Analysis of the Trade Network of Global Wood Forest Products and its Evolution from 1995 to 2020

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Abstract

Global trade of wood forest products is a complex system, and its flow between trading countries forms a trade network of wood forest products. The transmission efficiency of the trade network largely depends on its network structure. The commonly used method in recent years to analyze the network structure is complex network analysis. Therefore, this study used the complex network method, through using kernel density curves every 5 years to show distribution changes of complex network indictors to study the evolution of the trade network of global trade of wood forest products, based on trade data from 1995 to 2020. The results show that the trade relationship between countries is deepening. Compared with resource-based wood forest products, the trade of deeply processed wood forest products is larger in scale, more complex in structure, and more closely linked. The core countries in global wood forest products trade mainly comprise North American and European countries, while several developing countries in Asia with abundant forest and labor endowments are gradually joining the core tier and jointly control the trade market. We also revealed the intervention of world forestry development goals and national forestry policies on changes to trade structure and trade groups.

Wood forest products are indispensable resources for national economic development and meeting the needs of local communities. Although alternative materials are emerging, characteristics such as humidity control, electrical insulation, and thermal stability ensure that wood products remain the only suitable raw materials for many construction purposes and furniture products (Liu et al. 2022). Global forest resources are unevenly distributed, with 54 percent concentrated in five countries: Russia, Brazil, Canada, the United States, and China (FAO 2020). Thus, the forest products trade is an important link between regions with abundant forests and those with scarce forests. With an increasing number of countries participating in the global wood forest products trade, trade relations and trade flows have become more complex, and changes in the trade network affect the transmission efficiency and stability of the entire trade system (Wang et al. 2021). The consumption of wood forest products in many countries, such as China, is highly dependent on the international wood resources and product markets, and its trade security is readily affected by the global wood forest products trade relations and trade flows (Hou and Li 2020). Therefore, understanding global wood forest products trade patterns, and appreciating the spatial and temporal evolution of the global wood forest products trade network are most important problems to ensure the secure supply and demand of wood forest products and to formulate a global wood forest products trade policy.

Many researchers have studied the wood forest products trade; most have used indicators to reflect the intensity, breadth,

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and quality of trade to analyze the complementarity of the wood forest products trade (Tian and Wu 2018), trade potential (Shen et al. 2017, Yang et al. 2022), and international competitiveness (Zhang 2010), and then examine their influencing factors (Morland et al. 2020). These trade indicators can only reflect a certain aspect of direct trade between two countries (Guimera et al. 2005, Ma et al. 2016). To comprehensively analyze the trade characteristics of a country, the complicated trade relations among countries must be included within the scope of the investigation (Fagiolo et al. 2009). Given its ability to reflect a country's relative position (Serrano and Boguñá 2003) and a unified view of the system characteristics (Borgatti and Martin 2000) in the global trade network, complex network analysis has become an important tool to study international trade issues in recent years (Li et al. 2003; Garlaschelli and Loffredo 2005, 2009) and has been widely applied in studies of trade (Konar et al. 2011, Dalin et al. 2012, Suweis et al. 2012, Geng et al. 2014, Gephart and Pace 2015, Liu et al. 2022, Ren et al. 2022, Zhang et al. 2023). In studies of forest product trade, Lovric et al. (2018) addressed the role that prominent social network analysis metrics can have in understanding the structure and the trends of forest product international trade which cannot be gained from "classical" statistics and models. Long et al. (2019) observed that the wood forest products trade showed a multilateral trend, with an orderly trade network structure and frequent two-way exchanges among trading countries. Wang et al. (2021) used a trade network to analyze the competing relationships between major supply and demand countries of wood forest products trade. Li et al. (2022) analyzed the spatial and temporal evolution of the wood forest products trade network among the 15 Regional Comprehensive Economic Partnership (RCEP) countries and predicted its effect on China after the RCEP agreement comes into effect. Wu et al. (2022) constructed an exponential random graph model to analyze the trade pattern at macro and micro levels to identify the main factors affecting the formation of a forest product trade network. And Wang et al. (2022) paid more attention on overall changed trend of the wood forest product trade network. These studies detail the evolutionary trajectory of the global wood forest products trade network and provide a scientific basis for understanding the contest between the major suppliers and demanders.

However, if the product structure of a country participating in global trade changes, its position and role in the trade network of wood forest products will change accordingly. For example, Southeast Asian countries that traditionally exported mainly logs (e.g., Indonesia and Malaysia) gradually reduced the proportion of log exports 15 years ago, while increasing the proportion of exports of wood products (Sun and Yin 2006). China imports a large amount of resource-based wood forest products, such as logs, sawn timber, and wood pulp, and exports deeply processed wood forest products, such as wood furniture, wood products, plywood, and paper products. In the trade of wood forest products, resource-based wood forest products and deeply processed wood forest products are affected to different degrees by changes in a country's forest resource endowment and by issues such as the country's timber harvesting quota, forest certification, invasive alien species, and quarantine of forest products (Bonnefoi and Buongiorno 1990). For example, countries with relatively scarce forest resource endowment meet their demand by importing resource-based wood forest products and use their abundant factors, such as labor and technology, for the production and export of deeply processed products. Therefore, for different types of wood forest products, the overall and central evolution in the global trade network is different for each country. If the changes and differences in types of wood forest products are ignored and all wood forest products are aggregated and analyzed, the comprehension of trade networks will be biased and trade policies will lack relevance and effectiveness.

To organize the trade structure of wood forest products reasonably and effectively, and to formulate a forest products trade policy that is in line with the development of market trends is an issue that governments need to focus on in the future. Therefore, this paper divides wood forest products into resource-based wood forest products and deeply processed wood forest products, highlighting different evolutionary paths of these two types of wood forest products. We have used kernel density curves for every 5 years to show distribution changes of complex network indictors, rather than the trend analysis of time series of indictors used in many studies, enabling a more thorough insight into the structural changes of the international trade network. We also reveal the intervention of world forestry development goals and national forestry policies on changes of trade structure and trade groups.

The remaining sections include the following: description of the indictors of complex network in study of forest products trade, description of the data source and processing, presentation of the empirical results, discussion of the policy implications and possible reasons for empirical results, and summary of the main conclusions of the study.

Research Methodology

The essence of international trade is the network (Wu and Yang 2019), and the trade dependence between any two countries is indirectly influenced by the interdependence of other countries in the network (Dehghanian and Aslan 2018). Moreover, the perspective of network structure is more suitable for analyzing changes in multilateral trade structure than traditional econometric methods (Wang and Sun 2023). Consistent with the complex network theory (Watts and Strogatz 1998, Newman 2003, Wang 2016), the countries and regions involved in wood forest products trade are taken as nodes of the network: n denotes the number of nodes in the network. The trade relationship between two nodes is taken as the edge, denoted by s, and the trade volume between the nodes is the weight of the edge, denoted by w. These constitutes the directed weighted global resource-based wood product trade network, $G_g = (n, s_g, w_g)$, and the directed weighted global deeply processed wood forest product trade network, $G_p = (n, s_p, w_p)$. The metrics used in the study mainly comprise node degree, network density, average clustering coefficient, average path length, and modularity.

Node degree

Node degree refers to the degree centrality of node i, that is, the number of nodes directly connected to node i. The greater the degree centrality, the more countries trade with the country, which reflects the breadth of the country's foreign trade in wood forest products. In the global trade network of wood forest products, according to their different directions, they can be divided into point-entry degree and point-exit degree. The point-entry degree is the number of countries exporting forest products to country i, and the point-exit degree is the number of countries importing forest products from country i. They are expressed as the following:

$$P_i^{in} = \sum\nolimits_{j=1} a_{ij} \tag{1}$$

$$P_i^{out} = \sum\nolimits_{j=1} a_{ji} \tag{2}$$

$$P_i = P_i^{in} + P_i^{out} \tag{3}$$

where a_{ij} is the trade relationship between two nodes, P_i is the degree centrality of node i, P_i^{in} is the penetration of node i, and P_i^{out} is the output of node i.

Network density

Network density is the ratio of the actual number of connections between nodes to the maximum value of the network theoretical relationship, which describes the density of connections between nodes in the network. This study used this indicator to reflect the closeness of trade among countries in the global trade network of wood forest products. The value range of network density is [0, 1]. The higher the network density, the closer the trade relationship between countries. For directed networks, the calculation formula is as follows:

$$D = \frac{L}{n(n-1)} \tag{4}$$

where D is the density of the trade network, L is the actual number of connections in the trade network, and n is the number of nodes in the trade network.

Average clustering coefficient

The clustering coefficient is the average probability of interconnection between two nodes connected to the same node in the network. Its value range is [0, 1]. The greater the clustering coefficient, the higher the degree of clustering of nodes around the node. The average clustering coefficient $\overline{C}$ is the average value of all clustering coefficients in the trade network, which usually reflects the average clustering degree around nodes in the whole network, respectively expressed in the following way:

$$C_i = \frac{e_i}{p_i(p_i-1)} \tag{5}$$

$$\overline{C} = \frac{1}{n}\sum\nolimits_{i=1}^{n} C_i \tag{6}$$

where C_i is the clustering coefficient of node i, p_i is the degree of node i, and e_i represents the number of edges between adjacent nodes of node i.

Average path length

The average path length refers to the average steps of the shortest path between all possible connected nodes in the trade network, and is an indicator to measure the transmission efficiency of various trade goods in the network. Generally, the shorter the average path length, the more conducive to the rapid transmission of trade goods. The calculation formula is as follows:

$$l = \frac{1}{n(n-1)}\sum\nolimits_i\sum\nolimits_j d(i,j) \tag{7}$$

where $d\,(i, j)$ is the shortest path between nodes i and j.

Modularity

A group in a complex network refers to a subset of nodes composed of network nodes. The community discovery method is a module optimization method, which can divide the network into several relatively independent and highly connected modules to reveal the characteristics of the group structure in the network. The modularity index can be used to evaluate the degree of group separation. Its value range is [−1, 1]. The closer the modularity is to 1, the more obvious the network differentiation, and the higher the division quality. Q is the modularity index and its expression is this:

$$Q = \frac{1}{2m}\sum\nolimits_{ij}\left[A_{ij} - \frac{k_i k_j}{2m}\right]\delta(c_i, c_j) \tag{8}$$

where Q is the modularity, A_{ij} is the trade flow of countries i and j, k_i and k_j are the sum of all trade flows connected with countries i and j, c_i and c_j are the community indices of countries i and j, $\delta\,(c_i, c_j)$ indicates whether countries i and j are in the same cluster, and m indicates the total trade flow of the whole network. In this study, the modular algorithm in Gephi 0.92 was used to divide the global trade networks of resource-based wood forest products and deeply processed wood forest products into groups.

A kernel density map is an effective method for observing the distribution of continuous variables. This paper used Ucinet software to calculate the density values of the global wood forest product trade network structure from 1995 to 2020, and used Stata software to draw the kernel density curve, showing distribution changes of complex network indictors.

Data Source and Processing

Data used in this paper were sourced from the United Nations Comtrade database (UN Comtrade). To avoid double counting in the overall network, import data reported by each importing country are used. The database contains trade data for 235 countries and dependent territories worldwide from 1988 to 2021. To ensure the integrity of the global wood forest products trade network, this study did not set a threshold for the size of the trade volume, but included 229 countries and dependent territories that participated in the trade of wood forest products in the analysis: Caribbean Netherlands, Monaco, Liechtenstein, Sint Maarten, Isle of Man, and the US Virgin Islands were excluded from the analysis. For missing data, (1) if import data for a country was missing, export data of this country was supplemented by its trading partner; (2) given that import data in the UN Comtrade database are reported in cost insurance and freight, whereas export data are reported as free on board (FOB), the export data are replaced by FOB/0.9 as the import data (Jiang and Wang, 2020).

According to the Harmonized System (HS) classification codes, wood forest products are further classified into two categories, namely resource-based wood forest products (logs: HS4403; other raw timber: HS4401-4405;sawn timber: HS4406-07; and wood pulp: HS4701-4706) and deeply processed wood forest products (wood-based panels: HS4408-4413; wood products: HS4414-4421; paper products: HS4707, 48, 49; and furniture: HS940161, 940169, 940330, 940340, 940350, 940360).

Results

Distribution of network centrality of resource-based wood forest products

In order to demonstrate the evolutionary characteristics of a global wood forest products trade network in time clearly, this study illustrated the calculated results with 1995 as the starting point and values taken at 5-year intervals. Figures 1 and 2 show the in-degree centrality and out-degree centrality kernel density distributions of resource-based wood forest products trade. Overall, the kernel density estimates of both the in- and out-degree centrality of this trade network were single-peaked right-skewed distributions, showing a more obvious long-tail feature. The kernel density curves of in and out degrees declined steeply after the degree was greater than 20, and the density values of nodes with in and out degrees greater than 30 were all 0.01 and below; as the number of nodes increases, the density values continue to decrease, indicating that the more trading partners there are in the resource-based wood forest product trade network, the fewer countries there are. Between 1995 and 2000, both the out-degree centrality and in-degree centrality of the resource-based wood forest products trade network changed significantly. In the following 20 years, the peak kernel density decreased and the right tail of the distribution thickened, but the changes were not significant, indicating that the trade-participating countries gradually tended to disperse the resource-based wood forest products trade to different countries instead of centralizing it to a specific country.

Comparing the kernel density plots of in-degree and out-degree centrality of global wood forest trade, the distribution curves were similar, and the import and export relationships of resource-based wood forest products were symmetrical, indicating that the trade relationship between supplier and demander in this product market was in a state of relative equilibrium. Specifically, except for 1995 and 2000, when the kernel density of in and out degrees peaked at 0.04 and 0.03, respectively, the wave density values of the distribution of resource-based wood forest products trade network in and out degrees fluctuated above and below 0.02, corresponding to the concentration of in degree between 10 and 20, and out degree between 5 and 15. In addition, the number of exporting countries was smaller than the number of importing countries, which indicated that the resource-based wood forest products exports were relatively centralized, not every country had wood forest products resources available for export, and export competitors were smaller than import competitors. Over time, there was a downward trend in the wave of the distribution of in-degree and out-degree centrality kernel density, but the change was not obvious after 2005. Therefore, for resource-based wood forest products, the global wood forest trade network remained stable after 2005.

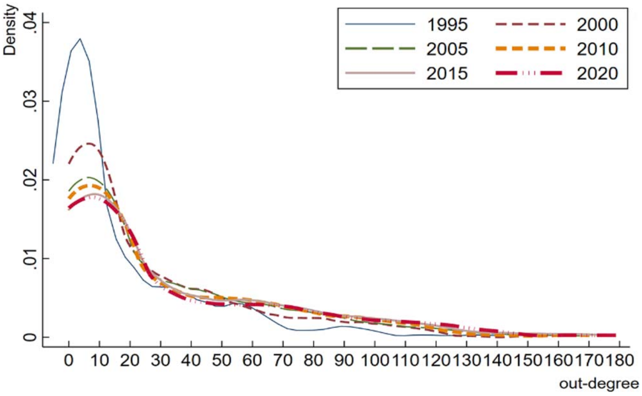

Figure 2.—Kernel density of out-degree centrality for resource-based forest products trade.

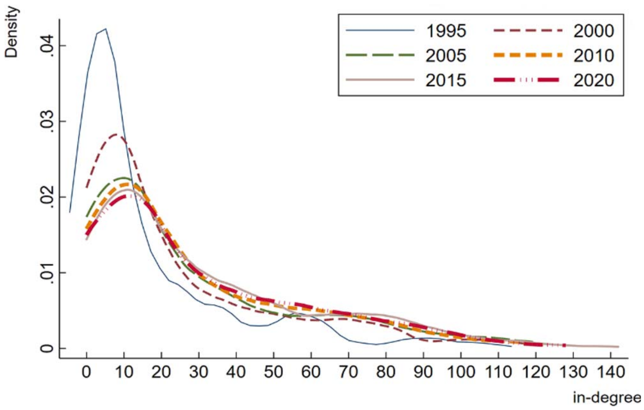

Figure 1.—Kernel density of in-degree centrality for resource-based forest products trade.

Distribution of network centrality of deeply processed wood forest products

Figures 3 and 4 show the in-degree centrality and out-degree centrality kernel density distributions of deeply processed wood forest products trade. The kernel density distribution of in-degree centrality showed an obvious bimodal distribution, with two high-frequency areas: one centralized in the in degree of about 20, and the other shifted significantly to the right over time, with the in degree centralized at approximately 40 in 1995 and at approximately 100 after 2010. The number of countries with many trading partners gradually increased and a country tended to import deeply processed wood products from an increasing number of countries. However, in an area where the in-degree centrality was 20, it remained a high-frequency area

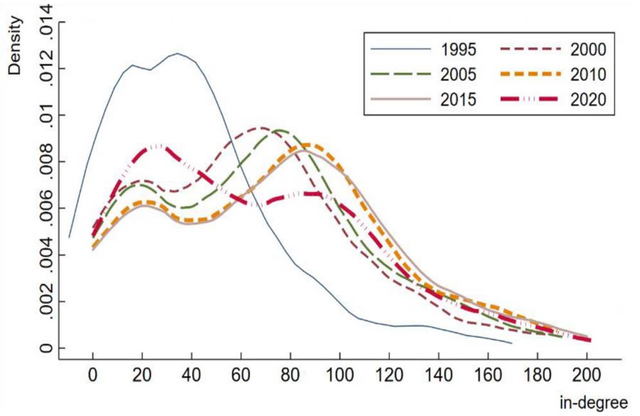

Figure 3.—Kernel density of in-degree centrality for highly processed forest products trade.

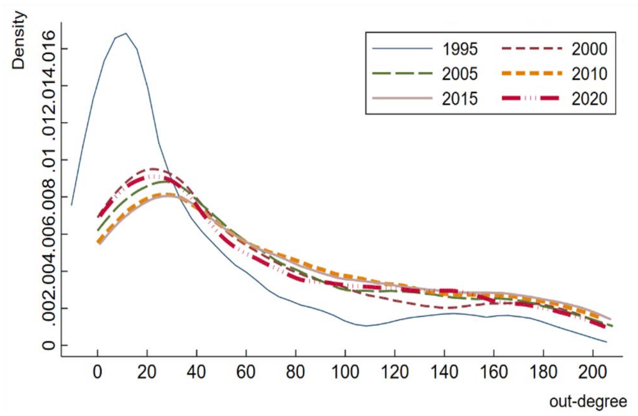

Figure 4.—Kernel density of out-degree centrality for highly processed forest products trade.

from 2000 to 2015. Over the 25 years of the study period, the two phases changed significantly, and the polarization phenomenon made the bimodal distribution gradually significant between 1995 and 2000. From 2015 to 2020, the peak of high in-degree centrality was lower than the peak of low in-degree centrality, and the density at in-degree centrality of 30 rose to about 0.009 in 2020, while the density around in-degree centrality of 100 decreased to 0.006, indicating that in 2015 the proportion of countries with few trading partners increased significantly from 2015 to 2020, and global deeply processed wood forest products tend to be imported from a few specific countries or regions.

The distribution of out-degree kernel density of the deeply processed wood forest products trade network shows a right-skewed distribution. Two peaks in out degree were apparent in 1995, but the inverted U-shaped distribution was flatter where the out-degree value was large. Over time, the peak decreased. From 1995 to 2000, the peak decreased to the greatest extent and shifted slightly to the right. After 2000, the out degree of the trade network remained stable. Although the peak increased slightly and shifted to the left from 2015 to 2020, the shape and peak did not change significantly, showing the stability of this trade network. The timing of change in out-degree kernel density was consistent with the timing of change in in-degree kernel density, which indicated that the global trade of deeply processed wood forest products was significantly changed by certain factors in these two time periods. Comparing the distribution shapes of Figures 3 and 4, it was clear that the in and out degrees of deeply processed wood forest products were asymmetric and there was a nonequilibrium trade relationship between the supply and demand countries for this wood forest products trade.

Network characteristics of global wood forest products trade

Based on the changes in the network characteristic indicators of global wood forest products trade from 1995 to 2020 (see Table 1), the number of nodes in the global trade of resource-based wood forest products and deeply processed wood forest products gradually increased. This indicated that the number of countries involved in the trade of wood forest products gradually increased. The participating countries increased significantly between 1995 and 2000, indicating that the degree of economic globalization was deepening and forestry resources were being reallocated in a broader space.

The density of the resource-based wood forest products trade network ranged from 0.09 to 0.14, and the density of the deeply processed wood forest products trade network ranged from 0.21 to 0.32, which was low, indicating that the relationship between wood forest products trading countries was relatively loose. However, from the perspective of time, the indicators showed a steady growth trend, indicating that countries were becoming increasingly closely linked in wood forest products trade and gradually increasing their external dependence. However, compared with other bulk commodities, the density of the wood forest products trade network was still small and the network structure was relatively fragmented. The values of edges, density, and average degree of the trade network of deeply processed wood forest products were two to three times higher than those of resource-based wood forest products, indicating that the trade of deeply processed products was larger in scale, more complex in structure, and more closely connected. However, all three indicators decreased between 2015 and 2020, and it seems that the relationship between countries trading wood forest products changed during this period.

The average shortest paths of the trade networks for both types of wood forest products steadily decreased, indicating that the efficiency of both trade networks improved, but the decrease was not more than 0.1; thus, there is still room for improving the efficiency of the networks. The average shortest path for deeply processed wood forest products was shorter than that for resource-based products, indicating that the transportation efficiency of resource-based wood forest products was lower than that of deeply processed wood forest products, and the transportation cost of resource-based wood forest

Table 1.—Network characteristic indicators and evolution of global forest products trade.

		1995	2000	2005	2010	2015	2020
Nodes	Resource-based forest products	205	218	217	221	224	226
	Highly processed forest products	206	221	225	224	229	229
Number of edges	Resource-based forest products	3,898	5,538	6,431	6,555	7,262	6,901
	Highly processed forest products	9,289	14,358	15,433	16,681	17,142	15,073
Density	Resource-based forest products	0.075	0.106	0.123	0.125	0.139	0.132
	Highly processed forest products	0.178	0.275	0.294	0.319	0.328	0.289
Average degree	Resource-based forest products	19.015	25.404	29.172	29.661	32.42	30.535
	Highly processed type forest products	45.092	64.968	69.588	74.469	73.856	65.821
Average clustering coefficient	Resource-based forest products	0.588	0.585	0.6	0.574	0.597	0.637
	Highly processing forest products	0.727	0.702	0.7	0.694	0.717	0.747
Average shortest path	Resource-based forest products	2.185	2.096	2.041	2.117	2.026	2.034
	Highly processed forest products	1.82	1.731	1.705	1.689	1.687	1.738

products in international trade was higher. The average class clustering coefficients of the trade networks of resource-based wood forest products ranged from 0.58 to 0.65, whereas those for the trade networks of deeply processed wood forest products ranged from 0.72 to 0.75, showing an increasing trend, indicating that the degree of group aggregation within the two types of trade networks was increasing. While the other trade network characteristic indicators declined to different degrees with the total trade volume, the average clustering coefficient and the average shortest path, on the contrary, rose to some extent, which further indicated that the global participation in wood forest products trade networks tended to be grouped.

Changes in the group structure of global wooden forest products trade network

A country tends to have a certain path dependence in forest products trade. This dependence is expressed in the group characteristics that will form trade groups of different sizes. The global trade network for resource-based wood forest products has always shown a “two majors and two minors” division, with four groups in both 1995 and 2020 but with substantial changes in the group members (see Figs. 5 and 6). In 1995, among the resource-based wood forest products trading groups, the trading group R1 was headed by Sweden and included 65 countries and regions, of which one-third were European countries; the trade volume accounted for 25 percent of the entire trading network. The trade group R2 had the United States as the absolute core, was mainly composed of American and Asian countries, had 85 members, and was the trade group with the largest number of member countries in the resource-based wood forest products trade network in 1995; the trade volume accounted for 22.3 percent of the whole network. Trade group R3 included 21 countries and regions, with a majority of Asian and African countries (regions); the trade volume accounted for only 0.5 percent of the world trade network. Trade group R4, led by Austria and the Czech Republic, was mainly composed of European and African countries, with a total of 34 member countries; the internal trade volume accounted for 3.9 percent of the global trade volume. By 2020, although the original R1 group continued to expand by a number of European and African countries (regions) joining, the former core nodes, Canada, Russia and Brazil, the largest countries in the world in terms of area, withdrew from this group, and the intragroup trade decreased to 24 percent of the overall trade network group. Canada joined the North American trade group R2 as a core node. Trade group R3 was expanded significantly by countries from five continents joining, with Russia as the core node, accounting for 24 percent of the global trade volume. Lastly, the India-led trade group R4 was the smallest trade group with 17 members; its intragroup trade accounted for 1.9 percent of the global trade volume.

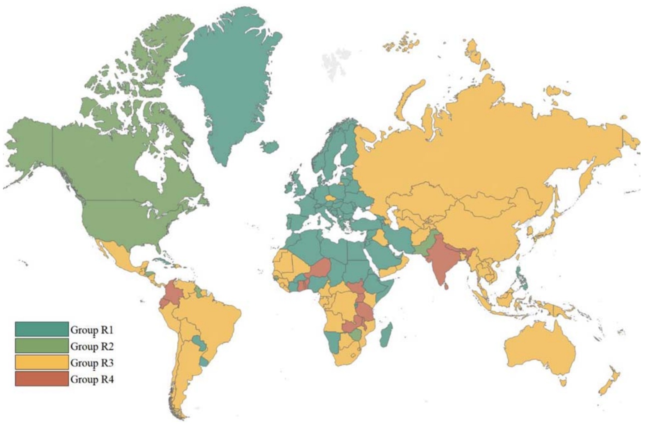

Figure 6.—Trading groups based on global resource-based forest trade linkages in 2020.

In 1995, the global trade group of deeply processed wood forest products as a whole showed a three-tier grouping pattern of “two majors and one minor” (see Fig. 7). Trade group M1 was led by Germany, the number of members attained 63, the intragroup trade volume accounted for approximately 45.7 percent of the world trade volume, and intragroup trade was basically based on two-way trade between the core countries. Trade group M2, led by Canada, was the smallest, with 48 members; the trade volume between member countries accounted for 16.8 percent of the total global trade volume, and more than 65 percent of the member countries were from North and South America. In 2020, the characteristics of the global trade groups for deeply processed wood forest products were significantly enhanced, and a total of five trade groups were detected in this period (see Fig. 8). The original M1 group was divided into two levels: the new M1 “Europe–Africa” group with Germany as the core and the “Nordic–South America” trade group M2 with Sweden as the core. The former M3 group of Southeast Asian and Oceania countries

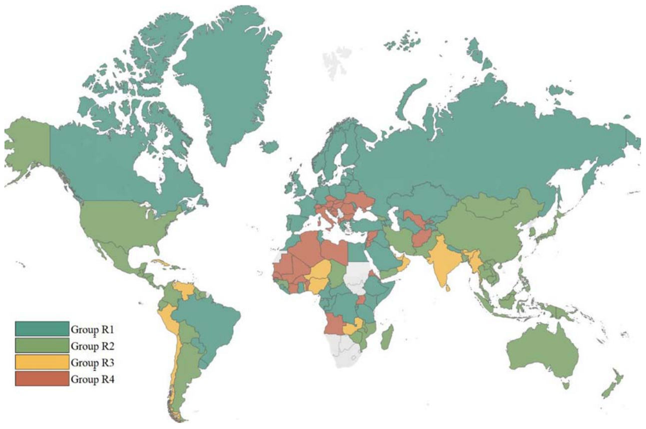

Figure 5.—Trading groups based on global resource-based forest trade linkages in 1995.

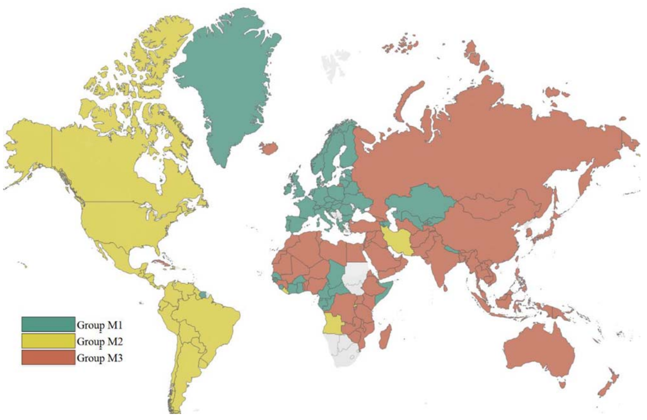

Figure 7.—Trading groups based on global highly processed forest products trade linkages in 1995.

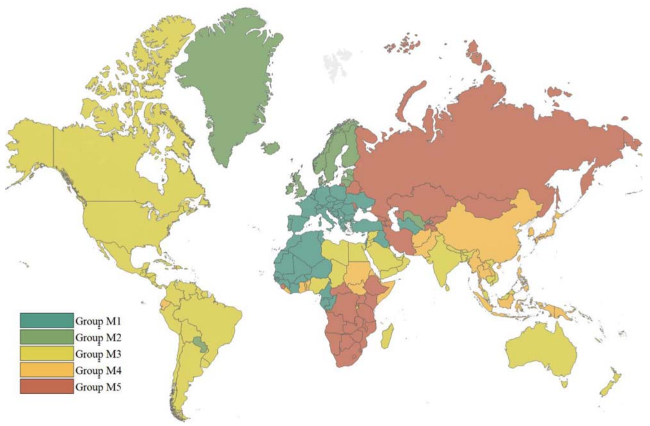

Figure 8.—Trading groups based on global highly processed forest products trade linkages in 2020.

merged into the original M2 group, forming a new M3 trade group, including a total of 80 economies from Africa, the Americas, Asia, and Oceania. The new M3 group is the largest in the network, but the intragroup trade accounted for only 16.2 percent. The "Asia–South America" trade group M4 contains 43 countries and regions, and the trade volume accounted for 6.2 percent of the entire network. The "Africa–Asia" trade group M5 has Russia as the core, including 31 countries and regions, and intragroup trade accounted for only 0.76 percent of the global trade volume.

Discussion

Since the 1990s, trade of wood forest products has shown a trend for multilateralization, with more two-way exchanges between trading countries and increasing economic cooperation. This result is consistent with those of Long et al. (2019) and Wang et al. (2021). However, if resource-based wood forest products and deeply processed wood forest products are distinguished, the complexity of the trade network for resource-based wood forest products is much less than that for deeply processed products. For resource-based wood forest products, the world's forest resources are unevenly distributed and, owing to the differences in resource endowment, geographic location, and transportation modes of resource-based wood forest products among countries, trade links are in the hands of several countries only, which have strong control of the trade network for such products. However, in the context of economic globalization, with the development of transportation and information technology, an increasing number of countries have conducted direct trade transactions with each other, the status of hub countries in the international trade network is declining, and the gap between the importance of node connections is decreasing, showing the development of a trend for multilateralization of global trade. After 2000, the trade network maintained strong stability. However, for deeply processed wood forest products, trade networks have changed markedly and are vulnerable to the impact of world's forestry development goals and national forestry policies. From the bimodal distribution shown in the trade network entry kernel density (Fig. 3) for deeply processed wood forest products, two possibilities are implied for the trade of this type of products. One is that two types of products with different trade characteristics are gradually distinguished among deeply processed wood forest products, and the appearance of the bimodal peaks may be the superposition of these different types of products. The other possibility is that the trade of wood forest products is distorted by specific policies or macro-environmental influences, leading to the concentration of exports of deeply processed wood forest products in two extreme directions.

If only the indicators of trade network characteristics in a particular year are analyzed, it would be concluded that the trade network is less heterogeneous, the trade in forest products between countries is closely linked, and the accessibility of trade exchanges is strong (Wu et al. 2022). By observing the evolution of the global wood forest products trade network, the present study found that the global wood forest products trade network changed more from 1995 to 2000 and from 2015 to 2020. Wang et al. (2021) and Long et al. (2019) reported that the network characteristics of the wood forest products trade changed significantly around 2010, and these authors concluded that the financial crisis in 2008 affected the wood forest products trade network to some extent. The reason is that the financial crisis had a huge effect on the global economy, and the countries important in the wood forest products trade tried to exert their advantages and increase their import and export trade to emerge from the crisis. However, the financial crisis led to a global economic recession, which caused small fluctuations in the global consumption of wood forest products and instability in the supply and demand of wood forest products, resulting in unstable relationships between trading partners (Long et al. 2016). In the present study, comparing the results for 2005 and 2010, no significant changes in the wood forest products trade network were detected, which may be because of the rapid recovery of wood forest products trade relations among countries under the global economic recovery after the financial crisis, similar to the effect of the financial crisis on the agricultural products trade network (Wang et al. 2018).

We argue that the significant changes in the trade network of wood forest products from 1995 to 2000 were associated with the changes in national forestry policies in the 1990s. For example, for resource-based wood forest products, the crackdown on illegal logging and related trade in each exporting country inevitably imposed psychological pressure on suppliers, buyers, importers, and exporters and affected normal trade. For example, Indonesia, to control illegal timber harvesting and trade and to protect the domestic ecological environment, implemented a ban on log exports and thus the number of log exports dropped sharply. As a result, countries such as Malaysia, Gabon, and Papua New Guinea became the main exporters of tropical logs. Following implementation of China's natural forest protection policy in 1998, the domestic timber supply decreased and imports soared, in addition to a large volume of sawn timber imports from Russia, but also from Indonesia, Malaysia, and Thailand in Southeast Asia and Cameroon, Ivory Coast, and Ghana in Africa. For deeply processed wood forest products, governments are paying increasing attention to the processing and use of domestic forest products and reducing the number of log exports to increase domestic employment opportunities and improve economic conditions in forest areas, for example, in Russia, Indonesia, and Malaysia. In addition, the forest certification developed by the United Nations Conference on Environment and Development in the early 1990s, as a mechanism to promote sustainable forest management, has formed a nontariff barrier, which has a greater effect on the export trade of China's outward-oriented wood-processing enterprises.

The substantial changes in the trade network for deeply processed wood forest products from 2015 to 2020 cannot help but bring to mind the changes in the development goals of world forestry and the environmental changes during this period (Hetemäki and Hurmekoski 2016). First, with the global acceleration in afforestation to increase carbon sinks in response to climate change, the United Nations identified 2021 to 2030 as a decade for ecosystem restoration. Under the impetus of the United Nations, governments, institutions, and the private sector have mobilized financial resources to increase investment in sustainable forest management, especially in developed countries such as the United Kingdom, Germany, Japan, and New Zealand, through a stimulus package for forest management activities and forest products. The supply chain of zero-deforestation commodities became the focus of global investment and financing attention. Meanwhile, extreme weather events during this period severely affected global forest health. In North America, climate change has led to the transformation of large areas of forests into dead wood, a shortage of raw materials for the timber industry, and a cold winter for the forest industry. In Europe, Indonesia, and South America, forest fires were frequent, including the fires in the Amazon rainforest in Brazil in 2019, which sparked global concern and heated debate, causing huge economic losses and also affecting global trade relations in wood forest products.

Conclusion

We delve into the intricacies of the global wood forest products trade network. The use of kernel density curves to illustrate changes in complex network indicators at 5-year intervals adds depth to the analysis, offering valuable insights into the evolving nature of the international trade network. In general, the trade relationship among countries is deepening day by day, and the number of countries and regions participating in the global wood forest products is increasing. Most countries tend to have trade ties with an increasing number of countries, and trade is more evenly distributed among the trading objects. The core countries of the global trade in wood forest products mainly comprise North American and European countries, but some developing countries in Asia with abundant forest and labor endowments are gradually joining the core tier and jointly controlling the global wood forest products trade market.

Our results highlighted the characteristics and evolution of the global resource-based wood products and deeply processed forest products trade network. Compared with resource-based wood products, trade in deeply processed forest products is larger in scale, more complex in structure, and more closely linked. With the changes in the world forestry development goals and national forestry policies, trade relations of deeply processed forest products are more variable. Trade-participating countries gradually tend to spread the trade of resource-based wood products to different countries rather than concentrating on a specific country or region and the trade relationship is more stable. Furthermore, these two types of networks also affect each other, and the relationship between them can be considered in future research.

We adeptly explore the impact of world forestry development goals and national forestry policies on trade structure and groups. However, how the impact of major negative events, such as natural disasters, trade frictions, epidemics, international strategic conflicts, etc., on trade network, and whether the trade network will be more resilient or vulnerable to external shocks are also questions that should be further studied in the future.

By using a complex network method for analysis, it is possible to gain a deep and systematic understanding of the global pattern and situation of wood forest product trade, which is beneficial for making relevant decisions to adjust the trade pattern of wood forest products and is of great significance for promoting the sustainable development of global wood forest product trade.

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