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Provenance of global seafood

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Abstract

Knowing where and how seafood is caught or farmed is central to empowering consumers, and the importers that supply them, with informed choices. Given the wide-ranging, complex and at times commercially sensitive nature of global seafood trade, it can prove very challenging to link imported seafood with information about its provenance. The databases involved are incomplete, at times vague and not harmonized. Here, we present a first attempt to link all global seafood imports through a virtual marketplace to exports and map their origins. Considerable work remains to ground-truth the specific origins of all seafood commodities. We illustrate the flow of seafood and its evolution since the 1970s when supporting records began. This work allows the impact of fishing or marine farming to be associated with seafood imports.

Keywords Export, import, mapping, seafood

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Introduction

Seafood is one of the world's most highly traded food commodities, exceeding the combined trade value of sugar, maize, coffee, rice and cocoa (Asche *et al.* 2015). Demand for seafood is growing (Delgado *et al.* 2003) with global seafood consumption increasing by 2.5% a year (Peterson and Fronc 2007; World Bank 2013). An important change in trade patterns has been the growth in seafood exports from developing countries (FAO 2014a, b). Developed countries continue to dominate world imports of fish and fishery products, although their share has decreased. As well as being a highly traded good and vital source of income, seafood is an important source of food and protein. Seafood provides at least 20% of animal protein for a quarter of the world's population (FAO 2009) and currently caters to critical food needs of 400 million poor people (Garcia and Rosenberg 2010).

Traceability in the food supply chain is increasingly a requirement in major fish importing countries (FAO 2014a); however, the flow of seafood from where it is caught or cultivated to where it is consumed is not well understood and is often not adequately reflected in official statistics. Furthermore, mislabelling of seafood products at the wholesale and retail level is common (Marko *et al.* 2004; Caswell 2006). This practice can be unintentional due to upstream confusion of commodity names, or deliberate to increase profit by marketing as a more acceptable or high-value species (Marko *et al.* 2004; Caswell 2006; Garcia-Vazquez *et al.* 2011). Poor traceability within global seafood supply chains (Pramod *et al.* 2014) makes matching of global seafood exports with imports challenging and has implications for ethical and sustainable fishing practices (Marko *et al.* 2004; Caswell 2006; Crona *et al.* 2015) and food safety (Caswell 2006; Lam and Pitcher 2012).

Illegal, unreported and unregulated (IUU) fishing (Agnew *et al.* 2009) is also enabled through loopholes that could be closed with better supply chain transparency (Flothmann *et al.* 2010). Chain of custody (CoC) programmes implemented by certification agencies such as Marine Stewardship Council (MSC) (Agnew *et al.* 2014) and through supermarket sustainable sourcing policy provide customers with information on seafood sources and production methods. Beyond these programmes, however, accessing information on the source of seafood can be difficult. Exports of seafood are recorded at a national level by customs officials who usually classify products using foreign trade harmonized systems codes (HS code). Some generic codes provide scant produce information, for example 'dead fish'. Codes also vary by country and export codes may not match importing codes. Re-exportation of seafood with or without processing is also common (Pramod *et al.* 2014).

Not all fish are equally valued. Species such as tuna, lobster, prawns and abalone receive high value due to their status as luxury items (Fabinyi and Liu 2014; Norman-Lopez *et al.* 2014), and so are traded in small volumes to wealthy markets, while other species and products are traded in higher volumes at lower prices. Value-added processing such as breading may increase the value of seafood per unit of weight (and lower its actual 'seafood' proportion). Trading seafood in the global marketplace means that many countries consume far more seafood than they produce. Australia, the USA, the European Union and China import more than 70% of their seafood (Ruello 2011). Many countries receive some or the majority of their seafood through imports, and some of this is not caught or produced in the country that it was imported from. Since 2011, China has become the world's third-largest importing country, after the United States of America and Japan (FAO 2014b), and this is partly on account of China processing and then re-exporting an increasingly large proportion of the world's seafood (Pramod *et al.* 2014). As drivers for increased food consumption such as income, urbanization, trade liberalization, food corporations, retailing and marketing (Kearney 2010), and allied commoditization (Lam and Pitcher 2012; Pitcher and Lam 2014), spread from the Western world, pervading other cultures, food consumption and trade will increase.

The ecological impacts of seafood trade have not been well examined, although Cinner *et al.* (2013) found fish biomass to be lowest closer to markets, Watson and Pauly (2013) and Brewer *et al.* (2012) have linked expanding seafood markets and trade to declines in some fisheries and marine ecosystems. Global fisheries landings have previously been mapped to their approximate $0.5° \times 0.5°$ spatial origin to examine potential impacts of fishing on habitats or wildlife (Watson *et al.* 2004). The consideration of trade routes, in addition to the complications associated with mapping landings, poses additional challenges when these landings are linked to subsequent seafood exports. Seafood produced by mariculture has additional challenges as precise farm locations and production details are lacking for many countries (Lucas and Southgate 2012).

To more clearly demonstrate the interrelationships between global seafood production and consumption and potential ecological impacts, in this paper we identify where traded seafood is caught or produced, where it is exported from and where it is consumed. Incomplete and inaccurate labelling of imported and exported commodities makes this task highly challenging. We have matched all seafood imports and exports via fuzzy matching to global landings and mariculture production databases, to start identifying the source of global seafood exports. This process of matching landings with exports and consumption clarifies the provenance of global seafood and allows for further research into the drivers behind potential impacts of seafood production on ecosystems. This research will also allow calculation of the production limits imposed on marine habitats with seafood consumption patterns. Here, we present the results of our analysis for a selection of importing countries both by specific production areas and by marine ecosystem, represented here by large marine ecosystems (Sherman *et al.* 1990).

Methods

Global fisheries landings, aquaculture production and seafood trade data sets were synthesized into a single data set for analysis. The data were truncated to include only marine taxa as we want to focus on seafoods rather than all aquatic foods. The details of the synthesis are explained below and within the online supplementary information.

Spatially disaggregated global fisheries landings data

Spatially disaggregated global catch data was sourced from the *Sea Around Us* project database, updated to 2011 (Watson *et al.* 2004). Catch here refers to reported landings. This database is derived predominately from global fisheries catch statistics assembled by the Food and Agriculture Organization of the United Nations (FAO) from submission by its member countries (FAOSTAT 2014), complemented by the statistics of various international and national agencies. These include the International Council for the Exploration of the Sea (ICES), the Northwest Atlantic Fisheries Organization (NAFO), the General Fisheries Commission for the Mediterranean (GFCM), the Regional Commission for Fisheries (RECOFI), the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), the South East Atlantic Fisheries Organisation (SEAFO) and Fisheries Committee for the Eastern Central Atlantic (CECAF). These data sets with higher spatial resolution were nested into the broader FAO regions, replacing the data reported at the coarser spatial resolution. Some landings reported by China were reassigned to other FAO statistical reporting areas (Pauly *et al.* 2013).

These statistics, after harmonization, were disaggregated into a spatial grid system that breaks down the world's ocean into nearly 180 000 cells (0.5° latitude by 0.5° longitude), based on the geographical distribution of over 1500 commercially exploited fish and invertebrate taxa and ancillary data such as the fishing agreements regulating foreign access to the Exclusive Economic Zone (EEZ) of maritime countries.

The bathymetric distribution of each reported species or group of commercial fish or invertebrate was determined based on knowledge of their habits, as described in FishBase (www.fishbase.org accessed 22 August 2014) for fishes and SeaLifeBase (sealifebase.org accessed 22 August 2014) for invertebrates. Here, we were most concerned with approximate estimates for where the taxa were caught and not with their fine-grained biological distribution.

Mariculture

Data for global mariculture production was sourced from an online database (FAO 2014b, FAOSTAT 2014) for 1984–2011. Our study focused on marine seafoods; therefore, only marine species of fish, crustaceans and molluscs were included. Plants, shells and corals were excluded (using FAO's ISSCAAP coding). The data are reported by scientific name (at the species, genus, family or higher taxonomic levels). Mariculture data were not spatially disaggregated as it was for wild capture landings, as maps of specific farm sites were not available. It was assumed that all aquaculture production was from the coastal area of the producing country.

Seafood exports and imports

Data on global seafood exports and imports were sourced from online databases (FAO 2014b; FAOSTAT 2014). These provided data on seafood trade for each country from 1976 to 2009 specifically the import and export (and re-export) of commodities (in tonnes). Mislabelling and vague labelling make identifying some imported and exported commodities difficult. Procedures were programmed to allocate one or more taxa to each of the seafood commodities (Figure S1 – supporting information). Only marine species of fish, crustaceans and molluscs were included. Those that could have originated through marine aquaculture (mariculture) production were identified.

Seafood consumption per capita

Data on national seafood consumption per capita were obtained from FAOSTAT (2014) for the period 1961–2009.

Synthesizing seafood trade to global landings and mariculture production

For each marine fish, crustacean and mollusc record in the seafood trade database procedures were used to attempt to match the tonnage described to either mariculture production (where appropriate) or wild capture (Figure S1 – supporting information). The data set of matches between catch/production and exports represents a 'virtual marketplace', and importantly, it also creates a link from the traded commodity to a spatially explicit estimate of the capture location of wild-captured seafood; or for mariculture production, the assumed coastal location of the country of production.

The simplest cases were matching clearly identified commodities such as 'Alaska Pollock fillets, frozen' to the fisheries landing data. If the trade commodity name was ambiguous, such as 'Anchovies, fillets, prepared or preserved' where a match involved potentially several species and genera, a hierarchical approach was applied. The closest and most specific taxonomic match was used before the search range was broadened to a wider taxonomic group. This means that if species matches could not be made, then matches at the genus level were pursued. If these did not satisfy the tonnage required, then higher taxonomic levels were applied. Vague commodity names, such as 'Marine fish fillets, nei, frozen', where a wide range of potential matches were possible meant that in some cases, a wide range of taxa groups were allocated to a commodity. In these cases, the tonnage of each of the included taxa groups was pro-rated by the reported wild catch or mariculture production tonnages from the appropriate country and year. The breadth of the search required to match databases was also recorded so that the precision of the match given the clarity of the commodity description could be documented (Figure S2). Seafoods were exported in a range of forms but mostly as frozen or chilled products (Figure S3).

Matching global import tonnage to export tonnage

Importantly, this initial attempt does not attempt to address the problem of import–re-export of seafood which make tracking the origin of seafoods difficult for some countries like China (Pramod *et al.* 2014).

Having created a 'virtual marketplace' with seafood products linked to wild capture or mariculture production, we then matched FAO's database of imports to this marketplace. This presented two challenges. Firstly, the commodity names in the export and import data sets were not consistent, although in many cases they were similar. As above, a procedure had to be developed to generalize the range until a credible match was achieved. Secondly, the import and export tonnage had not been harmonized and the volumes of similar products did not always match. This creates issues when attempting to balance the virtual marketplace model.

A third challenge was to decide, for each import record, which marketplace record of the appropriate taxon was the correct match. This decision was informed by the database provided by the World Trade Organisation (WTO) of primary trading partners (http://www.wto.org accessed Jan 2015). When this database did not provide sufficient guidance, we allocated selection by the proportional volume supplied to the marketplace. It should be noted that for some seafood commodities, a misallocation to the exact country of origin would not greatly alter the source location as the geographical location of the taxon is in a limited region and caught by several countries.

The design of the virtual marketplace model presented here does not attempt to match seafood that was imported only to be subsequently exported, known as re-exported commodities, although as reported by FAO this is currently a very small proportion of all exports.

Results

We constructed an elementary virtual marketplace linking national exports of seafood with wild capture landings and mariculture production. Within this virtual marketplace, it was possible to credibly match these commodities to subsequent global imports. This allowed for a putative trace of seafood from its origin (quite specifically for wild captures), which was spatially mapped to the countries where it was imported and, we assume, consumed. For mariculture production, mapping was to countries only. At this stage, however, authenticating the origin of seafoods via specific trade databases or other independent measures is not yet possible. There are uncertainties incorporated at each step of constructing the provenance link from export to import records.

Matching exports to mapped global landings and mariculture

Over 85% of the reported tonnage of exported seafood in 1976 could be matched to global catch data (Fig. 1a), capturing most major trade flow patterns of commodities from source location to export destination. This percentage dropped to about 75% in subsequent years. We assumed in our analysis that seafood that was not matched came from the same sources as seafood of the same type that was matched, but its lack of provenance information was recorded. There was specific recognition that seafood reported as landed in one calendar year might actually be reported as exported (frozen or preserved) one or even 2 years later. Our search for a match allowed for this possibility.

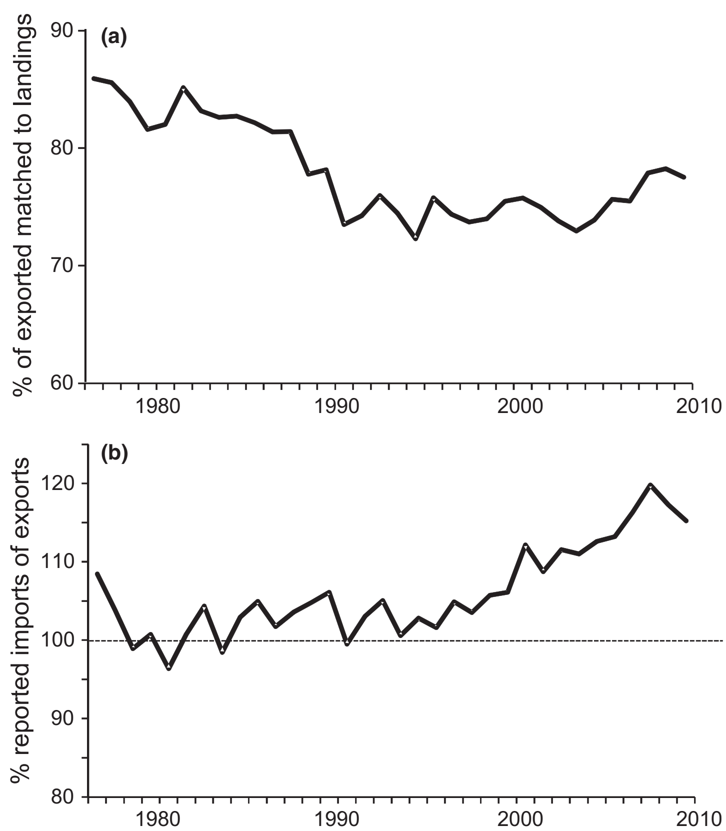

Figure 1 (a) Per cent of exported landings matched by reporting year and (b) the per cent reported global imports form of reported exports (100% shown by horizontal line).

Matching imports to exports

The percentage of export tonnage reported in the data relative to import tonnage fluctuated over time. For the first 15 years, the fluctuation was within approximately 5% of being harmonized at 100% (Fig. 1b). As trade has increased over time, however, the harmonization has continued to diverge, with an increasing trend in the proportion of import tonnage reported relative to exports. Although some of this may be explained by value adding through processing, including adding a range of other ingredients, the excess of imports did challenge our attempts to make matches and hence complete the provenance chain.

Mapping seafood provenance

Over the period 1976–2009, the number of countries exporting greater than 500 000 t increased, and there has been a degree of redistribution (Fig. 2a,b). In 1976, only Norway, Japan, Denmark, Peru and the former USSR were reported as exporting more than 500 000 t of seafood. By 2009, although Japan had scaled back, many other countries had exports of this scale or greater. The USA, Norway, Spain and several others particularly in Asia (China, Thailand) now exported in excess of 1 M t per year. From the USA, exports were dominated by volume by Alaska Pollack, while along the west coast of South America (Peru and Chile) it was the anchoveta, with it enormous landings originating from the productive upwellings. The intensity of fishing effort by fleets from Asian countries contributed to their greatly increased seafood exports (Watson *et al.* 2013; Pauly *et al.* 2013). In recent years, however, this has been increased further by countries like Thailand and China, which import seafood for further processing and later export.

Seafood consumption per capita has increased greatly in this time. In 1961, only four countries (Norway, Iceland, Japan and Portugal) had seafood consumption rates of greater than 40 kg per person per year (Fig. 2c). By 2009, per capita seafood consumption (including that from aquaculture) had greatly increased (Fig. 2d). The number of countries with a consumption rate greater than 40 kg per capita in 2009 increased to 11 with the addition of Greenland, Lithuania, Spain, Nepal, Burma, Malaysia and South Korea (Fig. 2d). Countries such as China and Lithuania where seafood was barely consumed in the 1960s (<5 kg pax^{-1} year^{-1}) now top seafood consumption rates at >30 kg pax^{-1} year^{-1}. Consumption in the US has more than doubled in this time to 24 kg pax^{-1} year^{-1}. The overall increase in seafood consumption was not always for those with the highest GDP, as countries such as Nepal and Burma also showed an increasing trend in

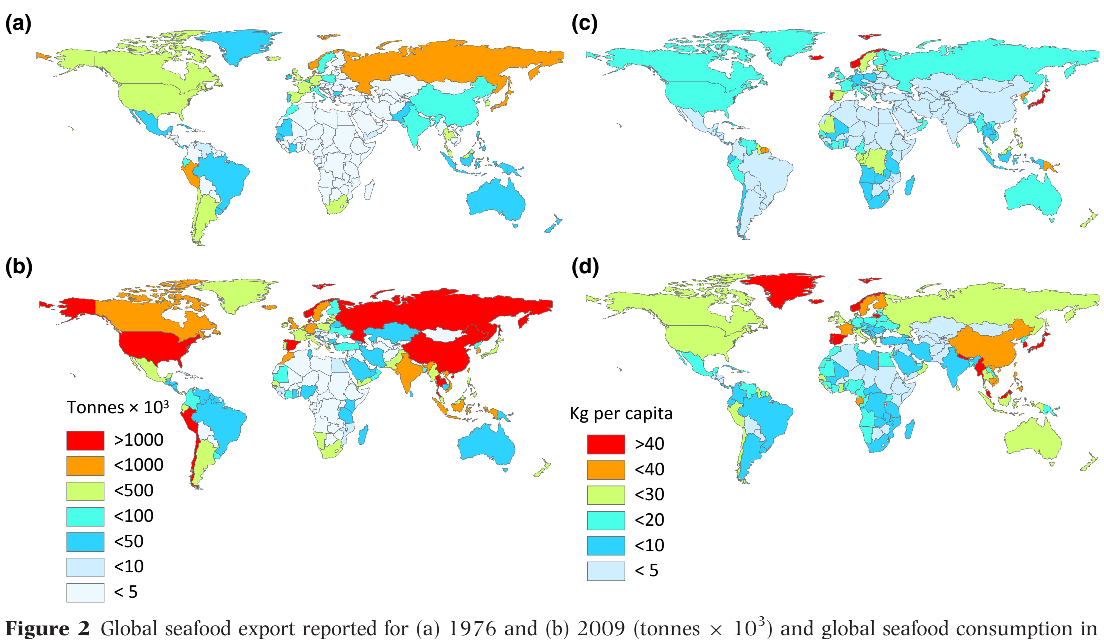

Figure 2 Global seafood export reported for (a) 1976 and (b) 2009 (tonnes × 10^3) and global seafood consumption in kg per capita for (c) 1961 and (d) 2009.

consumption. Very few countries have reduced their seafood consumption in this time. They included the African nations of Mauritania, DRC and Congo, as well as Surinam and French Guiana in South America as well as North Korea and Papua New Guinea.

The matching of exports to wild capture landings allowed this seafood to be associated with landings from specific 30-min spatial cells. For the 1970s, this was concentrated in coastal areas, particularly where there was productive nutrient upwelling (Fig. 3a). An exception to the concentration of catch coming from coastal areas was the capture of tunas, which were primarily sourced offshore and on the high seas. The North Sea, NE North America, Alaska, most of Asia and the western coast of South America accounted for the source of most exported seafoods. By the 1980s, the concentration of catch from these areas had slightly intensified, but also an expansion of catches from other areas was evident (Fig. 3b). By the 1990s, when global capture of wild fisheries was peaking, the North Sea and the north-western coast of South America had increased export landings. NW Africa had become a major source of wild-captured seafood for export. Generally, this pattern continued to the 2000s with the landings from some areas intensifying further (Fig. 3d).

Having matched seafood from its capture source (in the case of wild landings) or national coastline (in the case of aquaculture), it was possible to show the actual source to sink flow of the global seafood trade. In Fig. 4, we show the trade flow of seafoods from two of the most productive large marine ecosystems (LME) as representative case studies accounting for 14% of global landings since 2000. Flow for the 1970s from the Canary Current LME (shown in yellow) to ports of importing countries (red dots) is shown in Fig. 4a. The thickness of the line is proportional to the tonnage transferred. By the 1990s, the flow had increased and had slightly diversified (Fig. 4b). In the 1970s, the flow of seafood from the Humboldt Current LME, which was rich in small pelagics, can be traced to many importing countries in North America, Europe, West Africa and East Asia (Fig. 4c). By the 1990s, the flow had altered and, although generally more intense, favoured European markets more heavily.

Discussion

Rising incomes and urbanization have led to a global growth in seafood consumption (Villasante *et al.* 2013) along with product commoditization of an increasingly global seafood industry (Lam and Pitcher 2012). Meeting this growth in demand and the pressure of global corporate profits, there is a concurrent global increase in seafood production and trade, with much recent growth

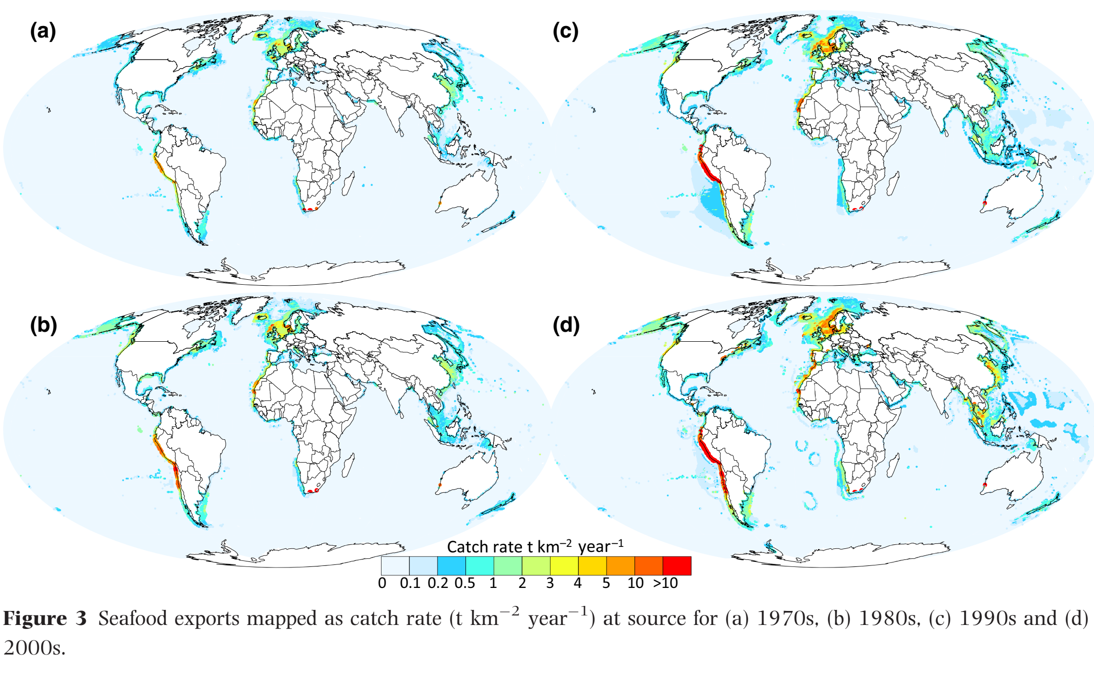

Figure 3 Seafood exports mapped as catch rate (t km^{-2} $year^{-1}$) at source for (a) 1970s, (b) 1980s, (c) 1990s and (d) 2000s.

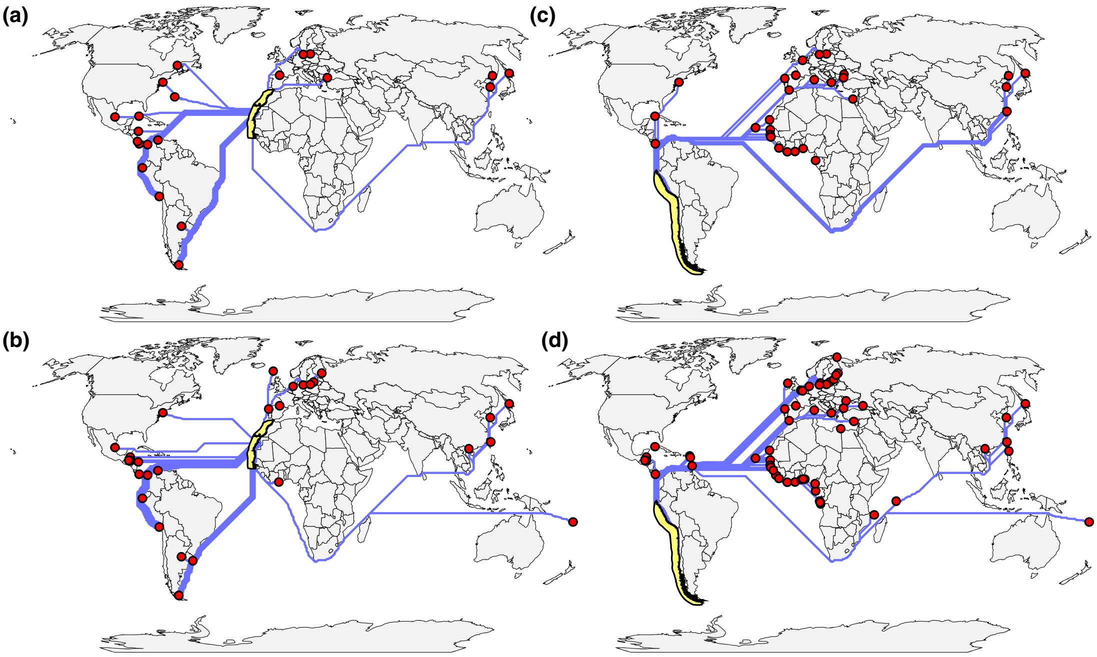

Figure 4 Distributional flow of seafood from the Canary Current Large Marine Ecosystem (LME) waters for (a) 1970s and (b) 1990s, and from the Humboldt Current LME for (c) 1970s and (d) 1990s (flow rate in t year^{-1} is proportional to the thickness of the connection).

coming from increased aquaculture production (FAO 2014a) which also promotes the importation of fish meals and oils for feeds. Here, we have demonstrated the increased consumption, trade and expansion of trade routes over time. Using the methodology published here, it is possible to establish that seafood actually travels farther to markets than it did previously (Watson *et al.* 2015). It is interesting that this expansion in seafood trade is driven by increased individual wealth and a corporate drive for profit, not, as many may have predicted by the need for quality nutrition and food security in a hungry and dangerous world (Pitcher and Cheung 2013).

Understanding the provenance of seafood is important for reducing illegal, unreported and unregulated fishing (Pramod *et al.* 2014), reducing environmental impacts (Brewer *et al.* 2013), making informed consumption choices (von der Heyden *et al.* 2014) and ensuring food safety. As the push for understanding the links between diet-driven increases in global food demand and environmental consequences increases (Tilman and Clark 2014), the need for tracing provenance will grow. Here, we have created the first virtual global marketplace that matches seafood capture/production to imports and exports providing links that allow the associated consequences of production to be better investigated.

General observations about seafood provenance analysis

Within the FAO databases, exports can exceed imports, as these statistics are not harmonized. One interpretation would be that wild capture (or mariculture production) was underestimated. This was our default assumption as opposed to the possibility that exports were exaggerated. Underestimation can occur because the seafood content is diluted through the addition of other products and we attempted to account for this. The other possibility is that the exported seafood did not originate within the exported country (the product was re-exported). We did not deal specifically with this route in this initial attempt, but it will be the focus of future work and is a known pathway for some exporting countries. It is challenging matching national imports to the 'virtual' marketplace we constructed. Arguably, what is required to improve this procedure is an expert database of seafood buyer–seller pairs – that is which countries are the main supplies to each importing country over time. We are developing such a database; however, it was not available for this current work.

The increase in fish consumption by China found here reflects that found elsewhere, although the magnitude varies. Villasante *et al.* (2013) described a fourfold increase in China fish consumption since 1961, while we have described an eightfold increase. Both estimates, coupled with their population size, make China the largest global seafood consumer (Villasante *et al.* 2013). Such variation in estimates demonstrates the difficulty in getting reliable data even for seafood consumption for some countries (see Challenges in supporting information).

Benefits and risks of fish trade

There are a range of benefits and risks from the increased trade in fish (McClanahan *et al.* 2015), with increase in revenue of 83% between 2000 and 2008 (Hall *et al.* 2011) coinciding with increasing environmental harm (Brewer *et al.* 2013), and decline in stocks (Cinner *et al.* 2013; Johnson *et al.* 2013). Globalization has boosted economic growth and reduced poverty due to improved trade conditions (Anderson 2010). Seafood exports are the primary source of export earnings for many developing nations, which are rapidly increasing fisheries production (FAO 2014a). For instance, artisanal coral reef fisheries provide food and employment to hundreds of millions of people (Johnson *et al.* 2013). This trade liberalization can impact food security negatively, as poor quality fish are retained for domestic consumption and higher valued fish exported (Roheim 2004), and increase exploitation of human capital through child labour, forced labour, violence and unsafe working conditions (Ratner *et al.* 2014; Simmons and Stringer 2014). There is also increased risk to consumers as the food safety practices vary along global supply chains (Marler 2013; Kirezieva *et al.* 2015). The present analysis provides a mechanism to track the trade and will provide the framework for tracing benefits and risks to producers and consumers.

Global patterns of seafood consumption and exports

The changing global landscape in fisheries production, consumption and trade reflects changing wealth within countries. Marine protein is traded to meet the desires of the affluent (Smith *et al.* 2010). Increased exports from some of the poorest nations including India, Myanmar, Thailand, Vietnam and Indonesia were matched by increased imports and consumption in some of the wealthy nations of USA, Canada, Australia, France, Finland and China. As people get wealthier, they consume more food generally and specifically more protein (Tilman and Clark 2014). The richest 15 nations had a 750% greater per capita demand for meat protein than the 24 poorest nations (Tilman and Clark 2014). As China's wealth grows, it has increased its production and consumption and has shifted from minor to major stakeholders for both, and now accounts for 25% of global fish demand and contributes 60% of global aquaculture volume (Cao *et al.* 2015). China's strategy to meet its future seafood consumption needs is to import fish, processing waste fish from other nations to supply their growing aquaculture industry (Cao *et al.* 2015), as they cannot do this from wild fisheries (Pauly *et al.* 2014).

As trade routes become longer and more complex with increasing globalization, the need to trace seafood through these routes from source to consumption will enable better governance. If the source of seafood cannot be traced, then it cannot be monitored and managed for safety and sustainability. The future of sustainable fisheries can only be assured if consumption is linked to production of sustainable products. This is the first step in linking global seafood consumption with production. Our ability to authenticate the provenance of seafood imports, and especially to associate them with specific fisheries landings or mariculture production on a global scale, is still relatively primitive, and subject to uncertainties at each stage; however, through wider collaboration and the creation of ancillary databases, this can rapidly improve in the future. Consumers of seafood are concerned about whether it is safe to consume and whether its capture and/or production has come with unacceptable trade-offs. Local suppliers of seafood no longer know the origins or provenance of the seafood they sell. We make attempt to establish the provenance of the seafood we eat.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Figure S1. Flowchart showing process of matching global seafood exports and imports to wild capture and mariculture production to establish provenance.

Figure S2. The quality of fit when matching global seafood exports to wild caught landings and mariculture production. Categories on top (i.e. Starting species) are more direct matches whereas those at the bottom were less specific.

Figure S3. The preservation method of exported seafood from FAO's database.