Main actors in the Cephalopod Global Trade Network: a graph theory analysis

Andres Ospina-Alvarez (✉ aospina.co@me.com)

Mediterranean Institute for Advanced Studies, IMEDEA (UIB-CSIC) <https://orcid.org/0000-0003-2454-7169>

Silvia de Juan Mohan

Institut de Ciències del Mar, ICM - CSIC

Pablo Pita

University of Santiago de Compostela

Gillian Ainsworth

University of Santiago de Compostela

Fabio Matos

Universidade de Aveiro

Cristina Pita

University of Aveiro

Sebastián Villasante

Universidad de Santiago de Compostela <https://orcid.org/0000-0001-6296-4479>

Article

Keywords: Cephalopods, Network analysis, Seafood markets

Posted Date: July 15th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-721404/v1>

License: This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

The global cephalopod trade is a multi-billion-dollar industry that involves fishing and captive breeding of a dozen species of high commercial value. It also contributes wholly or partly to the income and subsistence of thousands of families around the world. Despite its broad ecological, social, and economic importance, limited research has been conducted to describe the scope and scale of the global cephalopod trade. To date, there is no specific regulation, nor have tracking systems been implemented, to study the traceability of the global cephalopod trade at an international level. We provide, for the first time, a comprehensive description of the legal trade in cephalopods to understand who the key world players in the cephalopod seafood markets are. We analysed 20 years of records compiled by the United Nations COMTRADE database. The database contained 115,108 entries for squid and cuttlefish and 71,659 entries for octopus, including the product flow between traders (countries or territories) weighted by volume (kg) and monetary value (USD). Graph theoretic analysis was used to explore the emergent properties of this database through the analysis of different measures of centrality that provide insights on the key role of the traders in the network. Our findings show that most of the market movements between ca. 250 traders are led by three countries (China, Spain, and Japan), involving 11 clusters of traders based on the volume and value of cephalopod trade and number of transactions. The most important cluster, that dominates the cephalopod seafood market, is composed by 5 Asian countries (China, India, Republic of Korea, Thailand, and Vietnam), 2 European countries (the Netherlands and Spain) and the USA. This work identifies the traders that act as major exporters and/or importers, the modulators, intermediaries or accumulators, the best-connected traders, the principal flow routes and the weaknesses of the global cephalopod trade network. This network information is essential to advance towards a transparent and sustainable cephalopods world trade.

Introduction

Cephalopods account for around 2.5% of global fish production. Landings have increased in relative terms by 416% since 1961 to reach an all-time maximum of around 4 million tonnes in 2013, before dropping to around 3 million tonnes in 2019 (Fig. 1a). East Asia and South America, led by China and Peru, drive the increase in production, while Japan has halved its cephalopod production over the past 50 years^{1,2} (Fig. 1b, 1c). Even with the clear global trend of declining cephalopod catches since 2013, their commercialisation in volume (tonnes) and monetary value (USA dollars, hereafter USD) has followed a steady increasing trend since the 1950s, by 6-fold in volume and 14-fold in USD. East Asia and South America (particularly Peru and Argentina, including Malvinas/Falkland Islands) have concentrated the highest production of volume in the last 20 years, staying in the same predominant position since the 80's (Fig. 1b, 1c). Regarding cephalopod market value, Asian (China, Japan, Thailand, Republic of Korea (South Korea), Vietnam, India), European (Spain, Italy), African (Morocco) and North American (the USA) countries hold the 10 most important fishing fleets in the world².

Considering relevant stocks of squid and octopus, worldwide catches of shortfin squid (*Illex* spp., see family Ommastrephidae in Fig. 1a) fell from 850,000 tonnes in 2014 to 200,000 tonnes or less in recent years. Shortfin squid catches in the Malvinas/Falkland Islands had been low (43,400 t) in recent years and the year 2019 marked the third consecutive year of slow recovery of the South Patagonian stock after its extremely low abundance observed in 2016³. Non-favourable oceanographic conditions for stock migrations and intense activity of foreign fishing fleets (China, Japan, Republic of Korea, Taiwan, Spain) are key factors affecting the current abundance of the stock^{3,4}. The United Kingdom's departure from the European Union (Brexit) in 2020 has also increased uncertainty within the cephalopod market because the structure and dynamic of the global squid trade are expected to be seriously altered. For example, squid producers and traders from the Malvinas/Falkland Islands may lose access to the highly relevant Spanish market. This would affect the profitability of the Spanish fishing fleet based in the Port of Vigo, for which the *Illex* fishery generates €200 million (c.a. USD\$ 235 million) per year⁵. Conversely, Peru estimates that squid landings reached record levels in 2019. The Chinese market is currently open to Peru; therefore, larger volumes may be exported. Landings of Japanese flying squid (*Todarodes pacificus*, see family Ommastrephidae in Fig. 1a) were high in 2019, after some years of declining catches; while squid stocks in the USA waters are not overfished⁶. Meanwhile, octopus' landings have recently decreased in the most important supplier countries (Morocco and Mauritania in Northern Africa), which influences global supply for this group. Morocco and Mauritania are currently implementing more restrictive management measures to protect their octopus' fisheries resource⁷.

To decipher the cephalopod trade network, it is important to understand both the key supplier dynamics and the main consumers of cephalopods over time. According to the Food and Agriculture Organization^{2,8}, Eastern and Southeast Asian and Southern European countries or territories had the highest per capita supply of domestic cephalopods in 2013 (Fig. 2). In 2013, the Republic of Korea, Japan, Taiwan, and Spain had the highest availability of cephalopods for local consumption, all exceeding 10 g/capita/day (Fig. 2). Although the Republic of Korea and Japan dominate cephalopod consumption today, squid consumption in some Asian countries, such as Japan, has declined since the 1980s. Conversely, in Spain, consumption of all cephalopod groups has increased in line with imports (in volume) since the 1980s, although catches by the Spanish fleet have gradually declined².

Despite good knowledge on the current global state of cephalopod catches and consumption, vast information gaps exist about the major global players in the cephalopod seafood market. Faced with one of the world's greatest challenges – how to feed more than 9 billion people by 2050 in a context of climate change, economic and financial uncertainty, and growing competition for natural resources – the international community made unprecedented commitments in September 2015 when UN Member States adopted the 2030 Agenda for Sustainable Development (UN SDG), namely UN SDG 14 (Life Below Water)⁹. As global fish stocks have been progressively overfished², global cephalopod biomass has increased¹⁰; however, there is evidence of overexploitation of some cephalopod species. To achieve the UN SDGs, complex interactions between the ecological abundance of commercial marine species and economic trends need to be fully understood. Ecological^{10,11} and economic studies have focused on

biomass and environmental changes in key cephalopod fisheries (e.g., the Patagonian shortfin squid fishery)⁴, while global patterns of cephalopod seafood markets are still unknown.

Global fisheries and trade databases have been extensively analysed to extract the main harvesting, importing, and exporting traders (countries or territories); however, less effort has been devoted to understanding international cephalopod trade flows and their characteristics, despite their scale and scope. By addressing this knowledge gap, complex network methods have the potential to analyse the global trading system in a way that reveals many new topological and dynamic features of a network of interacting elements (e.g., stakeholders, enterprises, or countries). One relevant topic in the study of world trade is to explore the role of traders geographical entities, their influences, and the situation they occupy in the network¹². It has been observed that the forces of complex network links, called weights in graph theory, also provide promising properties, and can allow insights into the details of networks. In graph theory, a system of connected elements can be defined as a "network", also called a "graph". Network elements are modelled as "vertices" or "nodes" in the graph and their connections or links are represented as "edges" or "arcs". In a trade network, the graph represents the network itself, with each trader being a vertex or node, and the probability of connection or flow of commodities between traders being the arcs or edges. Graph theory provides insights into the system properties and identifies critical nodes with high centrality (i.e., connected to many other traders) or clusters of well-connected nodes with high potential trade flow and acting as bridges between distant world regions. Centrality is a measure that indicates the relevance of a node in a network. It should measure the 4 P's - Prestige, Prominence, imPortance and Power¹³. Each node could be important from a different point of view depending on how that "relevance" is defined. The study of centrality in graph theory is intended to identify the most important nodes in a graph given its topology.

The aim of this work is to apply graph theory to the global cephalopods trade network to identify the trading relationships between traders. We explored the cephalopod trade flow globally by using 20 years of records compiled by COMTRADE, the United Nations International Trade Statistics Database, freely accessible at <https://comtrade.un.org/data/>. The database used includes over 185,000 records, including the flow between traders weighted by volume (kg) and monetary value (USD). By exploring different measures of network centrality, we could assess emerging patterns in what we called the Cephalopod Global Trade Network (CGTN) to identify the most relevant actors for cephalopod global trade.

Methods

In this study, we compute measures of network analysis and apply network graph visualization tools to cephalopod fishery trade flows to understand their nature and dynamics at a planetary level. Specifically, we study the octopus, squid, and cuttlefish global trade networks where the extent of trade between a pair

of traders can be treated as the link weight. Data was extracted for 252 countries or territories and 20 consecutive years (2000 - 2019) from the UN COMTRADE database. Data extraction was done through the COMTRADE API using the package “comtradr” v.0.2.2¹⁴ for the R language and environment for statistical computing version 4.0.3, released on 2020-10-10¹⁵. The COMTRADE API requires that searches for specific commodities are done using commodity codes. Codes used for cephalopods are listed in Table 1.

Using these codes, we conducted queries on all imports and exports reported by any trader from 2000 to 2019. The output was a database having each transaction reported by trader organized in a timestamped (year) origin-destination format, followed by the quantity of the product traded in volume (kilograms) and the value of the transaction (USD). The traded products were identified as either fresh (live, fresh, or chilled product) or elaborated (frozen, dry, salted, in brine) for (1) octopus and for (2) cuttlefish and squid. These two categories are predefined in the COMTRADE database following the Harmonized System Nomenclature (“HS”) and cannot be disaggregated by species or other taxonomic groups. The HS is an international customs terminology for the classification of goods that is currently applied by more than 200 traders around the world. Data were processed and analysed to rank the top five exporters, importers and trade flows regarding volume or monetary value in four five-year periods (i.e., 2000-2004; 2005-2009; 2010-2014 and 2015-2019).

We used graph theory to establish sound theoretical connections between traders involved in the CGTN and analyse the emergent structure of the underlying network of trade connections. We first constructed a directed graph weighted by monetary value (USD) or volume (kg). We considered these different measures to identify potential different patterns in the trade network driven by monetary or volume transactions of cephalopod products. Each node in the graph is identified as a country or territory involved in a trade transaction. However, since not all traders shared trade relationships, the number of nodes was always less than the 230 traders originally identified in the database.

The relationship between each pair of nodes was identified in the network with a link (edge) and the nature of the trade operation (export or import) is determined by the directionality of the link. Therefore, the directionality was denoted with an arrow pointing to the importing country or territory. Each edge in the graph was weighted by the total monetary value or volume involved in all transactions between two nodes over time. Therefore, the size of the nodes represents the relevance of the traders in the global trade network according to the sum of the weights of the edges, in monetary value or volume, flowing from or to each trader (i.e., the node strength or the weighted degree of the nodes). The edges represent the flow of trade, the width of the edge represents the quantity of commodity traded between two nodes. Multi-annual data were normalised to indicate relevance rather than gross values. Finally, for

a better understanding of the trade relations between the different countries and territories, the nodes were geolocated on a world map.

To identify emerging properties within the CGTN, we calculated different centrality measures considering trade links generated by aggregate gross export flows (in either monetary value or volume) calculated for the sum of all trades over the years. Centrality measures are useful to determine the relative importance of nodes and edges within the overall network¹⁶. In networks consisting of several nodes, some nodes play a decisive role in facilitating many network connections. Such nodes are central in network organization and are often identified by a range of metrics known as centrality measures. Here, we calculated 11 measures of centrality for the CGTN: Degree, In-degree, Out-degree, Strength, In-strength; Out-strength; Betweenness, Eigenvector centrality; Kleinberg's hub centrality score (hereafter Hub score); Kleinberg's authority centrality score (hereafter Authority score); and Page Rank. We selected these centrality measures as those metrics potentially useful in trade network studies. They are a product of a first screening that included all existing measures of centrality, identified from a review of the existing literature. A full description of each centrality measure selected, its scope, and market interpretation, is provided in Table 2. Note that Degree of a node is the number of edges that arrive at that node. In a directed graph the degree is usually divided into the In-degree and the Out-degree (whose sum is the degree of the node). Out-strength and In-strength correspond to the weighted Out-degree and weighted In-degree of the node, respectively, and Strength (weighted Degree) corresponds to the sum of In-strength and Out-strength.

Hierarchical clustering of agglomerations using the Ward's clustering method was used to produce groups of traders that minimize within-group dispersion at each binary fusion. A priori statistical significance of the clusters was tested using the similarity profile (permutations = 999, number of expected clusters = 1000) of the members of the identified density clusters.

All analyses were performed using the R language and environment for statistical computing¹⁵. Network graph analyses were performed using R package "igraph" v.1.2.5¹⁷. Hierarchical clustering analyses were performed using the package "flashClust" v.1.01-2¹⁸. Network visualisations were made with R packages: "ggplot2" v.3.2.1 and "ggraph" v.2.0.0^{19,20}.

Results

3.1. Trends of cephalopods trade

Since 2000, trade in fresh octopus has been constantly dominated by the flow from China to Korea, followed by Vietnam to Japan, Portugal to Spain and Spain to Italy. However, there has been a marked

decrease in the traded volume and monetary value over time, and it has been reduced by 50% in the top 5 trading traders.

Over the last 20 years, fresh octopus exports have been strongly dominated by China, followed by Spain, Vietnam, Portugal, and France, and recently by Morocco and Thailand. While Vietnam was the most important exporter in the first period (2000-2005), it has disappeared from the top 5 traders in the last five years. Imports have been dominated by Korea, Italy, and Portugal, with no notable changes in the whole period. Regarding trade of processed octopus, the largest transactions have been performed from Morocco to Spain, Morocco to Japan, Mauritania to Japan (and more recently also to Spain) and China to Korea. Since 2000, exports of processed products have been dominated by Morocco, Mauritania, China, Spain, and Vietnam, while imports have been led by Japan, Spain, Italy, Korea, and the United States.

Trade of fresh cuttlefish and squid in volume includes some fewer clear relationships over time, such as transactions from Malaysia to Singapore (2000-2004 and 2005-2009); from Myanmar to Thailand (2005-2009 and 2015-2019); and from Yemen to Vietnam (2010-2015). For the first five years, exports of fresh commodities were dominated by Vietnam. However, since 2005, India, Spain and France have increased their exports in both monetary value and volume, displacing Vietnam from the top rank. The main importing traders were Spain and Italy. Although China was important in the first decade, it was replaced by Vietnam in the last decade. The trade of elaborated cuttlefish and squid products was dominated by monetary value flow from Thailand to Japan and from Malvinas/Falkland Islands to Spain in the first decade, while in the last decade the flow from China to other traders (Japan, the USA, and Thailand) became more relevant. However, the volume follows a different pattern, with flow from the Malvinas/Falkland Islands to Spain and from Korea to China in the first decade, while in the last decade, flows from Peru to China and from China to Thailand were significant. A disparity exists between the top five traders in terms of monetary value flow and volume flow in the first fifteen years; but in the last five years the top positions are constant, with China, Peru, India, and Spain dominating. Italy, Japan, China, and the USA are important importers in terms of monetary value and volume, although in the last decade Thailand has increased its importance, replacing the USA in the top 5 in the last five years.

The CGTN involves 220 traders (countries or territories) around the globe (Fig. 3). The remaining 32 traders either have no reported exports or were negligible (less than 500 kg in 20 years). The most important cluster of traders is composed by 8 countries that dominate the cephalopod global markets in Asia (China, India, Republic of Korea, Thailand, Vietnam), Europe (the Netherlands, Spain) and the USA.

The second most relevant cluster is composed by 11 traders involving 3 developed (Belgium, Canada, Denmark) and 8 developing countries (Argentina, Chile, Malaysia, Morocco, Philippines, Senegal, South Africa, UAE). Some of these traders have the most productive cephalopod fisheries in the world (e.g., Patagonian shortfin squid in the Southwest Atlantic Ocean).

3.2. Octopus trade network

3.2.1. Live, fresh, or chilled octopus

The normalised strength (Fig. 4) revealed the importance of China and Republic of Korea in the trade of fresh octopus in monetary value, with high importance of flows between these two traders. Other relevant traders are Spain, Portugal and Italy in Europe, and Vietnam in Asia. The network based in volume shows similar results.

‘Betweenness’ identifies important actors facilitating flow through the network. For fresh octopus, the most relevant traders are Spain, France, and Italy, followed by Thailand, Portugal and the USA. Again, no major differences exist between the monetary value and volume networks. However, the ranking of traders changes when considering volume, as Italy replaces France in the second place, Indonesia adopts a more key role, and the most important bridge moves from Spain-Thailand to Spain-the USA (Fig. S1).

Traders with a higher closeness have a high probability of exporting to the nearest neighbouring countries or territories; this measure also identifies important traders in a regional context. The traders with the highest closeness considering the monetary value and volume networks are China, Spain, Portugal, and Vietnam (Fig. S2). The Eigenvector reveals traders that are well connected in the network, identifying their area of influence within the network (traders with which they are connected). In this case, there are differences between the monetary value and volume networks. The influential nodes in the monetary value network are European traders including the Netherlands, Ireland, Belgium, and Romania. On the other hand, the influential traders regarding the volume network are globally distributed, including Indonesia, Canada, Russia, Republic of Korea, the Netherlands, and Czech Republic (Fig. 5).

Traditionally, Indonesia has acted as a hub importing a large volume (kg) of fresh octopus from 37 traders (e.g., India, Philippines, Vietnam, Singapore, Slovenia) and redistributing it to over 200 traders. Other traders that act as worldwide hubs are Slovakia (Europe), Canada (North America), Peru (South America) and Kenya (Africa). Regarding monetary flow, Peru appears as the most important hub.

Although Peru is a large producer, it imports fresh octopus from Chile which it then markets to over 26 traders (Fig. S3).

Authority scores for the volume network reveal which traders have multiple import routes and strong preferential relationships with specific buyer traders in the network (e.g., Czech Republic, Russia, Korea, Canada) (Fig. S4 top). For the monetary value network, Authority scores reveal which traders import from many sources then export to a few destinations while increasing the value of the product. Traders with high Authority scores for the monetary value network could be acting as regulatory actors of the selling price (e.g., Belgium, the USA, the Netherlands, Spain, Hong Kong, Brazil, Japan, Canada, Chile) (Fig. S4 bottom).

3.2.2. Elaborated octopus

The normalised strength reveals a diversified trade network for elaborated octopus products. Several relevant actors are distributed globally (e.g., Spain, Japan, Morocco, Mauritania, Italy, China, Republic of Korea, Vietnam, Portugal, the USA) and are developing different important routes (e.g., from Morocco to Spain; from Mauritania and Morocco to Japan; from Mauritania to Spain and from China and Vietnam to Korea). These routes show a common pattern: the origin is in developing countries or territories (that emerge as producers) while developed countries show a high and stable consumer demand. The network based on volume is highly similar to the monetary value network. However, Italy, China, Korea, Vietnam, and the USA reduce their importance compared to the top-ranked traders (i.e., Spain, Japan, and Morocco). The most important routes of the volume network are from China to Korea; Morocco to Spain; Morocco and Mauritania to Japan and Vietnam to Korea (Fig. S5).

The Betweenness measure highlights the role of Spain as a facilitating actor in the trade network of elaborated octopus, followed by Italy, China, and the USA. Similarly, the routes from Italy to Spain, and from Spain to China and the USA emerge as relevant in the network structure (Fig. 6). There are no major differences between the most central traders in this network and the volume-based one. Notably, the route between the USA and the Philippines is more important in the volume-based network (Fig. S6).

The most important traders according to the closeness measure for both the monetary value network and the volume-based network are Morocco, Mauritania, China, Vietnam, and Spain. These traders may place their commodities quickly and effectively in the network, influencing the transactions of their closest partners (Fig. S7).

The eigenvector reveals the foremost importance of the Netherlands as a gateway for elaborated octopus to the European market, both in monetary value and volume (Fig. S8). Other European traders with a high eigenvector in the monetary value network are Malta, Lithuania, Cyprus and the United Kingdom. Elsewhere, China and Japan play a key role (Fig. S8 top). Central and Eastern European traders also have high eigenvector values in the volume-based network (e.g., Estonia, France, Lithuania, Luxembourg, Poland, Slovenia, Austria), highlighting a strong network of connections across the continent (Fig. S8 bottom).

The hub scores for monetary value and volume-based networks for elaborated octopus mostly highlight European traders as actors that buy from few sources and sell to several partners (Fig. S9). The Authority score again reveals the foremost importance of the Netherlands as a gateway to the European market, both in monetary value and volume. The Netherlands is a trader with many import routes that sells to few traders, mostly in Europe (Fig S10).

3.3. Squid and cuttlefish trade network

3.3.1. Live, fresh, or chilled squid and cuttlefish

The normalised strength revealed the importance of Spain, France, Italy, and India in the trade network of fresh squid and cuttlefish products, especially the route between east Asia and Spain (Fig. 7). The volume-based network (Fig. S11 bottom) is highly similar to the monetary value network.

For fresh squid and cuttlefish, Betweenness identifies Spain as leading the worldwide trade flow in both monetary value and volume networks, while Italy, France, India, China, and the USA are facilitators in terms of both monetary value and volume. However, in the volume-based network, the Netherlands and Myanmar stand out, forming a bridge between the European and Asian markets (Fig. 8).

According to the closeness centrality measure for monetary value and volume-based networks, India may be able to commercialize fresh commodities quickly and effectively among its trading partners (Fig. S12). To a lesser extent, this property is also observed for France, Spain, Yemen, and Morocco.

The Eigenvector score reveals a similar pattern to that emerging from the fresh octopus network, highlighting many quality links among European traders (i.e., relationships with other well-connected traders) in the volume-based network. In this network, the Netherlands is revealed as an important gateway to Europe. In Asia, Thailand takes this role. In the monetary value network, Peru stands out due to its strategy of sourcing only from Chile and redistributing to 26 traders around the world (Fig. S13).

Hub centrality highlights Peru in the monetary value network. This may be driven by its role as an accumulator of fresh commodities from Chile, and exporter to traders with a dominant position in cephalopod pricing (Fig. S14). Authority centrality highlights several traders around the world in the monetary value network: Thailand, Korea, Canada, Denmark, South Africa, Singapore, Chile, Australia, and Spain. In the volume-based network, the central traders are European, with Ireland and the Netherlands at the top, while the rest of the world is dominated by Singapore and Thailand (Fig. S15).

3.3.2. Elaborated squid and cuttlefish

The trade networks based in monetary value and volume for elaborated squid and cuttlefish emerge as global and complex, where several far distant traders have relevant roles in the import/export network (Fig. 9). Although the most important nodes in the volume-based network reflect important nodes in the monetary value network, the strengths of the links, i.e., the flow of value and volume, do not. For example, in the volume-based network, Peru exports the largest quantities of squid and cuttlefish to China (Fig. 9 bottom), but the flow of money for these transactions has lower importance (Fig. 9 top).

The betweenness centrality metric (both monetary value and volume based) shows the importance of China, the USA, and Spain (followed by Italy, Korea, and Thailand) as facilitators in the processed goods trade network (Fig. S16). While the main bridges in volume transactions are between Italy and Spain, Spain and China, and China and the USA (Fig. S16 top), the main monetary bridges are from the USA to China, followed by the routes from Spain to the USA and from Italy to Spain (Fig. S16 bottom). That is, the key protagonists are the same, but they follow different directions.

Closeness centrality highlighted the main actors in a regional context (Fig. 10). In both the monetary value and volume-based networks, China, North and South Korea, India, Indonesia, Thailand, and Vietnam form a strong trade network for squid and cuttlefish processed in Asia. Key players include South America (Peru, Argentina, Chile, the Malvinas/Falkland Islands); the USA; the Mediterranean (Morocco, Spain); Africa (South Africa, Mauritania); and the West Pacific region (New Zealand, Japan) (Fig. 10).

The eigenvector centrality shows the most important international gateways for the monetary value and volume-based networks and their main destinations. For example, the Netherlands and neighbouring destination traders within Europe; Indonesia, Singapore, Korea and Japan on the Asian continent; or South Africa or the United Arab Emirates in the rest of the world (Fig. S17).

The combined hub score of the monetary value and volume-based networks identifies hubs and redistributors of elaborated squid and cuttlefish products around the world: Indonesia, Japan, Thailand, the Netherlands, Portugal, Poland, United Kingdom, and many other European traders (Fig. S18).

Discussion

Although trade involving cephalopods increased its contribution to the global seafood market in monetary terms (USD), as well as in volume, from 2000 to the mid-2010s, there has been limited research to describe the scope and scale of global trade in cephalopods. There is no specific regulation, nor have monitoring systems been implemented, to study the traceability of cephalopods at the international level.

In European waters, the catch of cephalopods in large-scale fisheries is virtually unregulated. Since they are often not the target species, cephalopod catches are only indirectly controlled, for example through restrictions on the types of fishing gear that can be used and catch quotas set for non-cephalopod species. In artisanal cephalopod fisheries, especially in southern Europe²¹, regulatory restrictions on fishing activity are numerous, but few regulations are aimed at maintaining the status of cephalopod stocks, and these regulations are not always enforced, resulting in suspected high levels of illegal, unreported and unregulated (IUU) fishing.

Sanctions on international trade agreements can be a persuasive tool to discourage unsustainable practices such as illegal, unreported, and unregulated (IUU) fishing²². For example, the European Commission has repeatedly sanctioned seafood imports from Southeast Asian traders related to IUU fishing. Countries like Vietnam joined the Association of Southeast Asian Nations (ASEAN) to combat such practices and to benefit from a new Free Trade Agreement with the EU with 99% of tariffs eliminated, including those for octopus and squid products^{23,24}. Other impediments to trade tend to include weak transportation links, inefficient customs clearance, bureaucracy, and red tape²⁵. The European Union's Rapid Alert System for Food and Feed (RASFF) detects risks to health in consignments of food imports into the EU, such as the presence of heavy metals or breaches of the cold chain which can lead to border rejection²⁶. In this context, trade control is a powerful tool to regulate unsustainable practices of the largely unregulated cephalopod fisheries. We provide the most comprehensive description of the legal trade in cephalopods to understand the routes and key world players i with a

methodology that, systematically applied, could contribute to achieving transparency and traceability of cephalopod seafood markets.

In the context of global trade, the ability of a given trader to connect with other traders that demand products from it, thus creating a flow of goods, is often referred to as connectivity. Therefore, from an economic perspective, the main concern is the role of each trader and its influence on the trade network, which is closer to the term "centrality" from a graph theory perspective. Many economic studies use well-known centrality measures, but do not identify them as such²⁷. In this study, we have identified the best-connected traders according to different measures of centrality weighted by monetary value or volume. The Eigenvector centrality measure reveals hubs in the trading network, such as Peru that imports squid and cuttlefish products from Chile and redistributes them to many traders. Another centrality measure, Betweenness, reveals the modulators that connect clusters of traders. Elimination of a modulator can fragment the trading network. For example, in the elaborated octopus trading network, Spain, Italy and China are key network modulators.

Our analysis reveals that traders with the highest import and export rates in many cases are not the most important gateways. In the case of fresh octopus, China and Korea were the largest capital players (highest strength), but the Netherlands is the trader that controlled world trade flow (highest eigenvector). However, three European countries (Spain, Italy, and France), with the highest betweenness, played a critical role for connectivity at the international level. They acted as bridges between different communities of traders, and thus allow traders from different communities to be connected not only with their neighbours, but also with traders from other communities. The commercial routes for fresh octopus have been strongly dominated by four trade flows concentrated in China and Southern Europe: China to Korea, Portugal to Spain and Spain to Italy and Portugal. These countries are characterised by high consumption of octopus (e.g., Korea, Spain, Italy), or by the size and scale of its production and transformation, and with the capacity to shift global seafood markets (e.g., China). Note the particularity of the bi-directional route: Portugal-Spain-Portugal, as Portugal exported fresh octopus' products to Spain and Spain to Portugal. Yet, whether these exports corresponded to different catches or to redistribution of the same product remains unclear. These are the principal routes, and although the quantities of products traded through these routes have markedly decreased in recent years, the monetary value has increased.

In monetary terms, the flow of capital has changed from being highly diversified, with several traders in the top 5 in the first decade of the 2000s, to almost total dominance by China in the last decade. **These patterns illustrate the increasing complexity of the international market for cephalopods, where efficient processes for logistics and meeting standards and regulatory requirements are critical to participation in the global value chain (GVC) while low unit labour costs are critical for competitiveness²⁵.**

Processed octopus is principally traded from China to Korea. However, the routes are more diverse and variable over time, with important routes including Morocco to Spain, Italy to Japan, Mauritania to Japan, and Vietnam to Korea. The list of top exporting traders for processed octopus is also diverse including countries like Vietnam, Mauritania, and Spain. Note that the trade routes for live octopus are characterised by proximity between traders (e.g., Spain, France, Italy, Portugal), while processed octopus trade routes are longer (e.g., Morocco to Japan or Mauritania to Japan). This rule is not true for fresh squid and cuttlefish, with a trade from India to Europe being one of the important routes.

Proximity and agglomeration benefits are important. For example, in the fresh squid trade network, although numerous Asian traders have many connections and a considerable flow of money and volume with other traders, India occupies a central strategic position with high leverage among its proximate partners (high closeness).

Geography is important for developing countries to take part in cephalopod trade. Developing countries tend to trade with the hub that is geographically closest, with large firms tending to be involved in global production networks while small firms trade within the region²⁵. See for example the case of Peru, which imports a large quantity of fresh octopus from Chile for further processing or reallocation, a typical example of a trade relationship mediated by geographical and cultural proximity.

However, global trade networks are complex and geographic proximity does not imply trade proximity. For example, Morocco and Mauritania are geographically close and have high closeness values but have a much lower trade flow of processed octopus between them compared to the trade each has with several Southeast Asian traders. On the other hand, Peru (in monetary terms) and Indonesia (in volume terms), with the highest Hub scores, are aggregators or accumulators of fresh octopus imported from a few trading partners and then exported to many other traders, through networks involving numerous connections. In the other direction, there are traders, such as South Africa in the elaborated squid network, that act as aggregators, but in this case importing (enormous quantities in USD) from many different traders and then exporting to a few destinations (high Authority score).

All the above situations may be due to multiple or interrelated factors such as high GDP, foreign direct investment, the presence of trade agreements, economic complementarity, and historical and cultural ties that make a country or territory the most important trading partner for a single country or group of countries²⁷. The flow of elaborated squid and cuttlefish in volume presents some interesting

particularities that, as mentioned, could be affected by external factors. For example, the strong Malvinas/Falkland Islands-Spain relationship and, in the last decade, Peru-China. This scenario might change as Brexit-associated economic risks include the adoption of new taxes for cephalopod exports for Spanish fishing vessels which have been operating in Malvinas/Falkland waters over the last three decades.

We identified the second most relevant cluster in the CGTN as being composed of eight developing countries (Argentina, Chile, Malaysia, Morocco, Philippines, Senegal, South Africa, UAE), some of which host the most productive cephalopod fisheries in the world. Our results also identified that elaborated octopus products tend to move from developing to developed countries. These findings reflect the global North's increasing importance as a net importer of natural resources from the South, showing a high specialization on a growing demand for cephalopods.

Simultaneously, these results also cause traders in the South to place greater economic importance on resource intensive primary sectors and taking on a greater environmental burden as a result²⁸. Some developing countries have trade deficits due to exporting more fisheries resources to developed countries than they import. There is ongoing debate about whether this is beneficial or detrimental to the exporting traders in terms of loss of access to the exported foods compared with increased purchasing power from income generated from those exports²⁹. The flow of cephalopod products may contribute to food distribution equity by improving access to nutrient rich foods across countries or territories and socio-economic groups³⁰.

Nevertheless, a growing demand for fisheries resources can lead to increased exploitation of stocks with implications for the environmental, social, and economic sustainability of fisheries in developing countries where corruption and illegal fishing practices are often the logical response to a lack of effective policy and regulatory frameworks^{31,32}. Furthermore, the energy cost of transporting products through the complex trade links as well as the carbon sink prevented by the removal of cephalopods we have described from the oceans³³, must also be considered in terms of resource use and carbon emissions.

Rising from 13% in 2000 to 16% at their peak in monetary terms between 2014 and 2016, and from 29% in volume terms in 2000 to 30% in 2014, cephalopods are one of the fastest growing products in terms of market share in the global seafood trade. However, in the last three years they have reached their lowest global seafood market share for the last two decades, at 5% in both monetary value and volume. On

average, the price of fresh octopus was ca. 2.2 USD/kg in 2000, and by 2018, it had increased 5-fold to ca. 11.6 USD/kg. Similarly, but at a lower rate, the traded quantities of elaborated octopus have decreased in recent years and the monetary value of these transactions has increased. On average, the trade of elaborated products has increased from 2.6 USD/kg in 2000 to 10.2 USD/kg in 2019. These results suggest that trade for live, fresh, or chilled octopus is better positioned in the market, either due to growing consumer interest or to a shift towards healthier consumption habits. There is a growing interest among chefs and gastroscientists to promote novel uses of cephalopods to replace meat from land-animal production³⁴.

The complexity of the trade flows we have described along with variations in (or lack of) labelling systems and official lists of seafood trade names in different countries or territories can make it difficult to accurately identify the origin of raw material used in cephalopod products, especially in processed preparations where potentially identifiable anatomical features have been removed³⁵. Lack of traceability measures creates opportunities for exploitation through product mislabelling or substitution with species of lower commercial value, as well as abusive practices such as the addition of water to artificially increase product weight^{35–37}. Mislabelling can have significant impacts on efforts to sustainably manage associated fishers³⁸. There are several ways of communicating to consumers about the environmental sustainability of seafood products and fishing activities. This is mostly done through labelling, certification and ratings programs, in some cases also supported by guides for consumers, and most of them are operated by non-governmental organizations (NGOs). The most rigorous and credible ones have been recognized by international initiatives, such as the Global Sustainable Seafood Initiative (GSSI) and the Certification and Ratings (Cert&Rat) Collaboration, that analyse the alignment of these programs with the FAO Code of Conduct for Responsible Fisheries and the FAO Guidelines for the Ecolabelling of Fish and Fishery Products from Marine Capture Fisheries.

Conclusions

Our findings show that the Cephalopod Global Trade Network involves 220 traders around the globe, involving 11 clusters of traders based on the volume and monetary value of cephalopod trade and the number of transactions between 2000-2019. The most important cluster is composed by only 8 traders which dominate cephalopod seafood markets located in Asia (China, India, Republic of Korea, Thailand, and Vietnam), Europe (Netherlands and Spain) and the USA.

The commercial routes of live, fresh, or chilled octopus have been strongly dominated by four trade flows concentrated in China and Southern Europe (i.e., China to Korea, Portugal to Spain and Spain to Italy and Portugal). Traders with a higher closeness have a high probability of exporting to the nearest neighbouring trading partners (not always geographically close), and it also identifies key traders in the

regional context. The traders with the highest closeness are China, Spain, Portugal, and Vietnam. Well-connected traders have a high flow of imports and exports with traders that also have a high flow of imports and exports; while traders that have multiple trade routes with strong relationships with buyer traders prefer them over other traders in the network.

These results suggest that trade in live, fresh, or chilled octopus is better positioned in the market, either due to growing consumer interest or a shift towards healthier consumption habits. The processed octopus is also principally traded from China to Korea. However, the routes are more diverse and variable over time, with important routes including Morocco to Spain, Italy and Japan, Mauritania to Japan, and Vietnam to Korea. Trade routes for fresh squid and cuttlefish have been highly concentrated by the largest monetary transactions from India to Spain, losing relevance in the last five years, when the flow of capital has been greater between European traders (e.g., from Spain and France to Italy and from France to Spain).

Our findings identify the traders that act as major trade actors, modulators, intermediaries, accumulators, the best connected, the flow routes and the possible weaknesses of the global cephalopod trade network. This work provides essential input to advance towards transparent and sustainable cephalopod world trade. Given the increasing scale and speed of the cephalopod industry activity, we conclude that the industry has truly global effects today.

Finally, we highlight a few considerations when interpreting the results. First, our research does not include illegal, unreported, and unregulated (IUU) trade and discards data. Second, the level of data disaggregation for all categories of species is not always the most accurate. Third, we only focus on the trade dimension of the cephalopod industry, but global cephalopod trade could mask the constraints of marine ecosystems and thus allow actors through the value chain to ignore them by enabling substitution of input sources, or even sequential (over)exploitation³⁹.

Declarations

Author Contributions

SV and AO conceived the idea; AO and SdJ designed the methodology; AO, PP, GA, CP, FM and SV contributed to data; AO and SdJ performed model simulations and formal analysis; AO and SV led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

Acknowledgements

AO was supported by H2020 Marie Skłodowska-Curie Actions [746361] and Contract financed through the call for postdoctoral fellowships of the Government of the Balearic Islands, program “Vicenç Mut” 2020. SV, GA, PP knowledge the financial support from the INTERREG Cephys and Chefs Project, and *Xunta de Galicia Grupos de Referencia Competitiva* (under Grant ED431C2019/11). PP was supported by *Xunta de Galicia* (RECREGES II project under Grant ED481B2018/017).

Supplementary information

Supplementary figures can be found in the public repository Figshare under the link <https://figshare.com/s/c1cac41905cf17710b5d>. The DOI 10.6084/m9.figshare.14987001 has been pre-assigned to this dataset.

References

1. Ritchie, H. & Roser, M. Seafood production. *Our World in Data* (2019).
2. FAO. *The State of World Fisheries and Aquaculture 2020*. (FAO, 2020). doi:10.4060/ca9229en.
3. Falkland Islands Government. *Fisheries Department Fisheries Statistics, Volume 25, 2020*. 98 <https://www.fig.gov.fk/fisheries/publications/fishery-statistics?task=download.send&id=210&catid=7&m=0> (2021).
4. Villasante, S., Sumaila, R. & Antelo, M. Why cooperation is better? The gains of cooperative management of the Argentine shortfin squid fishery in South America. *Environment and development economics: Essays in honour of Sir Partha Dasgupta* 270–294 (2014).
5. Villasante, S., Carpenter, G. & Antelo, M. Sea of risks or opportunities? Potential economic impacts of Brexit on the Spanish fishing fleet. in (Fundación FREMSS, 2017).
6. GLOBEFISH. Tight supplies and high prices. <http://www.fao.org/in-action/globefish/marketreports/resource-detail/es/c/1207720/> (2019).
7. GLOBEFISH. Volatile octopus prices and uncertainty in the squid industry. <http://www.fao.org/in-action/globefish/market-reports/resource-detail/en/c/1268629/> (2020).
8. FAO. *FAO Yearbook. Fishery and Aquaculture Statistics 2018/FAO annuaire. Statistiques des pêches et de l'aquaculture 2018/FAO anuario. Estadísticas de pesca y acuicultura 2018*. (FAO, 2020).

doi:10.4060/cb1213t.

9. Folke, C., Biggs, R., Norström, A. V., Reyers, B. & Rockström, J. Social-ecological resilience and biosphere-based sustainability science. *E&S* **21**, art41 (2016).
10. Doubleday, Z. A. *et al.* Global proliferation of cephalopods. *Current Biology* **26**, R406–R407 (2016).
11. Caddy, J. F. & Rodhouse, P. G. Cephalopod and Groundfish Landings: Evidence for Ecological Change in Global Fisheries? *Reviews in Fish Biology and Fisheries* **8**, 431–444 (1998).
12. Lee, K.-M. *et al.* Impact of the Topology of Global Macroeconomic Network on the Spreading of Economic Crises. *PLoS ONE* **6**, e18443 (2011).
13. Rusinowska, A., Berghammer, R., De Swart, H. & Grabisch, M. Social Networks: Prestige, Centrality, and Influence: (Invited Paper). in *Relational and Algebraic Methods in Computer Science* (ed. de Swart, H.) vol. 6663 22–39 (Springer Berlin Heidelberg, 2011).
14. Muir, C. *comtradr: Interface with the united nations comtrade API*. <https://CRAN.R-project.org/package=comtradr> (2018).
15. R Core Team. *R: A Language and Environment for Statistical Computing*. (R Foundation for Statistical Computing, 2019).
16. Freeman, L. C. Centrality in social networks conceptual clarification. *Social Networks* **1**, 215–239 (1979).
17. Csardi, G. & Nepusz, T. The igraph software package for complex network research. *InterJournal Complex Systems*, 1695 (2006).
18. Langfelder, P. & Horvath, S. Fast R Functions for Robust Correlations and Hierarchical Clustering. *J. Stat. Soft.* **46**, (2012).
19. Chang, W. *R Graphics Cookbook*. (O'Reilly, 2012).
20. Wickham, H. *ggplot2: Elegant Graphics for Data Analysis*. (Springer International Publishing, 2016). doi:10.1007/978-3-319-24277-4.
21. Pita, C. *et al.* Fisheries for common octopus in Europe: socioeconomic importance and management. *Fisheries Research* **235**, 105820 (2021).
22. Lewis, S. G. & Boyle, M. The expanding role of traceability in seafood: tools and key initiatives. *Journal of Food Science* **82**, A13–A21 (2017).
23. European Commission. Questions and Answers on the EU's fight against illegal, unreported and unregulated (IUU) fishing. *Questions and Answers on the EU's fight against illegal, unreported and*

- unregulated (IUU) fishing* https://ec.europa.eu/commission/presscorner/detail/en/MEMO_15_5738 (2015).
24. European Commission. EU-Vietnam Agreement. *EU-Vietnam Agreement* <https://ec.europa.eu/trade/policy/in-focus/eu-vietnam-agreement/> (2021).
25. World Bank. *Global value chain development report 2017: Measuring and analyzing the impact of GVCs on economic development*. (World Bank Group Publishing, 2017).
26. European Commission. Directorate General for Health and Food Safety. *RASFF annual report 2019*. (Publications Office, 2020).
27. Calatayud, A., Mangan, J. & Palacin, R. Connectivity to international markets_ A multi-layered network approach. *Journal of Transport Geography* **61**, 61–71 (2017).
28. Giljum, S. & Eisenmenger, N. North-South Trade and the Distribution of Environmental Goods and Burdens: a Biophysical Perspective. *The Journal of Environment & Development* **13**, 73–100 (2004).
29. Asche, F., Bellemare, M. F., Roheim, C., Smith, M. D. & Tveteras, S. Fair Enough? Food Security and the International Trade of Seafood. *World Development* **67**, 151–160 (2015).
30. Tlustý, M. F. *et al.* Reframing the sustainable seafood narrative. *Global Environmental Change* **59**, 101991 (2019).
31. Rosales Raya, M. L. & Berdugo, J. E. F. Decision Making in the Campeche Maya Octopus fishery in two fishing communities. *Maritime Studies* **18**, 91–101 (2019).
32. Coronado, E., Salas, S., Cepeda-González, M. F. & Chuenpagdee, R. Who's who in the value chain for the Mexican octopus fishery: Mapping the production chain. *Marine Policy* **118**, 104013 (2020).
33. Mariani, G. *et al.* Let more big fish sink: Fisheries prevent blue carbon sequestration—half in unprofitable areas. *Sci. Adv.* **6**, eabb4848 (2020).
34. Mouritsen, O. G. & Styrbæk, K. Cephalopod Gastronomy—A Promise for the Future. *Front. Commun.* **3**, 38 (2018).
35. Wen, J. *et al.* An insight into the Chinese traditional seafood market: Species characterization of cephalopod products by DNA barcoding and phylogenetic analysis using COI and 16SrRNA genes. *Food Control* **82**, 333–342 (2017).
36. Naaum, A. M., Warner, K., Mariani, S., Hanner, R. H. & Carolin, C. D. Seafood Mislabeling Incidence and Impacts. in *Seafood Authenticity and Traceability* 3–26 (Elsevier, 2016). doi:10.1016/B978-0-12-801592-6.00001-2.

37. Silva, A. J., Hellberg, R. S. & Hanner, R. H. Seafood fraud. in *Food Fraud* 109–137 (Elsevier, 2021). doi:10.1016/B978-0-12-817242-1.00008-7.

38. Helyar, S. J. *et al.* Fish Product Mislabelling: Failings of Traceability in the Production Chain and Implications for Illegal, Unreported and Unregulated (IUU) Fishing. *PLoS ONE* **9**, e98691 (2014).

39. Berkes, F. *et al.* Globalization, roving bandits, and marine resources. *Science* **311**, 1557–1558 (2006).

Tables

Table 1. UN COMTRADE Harmonized System Codes and code descriptions that include octopuses, cuttlefish, and squids.

Species	Presentation	Code	Description
Octopuses	live	030751	Molluscs; octopus (octopus spp.), live, fresh or chilled
	elaborated	030759	Molluscs; octopus (Octopus spp.), frozen, dried, salted, in brine, or smoked, cooked or not before or during the smoking process
Cuttlefish and squids	live	030741	Molluscs; cuttle fish and squid, whether in shell or not, live, fresh or chilled
	elaborated	030749	Molluscs; cuttle fish and squid, whether in shell or not, includes flours, meals, and pellets of molluscs, fit for human consumption, dried, salted, in brine, or smoked, cooked or not before or during the smoking process

Table 2: Measures of centrality, definitions, and rationales in a context of a seafood trade network. See references for additional information. The formula used in each centrality measurement can be found in the documentation of the "igraph" package for R.

Measure	Reference	Definition	Rationale
Strength	Barrat et al. 2004	Also named weighted degree. The node degree is the number of relations (edges) of the nodes. In weighted networks, node Strength is the sum of weights of links connected to the node.	The degree is the number of other traders with which a trader has trade relationships. Strength could indicate if a trader is involved in important (by weight) trades with other traders. Traders with high Strength can be acting as keystones since they are connected by imports and exports to many neighbouring traders.
In-strength	Barrat et al. 2004	In directed networks, the In-strength is the sum of inward link weights.	Traders with a high in-strength could act as important importers or hubs for the distribution of raw materials. High in-strength could also be targeting traders acting as major consumers of products.
Out-strength	Barrat et al. 2004	In directed networks, the Out-strength is the sum of outward link weights.	Traders with high out-strength may be acting as raw producers with high export flows. This may indicate the geographical origin of the commodities and essential habitats for the species. Out-strength can also indicate whether a trader is a major exporter of processed products.
Closeness	Freeman 1979	Closeness centrality indicates how long it will take for information from a given node to reach other nodes in the network.	Traders with a higher closeness have a high probability of exporting to the nearest neighbouring traders. These traders could be important in trade at regional or continental geographic scales.
Betweenness	Freeman 1979	Betweenness centrality is a measure of the influence of a node over the flow of information between every pair of nodes under the assumption that information primarily flows over the shortest paths between them.	Imports and exports are important, but they are not the whole picture. Traders with high Betweenness centralities have been called "bottlenecks" or "bridges" and prevent network fragmentation. A trader that acts as a bridge between two well differentiated groups of traders usually has a high Betweenness.
Eigenvector centrality	Bonacich 1987	The Eigenvector centrality network metric takes into consideration not only how many connections a node has (i.e., its Degree or Strength), but also the centrality of the vertices that it is connected to.	It is a measure of a trader's influence in the trade network. In general, a connection to a well-connected trader is more important than a connection to a poorly connected trader. Traders with high Eigenvector centralities have a high flow of imports and exports mainly with traders that also have a high flow of imports and exports.
Kleinberg's hub centrality score (aka. Hub score)	Kleinberg 2000	The Hub score of a node shows how many highly informative nodes or authoritative nodes this node is pointing to.	High Hub scores may be associated with traders that import products from a few traders for export to several other traders. They may indicate those traders that act as collectors of raw products to be

			redistributed as such or processed before export.
Kleinberg's authority centrality score (aka. Authority score)	Kleinberg 2000	The Authority score of a node is a measure of the amount of valuable information that this node holds.	High Authority scores may be associated with traders that import from many traders to export to a few others.
Page Rank	Brin and Page 1998	Algorithm developed by Larry Page and Sergey Brin, founders of Google. Page Rank works by assigning importance to a webpage (node) if important pages (other nodes) point to it.	It is interpreted similarly to the authority score. The approximate estimation of the importance of a trader is based on the number and quality (weight) of the links pointing to it. The most important traders are likely to import more products from other traders in the network.

Figures

Figure 1

Time series of cephalopod landings by (a) taxonomic group and (b to f) by continents and sub-continent. Values are given in tonnes. Data source: FAO2.

Figure 2

Worldwide cephalopod food supply in g/capita/day for 2013. Per capita supplies are only the average supply available for everyone in the country or territory population as a whole and do not show what is actually consumed by individuals. Data source: FAO8.

Figure 3

The Cephalopod Global Trade Network. The top 220 traders of the CGTN as nodes (circles) and their trade links as lines. The size and colour of the nodes represent the cluster membership and relative importance of the trader in the CGTN, estimated from the number of trade links with other traders (i.e., degree): warm colours represent a high number of trade links (i.e., high degree) and cold and grayscale colours represent a small number of trade links (i.e., low degree). The thickness and colour of the edges

represent the sum of trade links for all years between each pair of traders. The clusters were made using Ward's method.

Figure 4

Global trade network for octopus live, fresh or chilled between 1 January 2000, and 31 December 2019 in monetary value (USD). The numbers correspond to the normalised strength for the monetary value. Each node represents a trader, and each edge represents the export-import 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 represents the relative importance of the relationship between two traders in terms of their edge strength.

Figure 5

Global trade network for octopus live, fresh or chilled between 1 January 2000, and 31 December 2019 in monetary value (USD) above and mass (kg) below. The numbers correspond to the normalised eigenvector for the monetary value and mass (kg) traded, respectively. 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 eigenvector.

Figure 6

Global trade network for octopus elaborated between 1 January 2000, and 31 December 2019 in monetary value (USD). The numbers correspond to the normalised betweenness for the monetary value. 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 betweenness. The width and colour of the edge represents the relative importance of the relationship between two traders in terms of their edge betweenness.

Figure 7

Global trade network for squid and cuttlefish live, fresh or chilled between 1 January 2000, and 31 December 2019 in monetary value (USD). The numbers correspond to the normalised strength for the monetary value. Each node represents a trader, and each edge represents the export-import 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 represents the relative importance of the relationship between two traders in terms of their edge strength.

Figure 8

Global trade network for squid and cuttlefish live, fresh or chilled between 1 January 2000, and 31 December 2019 in monetary value (USD) above, and mass (kg) below. The numbers correspond to the normalised betweenness for the monetary value (USD) and mass (kg) traded, respectively. 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 betweenness. The width and colour of the edge represents the relative importance of the relationship between two traders in terms of their edge betweenness.

Figure 9

Global trade network for squid and cuttlefish elaborated between 1 January 2000, and 31 December 2019 in monetary value (USD) above, and mass (kg) below. The numbers correspond to the normalised strength for the monetary value (USD) and mass (kg) traded, respectively. Each node represents a trader, and each edge represents the export-import 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 represents the relative importance of the relationship between two traders in terms of their edge strength.

Figure 10

Global trade network for squid and cuttlefish elaborated between 1 January 2000, and 31 December 2019 in monetary value (USD) above, and mass (kg) below. The numbers correspond to the normalised closeness for the monetary value (USD) and mass (kg) traded, respectively. 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 closeness.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [SupplementaryTables.docx](#)