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

Seafood, mapping, import, export

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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, 2007, World Bank, 2013). An important change in trade patterns has been the growth in seafood exports from developing countries (FAO, 2014d). 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, 2014d), 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, mislabeling of seafood products at the wholesale and retail level is common (Caswell, 2006, Marko et al., 2004). 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 (Caswell, 2006, Marko et al., 2004, Garcia-Vazquez et al., 2011). Poor traceability within global seafood supply chains (Pramod et al., 2014b) makes matching of global seafood exports with imports challenging and has implications for ethical and sustainable fishing practices (Caswell, 2006, Marko et al., 2004, Crona et al., 2015) and food safety (Lam and Pitcher, 2012, Caswell, 2006).

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) programs 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 programs 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., 2014b).

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, 2014a) and this is partly on account of China processing and then re-exporting an increasingly large proportion of the worlds seafood (Pramod et al., 2014b). As drivers for increased food consumption such as income, urbanization, trade liberalization, food corporations, retailing and marketing (Kearney, 2010), and allied commoditization (Pitcher and Lam, 2014, Lam and Pitcher, 2012), 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° x 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).

In order 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 labeling 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 (AAAS, 1992).

Methods

Global fisheries landings, aquaculture production and seafood trade datasets were synthesized into a single dataset for analysis. The data was 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 (FAO, 2013), 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 datasets 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 nearly180,000 cells (0.5° latitude by 0.5° longitude), based on the geographical distribution of over 1,500 commercially exploited fish and invertebrate taxa and ancillary data such as the fishing agreements regulating foreign access to the Exclusive Economic Zone (EEZs) 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 on-line database (FAO, 2014a, FAOSTAT, 2014) for 1984 to 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 is reported by scientific name (at the species, genus, family or higher taxonomic levels). Mariculture data was 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 was sourced from on-line databases (FAO, 2014a, 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). Mislabeling and vague labeling makes identifying some imported and exported commodities difficult. Procedures were programmed to allocate one or more taxa to each of the seafood commodities (Figure S1 –

supplemental material). 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 was obtained from FAOSTAT (2014) for the period 1961 to 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 (Fig 1S – supplementary material). The dataset 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 were 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., 2014b).

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 datasets 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, though 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 (Figure 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 two years later. Our search for a match allowed for this possibility.

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% (Figure 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. Though 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 to 2009, the number of countries exporting greater than 500,000 t increased, and there has been a degree of redistribution (Figure 2a & Figure 2b). In 1976 only Norway, Japan, Denmark, Peru and the former USSR were reported as exporting more than 500,000 t of seafood. By 2009, though 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 form the productive upwellings. The intensity of fishing effort by fleets from Asian countries contributed to their greatly increased seafood exports (Watson et al., 2012, 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 40kg per person per year (Figure 2c). By 2009, per capita seafood consumption (including that from aquaculture) had greatly increased (Figure 2d). The number of countries with a consumption rate greater than 40kg per capita in 2009 increased to 11 with the addition of Greenland, Lithuania, Spain, Nepal, Burma, Malaysia and South Korea (Figure 2d). Countries such as China and Lithuania where seafood was barely consumed in the 1960's (<5 $kg.pax^{-1}.yr^{-1}$) now top seafood consumption rates at >30 $kg.pax^{-1}.yr^{-1}$. Consumption in the US has more than doubled in this time to 24 $kg.pax^{-1}.yr^{-1}$. The overall increase of seafood consumption was not always for those with the highest GDP, as countries such as Nepal and Burma also showed an increasing trend in 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 (Figure 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 (Figure 3b). By the 1990s, when global capture of wild fisheries was peaking, the North Sea and the northwestern coast of South America had increased export landings. NW Africa had become a major source of wild capture seafood for export. Generally this pattern continued to the 2000s with the landings from some areas intensifying further (Figure 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 Figure 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 Figure 4a. The thickness of the line is proportional to the tonnage transferred. By the 1990s the flow had increased and had slightly diversified (Figure 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 (Figure 4c). By the 1990s the flow had altered, and though 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 coming from increased aquaculture production (FAO, 2014c) which also promotes the importation of fishmeals 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., 2014a), 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) were 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 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 – i.e., 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 supplementary materials).

Benefits and risks of fish trade

There are a range of benefits and risks from the increased trade in fish (McClanahan et al., 2013), 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 (Johnson et al., 2013, Cinner 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, was 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 it 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 tradeoffs. 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.

Acknowledgements

Authors acknowledge the provision of databases developed by the *Sea Around Us* project, a scientific collaboration between the University of British Columbia and the Pew Environment Group. We thank Bob Gerlt (ESRI – Applications Prototype Lab) for making the procedures we used for mapping the distributed flow of seafood available. R.A.W., B.S.G. and S.T. acknowledge funding support from the Australian Research Council Discovery project support

(DP140101377). T.J.P acknowledges an operating grant from the Science and Engineering Council of Canada.

References

AAAS 1992. Large marine ecosystems: patterns, processes, and yields. *In:* SHERMAN, K., ALEXANDER, L. M. & GOLD, B. D. (eds.). Washington, USA: American Association for the Advancement of Science.

AGNEW, D. J., GUTIÉRREZ, N. L., STERN-PIRLOT, A. & HOGGARTH, D. D. 2014. The MSC experience: developing an operational certification standard and a market incentive to improve fishery sustainability. *ICES Journal of Marine Science,* 71**,** 216-225.

AGNEW, D. J., PEARCE, J., PRAMOD, G., PEATMAN, T., WATSON, R., BEDDINGTON, J. R. & PITCHER, T. J. 2009. Estimating the Worldwide Extent of Illegal Fishing. *Plos One,* 4.

ANDERSON, K. 2010. Globalization's effects on world agricultural trade, 1960-2050. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 365**,** 3007-3021.

ASCHE, F., BELLEMARE, M., ROHEIM, C., SMITH, M. & TVETERÅS, S. 2015. Fair Enough? Food Security and the International Seafood Trade. *World Development,* 67**,** 151-160.

BREWER, T. D., CINNER, J. E., FISHER, R., GREEN, A. & WILSON, S. K. 2012. Market access, population density, and socioeconomic development explain diversity and functional group biomass of coral reef fish assemblages. *Global Environmental Change-Human and Policy Dimensions,* 22**,** 399-406.

BREWER, T. D., CINNER, J. E., GREEN, A. & PRESSEY, R. L. 2013. Effects of Human Population Density and Proximity to Markets on Coral Reef Fishes Vulnerable to Extinction by Fishing. *Conservation Biology,* 27**,** 443-452.

CAO, L., NAYLOR, R., HENRIKSSON, P., LEADBITTER, D., METIAN, M., TROELL, M. & ZHANG, W. B. 2015. China's aquaculture and the world's wild fisheries. *Science,* 347**,** 133-135.

CASWELL, J. A. 2006. Quality assurance, information tracking, and consumer labeling. *Marine Pollution Bulletin,* 53**,** 650-656.

CINNER, J. E., GRAHAM, N. A. J., HUCHERY, C. & MACNEIL, M. A. 2013. Global Effects of Local Human Population Density and Distance to Markets on the Condition of Coral Reef Fisheries. *Conservation Biology,* 27**,** 453-458.

CRONA, B. I., DAW, T. M., SWARTZ, W., NORSTRÖM, A. V., NYSTRÖM, M., THYRESSON, M., FOLKE, C., HENTATI-SUNDBERG, J., ÖSTERBLOM, H., DEUTSCH, L. & TROELL, M. 2015. Masked, diluted and drowned out: how global seafood trade weakens signals from marine ecosystems. *Fish and Fisheries,* On-line Early View.

DELGADO, C., WADA, N., ROSEGRANT, M. W., MEIJER, S. & AHMED, M. 2003. Fish to 2020: suppy and demand in changing global markets. *World Fish Center Technical Report.* Washington, USA: International Food Policy Research Center.

FABINYI, M. & LIU, N. 2014. Seafood Banquets in Beijing: Consumer Perspectives and Implications for Environmental Sustainability. *Conservation & Society,* 12**,** 218-228.

FAO 2009. The state of world fisheries and aquaculture 2008. Rome, Italy: FAO Fisheries and Aquaculture Department, Food and agriculture organisation fo the United Nations.

FAO 2013. FishStatJ. http://www.fao.org/fishery/statistics/software/fishstatj/en.

FAO. 2014a. *Fishery commodities and trade (Fishstat database)* [Online]. Available: http://www.fao.org/fishery/statistics/global-commodities-production/en [Accessed January 15, 2014 2014].

FAO 2014c. The state of fisheries and aquaculture. . *In:* ORGANISATION, F. A. A. (ed.). Rome: United Nations.

FAO 2014d. The State of World Fisheries and Aquaculture 2014: Opportunities and challenges. Food and Agriculture Organzation of the United Nations, Rome.

FAOSTAT 2014. FAO Statistical Databases. http://faostat.fao.org.

FLOTHMANN, S., VON KISTOWSKI, K., DOLAN, E., LEE, E., MEERE, F. & ALBUM, G. 2010. Closing Loopholes: Getting Illegal Fishing Under Control. *Science,* 328**,** 1235-1236.

GARCIA, S. M. & ROSENBERG, A. A. 2010. Food security and marine capture fisheries: characteristics, trends, drivers and future perspectives. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 365**,** 2869-2880.

GARCIA-VAZQUEZ, E., PEREZ, J., MARTINEZ, J. L., PARDIÑAS, A. F., LOPEZ, B., KARAISKOU, N., CASA, M. F., MACHADO-SCHIAFFINO, G. & TRIANTAFYLLIDIS, A. 2011. High level of mislabeling in Spanish and Greek hake markets suggests the fraudulent introduction of African species. *Journal of Agricultural and Food Chemistry,* 59**,** 475-480.

HALL, S. J., DELAPORTE, A., PHILLIPS, M. J., BEVERIDGE, M. & O'KEEFE, M. 2011. Blue Frontiers: Managing the environmental costs of aquaculture. Penang Malaysia: The Worldfish Center.

JOHNSON, A. E., CINNER, J. E., HARDT, M. J., JACQUET, J., MCCLANAHAN, T. R. & SANCHIRICO, J. N. 2013. Trends, current understanding and future research priorities for artisanal coral reef fisheries research. *Fish and Fisheries,* 14**,** 281-292.

KEARNEY, J. 2010. Food consumption trends and drivers. *Philosophical Transactions of the Royal Society B-Biological Sciences,* 365**,** 2793-2807.

KIREZIEVA, K., LUNING, P. A., JACXSENS, L., ALLENDE, A., JOHANNESSEN, G. S., TONDO, E. C., RAJKOVIC, A., UYTTENDAELE, M. & VAN BOEKEL, M. 2015. Factors affecting the status of food safety management systems in the global fresh produce chain. *Food Control,* 52**,** 85-97.

LAM, M. & PITCHER, T. J. 2012. Fish Commoditization and Strategies to Protect Living Fish. *Bulletin of Science, Technology and Society,* 32**,** 31-40.

LUCAS, J. & SOUTHGATE, P. 2012. *Aquaculture: farming aquatic animals and plants.,* West Sussex, UK, Wiley-Blackwell.

MARKO, P. B., LEE, S. C., RICE, A. M., GRAMLING, J. M., FITZHENRY, T. M., MCALISTER, J. S., HARPER, G. R. & MORAN, A. L. 2004. Mislabelling of a depleted reef fish. *Nature* 430**,** 309.

MARLER, B. 2013. Food Safety and the Global Supply Chain. *Journal of Environmental Health,* 76**,** 48-49.

MCCLANAHAN, T., ALLISON, E. H. & CINNER, J. E. 2013. Managing fisheries for human and food security. *Fish and Fisheries***,** n/a-n/a.

NORMAN-LOPEZ, A., PASCOE, S., THEBAUD, O., VAN PUTTEN, I., INNES, J., JENNINGS, S., HOBDAY, A., GREEN, B. & PLAGANYI, E. 2014. Price integration in the Australian rock lobster industry: implications for management and climate change adaptation. *Australian Journal of Agricultural and Resource Economics,* 58**,** 43-59.

PAULY, D., BELHABIB, D., BLOMEYER, R., CHEUNG, W., CISNEROS-MONTEMAYOR, A., COPELAND, D., HARPER, S., LAM, V., MAI, Y., LE MANACH, F., ÖSTERBLOM, H., MOK, K., VAN DER MEER, L., SANZ, A., SHON, S., SUMAILA, U., SWARTZ, W., WATSON, R., ZHAI, Y. & ZELLER, D. 2013. China's distant water fisheries in the 21st century. *Fish and Fisheries,* 15**,** 474-488.

PAULY, D., BELHABIB, D., BLOMEYER, R., CHEUNG, W., CISNEROS-MONTEMAYOR, A. M., COPELAND, D., HARPER, S., LAM, V. W. Y., MAI, Y. N., LE MANACH, F., OSTERBLOM, H., MOK, K. M., VAN DER MEER, L., SANZ, A., SHON, S., SUMAILA, U. R., SWARTZ, W., WATSON, R., ZHAI, Y. L. & ZELLER, D. 2014. China's distant-water fisheries in the 21st century. *Fish and Fisheries,* 15**,** 474-488.

PETERSON, H. C. F., KARL 2007. Fishing for consumers: market-driven factors affecting the sustainability of the fish and seafood supply chain. *In:* TAYLOR, W. S., MG; WOLFSON, LG (ed.) *Globalization: Effects on Fisheries Resources*

PITCHER, T. J. & CHEUNG, W. W. L. 2013. Fisheries: Hope or Despair? *Marine Pollution Bulletin,* 74**,** 506-516.

PITCHER, T. J. & LAM, M. E. 2014. Fish commoditization: The origins of catching fish for profit. *Maritime Studies,* 14**,** 1-19.

PRAMOD, G., NAKAMURA, K., PITCHER, T. J. & DELAGRAN, L. 2014a. Estimates of illegal and unreported fish in seafood imports to the USA. *Marine Policy,* 48, 102-113.

PRAMOD, G., NAKAMURA, K., PITCHER, T. J. & DELAGRAN, L. 2014b. Estimates of illegal and unreported fish in seafood imports to the USA. *Marine Policy,* 48, 102–113.

RATNER, B. D., ASGARD, B. & ALLISON, E. H. 2014. Fishing for justice: Human rights, development, and fisheries sector reform. *Global Environmental Change-Human and Policy Dimensions,* 27, 120-130.

ROHEIM, C. A. 2004. Trade liberalization in fish products: impacts on sustianability of international markets and fish resources. *In:* A. AKSOY AND J. BEGHIN (ed.) *Global Agricultural Trade and Developing Countries.* Washington, D.C.: The World Bank.

RUELLO, N. 2011. A study of the composition, value and utilisation of imported seafood in Australia. Canberra, Australia: Fisheries Research and Development Corporation.

SIMMONS, G. & STRINGER, C. 2014. New Zealand's fisheries management system: Forced labour an ignored or overlooked dimension? *Marine Policy,* 50, 74-80.

SMITH, M. D., ROHEIM, C. A., CROWDER, L. B., HALPERN, B. S., TURNIPSEED, M., ANDERSON, J. L., ASCHE, F., BOURILLON, L., GUTTORMSEN, A. G., KHAN, A., LIGUORI, L. A., MCNEVIN, A., O'CONNOR, M. I., SQUIRES, D., TYEDMERS, P., BROWNSTEIN, C., CARDEN, K., KLINGER, D. H., SAGARIN, R. & SELKOE, K. A. 2010. Sustainability and Global Seafood. *Science,* 327, 784-786.

TILMAN, D. & CLARK, M. 2014. Global diets link environmental sustainability and human health. *Nature,* advance online publication.

VILLASANTE, S., RODRIGUEZ-GONZALEZ, D., ANTELO, M., RIVERO-RODRIGUEZ, S., DE SANTIAGO, J. A. & MACHO, G. 2013. All Fish for China? *Ambio,* 42, 923-936.

VON DER HEYDEN, S., BEGER, M., TOONEN, R. J., VAN HERWERDEN, L., JUINIO-MENEZ, M. A., RAVAGO-GOTANCO, R., FAUVELOT, C. & BERNARDI, G. 2014. The application of genetics to marine management and conservation: examples from the Indo-Pacific. *Bulletin of Marine Science,* 90**,** 123-158.

WATSON, R., KITCHINGMAN, A., GELCHU, A. & PAULY, D. 2004. Mapping global fisheries: sharpening our focus. *Fish and Fisheries,* 5**,** 168-177.

WATSON, R. A., CHEUNG, W. W. L., ANTICAMARA, J. A., SUMAILA, R. U., ZELLER, D. & PAULY, D. 2012. Global marine yield halved as fishing intensity redoubles. *Fish and Fisheries*.

WATSON, R. A., NOWARA, G., HARTMANN, K., GREEN, B. S., TRACEY, S. & CARTER, C. G. 2015. Marine foods sourced from farther as their use of global ocean primary production increases. *Nature communications,* 6.

WATSON, R. A. & PAULY, D. 2013. The changing face of global fisheries—The 1950s vs. the 2000s. *Marine Policy,* 42**,** 1-4.

WORLD BANK 2013. World Development Indicators. http://data.worldbank.org/.

Figure Legends

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

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

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

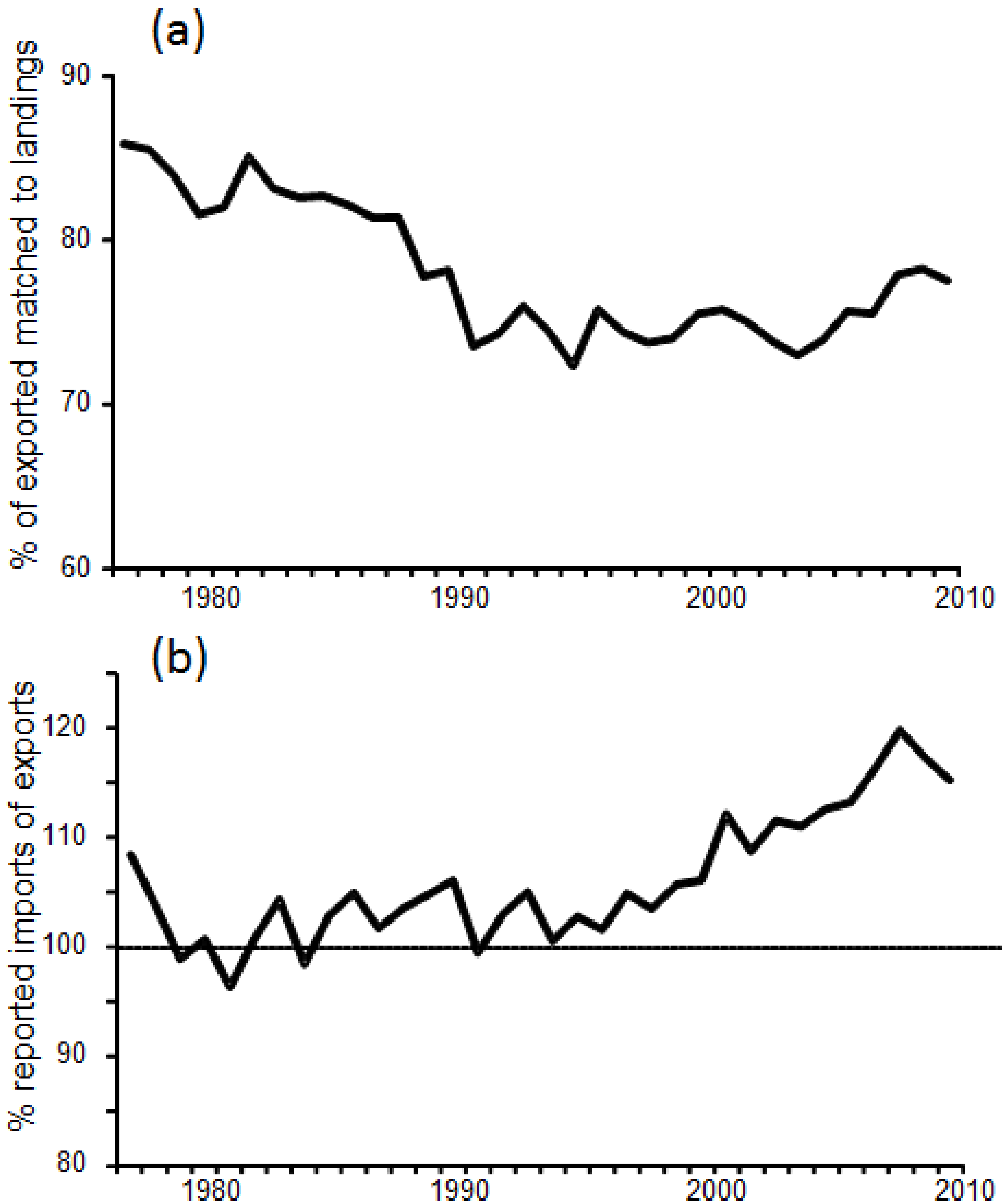
Figure 4 Distributional flow of seafood from the Canary Current Large Marine Ecosystem (LME) waters for a) 1970s and b) 1990s, and from the Humboldt Current LME for c) 1970s and d) 1990s (flow rate in t yr^{-1} is proportional to the thickness of the connection)

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.

Figure 1



Figure

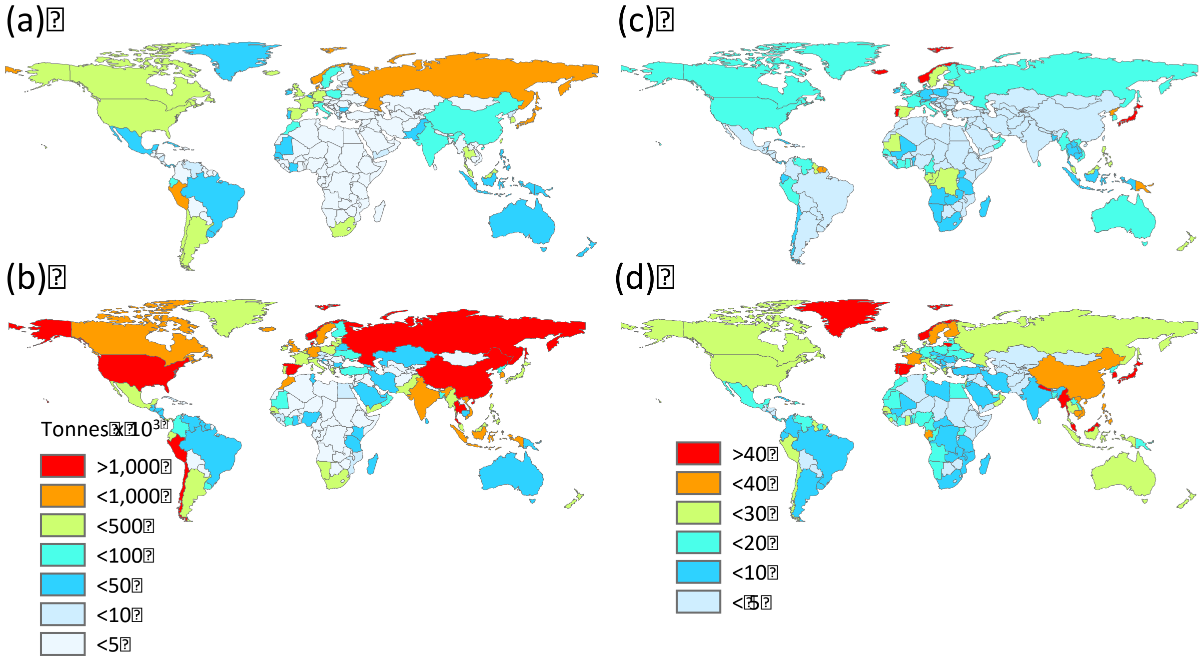


Figure 2

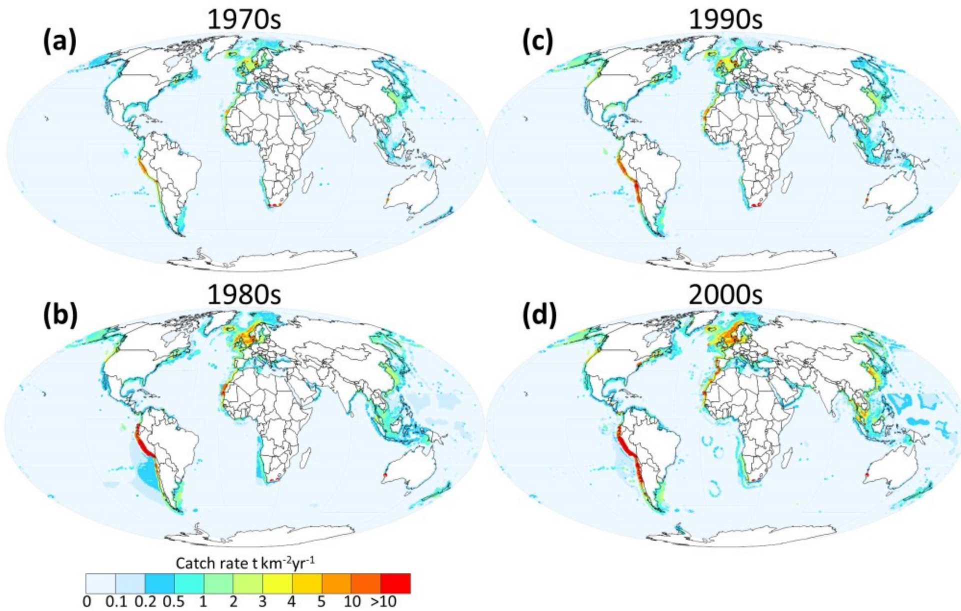

(a)
1970s
(c)
1990s
(b)
1980s
(d)
2000s
Catch rate t km-2yr-1
0 0.1 0.2 0.5 1 2 3 4 5 10 >10

Figure 3

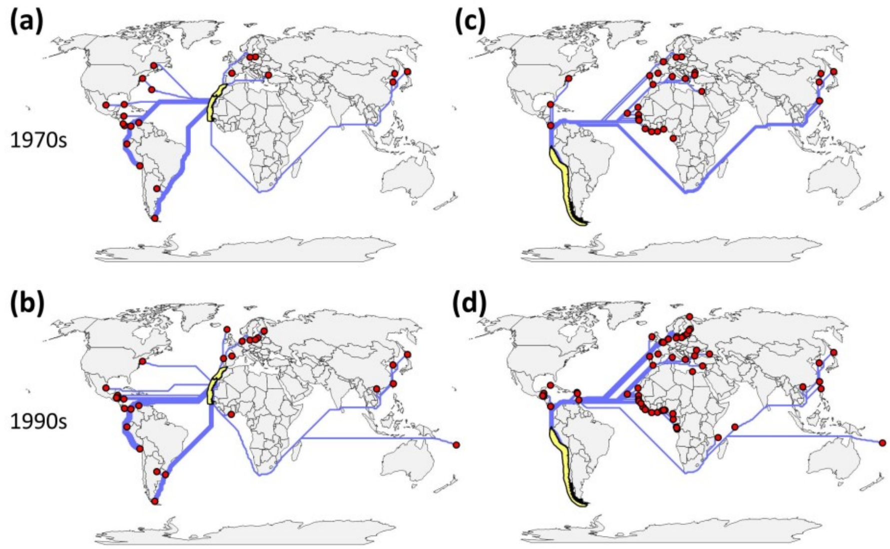


Figure 4