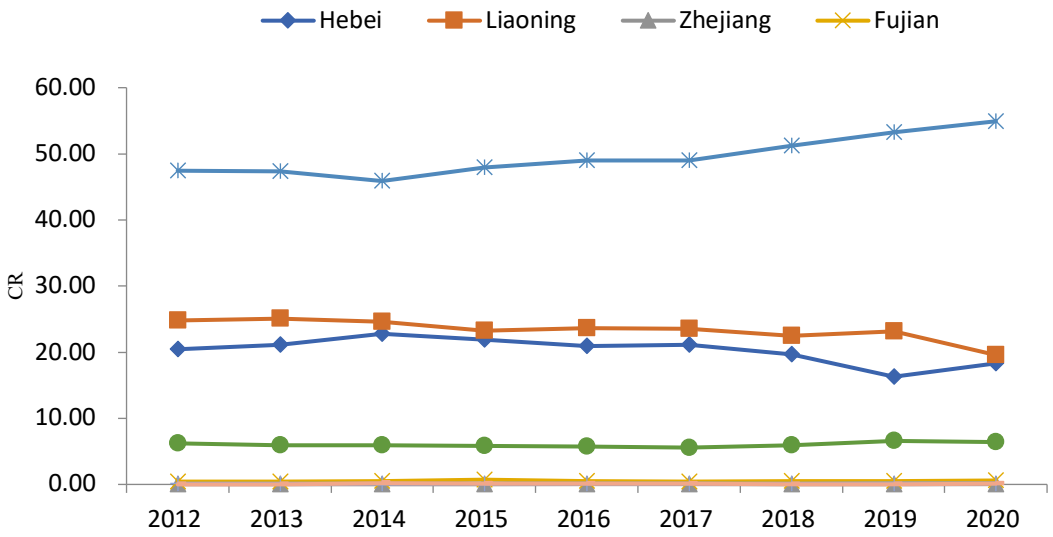

Figure 9 Trend of change in concentration rate of scallop cultivation industry in different provinces from 2012 to 2020

Discussion

The comparative efficiency advantage, scale comparative advantage, comprehensive comparative advantage, and agglomeration level of scallop cultivation in Hebei ranked first in China. There are two main reasons for this. First, Hebei has a multitude of natural resources suitable for scallop cultivation, and it is the only province among the eight provinces studied for which the per unit yield of scallop cultivation exceeds that of marine scallop cultivation in the entire province; thus, scallop cultivation has the best comparative advantage in terms of efficiency. Second, scallop aquaculture, as one of the pillar fishery industries in Hebei, was supported by policies and driven by economic benefits and other factors, and its scallop aquaculture area was maintained at about two-thirds of the entire province's seawater shellfish aquaculture area throughout the year (Sun et al., 2014), which was far higher than that of other provinces; thus, it had apparent comparative advantages in terms of scale. In addition, scallop aquaculture production accounted for more than 80% of the seawater shellfish aquaculture production in the province, a higher corresponding ratio than that of other provinces. Therefore, the scale comparative advantage is remarkable, and the agglomeration level is the highest.

The Liaoning scallop breeding efficiency comparative advantage was lower than the national average. The main reason for this is this province’s unique breeding method, mainly bottom sowing aquaculture in terms of the scallop culture process. However, its breeding area accounts for over half of the scallop culture area throughout the year, sometimes nearly three-quarters. Thus, the scale effect is evident.

Scallop farming in Shandong has a particular comparative advantage in terms of efficiency. In recent years, through policy guidance, the development of cooperative organizations, and input from production factors, large-scale and specialized production in Shandong has developed rapidly, and the scale comparative advantage has increased dramatically. The Shandong scallop aquaculture industry had a higher industrial concentration rate for several reasons. First, the Shandong scallop aquaculture industry has the highest industrial concentration rate because the long coastline of Shandong is filled with bait for scallop aquaculture, the sea is vast, the perennial scallop aquaculture area ranked second in the country, and the yield levels were higher than the other two scallop-production-culture provinces, Hebei and Liaoning, with yield levels as much as approximately 5–8 times those of Liaoning. Therefore, this province has the highest production in the nation. Second, the Shandong coastal governments at all levels have always attached great importance to the mariculture industry, such as in the 1990s. These governments have aimed to vigorously promote the development of the bay scallop aquaculture industry through relevant favorable policies designed to speed up the transformation of traditional fishery development and promote the development of aquaculture scale, intensive, standardization, and so on (Chen et al., 2011). This has resulted in the Shandong scallop aquaculture industry’s agglomeration level increasing rapidly.

Conclusion

Based on the analysis of scallop culture efficiency comparative advantage, scale comparative advantage, and comprehensive comparative advantage in eight provinces from 2012 to 2020, the trend of change in scallop culture efficiency comparative advantage, scale comparative advantage, and comprehensive comparative advantage in each province can be determined. Overall, Hebei Province had the highest efficiency comparative advantage, followed by Fujian, Guangdong, Shandong, Guangxi, Liaoning, and Zhejiang Provinces. Hebei Province had the largest scale comparative advantage, followed by Liaoning, Shandong, Hainan, Guangdong, Guangxi, Fujian, and Zhejiang Provinces. Hebei Province had the highest comparative advantage, followed by Shandong, Liaoning, Guangdong, Hainan, Fujian, Guangxi, and Zhejiang Provinces. By analyzing the location entropy and industrial concentration rate of

scallop cultivation in these eight provinces from 2012 to 2020, it was found that Hebei, Liaoning, and Shandong, which have the most developed scallop cultivation, have large scale comparative advantage, high comprehensive comparative advantage, and significant industrial agglomeration.

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Data accessibility

The datasets generated and analyzed during the current study are available from the corresponding authors upon reasonable request.

Author Contributions

QJ and YM performed all experiments and analyzed all data, and QJ wrote the manuscript with the help of all authors. DZ modified the article. ZZ and BW contributed to the theoretical designs. All authors contributed to the final version of the manuscript.

Conflict of Interest Statement

The authors declare that this article was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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