

Ending fishery overexploitation by expanding from local successes to globalized solutions

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The United Nations has launched several initiatives to achieve sustainable development, with the most recent being the Sustainable Development Goals within the 2030 Agenda. In a fisheries context, this initiative sets a target of ending overexploitation by 2020. Despite such efforts, the percentage of overfished fish stocks has oscillated around 30% globally since 2009. Here, we show that while developed countries are improving the way they manage their fisheries, developing countries face a worsening situation in terms of overcapacity, production per unit of effort and stock status. This situation is fuelled by economic interdependencies through international trade and fisheries agreements coupled with limited management and governance capacities in developing countries. We conclude that the present successes accomplished in some countries and regions are not sufficient to address the fisheries crisis and achieve the Sustainable Development Goals target globally. We highlight an urgent need to replicate and readapt successful policies and measures in the light of the realities of specific fisheries, and to implement transformational changes in fishery management and governance that influence entire sectors of the economy.

Recognizing the significant contribution of fisheries to global food security, livelihoods and economies, a wide variety of initiatives aimed at achieving fisheries sustainability have been put in place^{1,2}. Most recently, the Sustainable Development Goal 14 within the 2030 Agenda for Sustainable Development³ has set a target of ending overfishing and restoring depleted fish stocks. Despite such goals and aspirations, the world's fisheries have not yet achieved this target and the percentage of overfished stocks has remained rather stable around 30% globally since 2009⁴.

Mechanisms that help achieve sustainability of fisheries vary among countries with different economic development levels, institutional capacity and social-cultural traditions^{5,6}. Here, we analyse global fisheries data with the aim of comparing status and trends between developed and developing countries, and identifying areas that need to be improved to achieve the global target of restoring overfished stocks by 2020³. We also suggest reinforced policies and instruments needed to move beyond national and regional successes towards globalized solutions to the world's fisheries crisis.

Divergent fishery patterns

According to the Food and Agriculture Organization (FAO) of the United Nations (UN), globally reported capture fish production peaked in 1996 (87.5 million tonnes), then decreased until 2006 (81.4 million tonnes) and has remained stable since then (81.5 million tonnes in 2014). Moreover, the percentage of stocks classified as overfished has remained stable at around 30% since 2009⁴. However, such apparent stability masks a divergence in patterns between developed and developing countries.

Landings. Marine capture fishery production increased linearly in the developed world from 13 million tonnes in 1950 to 40 million tonnes in 1988, then decreased dramatically by about 50% to 20 million tonnes in 2013. In contrast, developing countries saw a continuous increase in fish production over the whole period of time from 1950 to 2013, but with a much slower growth rate after 1995 (Fig. 1a).

Fishing effort. Fishery production patterns in both categories of country are supported by changes of fishing input. Developed countries started their expansion in fishing effort from the late 1950s, accelerated in the 1970s and 1980s, and fell rapidly afterwards from 6,000 million kW days in 1990 to 3,200 million kW days in 2012⁷, only about half of its peak level (Fig. 1b; Supplementary Fig. 2). The decline in effort was a result of stringent regulations and management interventions, as well as translocation of fishing fleets to other countries^{8,9}, triggered by decreased catch rates (Fig. 1c), high fuel prices and the collapse of Atlantic cod—the largest fisheries in the world in 1992¹⁰. In contrast, developing nations experienced a continuous increase in fishing effort, particularly after 1980, with no clear signs of levelling off up to the present time (Fig. 1b).

Production rate. Fishing effort is a measure of the amount of inputs to fisheries, thus production divided by effort gives production per unit effort (PPUE). Through a combination of improved fishing technology and targeting under-exploited species, developed and developing countries reached comparable production rates by 1995. Over the past 20 years, however, PPUE in developed nations stabilized or slightly recovered, consistent with the decline of fishing effort in the same period. Conversely, production rates in developing countries continued to decline and reached 0.002 tonnes per kW day in 2012, half the level of developed nations (Fig. 1c).

PPUE mainly depends on technology and resource abundance. As technical advances will make fishing more productive through efficiency gains, it follows that technology will not revert and that the decrease in production rates shall reflect a decline in fish abundance. Therefore, comparing PPUE between developed and developing nations highlights a worsening situation for the latter. In contrast, developed nations have stopped their overall production rate from falling by recovering overfished stocks and reducing fishing pressure in many jurisdictions (Figs 1c and 2).

Stock status. The status of a stock relative to a given reference point often defines how healthy a population is. If PPUE reflects abundance

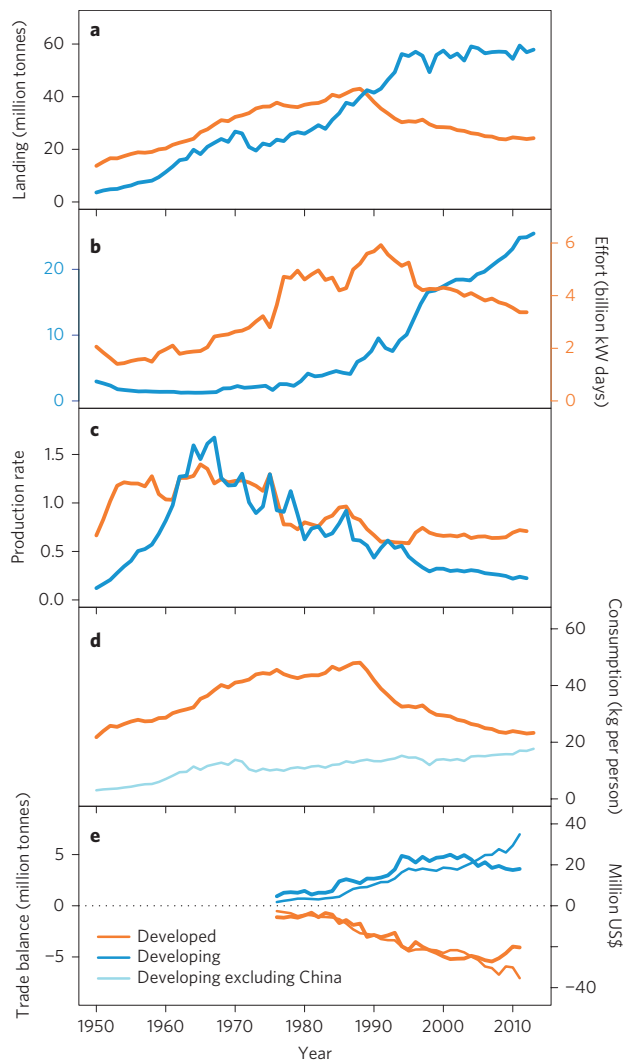


Figure 1 | Human development inequality and disparity in fishery patterns. **a**, Landings of marine fisheries estimated from national reports (in millions of tonnes). **b**, Fishing effort of marine fisheries. **c**, Production rate of marine fisheries calculated as total landings (million tonnes) divided by total effort (per kW day). **d**, Fish consumption (kg per capita) from marine fisheries. **e**, Seafood trade deficit in volume (millions of tonnes; thick lines) and in price (millions of US dollars; thin lines). Estimates from wild harvest and aquaculture could not be separated. Details in Supplementary Information.

trends, it follows that fish resource is lower and declining faster in developing nations than in the developed world. In fact, estimated median abundances relative to target levels (B/B_{target}) for stocks in a global stock assessment database¹¹ (Supplementary Tables 1 and 2) were 41% higher in developed countries with respect to their developing counterparts. In addition, unassessed fisheries typical of developing countries are at a lower abundance and declining at a faster rate than assessed fisheries^{12,13} (Supplementary Fig. 2; Fig. 3).

Fish consumption and trade. Developed nations responded to their decline in fish production by eating less fish and importing more of it. Nominal consumption of wild-caught marine fish decreased from a peak of ca. 50 kg per capita in 1988 to about 23 kg per capita in 2013 (Fig. 1d), a pattern similar to its production. Meanwhile, the total seafood trade deficit (import minus export) in the developed world more than doubled in the same period (from 1.7 million tonnes in 1988 to 4.1 million tonnes in 2007; Fig. 1e). Such increases

in net trade flow from developing to developed countries arose from mutual needs, the former after hard foreign currencies and the latter compensating for the declined domestic supply of high-quality-protein fish. This increasing negative trend in developed countries' trade deficit is accentuated when comparing trade in value (US\$) and further supported by price differences between imported (\$4.9 kg⁻¹) and exported (\$3.8 kg⁻¹) fish in 2011.

In the developing world, average nominal fish consumption increased from 2 kg per capita in 1950 to ca. 23 kg per capita in 2013, still half the amount consumed in the developed countries (Fig. 1d). These contrasting trends between production and consumption in developing countries arise mostly from their need to generate surplus value from international trade¹⁴.

Impact of economic and governance status. Despite the disproportionate importance of natural resources to the economy of developing countries, preference is often given to immediate economic development needs over resource conservation. To highlight countries' effectiveness in regulating fishing effort, we calculated effort increments between 1970 and 2013, and depict them with their corresponding governance index (GI) scores¹⁵. It seems undisputable that countries with lower GI scores, mostly from the developing world, have on average greater increases in effort (Fig. 3). Although reducing effort is not always desirable, and changes in fishing patterns are often determined by drivers such as food demand, employment and social needs, countries with higher GI scores are more likely to regulate fishing to achieve long-term sustainability. In fact, by comparing the proportion of overfished stocks by GI scores, we found that median scores of less than -0.5 were associated with 42% of overfished stocks and those greater than 1.5 with half that proportion (22%; Fig. 3). Low GIs have also been associated with high levels of illegal, unreported and unregulated (IUU) fishing¹⁶, and low compliance with the Code of Conduct for Responsible Fisheries¹⁷ (CCRF), highlighting the importance of strengthening institutional and governance capacities in developing countries.

Exporting the fisheries crisis

Since the 1990s, overexploitation and decline of fishery resources have been evident, prompting reforms in fishery management. Such reforms, requiring strong economies to bear short-term losses and support of appropriate infrastructure and governance, and sufficient human and financial resources, were deemed successful in many developed countries. For example, with the passage of the Sustainable Fisheries Act in 1996 and reauthorization of the Magnuson–Stevens Fishery Conservation and Management Act in 2007, the USA has been able to reduce overfishing and actively rebuild overfished stocks¹⁸ (Fig. 2). Similarly, the European Union (EU) has taken significant steps to establish quantitative targets through management plans, reducing fishing pressure on European stocks by about half in the past decade¹⁹ (Fig. 3). These rebuilding targets and catch restrictions have resulted in reduced domestic seafood production and self-sufficiency²⁰. To compensate for the decline in production and maintain high demand, consumption and/or competitive advantage⁴ (Fig. 1), developed countries increased imports of fish products through international trade, particularly from developing countries (Supplementary Fig. 4).

Seafood transfer to developed countries comes not only through international trade but also through bilateral or private fisheries agreements and fishing in the high seas. For example, more than a quarter of the fish caught by European fishing fleets are actually taken from outside EU waters²¹. Fisheries agreements with third countries are not only aimed at increasing seafood supply, but are also a way to alleviate overcapacity of developed countries' exclusive economic zones (EEZs). These agreements often include financial assistance and support to the implementation of national fisheries policies in return for providing the other party with fishing rights in its EEZ²². In many cases, they also subsidize development objectives

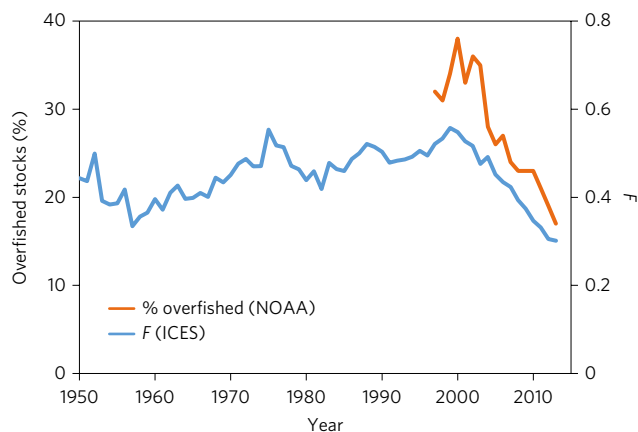


Figure 2 | Fishery trends in the USA and Europe. Fishing mortality (F) for European fisheries managed under the International Council for the Exploration of the Sea (ICES) and stock status for US fisheries managed under the National Oceanographic and Atmospheric Administration (NOAA). Data in Supplementary Information.

such as port infrastructure, fleet modernization and processing facilities, ultimately increasing fishing capacity²² (Fig. 1b).

High seafood demand for exports and increasing prices (Fig. 1e) also incentivize the expansion of fishing effort and IUU fishing^{17,23}. Coupled with weak institutions and governance, limited human and financial resources, and low capacity of management and enforcement, developing nations often end up with expanded fishing capacity and overfished resources (Fig. 1b; Supplementary Fig. 3). This situation is particularly critical as developing countries are responsible for 88% of fishing effort and 73% of marine capture landings⁴.

Globalized solutions

A global scale effort to achieve sustainability is justified by the relative indivisibility of marine ecosystems and roaming of long-distance fleets, the common nature and dynamics of fishery resources, and the intertwined connection between countries through international trade and bilateral fishing agreements. To change the current disparity between developed and developing countries, and make progress towards the zero-overfishing target set by the Sustainable Development Goals³, the global community needs to work on multiple dimensions simultaneously in a comprehensive and cohesive approach. In particular, we propose the areas described in the next three subsections for improvements.

Implement an effective global partnership to share management knowledge and enhance institutional and governance capacities of developing countries. Achieving sustainable fisheries is a common goal for all countries, yet the capacity to achieve varies greatly among them. The current model common in developed states—relying on complex stock assessment as a basis for establishing fishing quotas—is economically costly, technically demanding and operationally difficult⁵. Therefore, replicating such a model may be ineffective and counterproductive because the necessary facilities and mechanisms are unattainable for least developed economies. Simpler, easy-to-implement indicator-based management plans resting on a participative approach are needed for developing nations. In addition, seafood-importing nations are to some extent externalizing part of their management costs by importing fish from, and exporting fishing effort to, other countries. Therefore, reciprocal mechanisms to enhance institutional, management and governance capacities through delivering and financing training, technology transfer and equipment to least developed countries are justified and should be prioritized and implemented. This level-the-field strategy

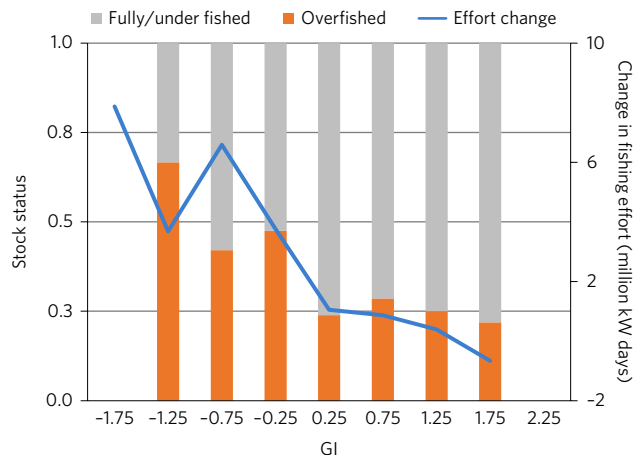


Figure 3 | Linking fishery patterns to governance. Relationship between GI scores of countries and their capacity to restrict fishing effort (as change in efforts from 1970 to 2013; blue line) and to manage their fish stocks sustainably (as percentage of stocks not overexploited¹³; bars). Given that some stocks are targeted by several countries with different GI scores, the proportion of overexploited stocks for the most extreme GI median interval (−1.75) is missing. ANOVA: $F(6,275) = 2.44$, $P = 0.026$. Data and details in Supplementary Information.

will allow developing countries to improve their management and governance capacity to address overfishing in their EEZ.

Adjust fishing capacity to sustainable levels through policy and regulations, including judicious use of subsidies and eradication of IUU fishing. Runaway increases in fishing capacity in developing countries, facilitated by government policies favourable to fishing, including subsidies for vessel construction or modernization and fuel tax concessions, have compromised beneficial adjustment towards sustainability²³. Therefore, government funds should be used, in line with Target 14.6 (ref. ³), as temporary support to help fishers transition to sustainable exploitation (for example, the Australian government supported the reduction of fishing vessels by about 40% in the Northern Prawn Fishery in 2006²⁴). In particular, financial support towards sectorial development should aim at sustaining the transition from short-term development to long-term sustainability by keeping fishing effort at bay. Bottom-up commitments, as seen in climate change negotiations, where countries voluntarily declare an amount of harmful subsidies to be eliminated within a certain period, should be encouraged. Similarly, agreements allowing foreign access to fish resources should be assessed for their sustainability, and current efforts to eradicate IUU fishing as requested by Target 14.4 (for example, through implementation of key international obligations and guidelines^{25,26}) should be enhanced.

Establish a seafood trading system that promotes resource sustainability. Thirty-seven percent of seafood production is being traded internationally⁴. Therefore, trade rules and restrictions can drive seafood demand and supply, and ultimately influence exploitation and conservation of fishery resources beyond what is achievable within national jurisdictions. These external instruments should be used to incentivize sustainable fisheries where international trade is greatly targeted for economic benefits. Specific articles in the World Trade Organization's rules that are both suitable to the unique characteristics of fisheries and cost-efficient enough to ensure their practical implementation should be encouraged. Restraining import from overfished stocks should become the norm, as prompted by Article XX of the General Agreement on Tariffs and Trade's 'measures relating to the conservation of exhaustible natural

resources'. Market-based approaches such as certification and eco-labelling, which have proved successful in rewarding sustainable fisheries, should be encouraged. However, complexities and costs of certification should be minimized to make these approaches scalable to developing world fisheries, where incentives to improve management practices are mostly needed²⁷.

A total of 167 parties have ratified the UN Convention on the Law of the Sea, in which the basic benchmarks for the sustainability of fisheries are set. The UN Fish Stocks Agreement, the FAO CCRF and the International Plan of Actions on IUU, specifying and strengthening these requirements, have been in place for decades without much progress. Most recently, Sustainable Development Goal 14.4 has been adopted with the specific objective of achieving zero overfishing³. Achieving this requires a strong political will and stable resource support, which will be particularly challenging in the context of developing countries. To ensure its success, a global, binding mechanism is needed to accelerate parties' fulfilment of their obligations to carry out all legislative and administrative actions within their domestic legal order. In addition, a trust fund should be established to support the least developed countries in their transition to sustainable fisheries. A transparent tracking system needs to be established to promote the implementation of legally binding instruments, and a name-and-encourage approach be adopted for non-binding instruments. Finally, measurable goals, such as the percentage of reduction in fleet capacity and accountability systems that are incorporated into management plans, should replace immeasurable statements of intent.

We argue that to meet the target of sustainable fisheries set by the 2030 Agenda for Sustainable Development, we need to move beyond national and regional success in fisheries and adopt a systems-thinking approach to implementation. A growing interconnection of economies urgently calls for greater international cooperation aimed at reconciling national policies with the globalized nature of fisheries. Although these recommendations are focused on sustainable exploitation of fisheries, a more holistic approach that includes reducing marine pollution, minimizing ocean acidification and protecting ecosystems as a whole is needed to secure sustainable use of the oceans. Such a planetary-bounded approach will require aligning benefits of individual actors with the collective gain of the overall system²⁸. Replicating and readapting successful policies (for example, in management interventions) and implementing transformational changes (that is, lasting policies that influence entire sectors of the economy) are needed if we are truly committed to sustainable exploitation of global fishery resources.

Methods

Data sources. The data used for these analyses came from a number of publicly available or published databases, including the 2015 FAO fisheries production and trade database²⁹, the World Bank governance database, the EU fisheries database³⁰, the RAM Legacy Stock Assessment Database¹¹ and the database from ref. ¹².

Country human development classification. Countries were divided into two groups: developed and developing, as classified by the UN Statistics Division. There is no established convention for the designation of 'developed' and 'developing' countries or areas in the UN system³¹. The designations 'developed' and 'developing' are intended for statistical convenience and do not necessarily express a judgement about the stage reached by a particular country or area in the development process. This study simply follows the UN classification for convenience. It should also be noted that there are large variations within each group in terms of either economic development or fishery contribution to a nation's gross domestic product. Therefore, one should not consider the overall situation of a group to be the same as a specific country of the group.

Landings. Landings data were drawn from the latest 2015 release of the FAO fishery capture production database²⁹. Landing data and other fishery statistics are generally submitted to the FAO by member states. Statistics made available by national authorities are complemented or replaced if better data from other origins are available³² (Supplementary Information). For example, the data received from national offices were replaced with those validated by regional fishery bodies (RFBs), following recommendation to its members by the 18th session of the Coordinating Working Party on Fishery Statistics in 1999. This is regarded as the

most reliable data held by the RFBs with assessment responsibility for a given stock, which are supposed to be the 'best scientific estimate'. Foreign catches reported in bulletins produced by northwest African countries (such as Guinea-Bissau and Mauritania) are checked against data submitted to the FAO by distant waters fishing nations (DWFNs) operating in the area, and catches identified as unreported by DWFNs are added into the FAO database as flag state's landings.

Fishing effort. Data on fishing fleets, vessel specifics and fishing times spent at sea are very rare, particularly at global level. There has been only one previous study³³ that attempted to estimate global fishing effort, but this study lacked data for most countries post 1995, limiting its ability to predict recent trends. Since then, the FAO has been able to create a relatively comprehensive database of the number of fishing vessels from most countries of the world. To estimate global fishing capacity and effort, a number of data sources were used and statistical models were developed to impute for missing years or countries in some typical years⁷. This study represents major improvements to the previous study mentioned³³ by using a more complete global fleet database (complete to 2012 for many countries) and by using bootstrapping techniques that eliminate many assumptions and allow estimates of uncertainty. The effort data in this paper are extracted from ref. ⁷ (Supplementary Information).

Production rates. Production rates are calculated by dividing the total wild capture fishery production of a country derived from the FAO database by its total fishing effort estimated in ref. ⁷. We use the term 'production' instead of 'catch' so as not to confuse 'production rates' in a national fishing sector with 'catch rates' usually referring to single stock's abundance indices. The estimates of PPUE represent a measure of the production efficiency of fisheries in a country. It must be noted that both fishery production and fishing effort within countries are aggregated across species, fisheries and areas. Therefore, PPUE may be better used as an indication that reflects the general trend of abundance. Such a relationship between PPUE and abundance is not likely to be linear and therefore its decline may not be proportional to the change in abundance of fishery resources.

Production rates within a certain area are influenced by two major factors when the level of fishing effort is fixed: resource abundance (hence natural fluctuations and management effectiveness) and technology. Technology includes all factors that can change the efficiency of fishing such as gear design, fish detection techniques, navigation equipment, catch handling facilities and human experience. With the advance of science and technology, and accumulation of human experience, technology will increase fishing efficiency over time³⁴. Therefore, in the absence of management constraints limiting 'total allowable effort' below the nominal effort of the total fleet, the decline in PPUE should reflect the change in fishery resources in a particular area (excluding macro environmental factors such as the Pacific Decadal Oscillation and El Niño/La Niña); although such a relationship is not likely to be proportional, such as the one between catch per unit of effort (CPUE) and stock abundance in single species stock assessment theory.

When calculating PPUE, nominal fishing effort was used for simplicity, that is, no increase in fishing efficiency derived from new technology, equipment and add-ons on vessels was explicitly taken into account. Existing studies show such increases could be up to 2.6% a year^{25,36}. Efficiency creep is an undeniable fact in fisheries, but its estimation, particularly at global level, is troublesome. Therefore, we decided to use nominal effort, which will make the decline trend in PPUE flatter.

Stock status. Although estimates of stock status based on biomass are not available for most fisheries, there have been several attempts to estimate the proportion of overexploited stocks globally. To understand how stock status differs between developed and developing countries, we used information from three available databases and peer-reviewed papers^{11–13}. Although, these databases are not comparable (and therefore difficult to harmonize), together they provide a reliable assessment of differences in stock health from developed and developing countries (details in Supplementary Information).

Fish consumption. Fish consumption in this study was calculated by dividing the total fish available (produced domestically from marine capture fisheries plus import minus export) by human population of a country—assuming a homogeneous consumption over the entire country, despite knowledge that fish consumption tends to be much higher around aquatic systems (coastal areas). The average consumption of a group of countries is a mean weighted by human populations. Fish consumption used in this study may differ from the real amount of fish consumed per person. This calculation was adopted because (1) it is simple and can be applied uniformly to every country; and (2) it is more reasonable in this kind of analysis, as fish not used directly for human consumption can also have an impact on fish consumption through fish-related activities—for example, certain forage fish used for aquaculture feeds.

Seafood trade. Seafood trade data were extracted from the FAO database on commodities and trade of fish and fishery products²⁹. Net import was calculated as production + import – export – re-export. There are no data available at the

moment that can be used to separate capture fishery from aquaculture products in international trade. However, it was estimated that more than 50% of the USA's imports (which, in fact, is the top seafood importer in the world) came from capture fisheries³⁷.

Additional trade information was obtained from the International Trade Centre (ITC) database³⁸ based on the UN Comtrade statistics by commodity. For this analysis, selected data included imports, exports and trade balance in US\$ for all seafood products (category 03: fish and crustaceans, molluscs, and other aquatic invertebrates). The database covers the period 2001–2014 and identifies partner countries, allowing filtering by developing market economies.

To understand the origin of imports by developed countries and their changes with time, we selected the top ten seafood importing countries from the ITC database³⁸. We observed that their proportion of imports from developing economies ranged from almost 20% in Germany to more than 80% in the USA in 2014 (Supplementary Fig. 4a). In addition, we found that seven of these ten countries showed an increase in the proportion of seafood imported from developing countries (from less than 1% increase in Japan to almost 12% increase in Korea) from 2001 to 2014. Conversely, Germany, the UK and France showed a slight decrease in seafood imported from developing countries in the same period. Lastly, on average, those ten top seafood importing countries increased their imports from developing countries by 4% for the period 2001–2014 (Supplementary Fig. 4b). It is important to note that the international trade database does not allow discrimination of products coming from wild harvest from those coming from aquaculture.

Governance. Governance consists of the traditions and institutions by which authority in a country is exercised. This includes the process by which governments and their institutions are selected, monitored, adapted and replaced; the capacity of the government to effectively formulate and implement sound policies; and the respect of citizens and the state for the institutions that govern economic and social interactions among them.

The governance defined by the World Bank consists of six dimensions¹⁵: voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law, and control of corruption. Following the methodology in ref. ¹⁷, our study used an aggregate GI by averaging the six indicators. Figure 3 shows GI scores aggregated by intervals of 0.5, highlighting an increase in effort control (that is, lower changes in fishing effort from 1970 to 2013) with higher GI scores. The figure also shows a decrease in the proportion of overexploited stocks¹³ as the GI scores increase, therefore highlighting better management and governance of fisheries by countries with better governance indices. The difference between the means of GI median bins tested statistically significant with a one-way ANOVA test (Supplementary Table 3).

Data availability. Data on global landings and seafood trade are available at <http://www.fao.org/>, the governance indices at <http://data.worldbank.org/data-catalog/worldwide-governance-indicators> and the RAM Legacy Stock Assessment Database at <http://depts.washington.edu/ramlegac/>. The global fishing effort data can be obtained by contacting the authors.

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Author contributions

Y.Y. and N.L.G. designed the study, developed the methodology, collected the data, performed the analysis and wrote the manuscript.

Additional information

Supplementary information is available for this paper.

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Competing interests

The authors declare no competing financial interests.