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Original Research Articles

Evolution and Factors Influencing the Spatial Patterns of Fisheries and Aquaculture Products Trade within RCEP Countries: A Complex Network Analysis

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This study aims to make visible and investigate changes in the patterns of trade in fisheries and aquaculture products, which are heavily traded and of high importance for food security in many Regional Comprehensive Economic Partnership (RCEP) member countries. The study uses fisheries and aquaculture products trade data from 2002 to 2022 and applies a complex network analysis to unveil the trade network of fisheries and aquaculture products within the RCEP region. It analyzes the topological structure and spatiotemporal evolution characteristics of the trade network, and utilizes QAP model to further examine the main factors influencing the characteristics of the fisheries and aquaculture products trade network. The study finds: (1) The density of the fisheries and aquaculture products trade network in the RCEP region has significantly increased, exhibiting "small-world" characteristics. With the increasing degree of trade integration, there is still much room for improvement in the cooperation and development of fisheries and aquaculture products trade; (2) The network displays a pronounced core-periphery structure, with China and Japan consistently occupying a central position in the RCEP region's fisheries and aquaculture products trade network; (3) Economic size, comparative advantage, foreign dependence degree, per capita arable land area, contiguity, and institutional quality are significant factors affecting the relationships and trade volume among countries in the fisheries and aquaculture products trade network.

INTRODUCTION

Due to the failure of the Doha Round of World Trade Talks, coupled with increased uncertainty in the international trade environment following the 2008 financial crisis, a wave of anti-globalization has emerged. This, highlighting weaknesses in WTO multilateral trade system. Consequently, attention has shifted towards negotiations on regional trade liberalization, with Regional Trade Agreements (RTAs) between countries being increasing rapidly and becoming a significant means for many countries to engage in international cooperation and competition. Up to July 2024, the Cumulative Notifications of RTAs in force to the WTO have risen from 28 to 608 between 1990 and 2024. Likewise, China also has accelerated its expansion of new spaces for international cooperation through regional trade agreements, with the Regional Comprehensive Economic Partnership (RCEP) – the largest in the Asia-Pacific region – which became effective in January 2022, bringing new momentum for growth in the post-pandemic era to both regional economy of Asia-Pacific and global economy.

Fisheries and aquaculture products are one of the most traded food commodities globally, with its trade value from developing countries exceeding that of all other agricultural products combined.[1] These products also serve as a crucial source of high-quality animal protein, nutrition, and contributing to food security.[2,3] Furthermore, the trade of fisheries and aquaculture products can contribute to the support of sustainable fisheries development.[4]

The signing and implementation of the Regional Trade Agreement between the 15 member States provides that the majority of products from member States will benefit from zero tariffs or preferential tariffs within the free trade area. This provides a collaborative platform for promoting trade in fisheries and aquaculture products. The trade volume of fisheries and aquaculture products within the RCEP

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region grew from $9.291 billion to $44.737 billion between 2000 and 2022, representing an increase of nearly fourfold. China's export of fisheries and aquaculture products has consistently ranked first globally for many years. Since 2002, China's fisheries and aquaculture products exports have continuously held the top spot globally.[5] According to United Nations Trade Statistics, in 2022, China's fisheries and aquaculture products export value exceeded 22.5 billion US dollars, with exports to other RCEP member countries accounting for as much as 48.59%. For China, the RCEP region represents a significant import and export market for fisheries and aquaculture products, and strengthening trade ties with RCEP countries is of great importance and far-reaching significance for ensuring food security and a safe and stable supply. Therefore, what evolutionary patterns and characteristics have emerged in the trade of fisheries and aquaculture products among RCEP countries between 2002 and 2022? What is the status of China and its fellow RCEP partner countries within this trade network? What are the influencing factors behind the changes in the RCEP fisheries and aquaculture products trade pattern? Exploring the answers to the above questions will assist policymakers and enterprises in understanding market dynamics, formulating more effective trade strategies, and establishing cooperation frameworks.

The alterations in the global trade environment have stimulated numerous investigations into the trade of fisheries and aquaculture products. These inquiries can typically be divided into studies focusing on the traits of fisheries and aquaculture products trade at national, bilateral, and regional dimensions.

At the national level, Yang et al. considered China, the world's largest fisheries and aquaculture products exporter, as a case study to investigate whether fisheries and aquaculture products trade patterns vary by product categories.[6] Zhang et al. explored the challenges posed by the global COVID-19 pandemic of 2020 to the global fish trade, particularly focusing on the impact on China's fish imports and exports.[7] Their analysis of the evolution of policies and trade highlighted the importance of seeking alternative markets, and recommended strengthening international cooperation and domestic regulation to enhance long-term disaster resilience. Prompatanapak and Lopetcharat studied the changes and risks in Thailand's fisheries and aquaculture products supply chain management,[8] while Fernández-González et al. analyzed the institutional changes in Spain's canned fish industry from the perspective of new institutional economics.[9] Marin et al. studied fisheries and aquaculture products trade in Nigeria, concluding that in terms of food security and nutrition, fisheries and aquaculture products trade has greater payoffs, thanks to the relatively low-cost of imported fisheries and aquaculture products.[10]

From a bilateral perspective, Lu et al. evaluated the impact of the recent trade conflict between the USA and China on China's fisheries and aquaculture products.[11] They found that China's exports and imports of fisheries and aquaculture products were only slightly negatively impacted, while the USA experienced the greater potential trade losses. Minh and Diep assessed the prospective influence of the UK-Vietnam Free Trade Agreement (UKVFTA) on Vietnam's imports of fisheries and aquaculture products from the UK.[12] They simulated and found that under the set conditions, the UK free trade zone can improve the welfare of Vietnam.

At the regional scale, Baylis et al. explored the number of EU fisheries and aquaculture products imports to estimate the relationship between changes in tariff rates and the implementation of non-tariff barriers.[13] From 1994 to 2012, Gephart and Pace scrutinized the composition and development of the global trade network for fisheries and aquaculture products.[14] Their findings indicated a growing prominence of Thailand and China, enhanced intra-regional trade, as well as increasing exports from South America and Asia. Besides, Solarin analyzed the trends in per capita consumption of fisheries and aquaculture products across EU27 nations and the UK.[15] Similarly, Belton et al. investigated the impact of COVID-19 and related policies on inputs, prices, and availability of fisheries and aquaculture foods in Asia and Africa.[16]

From the perspective of research methods, existing studies on fisheries and aquaculture products trade primarily employ different approaches: (1) The gravity model and its extensions are used to analyze fisheries and aquaculture products trade. For example, Natale et al. used the gravity model to investigate the effects of various factors including population, GDP, trade agreements, and geographic distance on fisheries and aquaculture products trade[17]; (2) The constant market share (CMS) model and its extensions are used to examine the competitiveness of fisheries and aquaculture products trade,[18,19] and factors affecting fisheries and aquaculture products export fluctuations[20]; (3) The general equilibrium models and local projection approach are employed to quantitatively assess the impact of specific trade policies[21-23]; (4) Social network analysis methods for visualizing trade network relationships, to some extent, have also been applied in the literature. For example, Elsler et al. revealed the role of developing global trade networks in sustainable fisheries promotion.[24]

In summary, the advantages of social network analysis have not yet been fully utilized in our field of fisheries and aquaculture products trade based on recent existing literature. The complex network analysis method is a mathematical analysis approach derived from graph theory and topology. By utilizing various metrics to measure the structural characteristics of real-world system networks and to delve into their dynamic spatiotemporal evolution patterns,[25] it has become an interdisciplinary research tool, with applications in various fields including social sciences, economics, and international trade.[26-29] Studies focusing on fisheries and aquaculture products trade under the RCEP agreement, which was implemented in 2022, are also relatively scarce. Given RCEP member countries are major players in fisheries and aquaculture products trade, this method could help depict an accurate multidimensional picture of the evolution of fisheries and aquaculture products trade patterns among RCEP countries and, particularly the changes in China's position. It includes aspects such as trade relationships, trade intensity, and community detection. Therefore, this study uses complex network analysis to explore the characteristics and evolution of the fisheries and aquaculture products trade network among RCEP countries and the changes in China's trade status. Additionally, the QAP model is employed to analyze the factors influencing the the fisheries and aquaculture products trade network among RCEP countries. This could help analyze the intricate trade relations of fisheries and aquaculture products among RCEP countries from a global perspective and provides valuable reference and insights to further expand China's imports and exports of fisheries and aquaculture products and ensure their reliability and stability in the future.

MATERIALS AND METHODS

DATA SOURCES

The Regional Comprehensive Economic Partnership (RCEP) stands out as a pivotal trade agreement within the Asia-Pacific region, which includes countries such as Australia, Brunei, Cambodia, China, Indonesia, Japan, South Korea, Laos, Malaysia, Myanmar, New Zealand, the Philippines, Singapore, Thailand, and Vietnam. This study focuses on the RCEP's 15 member countries as the research area, with aquatic products as the subject of investigation, guided by the FAO and the World Customs Organization (WCO) which presents HS codes for fisheries and aquaculture products.[30] Data on trade flow of aquatic products between countries comes from the United Nations Commodity Trade Statistics Database. Taking into account the availability of data as well as the impact of changes over time and the macroeconomic conditions on the trade network structure within the RCEP region, this research aims to explore the evolution and mechanism of aquatic products trade spatial patterns from 2002 to 2022. The years 2002, 2008, 2014, 2019, 2021, and 2022 have been selected as focal points for this study; By incorporating an examination of changes before and after the Covid-19, this study allows for a comprehensive reflection on the spatial evolution characteristics of the RCEP region's aquatic products trade network, thus ensuring the objectivity and scientific validity of the research findings.

Data pertaining to overall economic size, per capita income, per capita arable land area, and foreign dependence degree derive from the World Bank database, reflecting the proportion of foreign trade relative to GDP. Data on geographical distance and whether countries share borders were taken from the CEPII database. In addition, we used the most commonly method from Cvetković et al. to calculate the comparative advantage and measured the institutional quality by using the average of the six dimensions of the World Governance Index (WGI), of the World Bank.[31,32]

RESEARCH METHODS

FISHERIES AND AQUACULTURE PRODUCTS TRADE NETWORK MODEL

This study draws on the complex network theory, and constructs a weighted fisheries and aquaculture products complex network model $G = (V, E, W)$, where $V = \{V_1, V_2, \ldots, V_n\}$refers to the set of nodes constituted by the RCEP member countries, $E = \{E_1, E_2, \ldots, E_n\}$ denotes the set of edges formed by the trade relationships of fisheries and aquaculture products between two countries, and $W = \{W_1, W_2, \ldots, W_n\}$ is the trade volume of fisheries and aquaculture products between RCEP countries. To present the topological structure and describe the spatiotemporal evolution characteristics of the RCEP region's fisheries and aquaculture products trade network, this research adopts the following specific indicators:

INDEX OF OVERALL NETWORK

NETWORK DENSITY

Network density reflects the proportion of actual edges present in the trade network related to all possible edges, revealing the degree of connectivity and the intensity of interactions among nodes within the network. An increase in network density signifies a more compact arrangement of connections among the countries in the network, thereby enhancing the overall influence on the network. Such a tightly connected structural configuration facilitates the efficient flow and sharing of resources within the network. The network density D for the weighted directed fisheries and aquaculture products trade among RCEP countries is described by Eq. (1), where E represents the number of existing trade relationships within the entire network, and N denotes the total number of nodes.[33]

$$D = \frac{E}{N(N-1)} \tag{1}$$

AVERAGE PATH LENGTH

The average path length is the mean value of the shortest path lengths between all possible pairs of nodes within a network, reflecting the network's global connectivity. It can be utilized to assess the efficiency of fisheries and aquaculture products trade transmission throughout the entire network. A smaller value indicates closer relationships between nodes and higher transmission efficiency. Within a given network G, the formula for calculating the average path length L is defined by Eq. (2), where $d(i, j)$ is the shortest path length between the nodes of country i and country j.

$$L = \frac{1}{N(N-1)} \sum_{i \neq j} d(i, j) \tag{2}$$

AVERAGE CLUSTERING COEFFICIENT

The average clustering coefficient serves as indicator for measuring the extent to which nodes in a network tend to cluster together, reflecting the network's propensity for group formation. It is computed as the mean value of the clustering coefficients for individual nodes within the network. A higher clustering coefficient indicates a greater degree of aggregation among the nodes. The formula for the average clustering coefficient C is provided by Eq. (3), where E_i is the number of actual edges among the neighboring nodes of country node i and k_i denotes the degree of node i, i.e., the number of nodes directly connected to node i.

$$C = \frac{1}{N} \sum_{i=1}^{N} \frac{2E_i}{k_i(k_i - 1)} \tag{3}$$

INDEX OF INDIVIDUAL NETWORK

DEGREE CENTRALITY

The degree centrality in this study reflects the central position of a trading country in the spatial correlation network of fisheries and aquaculture products trade. The higher the degree centrality, the more trade links will be between countries and other countries, and the more likely they will be in central position in the network. S is the degree centrality that is shown in Eq. (4), where $w_{ij}(t)$ refers to the total trade volume of fisheries and aquaculture products between node i and node$j$ for t years, i.e., the weight of the edge and if there is any direct trade relationship between nodes i and$j$, then a_{ij}=1, otherwise it is 0.[34]

$$S = \sum_{j=1}^{N} a_{ij} w_{ij}(t) \tag{4}$$

BETWEENNESS CENTRALITY

Betweenness centrality reflects how centrally positioned a country is within the trade transmission network formed by other countries. For spatial correlation network structure of fisheries and aquaculture products trade, the higher the betweenness centrality of a country, a country with higher betweenness centrality tends to facilitate shorter trade association pathways between many pairs of countries. This enhanced centrality signifies a stronger capacity to influence trade relationships among other countries, thereby enhancing its function as a "bridge" relative to other countries. Eq. (5) serves for calculating the betweenness centrality C_b, where $b_{ij}(k)$represents the likelihood of node k being situated on the shortest path linking node i and node j, with the conditions that $i \neq j \neq k$.

$$C_b = \sum_{i=1}^{N} \sum_{j=1}^{N} b_{ij}(k) \tag{5}$$

CLOSENESS CENTRALITY

In this study, closeness centrality serves as a measure of the extent of direct connections that a trading country has with other nations within the spatial connection network of fisheries and aquaculture products trade. The higher the closeness centrality, the more direct will be the connections between the country and other countries, with the national node that belongs to the central player within the network. C_C represents the closeness centrality and can be computed by Eq. (6), where d_{ij} represents the shortest path distance between node i and node j.

$$C_C = 1 / \sum_{j=1}^{N} d_{ij} \tag{6}$$

COMMUNITY DETECTION

Through community detection, the nodes of countries with close contact in fisheries and aquaculture products trade in RCEP region can be grouped into the same community, which can clearly identify the groups with the closest contact in fisheries and aquaculture products trade network, as well as delineating the position of each country within these communities. The expression for calculating community detection is shown in Eq. (7), where m denotes the total of all connection weights in the network, c_i and c_j represent the respective communities of node i and node j. When both node i and node j are part of the same community, $\delta(c_i, c_j)$ will equal to 1, and vice versa.[35]

$$Q = \frac{1}{2m} \sum_{ij} \left[w_{ij} - \frac{w_i w_j}{2m} \right] \delta(c_i, c_j) \tag{7}$$

CONSTRUCTION OF QAP NETWORK MODEL FOR FISHERIES AND AQUACULTURE PRODUCTS TRADE

The Quadratic Assignment Procedure (QAP) is a randomized testing method for comparing the corresponding element values in two or more square matrices. This method determines the correlation coefficient for two matrices by examining the related values within each matrix and conducts a non-parametric test on that coefficient. Using this method to explore key factors affecting the trade relationships of fisheries and aquaculture products in the RCEP region can help avoid any multicollinearity issues that may exist among explanatory variables in traditional regression models. QAP analysis allows for repeated regression based on random permutations to estimate the standard error of the statistic, which makes the research findings more reliable and robust. According to the traditional trade gravity model and the existing research on fisheries and aquaculture products trade, this paper incorporates variables such as the GDP of the countries, the bilateral geographical distance, the comparative advantage of fisheries and aquaculture products, foreign dependence degree, per capita arable land, whether the countries are contiguous, and the quality of institutions into the QAP model for analysis. The constructed model is as follows:

$$\begin{aligned} TRADE = f(&GDP, PGDP, DIST, RCA, FDD, \\ &PLAND, CONTIG, INST) \end{aligned} \tag{8}$$

In Eq. (8), the explained variable TRADE represents the matrix of fisheries and aquaculture products trade relations among countries in the RCEP region; GDP represents the overall economic size of the two countries, PGDP represents the per capita economic level of two countries, DIST represents the matrix of geographical relations between countries, RCA represents the matrix of comparative advantage in fisheries and aquaculture products between two countries, FDD represents the matrix of foreign dependence degree levels between the two countries, PLAND represents the per capita arable land matrix, CONTIG represents the matrix of whether two countries are contiguous, and INSTQ represents the matrix of institutional quality of two countries.

Table 1. Network metrics of fisheries and aquaculture product trade in the RCEP region.

Index	*Year*					
	2002	*2008*	*2014*	*2019*	*2021*	*2022*
Density	0.7286	0.7190	0.8333	0.8333	0.8095	0.8048
Average Path Length	1.1593	1.1758	1.1714	1.1667	1.1905	1.1378
Average Clustering Coefficient	0.835	0.855	0.891	0.884	0.871	0.874

RESULTS

EVOLUTIONARY IN THE CHARACTERISTICS OF FISHERIES AND AQUACULTURE PRODUCTS TRADE NETWORK PATTERNS

CHARACTERISTICS OF OVERALL NETWORK STRUCTURE

The overall network characteristic indicators of fisheries and aquaculture products trade network in the RCEP region are shown in **Table 1**. Based on the available data, the network density for the year 2022 is 0.8048. This metric signifies a comparatively high degree of interconnectedness in the trade relations of fisheries and aquaculture products among the RCEP member States. Additionally, since the maximal possible value for network density is 1, this indicates that there is considerable room for improvement in trade cooperation among the countries investigated. The average path length is 1.1378, and the average clustering coefficient is 0.874, characterizing network attributes with shorter average path lengths and higher clustering coefficients, which means 'Small-World Network' feature of the trade network. Influenced by the COVID-19 pandemic, there has been slight fluctuation in the indicators for the last two years. However, the general trend indicates an upward trajectory for network density and the average clustering coefficient, alongside a downward trend in average path length. These trends affirm the consistency of the overarching conclusion that the level of integration within the RCEP region's fisheries and aquaculture products trade is on an upward trend.

CHARACTERISTICS OF INDIVIDUAL NETWORK STRUCTURE

In this study, we used Gephi 10.1 software to calculate the degree centrality, betweenness centrality, and closeness centrality of fisheries and aquaculture products trade among RCEP countries in 2002, 2019, and 2022. The results, as shown in Tables 2-4, reveal key centrality indicators within the trade network.

Data in **Table 2** show that: (1) Over the 21 years from 2002 to 2022, there has been a stable yet variable ranking in degree centrality. Leading countries include Japan, China, South Korea, Thailand, and Vietnam, while Myanmar, Cambodia, Brunei, and Laos ranked lower. China's fisheries and aquaculture products trade network's degree centrality increased from 35.99*10^8 in 2002 to 150.71*10^8 in 2019, marking over a threefold increase. With the effectuation of RCEP in 2022, the weighted centrality soared to 321.53*10^8, doubling from 2019 and indicating rapid growth. The rank of degree centrality for China ascended from second to first, maintaining stability and underscoring the closeness and core position of China's trade with other partner countries. Vietnam's weighted degree in RCEP rose notably from fifth in 2002 to third in 2022, signifying an increasing influence within the network. Myanmar, Cambodia, Brunei, and Laos remained relatively stable, consistently positioned at the network's periphery. The average degree centrality of the 15 RCEP member countries grew from 12.39*10^8 in 2002 to 59.65*10^8 in 2022, with each member country experiencing a significant growth, indicating an immense trade potential among RCEP members.

The findings show in **Table 3** reveal a notable trend in the betweenness centrality of Thailand, which demonstrates a decline from 7.27 in 2002 to 6.55 in 2019, further decreasing to 3.78 by 2022. This trend underscores a gradual diminishment in Thailand's bridging role within fisheries and aquaculture products trade network. In 2002, the overall network's average betweenness centrality was recorded at 1.93, with six countries, including Thailand, Malaysia, Singapore, China, Vietnam, and Japan, registering values above this mean. By 2019, the average betweenness centrality increased to 2.33, enlarging the group of countries surpassing this mean to seven, with the addition of South Korea. Progressing to 2022, despite the average betweenness centrality, which fell to 1.8, the number of countries exceeding this benchmark increased to eight, incorporating Australia into the previously established set. Intriguingly, countries like Brunei, Laos and Myanmar recorded a betweenness centrality of zero, indicating their negligible control within fisheries and aquaculture products trade network among other RCEP nations. The convergence of betweenness centrality metrics across the RCEP member countries indicates the dissolution of a scenario where a minority of nations exert control over the entire region. This trend signifies an increase in the frequency of exchanges between countries, leading to a gradual equilibrium in the distribution of resources among them. Consequently, the integration process within the RCEP region's fisheries and aquaculture products trade network is accelerating, reflecting a dynamic shift towards more cohesive and balanced regional trade dynamics.

The higher a country's closeness centrality, the shorter its trade routes, resulting in lower dependency on other nodes within the trade network. Consequently, it becomes less susceptible to restrictions from other countries, facilitating smoother trade. Observing the results from **Table 4**, in the 2002 fisheries and aquaculture products trade network among RCEP countries, China, Thailand, and Vietnam ranked among the highest in closeness centrality, indicating that these countries are less susceptible to be controlled

Table 2. The degree centrality of spatial correlation network of fisheries and aquaculture products trade of RCEP region.

	2002		*2019*		*2022*	
Country	*Centrality*	*Rank*	*Centrality*	*Rank*	*Centrality*	*Rank*
Japan	65.57	1	95.52	2	136.10	2
China	35.99	2	150.71	1	321.53	1
South Korea	20.77	3	47.73	5	76.62	4
Thailand	17.31	4	48.28	4	74.39	5
Vietnam	10.32	5	57.72	3	81.39	3
Indonesia	10.09	6	28.90	6	50.23	7
Australia	8.60	7	22.02	7	25.45	9
Singapore	5.49	8	11.05	10	17.81	10
Malaysia	4.51	9	19.24	8	61.14	6
New Zealand	4.34	10	10.32	11	11.22	11
Philippines	2.38	11	12.30	9	28.47	8
Myanmar	0.21	12	6.66	12	7.08	12
Cambodia	0.12	13	1.58	13	2.29	13
Brunei	0.09	14	0.31	14	0.72	14
Laos	0.02	15	0.30	15	0.30	15
Mean	12.39	——	34.18	——	59.65	——

Note: the data of Centrality are all multiplied by 10^8

by other nations within the network and possess strong capabilities to conduct fisheries and aquaculture products trade independently. A comparative analysis with the results of 2019 reveals that the number of countries with a closeness centrality of 1 increased to seven, including the addition of Indonesia, Japan, Singapore, and South Korea. By 2022, aside from a slight fluctuation in Australia's closeness centrality, other countries experienced an enhancement in closeness centrality compared to 2002. This means that the trade status of nations within the RCEP fisheries and aquaculture products trade network has improved, with some countries still having the potential to enhance their capacity to independently conduct fisheries and aquaculture products trade.

Table 3. The betweenness centrality of spatial correlation network of fisheries and aquaculture products trade of RCEP region.

	2002		*2019*		*2022*	
Country	*Betweenness centrality*	*Rank*	*Betweenness centrality*	*Rank*	*Betweenness centrality*	*Rank*
Thailand	7.27	1	6.55	1	3.78	2
Malaysia	4.82	2	2.78	6	4.05	1
Singapore	4.22	3	2.17	7	3.13	5
China	2.77	4	5.84	3	3.13	5
Vietnam	2.77	4	4.02	4	3.78	2
Japan	2.01	6	4.02	4	3.13	5
Australia	1.32	7	0.91	9	1.8	8
Cambodia	1.3	8	0	12	0	10
Indonesia	1.22	9	0.67	10	0	10
New Zealand	0.45	10	0.3	11	0.2	9
South Korea	0.44	11	6.55	1	3.78	2
Philippines	0.42	12	1.18	8	0.2	9
Brunei	0	13	0	12	0	10
Laos	0	13	0	12	0	10
Myanmar	0	13	0	12	0	10
mean	1.93	——	2.33	——	1.8	——

COMMUNITY DETECTION

Community discovery, also referred to as community detection, involves designing a mapping function F to partition the nodes of a given network $G = (V, E)$into N communities, such that connections within communities are dense, whereas connections between communities are sparse. The community structure is an important characteristic of complex networks.[36] Utilizing Gephi software and modularity for the selected six years, we further investigate and analyze the community structure and its evolution within the RCEP region's fisheries and aquaculture products trade network. As can be seen from **Figure 1**, from 2002 to 2022, the number of communities remains relatively stable, identifying two types of trade communities, although the internal structure of the communities has undergone significant changes.

In 2002, Community 2 primarily consisted of three countries: Myanmar, Malaysia, and Singapore, while Community 1 comprised the remaining 12 countries, including China, Japanese, Korean and the other countries in this region. By 2008, the number of countries in Community 2 expanded to 11, with Australia, Brunei, Japan, Laos, New Zealand, the Philippines, Thailand, and Indonesia being coming up, whereas Community 1 was reduced to four countries, including China, South Korea, Vietnam, and Cambodia. Compared to 2014, the number of countries in Community 2 in 2018 decreased to 5, namely Australia, Brunei Darussalam, Malaysia, New Zealand, and Singapore, while the number of countries in Community 1 increased to 11. In 2019, the number of countries in Community 2 remained unchanged, but its internal structure has undergone significant changes, by including Cambodia, Japan, Laos, the Philippines, and Thailand, whlie Community 1 consisting of 10 countries including China and South Korea. In 2021, the number of countries in Community 2 increased by 3, totaling 8, with the inclusion of Brunei, South Korea, and Vietnam. In 2022, the number of countries in Community 2 further increased to reach a total of 9 countries, including Australia.

The dynamic changes in community composition reveal that community members exhibit some geographical proximity characteristics, yet they transcend regional limitations. During the study period, the internal structure of the communities has undergone constant changes before 2014, exhibiting instability, particularly in 2008. The significant changes in Community 1 and Community 2 in that year might be associated with the global financial crisis, severe fluctuations in oil prices, an increased awareness of food safety and health, and increased trade protectionism. After 2014, the internal structure of the communities gradually stabilized. Community 1 consistently included countries like China, Myanmar, Malaysia, New Zealand, Indonesia, and Singapore, while Community 2 consistently comprised Japan, Cambodia, Laos, the Philippines, and Thailand.

In this paper, we employed Ucinet software to analyze the core-periphery structure of the RCEP fisheries and aquaculture products trade network, classifying nodes with a coreness ⩾0.4 as the core layer, those with a coreness between 0.1 and 0.4 as the semi-peripheral layer, and those with a coreness <0.1 as the peripheral layer. **Figure 2** shows that the RCEP fisheries and aquaculture products trade network exhibits distinct layer characteristics, with significant changes in its internal structure. China and Japan have consistently occupied core positions in fisheries and aquaculture products trade, but China's coreness has been increasing while that of Japan has been decreasing. China's

Table 4. The closeness centrality of spatial correlation network of fisheries and aquaculture products trade of RCEP region.

	2002		*2019*		*2022*	
Country	*Closeness centrality*	*Rank*	*Closeness centrality*	*Rank*	*Closeness centrality*	*Rank*
China	1	1	1	1	1	1
Thailand	1	1	1	1	1	1
Vietnam	1	1	1	1	1	1
Australia	0.93	4	0.88	11	0.93	7
Indonesia	0.93	4	1	1	0.93	7
Malaysia	0.93	4	0.93	8	0.93	7
New Zealand	0.93	4	0.93	8	0.93	7
Japan	0.88	8	1	1	1	1
Philippines	0.88	8	0.93	8	0.93	7
Singapore	0.88	8	1	1	1	1
Cambodia	0.78	11	0.61	14	0.58	14
South Korea	0.78	11	1	1	1	1
Brunei	0.56	13	0.67	13	0.61	13
Laos	0	14	0.56	15	0	15
Myanmar	0	14	0.82	12	0.82	12
mean	0.77	——	0.89	——	0.84	——

coreness increased from 0.58 in 2002 to 0.67 in 2022, whereas the Japanese one decreased from 0.67 in 2002 to 0.47 in 2022. This indicates that Japan's central position in the RCEP trade network has declined over time, while China's central position has improved, which is consistent with the analysis of individual network characteristics. South Korea enjoyed a brief period of reached a core position in 2008, likely due to a series of policies implemented by its government to support the development of the country's aquaculture industry. For instance, in 2008, the Korean Food and Drug Administration adjusted quality control standards for imported fisheries and aquaculture products, the Ministry of Oceans and Fisheries invested approximately 1.1 billion US dollars to promote advancements in aquaculture technology, and restructured the aquaculture industry.

Between 2002 and 2019, changes in the peripheral and semi-peripheral layers were minimal. In 2002, there were eight countries in the peripheral layer, including the Philippines, Cambodia, Australia, Singapore, Brunei, New Zealand, Malaysia, and Myanmar, and five in the semi-peripheral layer, including South Korea, Thailand, Laos, Vietnam, and Indonesia. Except for South Korea, which reached a core position in 2008, the statuses of other countries remained unchanged. In 2014, Laos dropped from the semi-peripheral to the peripheral position, with the statuses of other countries remaining stable. The core-peripheral structure in 2019 was consistent with that of 2014.

After 2019, there were significant changes in the peripheral and semi-peripheral layers. The number of countries in the peripheral layer gradually decreased, while those in the semi-peripheral and core layers increased. Specifically, in 2021, Malaysia and Brunei, which were in the peripheral position in 2019, shift to the semi-peripheral position, increasing the number of semi-peripheral countries to six and reducing peripheral countries to seven. In 2022, the number of semi-peripheral countries increased to seven, and the peripheral countries decreased to six. This suggests that the signing of RCEP would have had a certain impact on the regional fisheries and aquaculture products trade patterns.

FACTORS AFFECTING FISHERIES AND AQUACULTURE PRODUCTS TRADE NETWORK

CORE-PERIPHERY STRUCTURE

QAP CORRELATION ANALYSIS

We ran 5,000 random permutations to obtain the results of the QAP correlation analysis for the structure of the fisheries and aquaculture product trade network within the RCEP area from 2002 to 2022 (**Table 5**). As it can be seen from our findings, the coefficient of GDP is positive and significant at 5% for 2002, 2008, 2014, 2019, 2021, and 2022, indicating that during these periods, GDP significantly and positively influenced the formation of fisheries and aquaculture product trade relations within the RCEP region during the period under investigation. Besides, GDP per capita has a negative and significant impact($p<10\%$) on trade relationships of fisheries and aquaculture products in the RCEP region from 2014 onwards. In addition, the variable contiguity has a positive and significant influence on fisheries and aquaculture products trade network in the RCEP region at 5% level for the years 2002, 2019, 2021, and 2022, while the coefficient of the variable ‘‘quality of institutions'' is significant at 5% level for 2014. Thus, our findings indicate that GDP, GDP per capita, contiguity and quality of the in-

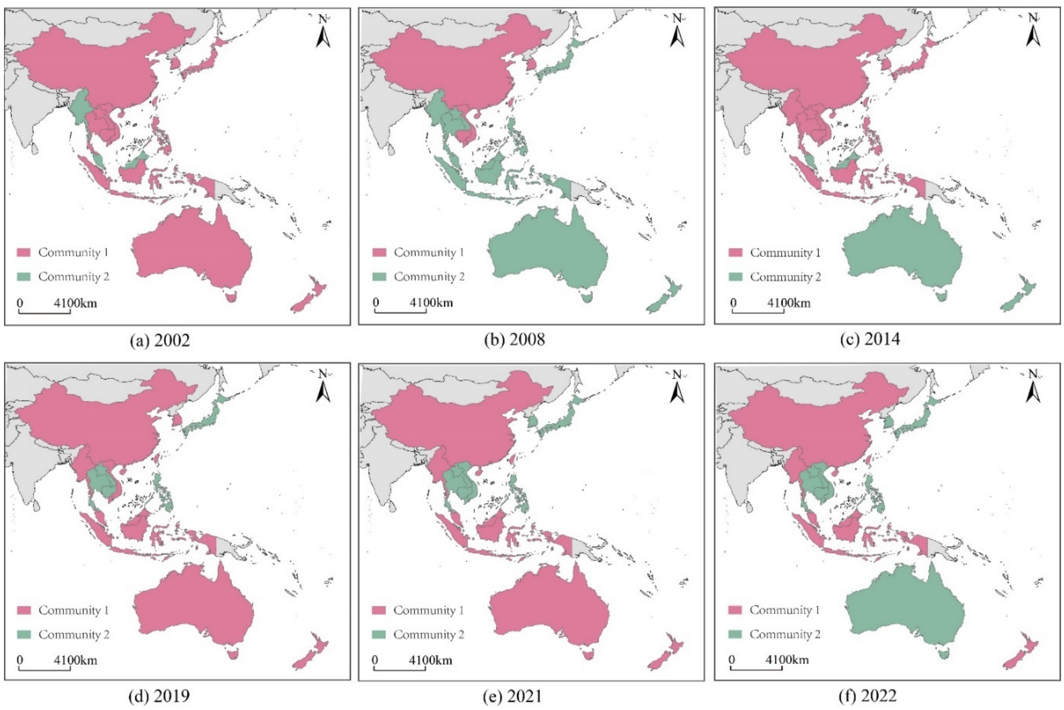

Figure 1. Community detection results of fisheries and aquaculture products trade in the RCEP region for the respective years: (a) 2002; (b) 2008; (c) 2014;(d) 2019;(e)2021;(f)2022.

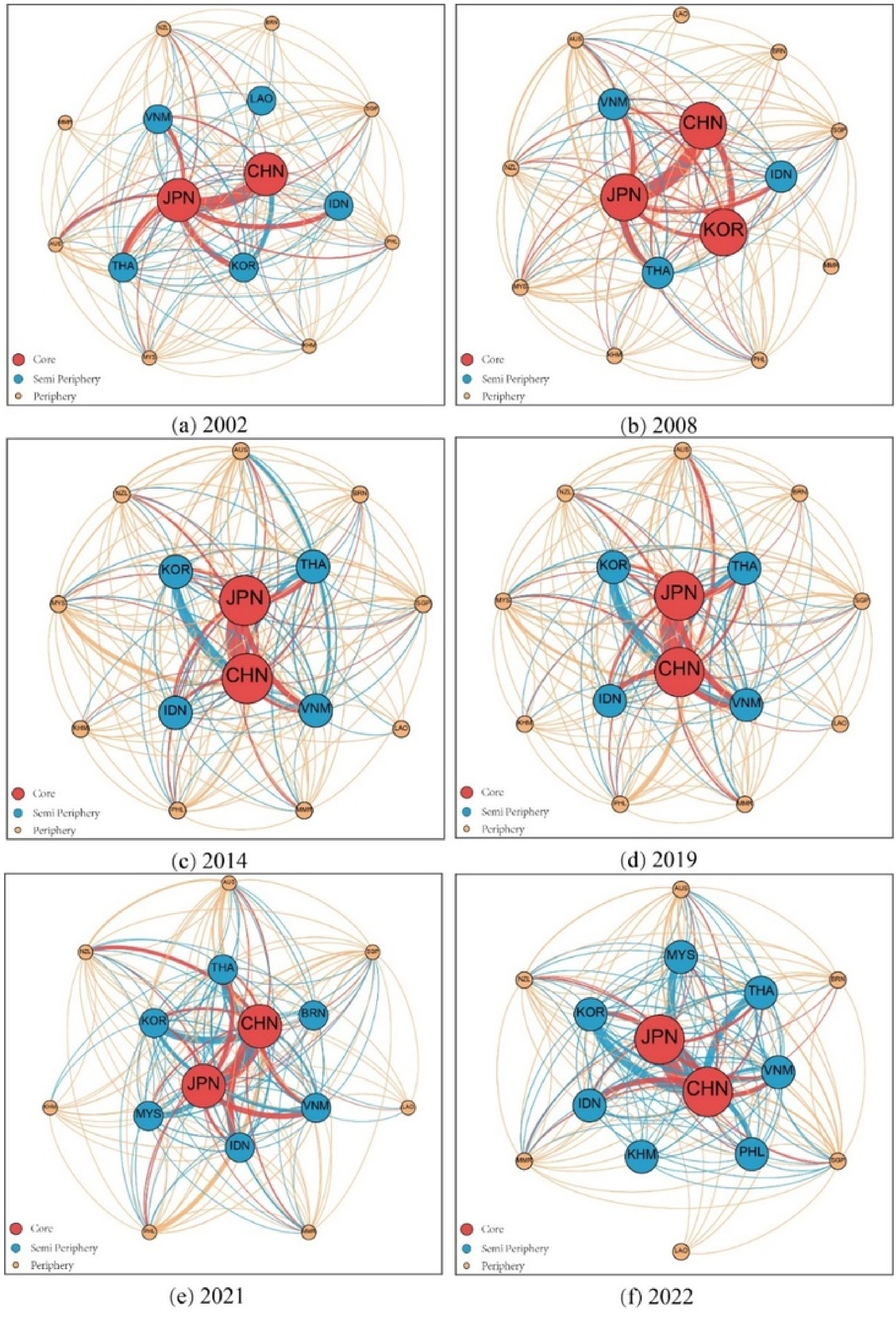

Figure 2. The evolution of core-periphery structure of fisheries and aquaculture products trade in RCEP region for the respective years: (a) 2002; (b) 2008; (c) 2014;(d) 2019;(e)2021;(f)2022.

Table 5. Results of QAP correlation analysis.

Variables	*2002*	*2008*	*2014*	*2019*	*2021*	*2022*
GDP	0.168**	0.145**	0.214**	0.299**	0.311**	0.356**
	(0.011)	(0.038)	(0.033)	(0.025)	(0.030)	(0.027)
PGDP	0.003	-0.066	-0.155**	-0.177*	-0.195**	-0.165*
	(0.487)	(0.217)	(0.049)	(0.051)	(0.033)	(0.084)
DIST	-0.103	-0.068	0.047	-0.057	-0.032	-0.064
	(0.215)	(0.321)	(0.312)	(0.421)	(0.483)	(0.407)
RCA	0.068	0.072	0.100	-0.069	0.090	0.069
	(0.178)	(0.215)	(0.165)	(0.310)	(0.224)	(0.276)
FDD	-0.034	-0.056	-0.017	-0.059	-0.070	-0.042
	(0.348)	(0.306)	(0.501)	(0.355)	(0.313)	(0.412)
PLAND	0.022	-0.038	-0.047	-0.088	-0.122	-0.109
	(0.338)	(0.403)	(0.362)	(0.228)	(0.120)	(0.145)
CONTIG	0.165**	0.118	0.109	0.256***	0.196**	0.253***
	(0.036)	(0.113)	(0.131)	(0.005)	(0.027)	(0.003)
INSTQ	0.052	0.008	-0.150*	-0.145	-0.139	-0.118
	(0.242)	(0.465)	(0.066)	(0.112)	(0.125)	(0.188)

Notes: P-value in parentheses; * p < 0.1, ** p < 0.05, *** p < 0.01.

Table 6. Results of QAP regression analysis.

Variables	*2002*	*2008*	*2014*	*2019*	*2021*	*2022*
GDP	0.219***	0.137**	0.311***	0.390***	0.410***	0.460***
	(0.001)	(0.026)	(0.001)	(0.001)	(0.001)	(0.001)
PGDP	-0.218*	-0.540***	-0.392*	-0.808***	-0.693***	-0.547***
	(0.054)	(0.009)	(0.072)	(0.003)	(0.002)	(0.001)
DIST	-0.048	-0.028	0.102	0.044	0.047	0.035
	(0.732)	(0.866)	(0.465)	(0.758)	(0.732)	(0.741)
RCA	0.082*	0.021	0.121*	-0.077	0.155**	0.150***
	(0.090)	(0.740)	(0.063)	(0.719)	(0.015)	(0.007)
FDD	0.052	-0.008	0.210**	0.311	0.237***	0.265***
	(0.343)	(0.903)	(0.012)	(0.146)	(0.005)	(0.002)
PLAND	0.084	0.066	0.141*	0.169*	0.128*	0.103*
	(0.117)	(0.312)	(0.092)	(0.063)	(0.078)	(0.090)
CONTIG	0.147	0.108	0.147	0.273***	0.213**	0.266***
	(0.108)	(0.262)	(0.127)	(0.003)	(0.018)	(0.002)
INSTQ	0.183*	0.485***	0.183	0.544**	0.486***	0.380***
	(0.092)	(0.008)	(0.295)	(0.020)	(0.003)	(0.006)
R-Square	0.080	0.074	0.123	0.220	0.217	0.264
Adj R-Sqr	0.044	0.037	0.088	0.189	0.186	0.235

Notes: P-value in parentheses; * p < 0.1, ** p < 0.05, *** p < 0.01.

stitutions significantly affected the formation of fisheries and aquaculture product trade relations within the RCEP region.

QAP REGRESSION ANALYSIS

Table 6 shows the results of the QAP regression analysis. Economic size, as measured by GDP, has a positive impact on fisheries and aquaculture product trade within the RCEP region during the sample years studied. The impact of GDP is highly significant at the 1% level, except in 2008 where is impacts is significant at the 5% level (potentially due to the influence of the financial crisis). GDP per capita is negative and significant at the 10% level in 2002 and 2014, and at the 1% level in the following years. Unlike the QAP correlation analysis, variables such as comparative advantage, foreign dependence degree, and per capita arable land area exhibited significant differences in their signs, significance, and fluctuations in standardized regression coefficients over different periods. The coefficient of the variable comparative advantage was not significant until 2019, after which its impact became statistically significant on fisheries and aquaculture product trade. Similarly, foreign dependence degreepositively and significantly ($p<1\%$) influenced fisheries and aquaculture product trade after 2019. In addition, per capita arable land has a positive impact($p<10\%$) on fisheries and aquaculture product trade from 2014 onwards. Contiguity also showed a significant positive impact on fisheries and aquaculture product trade in 2019 and the following years. Except from 2014, institutional quality consistently showed a positive and significant effect. However, the effect of geographical distance was not statistically significant, challenging the conclusions of prior studies. This may be due to factors such as the concentration of RCEP countries, the establishment of "Belt and Road" infrastructure, and rapid advancements in transportation and fresh storage technologies. Thus, GDP, per capita GDP, comparative advantage, foreign dependence degree, per capita arable land, contiguity, and institutional quality significantly influence the trade volume and trade relationship formation of fisheries and aquaculture products among RCEP nations.

Taking 2022 fisheries and aquaculture products trade network regression analysis as an example, the standardized regression coefficient of GDP is 0.460, which is significant at the 1% level. This indicates that countries with greater differences in GDP are more likely to establish trade relationships in fisheries and aquaculture products. The standardized regression coefficient for the level of per capita GDP is -0.547, also significant at the 1% level, suggesting that countries with similar levels of per capita GDP, likely reflecting analogous consumer preferences and purchasing power, are predisposed to form trade partnerships. The standardized regression coefficients for the RCA, foreign dependence degree, and institutional quality, which were 0.150, 0.265, and 0.380, respectively, were all statistically significant at the 1% level. These results show that comparative advantage in fisheries and aquaculture products, foreign dependence degree, and institutional quality have a notable impact on trade relationships. The coefficient for per capita arable land area is 0.103($p<10\%$), indicating a moderate effect on trade. The standardized regression coefficient for contiguity is 0.266 and significant at the 1% level, demonstrating that countries sharing a land border have a higher bilateral trade volume in fisheries and aquaculture products as compared to countries that share no land border. This highlights the critical role of variable geographical adjacency in the structuring of the RCEP regional fisheries and aquaculture product trade networks.

CONCLUSIONS AND POLICY IMPLICATIONS

In this paper, we examined the trade network of fisheries and aquaculture products within the RCEP region from 2002 to 2022 by using complex network analysis tools to construct and analyze the trade network's topological structure and its spatiotemporal evolution. Furthermore, we investigate the main contributing factors to the characteristics of the trade network. The main conclusions are as follows:

Fisheries and aquaculture products trade network within the RCEP region exhibits "small-world" characteristics, with the intermediary centrality of each country gradually becoming uniform. This indicates a continuous strengthening of the integration level of fisheries and aquaculture products trade within the RCEP area, suggesting that there is significant room for further enhancement of trade cooperation and development. Countries such as Japan, China, South Korea, Thailand, and Vietnam ranked higher in terms of degree centrality, which clearly indicates their central roles in the network, while Myanmar, Cambodia, Brunei, and Laos remain on the periphery. The network 's core-periphery structure identifies China and Japan as central to the RCEP region's fisheries and aquaculture products trade, with China's core status rising and Japan's decreasing. Over the years, the network's core-periphery structure is diminishing, revealing a more rationalized pattern of multi-centrality.

Community detection in the network indicates a stable division into two trade communities, although the internal structure of these communities has undergone significant changes. These changes reflect a degree of geographical proximity among community members but also show transcending geographical limitations. After 2014, the internal structure of these communities has stabilized, with community 1 consistently formed by China, Myanmar, Malaysia, New Zealand, Indonesia, and Singapore, and community 2 including Japan, Cambodia, Laos, the Philippines, and Thailand. The evolution of the RCEP region's fisheries and aquaculture products trade network suggests a stable and positive process of development.

Results from QAP analysis show that economic size, comparative advantage, foreign dependence degree, arable land per capita, contiguity, and institutional quality altogether positively influence the strengthening of fisheries and aquaculture products trade within the RCEP region. In contrast, the difference in per capita GDP has adversely affected the current trade conditions.

As policy implications, there is a need to enhance trade potential with RCEP partner countries, particularly those on the periphery. This would involve countries like Thailand, Malaysia, Singapore, China, Vietnam, Japan, South Korea, and Australia play a crucial role of "bridge" within the RCEP region, actively engaging in multilateral negotiations, and exploring more effective trade connections to maximize the efficiency of fisheries and aquaculture products trade within the area. In addition, the study suggests that RCEP member States focus on the connections between fisheries and aquaculture product communities within the region by broadening trade channels, and further strengthening the integration of fisheries and aquaculture products. Finally, countries should actively align with RCEP rules, promote industry cooperation, adopt advanced fisheries and aquaculture product technologies. At the same time, they could draw on the successful development experiences of other countries, to enhance market competitiveness of fisheries and aquaculture products by further expanding cooperation spaces.

While this study highlights significant trends and characteristics of trade networks in fisheries and aquaculture products within the RCEP region, several limitations warrant further investigation. Firstly, the trade data spans only from 2002 to 2022. Although this period covers a substantial timeframe, the lack of data availability means that the years following the RCEP agreement's implementation were not considered, limiting our assessment of the long-term impacts of the agreement. Furthermore, the focus on trade data alone overlooks other critical factors influencing fisheries and aquaculture trade. Non-trade elements such as environmental protection measures, consumer preferences, and technological innovations can also play a vital role in shaping trade patterns, yet these were not thoroughly examined in this study. As fishery resources continue to decline and sustainable development gains prominence, future research could benefit from integrating environmental and ecological variables into trade network analyses.

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AUTHORS' CONTRIBUTION

Conceptualization: Wei Tang (Lead). Methodology: Wei Tang (Lead), Di Zhang (Equal). Formal Analysis: Wei Tang (Equal), Di Zhang (Equal), Qiwen Wang (Equal). Investigation: Wei Tang (Equal), Di Zhang (Equal), Qiwen Wang (Equal). Writing – original draft: Wei Tang (Equal). Writing – review & editing: Wei Tang (Equal), Di Zhang (Equal), Qiwen Wang (Equal). Supervision: Wei Tang (Lead).

COMPETING OF INTEREST – COPE

The authors declare no conflicts of interest.

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All authors and institutions have confirmed this manuscript for publication.

DATA AVAILABILITY STATEMENT

All are available upon reasonable request.

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