Assessing bilateral trade and provision of frozen hake in the global market

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Abstract

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1.Introduction

International food trade has been increasingly recognized as a vital mechanism for enhancing food and nutrition security across countries. Various studies have argued that trade can distribute food more efficiently, diversify diets, and stabilise prices (Allouche 2011; Béné et al. 2016; Thilsted et al. 2016; Watson et al. 2016; Hicks et al. 2019; Tlusty et al. 2019; Ge et al. 2021). However, the benefits of trade are not universally distributed and can vary depending on a range of factors, including governance, infrastructure, and market access. While international food trade offers opportunities for enhancing food security, it also exposes countries to various shocks and vulnerabilities (Jennings et al. 2016; Gephart et al. 2017; Cao et al. 2023). Particularly concerning is the heightened exposure of low-income and food-insecure countries to external shocks in food trade. These countries often lack the adaptive capacity to mitigate the adverse impacts, thereby exacerbating existing food security challenges (Grassia et al. 2022).

Seafood is among the most highly traded food commodities and is susceptible to a multitude of potential shocks. These include fishery collapses, natural disasters, oil spills, policy changes, and aquaculture disease outbreaks (Gephart and Pace 2015). The volatility in seafood trade not only affects producers but also has far-reaching implications for global food security (Gephart et al. 2017). The management of fisheries is intrinsically linked with trade, as trade policies can either incentivize or discourage sustainable fishing practices (Asche and Smith 2009). Effective fisheries management is essential for ensuring that the benefits of trade are realised without compromising the long-term sustainability of marine resources (Klein et al. 2021).

Traceability in food supply chains is becoming increasingly important for both ethical and practical reasons (Asche and Smith 2009; Tlusty 2012). Poor traceability within global seafood supply chains, for instance, makes the matching of exports with imports challenging and has implications for ethical and sustainable fishing practices, as well as food safety (Watson et al. 2016). Network method analyses can reveal aspects of the global trade network, providing information on the dynamics of interaction between entities (Ospina-Alvaréz et al., 2022; Freitas et al., 2019). Accordingly, complex network analysis allows the identification of the positions and influences of trading countries within the trading system, with the connections between these entities being weighted based on factors such as the number of goods traded, mass or the monetary value exchanged. This approach provides information about the network's structure and characteristics (Ospina-Alvarez et al., 2022; Cawthorn et al., 2017; Blanchard et al., 2017).

The global trade network can be represented by graph theory, with trading countries represented as vertices or nodes, and the flow of goods depicted as connecting arcs or edges. The analysis of the network, represented by the graph, can identify critical nodes with a high degree of centrality, representing those nodes with the greatest number of connections or high relevance for trade flow. Such nodes act as bridges, connecting distant regions of the world and facilitating trade (Ospina-Alvarez et al., 2022; Yang, 2010).

The objective of this paper is to decipher the international hake trade network and to analyse the position of different countries within the network. We first examine the temporal trends of landings to know which are the main hake species exploited and the dominant fishing countries. Secondly, we focus our attention on determining where the highest apparent consumption occurs. Subsequently, we analyse the trade flow of hake on a global scale from 2016 to 2020. By applying the network analysis and exploring different measures of network centrality, we assess emerging patterns in the global hake trading network to identify the most relevant players to the market.

2. Methods

We studied the global hake trade network by analysing the amount of hake caught each year from 1950-2020. We grouped the data by species, continents, and subcontinents. From this analysis, we were able to determine which hake species were most commonly caught and who were the major producers over time. We directed our attention to the last five year period, between 2016 and 2020, to better understand the latest trend in landings. Having knowledge of the principal consumers is crucial to gain a comprehensive understanding of the trade network. However, detailed per capita consumption figures for individual hake species are not readily available in existing official databases. Therefore, we compute per capita hake availability for the 2016-2020 period based on an estimation that takes into account the total landings and imports while subtracting the exports. Landings statistics were obtained from the Food and Agriculture Organizations database (FAO, 2022b), and trade data were obtained from the UN Comtrade database (UN Comtrade, 2022).

Food supply is typically defined as the amount of food available for human consumption. At the national level, this is calculated by considering the balance between production, imports, and exports (food = production + imports - exports). However, this calculation frequently does not account for several factors that affect the actual amount of food consumed, such as stock withdrawals, industrial use, animal feed, seeds, wastage, or additions to stocks. In this paper, per capita supplies are calculated as the average supply available for everyone in the country's population as a whole and do not show what is actually consumed by individuals. The calculation presented in Table 1 tends to overestimate the average amount of food actually consumed. Nonetheless, it represents a reasonable compromise between data availability and data reliability.

The dynamics of the global hake trade network were analysed using complex network analysis methodology and graph visualisation tools. From the UN ComTrade database, we accounted for imports and exports of frozen hake (from the genus *Merluccius* and *Urophycis*) for 193 countries during the period 2016-2020. Although there are official databases that allow the disaggregation of the global hake trade to show market presentation as fresh and frozen, the vast majority of hake is traded frozen. Therefore, this study focuses on frozen hake and is based on UN ComTrade commodity codes 030366, 30378, 030474 (Aragão et al., 2022; UN Comtrade, 2022).

The graph's edges were weighted based on traded volume (tonnes) and monetary value (USD) across time and the directionality of the transaction represented by an arrow pointing in the direction of the flow. The country's significance in the trade network is denoted by the node's size, which corresponds to the sum of the edge values. To improve the visualisation of the network results, min-max normalisation was employed to normalise the data, with the minimum and maximum values of the characteristic being 0 and 1, respectively. Additionally, the nodes were geolocated on a world map for further analysis (Ospina-Alvarez et al., 2022).

Centrality measures are useful for determining the relative importance of nodes and edges within the overall network and identifying connectivity hubs, i.e. nodes that play a decisive role in facilitating many network connections (Ospina-Alvarez et. al 2022). To identify emergent properties within the global hake trade network, we calculated different centrality measures considering the trade links generated. For each pair of trading countries, the number of transactions that occurred within a year was obtained and summed. Thus, for each pair of traders, a single value per year was estimated. For the specific period analysed (2016-2020), the annual values traded by each pair of traders were summed. Several centrality measures exist to identify central nodes, but in this paper, we selected three centrality measures (strength or weighted degree, Betweenness and Page's Rank) as those that could be potentially useful in the study of the global hake trade network. These correspond to the product of a first screening that included all centrality measures commonly used in market network studies and identified from a review of the existing literature. A full description of each centrality measure, its scope and its interpretation from a trade market perspective are given in Table S2 (Supplementary material).

All analyses were performed using the R language and environment for statistical computing. Graphical network analyses were performed using the R package "igraph" v.1.2.527. Hierarchical clustering analyses were performed using the package "flashClust" v.1.01-228. Network visualisations were done with the R packages: "ggplot2" v.3.2.1, "ggmap" v.3.0.0 and "ggraph" v.2.0.013,29,30. All the databases, the codes for the analyses and the scripts to produce the visual representation of the networks are publicly available on GitHub.

3. Results

3.1 Global hake landings and food supply

Of the 22 hake species, encompassing the *Merluccius* and *Urophycis* genera catalogued in FAO databases, 6 of them accounted for 94% of the total catches from 1950 to 2020. Notably, Argentine hake (*Merluccius hubbsi*) and Cape hake (*Merluccius capensis*) have been the most commonly caught species, followed by North Pacific hake (*Merluccius productus*), South Pacific hake (*Merluccius gayi*), and European hake (*Merluccius merluccius*) (Figure 1). The highest catches were recorded in the 1970s, peaking at 23 million tonnes in 1973 (Figure 1).

The European and American fleets led the catches until the late 1970s when the latter took the lead as the primary exploiters of hake, a position they still hold to this day (Figure 2a). This shift can be attributed to a surge in South America catches in the late 1970s, largely driven by Argentina and Peru (in the early 2000s)(Figure 2b, Table S1, Supplementary material). The leaders in catches of the American continent for the period 2016-2020 were Argentina and USA (Table 1). European catches remained relatively stable with occasional fluctuations with a clear decline since the early 1990s (Figure 2c). Remarkably, Spain had the highest volume of hake catches on the European continent during the period 1950 to 2020, far exceeding the other countries in the region (Table S1, Supplementary material; Table 1).

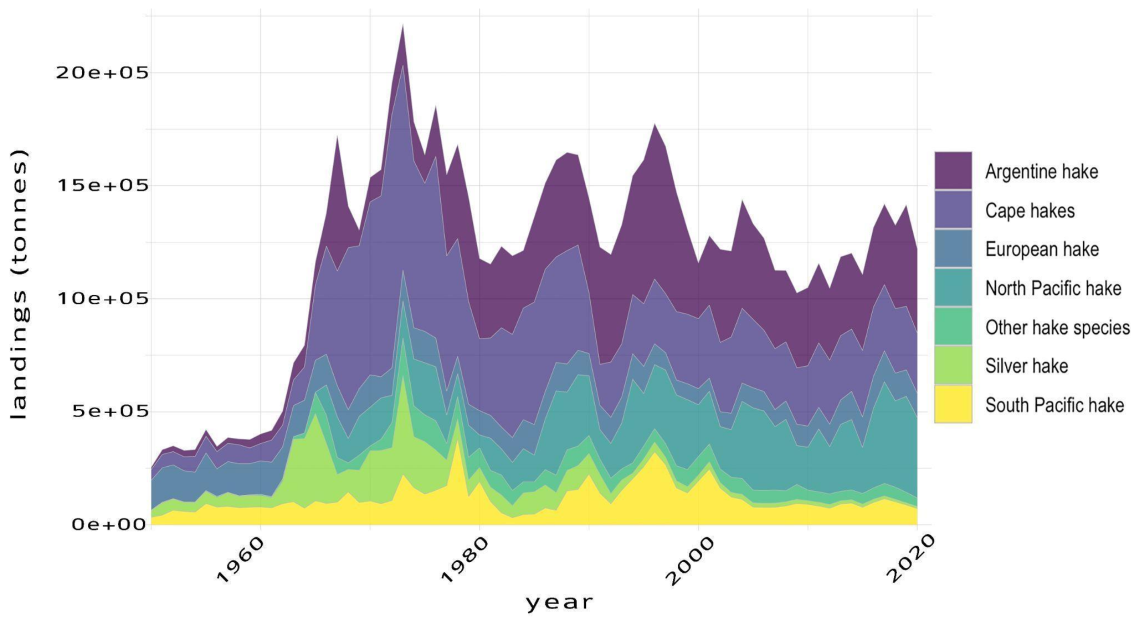

Figure 1. Hake landings by species 1950-2020. The "other hake species group" encompasses Benguela hake, Deep-Water Cape hake, Hakes nei, Offshore silver hake, Panama hake, Patagonian hake, Senegalese hake, Shallow-water Cape hake, Southern hake, Brazilian codling, Carolina hake, Gulf hake, Red hake, Southern codling,

Spotted codling, Urophycis nei, and White hake. Values are given in tonnes. (Data source: FAO[2]. The figure was created with R[12] (https://cran.r-project.org) package "ggplot2" v.3.2.1[13] (https://ggplot2.tidyverse.org).

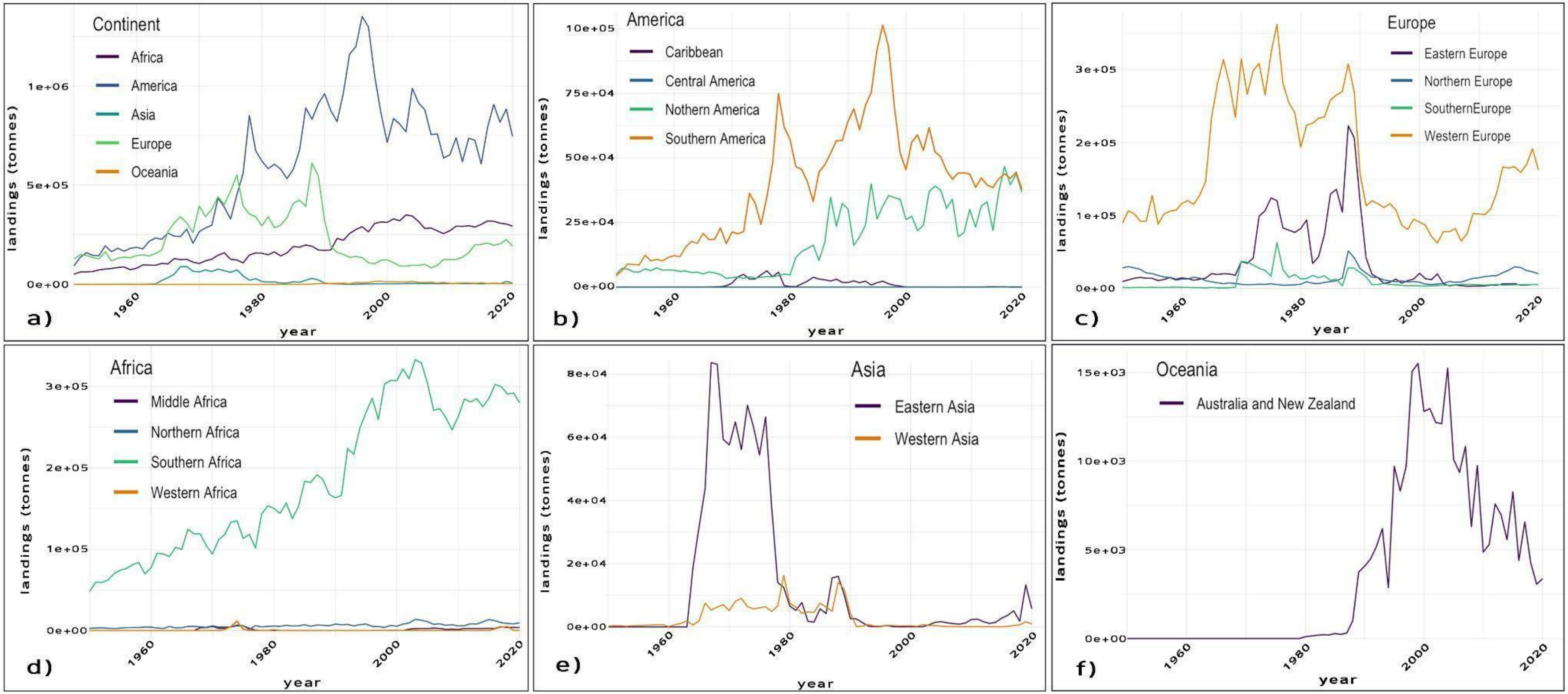

Figure 2. Time series of hake landings by (**a**) Continents and (**b** to **f**) by continents and sub-continents. Values are given in tonnes. Note that the x-axis values differ among the various graphs. Data source: FAO[2]. The figure was created with R[12] (https://cran.r-project.org) package "ggplot2" v.3.2.1[13] (https://ggplot2.tidyverse.org).

It is worth highlighting the role of Africa in this context, especially in the southern region of the continent, represented mainly by South Africa, which increased hake catches since the 1950s, with a leverage of this growth in 1990, when Namibia's catches increased significantly (Table S1, Supplementary material). That growth suffered a fall in mid-2005 and established a relatively constant level from then until the 2020s standing above the European catches (Figure 2d). Both countries, South Africa and Namibia, accounted for 21% of landings of Africa for the period 2016-2020 (Table 1). Concerning Asia and Oceania, with catches one and two orders of magnitude smaller than the abovementioned continents, both displayed in their historical catch trends peaks followed by abrupt falls, being for Asia between the 1960s and 1980s and for Oceania an accentuated growth from the mid-1990s with the beginning of the fall in mid-2005 following this trend steadily until 2020 (Figure 2e and 2f). The country with the highest volume of catches in Asia was Japan until the 1980s and the Republic of Korea from the 1990s to present), while the leader in Oceania was New Zealand (Table S1, Supplementary material, Table 1).

Table 1. Top ranking countries by continent in terms of landing contribution, food supply per capita and trade for the period 2016-2020. The food supply, measured in kg per person per day, represents the average availability of food for the entire population of a country or territory, but it does not indicate the actual consumption by individuals. The ISO 3166-1 alpha-3 international standard codes for countries are also indicated (https://www.iso.org/obp/ui/#search).

2016-2020											
Continent / Country	**ISO3**	**Landings Arithmetic mean (tonnes)**	**Landings Sum (tonnes)**	**%**	**Food Supply (kg/person year)**	**%**	**Sum of Exports (tonnes)**	**%**	**Sum of Imports (tonnes)**	**%**
Africa										
Namibia	NAM	149100	745501	10.98%	2.47	0.21%	191974	8.67%	101236	4.57%
South Africa	ZAF	134256	671282	9.89%	43.46	3.61%	344213	15.55%	14428	0.65%
Angola	AGO	9599	47995	0.71%	0.46	0.04%	2907	0.13%	12232	0.55%
Morocco	MAR	5914	29572	0.44%	0.25	0.02%	321	0.01%	7662	0.35%
Nigeria	NGA	3694	18471	0.27%	0.11	0.01%	0	0.00%	99018	4.47%
Senegal	SEN	2285	11425	0.17%	0.22	0.02%	1	0.00%	35328	1.60%
Americas										
USA	USA	296823	1484117	21.86%	6.29	0.52%	300840	13.59%	1624	0.07%
Argentina	ARG	285532	1427659	21.03%	0.77	0.06%	443299	20.02%	27070	1.22%
Canada	CAN	100525	502625	7.40%	1.64	0.14%	267131	12.07%	3665	0.17%
Peru	PER	62879	314397	4.63%	1.96	0.16%	32860	1.48%	86	0.00%
Chile	CHL	41207	206035	3.04%	2.15	0.18%	40869	1.85%	3603	0.16%
Uruguay	URY	15615	78074	1.15%	3.67	0.30%	27591	1.25%	987	0.04%

Mexico	MEX	9977	49884	0.73%	0.43	0.04%	25990	1.17%	314	0.01%
Ecuador	ECU	7975	39876	0.59%	0.09	0.01%	4976	0.22%	94	0.00%
Brazil	BRA	7060	35300	0.52%	0.11	0.01%	420	0.02%	75944	3.43%
Falkland Is. (Malvinas Is.)	FLK	5760	28800	0.42%	1109.13	92.11%	16804	0.76%	22	0.00%
Asia										
Republic of Korea	KOR	5924	29620	0.44%	0.13	0.01%	8447	0.38%	3721	0.17%
Georgia	GEO	725	3623	0.05%	0.09	0.01%	2889	0.13%	58564	2.65%
Syrian Arab Republic	SYR	31	153	0.00%	0.00	0.00%	46905	2.12%	88569	4.00%
Europe										
Spain	ESP	122246	611230	9.00%	3.72	0.31%	322022	14.55%	443008	20.01%
France	FRA	39109	195546	2.88%	0.82	0.07%	3561	0.16%	43256	1.95%
United Kingdom	GBR	12374	61870	0.91%	0.24	0.02%	3242	0.15%	14154	0.64%
Italy	ITA	7228	36140	0.53%	0.72	0.06%	1029	0.05%	173541	7.84%
Norway	NOR	5041	25204	0.37%	0.65	0.05%	504	0.02%	10660	0.48%
Greece	GRC	4088	20442	0.30%	0.96	0.08%	3276	0.15%	71	0.00%
Denmark	DNK	4039	20193	0.30%	0.76	0.06%	2908	0.13%	1484	0.07%
Ireland	IRL	3533	17665	0.26%	0.97	0.08%	420	0.02%	2911	0.13%
Russian Federation	RUS	1373	6863	0.10%	1.45	0.12%	90	0.00%	315984	14.27%
Croatia	HRV	1004	5022	0.07%	2.81	0.23%	17751	0.80%	147745	6.67%
Albania	ALB	848	4242	0.06%	0.48	0.04%	18877	0.85%	58538	2.64%
Germany	DEU	759	3797	0.06%	2.35	0.20%	7212	0.33%	38615	1.74%
Netherlands	NLD	467	2334	0.03%	0.07	0.01%	11096	0.50%	36001	1.63%
Oceania										
New Zealand	NZL	4333	21666	0.32%	0.32	0.03%	16342	0.74%	149	0.01%
Others		11963	63262	0.49%	14.34	1.19%	47069	2.13%	393553	17.78%
TOTAL		**1345300**	**8071800**		**1204.07**		**2213837**		**2213837**	

The Falkland/Malvinas Islands, located in South America, stand out for boasting the highest average supply of hake per person per year, measured in kilograms. Following closely behind are Namibia in Africa, Argentina in South America, Saint Kitts and Nevis in the Caribbean, and Montenegro, Spain, Portugal, and Lithuania in Europe. Also noteworthy are South Africa in Africa, as well as Uruguay and Chile in South America, which contribute significantly to the hake supply.

Hake international trade flows

Our results revealed a growth in hake total transactions in both volume and value during the analysed period. In 2016, the total volume of hake traded was 318,631 tonnes, with a value of 908,547 USD millions. This volume increased to 469,302 tonnes in 2017, with an estimated value of 1206 USD millions. In 2018, there was another volume increase, reaching 497,392 tonnes and a value of around 1338 USD millions. In 2019, the volume continued to grow, reaching 499,368 tonnes, while the value suffered a slight decline with a total of 1320 USD million. However, in 2020, a decline in the volume of hake trade was observed, falling to 429,142 tonnes, while the value remained around 1176 USD millions.

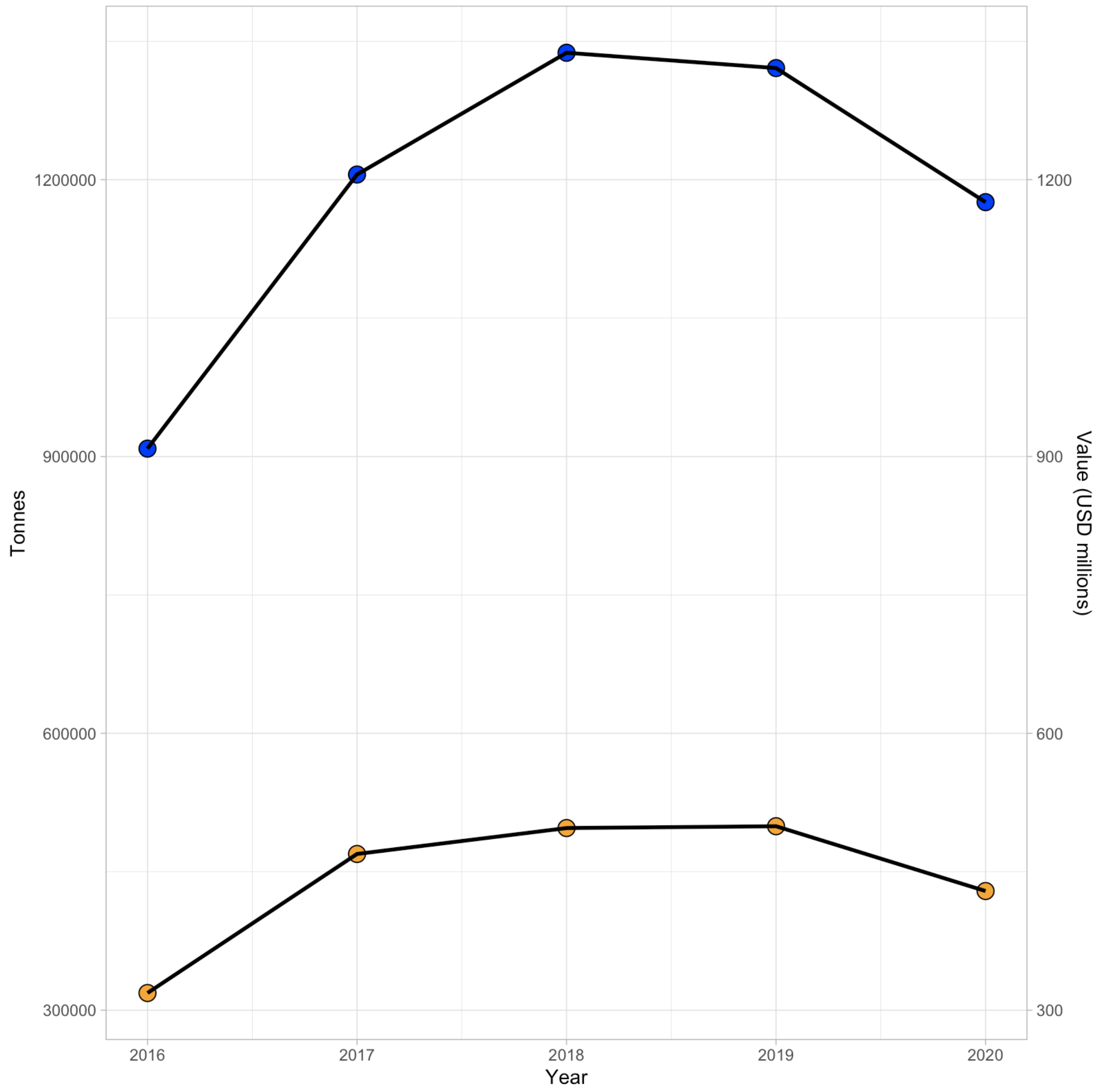

Figure 4. Time series evolution of total transactions in the global hake market. Orange dots representing mass (tonnes) and blue dots representing economic value (USD Millions) of the global hake trade for the period 2016-2020.

A cluster analysis based on a degree threshold unveils stable and frequent trade relations among trading countries. The analysis focuses on the number of import and export links (in-degree and out-degree) rather than the volume and value of traded goods (in-strength and out-strength). Stronger and more prominent links, indicating intense and significant bilateral trade relationships, are indicative of crucial trade flows, strategic partnerships, or preferential trade agreements between nations. In the Hake Global Trade Network, comprising 193 traders from diverse regions, 14 distinct clusters were identified (Fig. 5). The primary cluster includes Spain, the USA, Argentina, and China, forming an extensive and diverse trade sub-network involving Europe, North America, South America, and Asia, respectively. These countries, with higher degrees (more connections), act as trade hubs, facilitating the flow of goods and services among multiple partners. The second and third significant clusters consist of three and five traders, respectively, including developed countries like Germany, the Netherlands, Canada, France, and Portugal, as well as developing countries such as South Africa, Uruguay, and Namibia. These densely connected clusters reveal specific trade patterns, suggesting the presence of regional trade agreements or geographic factors influencing bilateral trade.

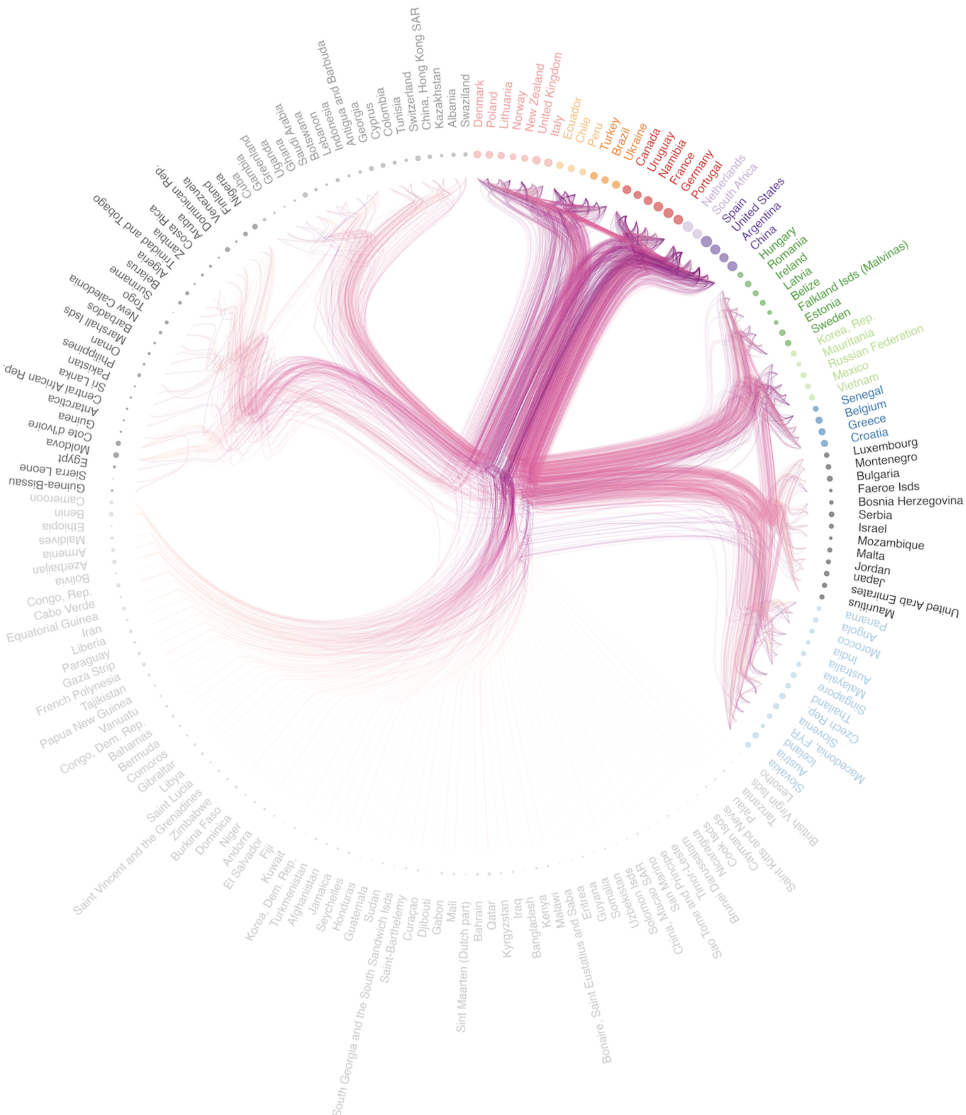

Figure 5. The Hake Global Trade Network. The ca. 190 traders of the Hake Global Trade Network as nodes (circles) and their trade links as lines. The colour and the size of the nodes represent, respectively, the cluster membership and relative importance of the trader in the Hake Global Trade Network, estimated from the number of trade links with other traders (i.e., degree). The colour of the edges represents the origin, destination and the proportion of trade links for all years between each pair of traders. The clusters were made using Ward's method. The figure was created with R (https://cran.r-project.org) packages: "ggraph" v.2.0.0 (https://ggraph.data-imaginist.com) and "ggtree" v3.0.2 (https://guangchuangyu.github.io/ggtree-book/chapter-ggtree.html).

The cluster analysis based on the degree threshold was followed by a network analysis using the weighted network, considering trade mass and value. This allowed for a deeper understanding of bilateral trade relationships within the hake trade network. The upcoming section explores the network's characteristics, emphasizing trade connection weights, key players, and trade patterns. By examining centrality measures, valuable insights into hake trade volume and value, as well as their implications for participating countries, are revealed.

Valuable information on international trade in hake, with the top 100 trade mass flows between countries, can be made (Fig. 6). Despite having a wide and extensive network of trade relations, China does not rank as a significant mover of large quantities of products or currency. When analyzing weighted networks, China emerges as the least important trading partner within the main cluster identified based on the degree threshold, which includes Spain, Argentina, and the United States. Notably, China's product movement network, in terms of tonnes, is characterized primarily by the flow of imports from Canada, marking a distinct feature. On the other hand, Argentina, Spain and the United States again stand out as the main producers and exporters of frozen hake in weight and value, with important export flows between them and/or to Ukraine, Portugal, Brazil or Russia, among others (Figure SM1). Similarly, Namibia plays an important role as a producer and exporter, with its main export flow going to Spain (Figure SM2). Canada also stands out as a producer and exporter of frozen hake, with exports to Ukraine in addition to the aforementioned flow to China (Figure SM3). The United States, for its part, plays a crucial role as an exporter of fish to Ukraine and Nigeria, indicating an active participation in the supply of these countries (Figure SM4). At this point, it is important to highlight Ukraine as an important importer of hake, but without large export flows, probably due to domestic consumption. Spain, on the other hand, acts as a vital connectivity hub between South American and African countries with Europe. It receives important flows of hake from Namibia, Argentina and the Falkland/Falkland Islands, of which a significant part is exported to Ukraine, Portugal, Italy and Serbia (Figure SM5). This underlines Spain's central position in facilitating the global hake trade. South Africa also plays a similar connectivity role, importing hake from Namibia, Canada and the US, and mainly supplying Spain, Portugal and Italy (Figure SM6). Of particular note is the trade relationship between South Africa and Namibia, where a significant proportion of the hake is shipped back, probably after value addition or processing. The analysis highlights the complexity and interconnectivity of the international hake trade network, underlining the trade relationships established between several countries. It also highlights the importance of key players such as the US, Spain, Canada and South Africa in driving the dynamics of the hake trade.

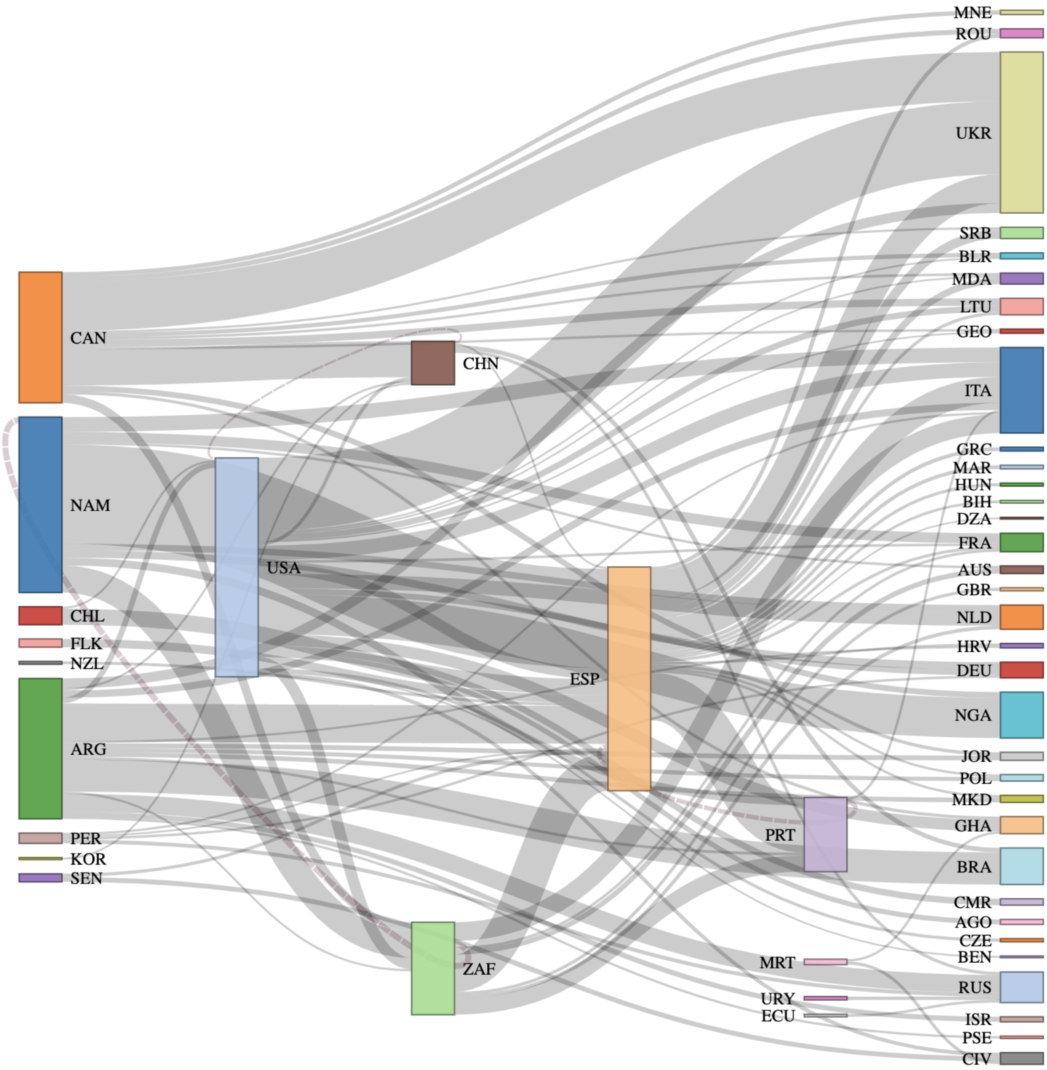

Figure 6. Sankey diagram of the international hake mass trade network. Countries (nodes) are represented by rectangles or text. Arrows or arcs are used to show the flows between them. The diagram shows the 100 largest flows (tonnes) between countries in the world. Countries are represented with the ISO 3166-1 alpha-3 international standard codes (https://www.iso.org/obp/ui/#search). The interactive diagram can be accessed at: https://mares-imedea.shinyapps.io/Hake_Global_Trade_Network/

The sum of imports and exports, in terms of either quantity or currency, is often a good indicator of the level of involvement and intensity of a country's trade relations with other nations. The centrality measure that represents this is called "Strength," which reflects a country's ability to actively participate in bilateral trade. Countries with higher strength typically play a crucial role in the bilateral trade network, as they have greater influence over trade flows. Their position can be indicative of their economic and commercial significance in the global context. The most important countries in this regard were Spain, Namibia, Argentina, South Africa, USA and Italy (Figure 7, Table SM3). Spain topped the ranking in imports, trading over $1.680 million, while the major exporters are Namibia ($1452 million), Spain ($881 million) and South Africa ($800 million). Regarding the largest importers, aside from Spain, the primary countries were Italy ($739 million), Portugal ($553 million), Ukraine ($464 million), Brazil ($224 million) and South Africa ($219 million)(Figure 7, Table SM3). The strength also reveals the relevance of the trade flows between Namibia and Spain in the period from January 2016 to December 2020, trading a total amount of $826 million (Table SM3, Figure 7). The second highest value flow was between Spain and Portugal ($338 million). Other important trade flows in the same period were between South Africa and Spain ($263 million), Argentina and Spain ($208 million), USA and Ukraine ($202 million), and Spain and Italy ($202 million) (Table SM3).

By considering the cost of connections as the weight and calculating the Betweenness centrality measure, countries that maintain efficient and cost-effective connections within the network can be identified. These countries may not necessarily facilitate large volumes of trade in terms of goods or currency, but they derive significant benefits from the presence of countries with high strength, enabling them to remain competitive and easily access desired products. Notably, Denmark, France, and Ukraine have emerged as pivotal nodes playing crucial roles in minimizing costs along trade routes. Additionally, Austria, Germany, and Thailand closely follow, underscoring their importance in maintaining efficient and cost-effective connections within the network (Table SM2, Figure SM2 in the Supplementary Material).

Countries with a high PageRank typically exhibit a significant number of inward relationships (imports) from countries that hold a prominent position in global trade, characterised by a substantial flow of exports and imports. This high PageRank suggests a resilient trade network as the loss of a connection with a partner would have minimal impact on import volumes, thanks to the country's diversified trade networks. From 2016 to 2020, Spain (in-degree = 47), Italy (in-degree = 38), Serbia (in-degree = 24), Germany (in-degree = 43), Montenegro (in-degree = 22) and Côte d'Ivoire (in-degree = 23) occupy such central positions in the global hake trade network (Table SM3, Figure 8).

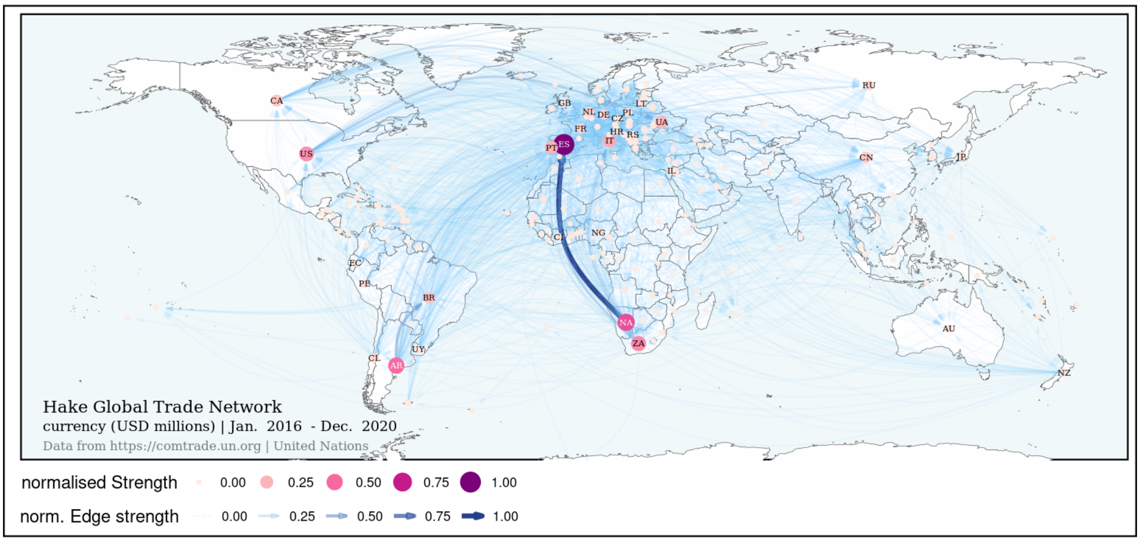

Figure 7. Global Trade Network for Hake between Jan. 1, 2016, and Dec. 31, 2020. The numbers correspond to the normalised amount of currency (USD million) traded. Each node represents a trader and each edge represents the relationship between two traders. The size and colour of the node represent the relative importance of the trader in the network in terms of its Strength. The width and colour of the edge represent the relative importance of the relationship between two traders in terms of their Edge strength. This graph is based on UN ComTrade 030366, 30378, 030474 commodity code(s).

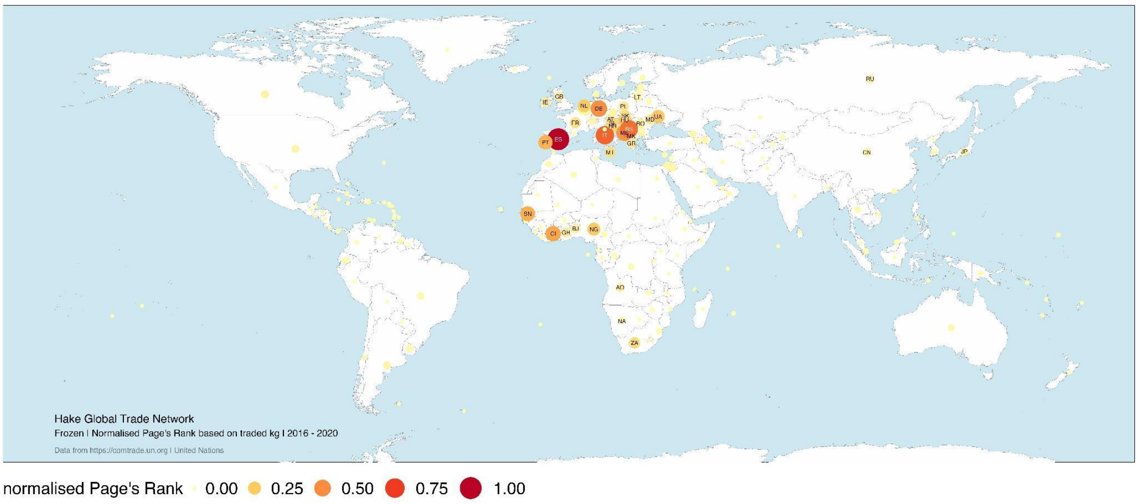

Figure 8. Global Trade Network for Hake between Jan. 1, 2016, and Dec. 31, 2020. The numbers correspond to the normalised amount of currency (USD million) traded. Each node represents a trader. The size and colour of the node represent the relative importance of the trader in the network in terms of its Page's Rank. This graph is based on UN COMTRADE 030366, 30378, 030474 commodity code(s).

4.Discussion

Overfishing has become a critical global issue that intersects with both the international trade of seafood and greenhouse gas emissions related to seafood transport (Vianna et al. 2020). Increasing demand for fish and growing international trade has led to widespread overfishing, posing significant challenges to the sustainability and conservation of fishery resources (Watson el al. 2016). In response to the depletion of fish stocks and a continued growth in consumer appetite for seafood, the fisheries sector faces increasing pressure to maintain catch levels and to meet market demand. Based on continuous advancements in fishing technology and the existence of harmful subsidies, the industrial fishing sector has been able to search for and exploit new resources (Villasante et al. 2022). These strategies include shifting fishing effort to deeper (Villasante et al. 2012) and more distant waters (Tickler et al. 2018) once traditional fishing grounds have been depleted (Pauly et al. 2002; Swartz et al. 2010). The depletion of stocks has also created a dependence of seafood supply on international trade to meet the growing demand, resulting in increased transportation of products across long distances (Gephart and Pace 2015; Watson et al. 2017).

The expansion of fishing activities into deeper and more distant waters and the transportation process related to the global seafood trade network entails higher fuel consumption and higher greenhouse gas emissions (Tyedmers et al. 2005; Parker and Tyedmers 2015; Aragão et al. 2022). Thus, the carbon footprint associated with deeper and longer fishing distances, the use of larger industrial vessels and the need for long journeys for seafood transportation thought the globe are contributing to widespread global change and global warming of the oceans.

These interconnected factors: (1) depletion of fish stocks, (2) increasing demand for seafood products, (3) expanding international trade and (4) the resulting increase in greenhouse gas emissions, highlight the complex challenges facing the fisheries sector. These challenges require a trans-disciplinary approach that includes sustainable fishing practices, discerning consumers who view extractive processes and think about their consumption decisions in an environmental context, and international cooperation to protect marine resources and mitigate the environmental impact of global seafood trade.

It is necessary to reconsider the rules of international trade and move again towards short-distance trade, which prioritises exports and imports between nearby countries in the same continent. Intra-regional trade remains important for low/lower-middle income countries and efforts to deepen regional integration through bilateral and regional trade agreements, and through investments in regional connectivity, would enhance nutrient adequacy at the regional level (Geyik et al. 2021). Obviously, this strategy means that developed countries have to reduce the consumption of large-distant (sea)food products. Moreover, In a globalised world with the current environmental and social crisis there is an urgent need to make transformative changes and it is important to plan new challenges that allow, among other things, the reduction of greenhouse gas emissions to the atmosphere.

Our study confirms that hake is no exception to these global patterns of international seafood trade. Apparent hake consumption has been steadily increasing worldwide, peaking at 3.5 million tons in 2018 according to FAO (2020), an increase also seen in the volume of hake in the global trade network which showed growth of approximately 200,000 tons from 2016 to 2019. In 2020, a disruption in this pattern occurs with a decrease in international trade, this decrease can be attributed to the impact of the Covid-19 pandemic, which significantly affected global trade. Border restrictions, restaurant closures, and reduced demand due to social estrangement contributed to the decline in export volume. This dynamic can also be explained by reduced supply due to fishing restrictions and transportation difficulties during the pandemic. This impact attributed to the COVD-19 pandemic highlights potential vulnerabilities in HTGN.

Importantly, the concentration of hake supply in specific countries can improve connectivity and facilitate trade flows. Spain, the Netherlands, China, Germany, the United States and South Africa emerge as key players in the global hake trade network, serving as cornerstones and connecting numerous traders through imports and exports (high degree). Among these countries, Spain and South Africa stand out as both significant exporters and importers. Furthermore, the United States, alongside Spain and South Africa, also ranks among the largest importers in the global trade landscape. This concentration of trade contributes, to a large extent, to the stability and functionality of the network. However, the concentration of hake supply in a few players poses challenges in terms of system vulnerability. The stability of the global hake trade network is highly dependent on these key players, and any disruption in their trade activities, socio-political situation or environmental conditions can have a significant impact on the network as a whole. See for example how our results highlight the importance of Ukraine in the global frozen hake trade network between 2016 and 2020. Ukraine was the world's second largest importer of hake in this period and, in the absence of updated data, it is to be expected that its privileged position after the Russian invasion in 2022 will no longer remain the same. This could result in another commercial player emerging to replace it or one of the major actors taking advantage of the situation. It is thus clear that this concentration highlights the need for diversification and resilience-building measures to ensure the stability and sustainability of the hake trade network.

On the other hand, it is important to note that the apparently highest average supply of hake per person per year found in the Falkland Islands is not entirely accurate. This is because, as the Falkland Islands are an overseas territory of the UK, trade statistics may reflect the broader categorization of the UK as an exporting entity, which is also the case for many other territories. Therefore, it is conceivable that hake exports from the Falkland Islands are reported as exports from the UK as a whole. This situation could explain the perception of lower hake exports specifically attributed to the Falkland Islands, despite the region having high landings. There is an urgent need for international trade data to follow clearer reporting practices and customs classifications that accurately reflect the specific origin of exported goods and enable better traceability of food products.

Effective fisheries management is crucial to address the environmental and social impacts associated with the hake fishery and to meet the demands of the international market. Our findings provide important information on the structure and dynamics of the global hake trade network, which can inform policy development. Sustainable fishing practices, such as the use of more selective fishing gear and the establishment of marine protected areas, are key to achieving a balance between the environmental and social impacts of the hake fishery and the demands of the international seafood market.

In addition, our study sheds light on the link between the hake trade network and proposals to decarbonise fishing activities. The fishing industry contributes to greenhouse gas emissions, mainly through fuel consumption in fishing vessels and transport. To address this problem, efforts should focus on improving the fuel efficiency of fishing vessels, exploring alternative energy sources and optimising transport routes. Decarbonising fishing activities can contribute to mitigating climate change and reduce the overall carbon footprint of the fishing industry. This is vital in a world where emerging economies are increasingly demanding access to quality sources of protein and essential nutrients. In this context, hake consumption plays a vital role in food security, particularly in regions where it is an important part of the diet. However, ensuring food security goes beyond availability; it also involves affordability, accessibility and nutritional quality. Sustainable management of hake stocks, equitable distribution of resources and fair trade practices can contribute to food security by ensuring the long-term availability and accessibility of hake as a vital food source.

Balancing global food security with the imperative to reduce the carbon footprint associated with fishing practices and international trade poses a significant and complex challenge. Addressing this challenge requires urgent and coordinated action, involving multiple strategies and stakeholder engagement. Achieving sustainable and resilient food systems that mitigate environmental impacts while ensuring food security for all is an attainable goal, necessitating a transdisciplinary effort supported by science, technology, and strong societal, political, and commercial support.

Conclusions

In conclusion, the concentration of hake production and trade in a few actors, together with the connectivity and vulnerability of the trade network, present both opportunities and challenges. Sustainable fisheries management practices, together with efforts to decarbonise fishing activities, are essential to ensure the long-term viability of the hake trade network and minimise its environmental impact. Furthermore, addressing food security issues requires a holistic approach that considers the availability, accessibility and nutritional quality of hake in the context of global trade dynamics.

Overall, this study provides, for the first time, insights into the global hake trade network, its key players, and their roles in the network. The centrality measures used in this study demonstrated that Spain is a critical country to avoid network fragmentation and maintain the stability and functionality of the global hake trade network. Other countries such as South Africa, the USA, and China also play important roles in connecting trade groups and ensuring the smooth flow of products and capital.

The relationship between the hake fishery and the international market highlights the interconnectedness of environmental, social, and economic systems. The international demand for hake products can drive unsustainable fishing practices and labour abuses, while also contributing to CO_2 greenhouse gas emissions and climate change. Therefore, addressing these issues requires a global and holistic approach that takes into account the environmental and social impacts of the hake fisheries and the demands of the international market. The findings of this study have implications for policymakers and industry stakeholders involved in the global hake trade. By understanding the key players and their roles in the network, policymakers can identify potential risks, challenges and opportunities to develop effective policies that promote sustainable practices through the hake network. Industry stakeholders can also use this information to make informed decisions regarding trade partnerships and investments.

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