Global fishing between jurisdictions with unequal fisheries management

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Abstract
The demand for seafood is increasing globally and is being met, in some cases, by unsustainable fishing practices. When a country fishes outside of its jurisdiction, any negative social and environmental impacts associated with fishing are displaced to the fished location and may not be compensated. This is particularly problematic when a country fishes in jurisdictions with poorer, less-effective, fisheries management than itself (henceforth 'unequal displacement'). Using two different indices for national fisheries management effectiveness, we calculated unequal displacement of wild-capture seafood globally. We found that up to 23% (19.8 Mt) of seafood was unequally displaced annually between 1976–2015, most of which was caught in the high seas. During the period that the management effectiveness data is most accurate (2007–2011), almost all 172 countries unequally displace seafood (n = 123), but a few are responsible for the majority (China, India, Japan, Norway, Russia, Republic of Korea, Spain, Taiwan, Thailand). Achieving both sustainable food provision and ocean health requires improving international fishing and trade policies targeted at these countries to encourage the reduction of unequal seafood displacement.

1. Introduction
Global per capita seafood consumption has more than doubled since the 1960s, providing billions of people around the world with a nutritious source of protein (Hicks et al 2019, FAO 2020). In addition to its health benefits, seafood supports the livelihoods of 100s of millions of people involved in capture fisheries (Teh and Sumaila 2013) and aquaculture (Anon 2020). Although aquaculture is a rapidly increasing seafood source (FAO 2020), fisheries remain important not only as a direct source of seafood, but indirectly, providing fishmeal required for many types of aquaculture and agriculture (Froehlich et al 2018, Guillen et al 2018). This reliance on fishing has had severe ecological (Hutchings 2000, Worm et al 2006, Myers et al 2007) and socioeconomic (Pauly et al 2005, Cheung and Sumaila 2015, Schuhbauer et al 2017) consequences, including widespread declines in fish populations, habitat destruction, local food insecurity, and slavery (Jackson et al 2001, Pauly et al 2002, Dickler et al 2018).

Individual countries are primarily responsible for managing fisheries within their own exclusive economic zone (EEZ: up to 200 nautical miles from the coast), and are supported by numerous national and international mandates and initiatives for sustainable, or effective, management (e.g. 2030 Agenda for Sustainable Development, USA Magnuson-Stevens Fishery Conservation and Management Act). However, a country can obtain fisheries products used for human consumption or animal feed (henceforth referred to as 'seafood') from waters outside their own jurisdiction through trade and international fishing (figure 1).
Wild caught seafood can be obtained by a country through fishing in its own exclusive economic zone (EEZ), in another country's EEZ (R_j), fishing in the high seas (H_k) and through trade (Q_j). The amount of wild-capture seafood obtained from outside of a country's own jurisdiction is summed to determine their 'seafood footprint displacement' separately using international fishing data (in the example, for country i, it is H_k + R_j) and trade data (for country i, it is Q_j). We characterize seafood footprint displacement as 'unequal' when seafood is obtained from a place with poorer, or less-effective fisheries management than the foreign country that catches (or imports) the seafood (in the example, H_k). The question marks between the fishing and trade sections represent uncertainty about where traded seafood was originally captured.

This definition draws upon the ecological economic theory of 'unequal ecological exchange' pioneered by Bunker (1984), which is the unequal material exchange structured by trade and the corresponding movement of ecological footprints of economically strong regions to weaker ones (Bunker 1984, Givens et al 2019). Unequal displacement is particularly problematic when the seafood is obtained from a country that is heavily reliant upon coastal resources for subsistence (Smith et al 2010) and/or is caught or consumed by a country that manages its own fisheries well. Although unequal seafood displacement has been discussed in the literature (Smith et al 2010), it has never been quantified at the global scale. Quantifying unequal seafood displacement will help us understand the scale of the issue, who is responsible, and what is required for further research around determining associated social and environmental implications.

One of the most significant challenges in assessing displacement is that the traceability of seafood supply chains is poor (Gephart et al 2019). However, substantial effort has been made to track global fishing and document seafood trade (Pauly and Zeller 2016, Watson et al 2016, Watson 2017, Kroodsma et al 2018, Watson and Tidd 2018). Resulting international fishing data is important for identifying which, and how much, countries are fishing outside of their own EEZ.
jurisdiction and where displaced fishing is occurring (figure 1). However, the fishing country does not necessarily consume the seafood they catch. Thus, trade data from wild-caught fisheries can help estimate which countries consume displaced seafood—these places play an important role in driving seafood displacement. Coupled with information on fisheries management effectiveness, the magnitude and spatial extent of unequal seafood displacement, and resulting social and environmental impacts, can be estimated. Such information can help identify how and where the social and environmental sustainability of global seafood could be improved.

We develop a metric—Seafood Footprint Displacement—and apply it to fisheries data from 1976–2015 to determine: (a) total Seafood Footprint Displacement—the amount of seafood each country catches outside its own jurisdiction, whether the high seas or another country’s EEZ and; (b) unequal Seafood Footprint Displacement—the amount of seafood each country catches from jurisdictions with less effective fisheries management (Mora et al 2009, Melnychuk et al 2017) and (c) where unequally displaced seafood was caught. The focus of our manuscript is on unequal Seafood Footprint Displacement from international fishing, but we calculate the Seafood Footprint Displacement from trade given that it also drives displacement. However, the analysis using trade data is only included in the supplementary as the data do not indicate where the seafood was originally caught and hence is not well paired with fishing management effectiveness data (figure 1). We refer to Seafood Footprint Displacement as ‘unequal fishing displacement’ when applied to the fisheries dataset and ‘unequal import displacement’ when applied to trade.

2. Materials and methods

2.1. Data

2.1.1. International fishing

We used a global catch database to estimate the annual volume of fish caught by each fishing country in industrial and non-industrial fisheries (Watson 2017, Watson and Tidd 2018). The database is spatially explicit, allowing estimation of the location and quantity of seafood at the place where it was caught (not landed), whether in a specific EEZ or the high seas. For the high seas, the data do not indicate catch per region; thus, we treat the high seas as one region. The data combines publicly available data from the Food and Agriculture Organisation of the United Nations (FAO) with a range of other input sources for reported fisheries landings, including the Regional Fisheries Management Organisation, the Sea Around Us Project, Global Fishing Watch, and satellite positional data. Previous comparisons have confirmed that the catch database we used has the same general patterns as the Sea Around Us project data (Watson 2017, Watson and Tidd 2018, Roberson et al 2020). The methods to map global catch have become increasingly harmonised and verified with an increasing array of data sources since their inception in 2000 including such sources as satellite tracking of fishing vessels. Each data version readressed the entire time series since 1950 allowing for updates and corrections from the input sources. In this study, we used the latest version described in full in Watson (2017).

2.1.2. Fisheries management effectiveness

We used three different datasets to represent fisheries management (described below): (a) Global assessment of national fisheries management effectiveness from Mora et al (2009) and; (b) National fisheries management index for 28 countries from Melnychuk et al (2017); and (c) effectiveness of fisheries management in the high seas from Cullis-Suzuki and Pauly (2010) (0 > nj > 100, where higher scores represent more effective fisheries management). The national data are consistent for some countries (e.g. supplementary figure 4), but are only moderately correlated for the 28 countries included in both datasets (Pearsons correlation coefficient = 0.534), largely due to the difference in score for China (Melnychuk et al 2017). This is likely due to a difference in some criteria used to determine the scores, as analysed in Melnychuk et al (2017). We assume that higher scores represent higher social and environmental sustainability.

We assumed management effectiveness for a given country was constant through time for temporal analyses (Coll et al 2013). However, given that it is likely to be more relevant when the fisheries management data were collected, most of the results are focused on 2007–2011. We calculated Seafood Footprint Displacement for countries containing data for management effectiveness and international fishing (n = 172 when Mora et al 2009 were used; n = 28 when Melnychuk et al 2017 were used).

2.2. Fisheries management effectiveness (Mora et al 2009)

Mora et al (2009) determined management effectiveness scores for all fishing nations based on 1188 responses to a survey that measured the degree of compliance with six conditions necessary for sustainable fisheries: (a) robust scientific basis for management recommendations, (b) transparency in turning recommendations into policy, (c) capacity to enforce and ensure compliance with regulations, and minimizing the extent of (d) subsidies, (e) fishing overcapacity, and (f) foreign fishing in the form of fisheries agreements. By sustainability, they meant sustainable catches and not social, economic, or institutional sustainability. For countries that had more than one management score for different areas (e.g. Hawai’i and Alaska within the
United States), we used the average of all scores for each surveyed area to obtain one overall management effectiveness score for each country as fisheries data used in our analysis were only available by country.

2.3. Fisheries management index (Melnychuk et al 2017)

Melnychuk et al (2017) calculated a fisheries management index for 28 major fishing nations. They used expert surveys from fisheries experts to characterize attributes of research, management, enforcement, and socioeconomics of fisheries management systems in 28 major fishing countries. Survey responses were correlated among research, management, enforcement, and socioeconomics dimensions and were averaged with equal weighting to obtain a Fisheries Management Index for each returned survey, which were subsequently aggregated by country. Survey responses were also weighted by confidence scores in answers provided for individual questions and self-assigned level of expertise. We use the ‘weighted and adjusted’ Fisheries Management Index from Melnychuk et al (2017).

2.4. High seas fisheries management (Cullis-Suzuki and Pauly 2010)

Cullis-Suzuki and Pauly (2010) assessed the effectiveness of the world’s regional fisheries management organizations (RMFO) at managing 48 fish stocks. We used the average management effectiveness value across RMFO ($m_i = 49$) for the high seas because the fishing data that we used considers the high seas as one unit. This value is consistent with the notion that high seas fisheries are poorly managed (Cullis-Suzuki and Pauly 2010) relative to most countries; it represents very low management effectiveness when compared to values used for individual countries ($m_i$, range 41–77; average 61).

2.5. Seafood footprint displacement

Seafood Footprint Displacement ($S_i$) is the total amount of seafood country $i$ sources from outside its own EEZ. We calculate $S_i$ for two different management effectiveness datasets that represent the amount of seafood exchanged between countries through international fishing (figure 1). The fishing data were the basis for estimating how much country $i$ caught in the EEZ of country $j$ and the high seas: $S_i = \sum_{j \neq i} R_{ij} + H_k$, where $R_{ij}$ is the amount of seafood (tonnes) obtained in the EEZ of country $j$ and $H_k$ is the amount obtained from the high seas, by country $i$. To determine the unequal Seafood Footprint Displacement, we calculate the amount (in tonnes) of seafood footprint displaced to places with less-effective fisheries management than the fishing country, a subset of $S_i$, annually between 1976–2015—referred to as ‘unequal fishing displacement’.

3. Results

3.1. Seafood footprint displacement (fishing)—Mora et al (2009) management effectiveness

Depending on the year, we found that 27%–53% (22.2–34.5 Mt) of all fisheries production was caught outside of the fishing countries’ jurisdiction (i.e. displaced) and 18%–23% (12.2–19.8 Mt) is displaced from less-effectively managed places annually (i.e. unequal fishing displacement; figure 2). Over time, the proportion of displaced seafood that is unequally displaced by fishing has steadily increased from 41%–73% between 1976–2015 (figure 2(c)). These results assume that the static estimate of management effectiveness is relevant across the entire time period, not just the period for when they were collected. Since 2005, the majority of unequally displaced seafood was caught in the high seas (up to 55%), but historically the majority (up to 79%) was caught in EEZs (figure 2(a); supplementary table 1).

We assessed average annual fishing displacement and unequal fishing displacement by each country between 2007–2011, years that roughly align with when the management effectiveness data were collected (supplementary table 1). Over 80% of fishing countries fished outside of their own EEZ ($n = 138$) and most of these counties ($n = 123$) fished in less-effectively managed areas (i.e. unequal fishing displacement; figures 3 and 4). Of the countries that partake in unequal fishing displacement, 117 (95%) did so in the high seas (71 of which only unequally fished in the high seas) and 50 (41%) did so in other EEZs (supplementary table 1). China, Thailand, Spain, Republic of Korea, India, Taiwan, Norway, and Russia accounted for the majority (52%) of unequal fishing displacement, all of which is conducted in both the high seas and in other country’s EEZs.

We found that 11 of the countries that fish outside of their own EEZ, did not unequally fish. These countries either have very low fisheries management scores (below the median), displace negligible amounts of seafood by fishing (<0.1% of displaced seafood collectively), and/or most are remote island nations (e.g. Palau). On the other end of the spectrum, there are 55 countries where 100% of their displaced fishing is done unequally (i.e. in places with less effective fisheries management)—these countries have a wide range of management effectiveness scores (figure 4).

Although a country with a high management effectiveness score may be expected to catch more in places with poorer management effectiveness, these two factors were not correlated ($R^2 = 0.0002$, when considering total tonnes of unequal fishing displacement; $R^2 = 0.12$ when considering the proportion of unequal fishing displacement (figure 4(a))).

We assessed which areas bear the burden of unequal fishing displacement, i.e. which areas have
Figure 2. Annual amount of seafood caught (in other EEZs or high seas) in total and unequally (from places with less effective fisheries management) between 1976–2015. Unequal displacement is based on fisheries management data from (a) Mora et al (2009) for 172 countries and in (b) Melnychuk et al (2017) for 28 countries.

Figure 3. Unequal seafood footprint displacement index, showing the relative amount of seafood displaced from less-effectively managed places through international fishing between 2007–2011 (a) and (b). The jurisdictions where seafood was caught by countries with more effective fisheries management are shown in (c) and (d). The left column (a) and (c) are based on Mora et al (2009) for 172 countries and the right the right column (b) and (d) are based on Melnychuk et al (2017) for 28 countries. The categories (very low, low, moderate, high, very high) represent the data in quintiles.

the largest amount of fish extracted by a country with more effective management (figure 3). The high seas had the most fish caught by countries with better management (8.2 million tonnes) from 2007–2011. The countries with the greatest amount of unequal fishing displacement occurring in their waters were (thousand tonnes): Russia (2479), Malaysia (816), Mauritania (695), Angola (660), Saudi Arabia (608), Ireland (397), Norway (316), Japan (309), Myanmar (265), Iceland (245), and Spain (199). The countries that are the sources of the greatest amount of unequal fishing displacement vary in size of EEZ,
spatial location and governance and fisheries management effectiveness.

3.2. Seafood footprint displacement (fishing)—Melnychuk et al (2017) management effectiveness

 Depending on the year, 6%–16% (5.3–11.9 million tonnes) of all fisheries production is displaced from less-effectively managed places, where only the 28 countries from Melnychuk et al (2017) and the high seas were considered. Between 1976–2015, the proportion of displaced seafood that is unequally displaced by fishing increased from 49%–55% until the early 90’s then gradually declined to 38% (figure 2(c)). Since 2003, the majority of unequally displaced seafood was caught in the high seas (up to 63%), but historically the majority (up to 80%) was caught in EEZs (figure 2(a); supplementary table 1).

We assessed average annual fishing displacement and unequal fishing displacement by each country between 2007–2011, years that roughly align with when the management effectiveness data were collected (supplementary table 1). All but three (of 28) countries (Myanmar, Vietnam, and Bangladesh) fished outside of their own EEZ and 17 fished in places that are less-effectively managed (figures 3 and 4). Of these 17 countries, nine unequally fished in both the high seas and other EEZs, whereas seven only unequally fished in the high seas and one (Thailand) only unequally fished in other EEZs (figure 4; supplementary table 1). Republic of Korea, Russia, Norway, and Japan accounted for the majority (57%) of unequal fishing displacement, conducted in both the high seas and in other country’s EEZs. Just three countries accounted for the majority (52%) of unequal fishing done in the high seas: Japan, Chile and Republic of Korea. Although a country with a high management effectiveness score may be expected to catch more in places with poorer management effectiveness, these two factors were not well correlated ($R^2 = 0.0009$, when considering total tonnes of unequal fishing displacement; $R^2 = 0.54$ when considering the proportion of unequal fishing displacement (figure 4(a))).

The high seas had the most fish caught by countries with better management (3.3 Mt) from 2007–2011. Twelve countries were fished in by one of the other 28 countries with greater management effectiveness, three of which that make up the majority (59%): China (696), United Kingdom (496) and Japan (309) (figure 3). These three countries that are the sources of the greatest amount of unequal fishing displacement vary in size of EEZ, spatial location and fisheries management effectiveness.

4. Discussion

Unequal seafood displacement is a widespread problem that has increased over time. Almost every country, despite the rigor of their fisheries management policies, obtains seafood from places with poorer managed fisheries than their own. Although our country-specific results were not always consistent when different management effectiveness indices were used (e.g. for China), they bring attention to an overlooked problem in seafood sustainability: unequal seafood displacement (Nash et al 2022). The reduction of unequal seafood displacement could improve the social and environmental sustainability of seafood globally, a goal that is ubiquitous in
national and global resource management policies (e.g. United Nations 2030 Sustainable Development Goals).

Negative social and ecological consequences of unequal seafood displacement have been documented (Whittman 2012, McCauley et al. 2018). For example, Africa has witnessed declines in ecosystems and fisheries due to foreign fishing in their waters, usually by European and Asian nations, leading to the erosion of food self-sufficiency, food security, and disappearance of livelihoods for many coastal communities in these regions (Taylor et al. 2019, Zeller et al. 2020). This often occurs because the developing nation is financially compensated by other fishing nations for access to their waters to fish. The displacement of environmental and social impacts from one jurisdiction to another is recognised as a fundamental challenge to environmental and conservation policies (Béné et al. 2010, Lewison et al. 2019), but requires more attention in global fishing and seafood trade given the important role that seafood has in sustainably feeding our growing population. Further research is required to determine what, if any, social and economic burdens are associated with seafood displacement, especially in jurisdictions that are the biggest source of unequally displaced seafood (figure 3(c)).

Our results support a commonly suggested improvement to fisheries management: the reduction of harmful fisheries subsidies (not subsidies that promote fishery resource conservation) (Sumaila et al. 2016). Fishery subsidies are estimated to range from US$14–54 billion per year, occur in 91% of the EEZs (Mora et al. 2009, Sumaila et al. 2016, Anon 2020) and are associated with other unsustainable fishing activities (e.g. overfishing and Illegal Unreported and Unregulated). Interestingly, some of the biggest subsidizers of fisheries capacity were also highlighted as drivers of unequal seafood displacement (e.g. China, USA, Spain, Republic of Korea and Japan), investing billions of dollars towards fishing, often in distant waters, in other nations’ EEZs (Sumaila et al. 2015, 2019). Thus, a reduction in fishing subsidies would result in a reduction in fishing effort due to its inefficiency, and subsequently help reduce unequal seafood displacement. This is in line with current World Trade Organization negotiations aimed to ‘prohibit subsidies that threaten the sustainability of fishing to help ensure the sustainable use and conservation of marine resources’ (WTO 2021).

We found that the source of unequal fishing displacement has changed over time, with more seafood obtained from the high seas in recent years than in another country’s jurisdiction. This is consistent with the well-known trend that the high seas is increasingly being fished (Swartz et al. 2010, Kroodsma et al. 2018). Existing fisheries management in the high seas has been woefully ineffective, with >60% of fish stocks on the high seas designated as ‘depleted or overexploited’ (Cullis-Suzuki and Pauly 2010). Our results emphasise that fisheries management in the high seas (e.g. reducing transhipment, commercial fishing, and subsidies) is urgently required (Sumaila et al. 2015, Ewell et al. 2017, Boerder et al. 2018, Miller et al. 2018, Tickler et al. 2018a).

As most countries practice unequal fishing displacement, improving country level policies focused on limiting fishing in less-effectively managed jurisdictions is critical to mitigating unequal seafood displacement (Roheim et al. 2018). Coordinated fisheries management relevant to the high seas and EEZs is important given the highly migratory nature of many commercially harvested species. For example, overfishing in one jurisdiction can lead to depleted stocks of that same species, in another jurisdiction (White and Costello 2014, Sumaila et al. 2015, Tickler et al. 2018a). Also, although challenging, coordination among jurisdictions is important as improving fisheries management in one jurisdiction, such as reducing fishing in the high seas, could negatively impact low-income countries that are reliant upon marine resources (Teh et al. 2016).

The responsibility for the majority of unequal fishing displacement lies with few countries: Thailand, Spain, Republic of Korea, Norway, Russia, Japan, and Chile were ranked in the top ten regardless of fisheries management index used to calculate unequal displacement. Policy changes in these countries that focus on limiting fishing in places with ineffective fisheries management would most effectively mitigate unequal seafood displacement globally. Countries that also allow a large amount of unequal fishing displacement to occur in their own EEZ (e.g. Russia and Japan) could make an even bigger contribution towards minimising unequal seafood displacement by imposing stricter fishing regulations in their EEZ. Reducing fishing in these places would also help mitigate any perverse social and environmental impacts of fishing that they are experiencing (Cabral et al. 2018).

Smith et al. (2010), developed countries need to effectively govern their own fisheries resources to achieve seafood sustainability globally. We build upon this and suggest that developed countries should consume seafood caught in places with effectively managed fisheries, but acknowledge this could negatively impact developing countries that financially benefit from such fishing or trade (Smith et al. 2010). A developed country that engages in unequal seafood displacement is benefiting from well-managed fisheries in their own country (e.g. healthy ecosystems) and obtaining seafood from places with poorer fisheries management for their benefit (e.g. nutrition (Nash et al. 2022), economic). For countries with the highest management effectiveness scores, it is difficult to source seafood from countries with equal
or better fisheries management and they may need to seek alternative sources of protein (e.g. seafood from sustainable, effectively managed aquaculture) if they cannot sustainably catch more seafood in their own, well-managed, waters. In contrast, there are countries with relatively good management that source most of their seafood from counties with equal or better fisheries management (figure 4); the policies of these countries should be investigated to help other countries improve.

Ideally, we would calculate Seafood Footprint Displacement using species-specific data that indicates where the seafood imported by a given country was caught (figure 1); data that are unavailable. Improving the traceability of seafood is a significant research priority that would help improve the certainty of results and ultimately improve fisheries policies globally (Gephart et al 2019). Our results are heavily dictated by historical static estimates of fisheries management effectiveness and would be more accurate if annual estimates of management effectiveness were available for each nation; this is especially true in places like the USA that have since introduced policies to improve fisheries management (e.g. Magnuson-Stevens Fishery Conservation and Management Act). Also, as both management effectiveness datasets were developed using expert surveys, inherent survey biases that impact the management effectiveness scores would also impact the results of our study. For example, the scores for China differ between the two datasets used to estimate management effectiveness, possibly due to such biases, resulting in conflicting ‘unequal displacement’ results. Further research into unequal displacement should explore thresholds for classifying ‘good’ and ‘poor’ fisheries management and include seafood from aquaculture (Agnew et al 2009, Pramod et al 2014).

Improving seafood policies is challenging as seafood production and trade is associated with a complicated mix of social (e.g. seafood preferences in different countries), political (e.g. alliances), economic (e.g. subsidies), and environmental factors (e.g. health of the ocean) (Smith et al 2010, Asche et al 2015, Gephart et al 2019). Thus, some of our policy recommendations may not be pragmatic, rely on imperfect data, and may not be at the relevant scale (national). Nevertheless, exploring governance and market options that reduce unequal seafood displacement has merit and could also be applied to particular commodities or companies. Improving the sustainability of seafood, including reducing unequal seafood displacement, is an innovative solution that individual countries can adopt to help protect the ocean outside of their own EEZ. This is unique as individual countries have limited opportunities to protect the marine environment beyond their own EEZ, but critical given the highly connected nature of the ocean and the socio-ecological marine system. Leadership by the few countries responsible for a majority of unequal seafood displacement could substantially improve ocean health and the people that it supports.

Data availability statement

We used five databases that have been published previously. The full databases \( n = 2 \) for the fishing and trade data are available upon request from the original authors. The full databases for the management effectiveness can be found in the original publications and/or supplementary table 1. We provide the subsets of the fisheries catch and trade data that are needed to reproduce the results and figures as in supplementary table 1.

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Code availability

Analyses were conducted in R and the code used to produce the figures and tables will be provided in R Markdown files in a public GitHub repository.

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