ENVIRONMENTAL STUDIES

High seas fisheries play a negligible role in addressing global food security

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Recent international negotiations have highlighted the need to protect marine diversity on the high seas—the ocean area beyond national jurisdiction. However, restricting fishing access on the high seas raises many concerns, including how such restrictions would affect food security. We analyze high seas catches and trade data to determine the contribution of the high seas catch to global seafood production, the main species caught on the high seas, and the primary markets where these species are sold. By volume, the total catch from the high seas accounts for 4.2% of annual marine capture fisheries production and 2.4% of total seafood production, including freshwater fisheries and aquaculture. Thirty-nine fish and invertebrate species account for 99.5% of the high seas targeted catch, but only one species, Antarctic toothfish, is caught exclusively on the high seas. The remaining catch, which is caught both on the high seas and in national jurisdictions, is made up primarily of tunas, billfishes, small pelagic fishes, pelagic squids, toothfish, and krill. Most high seas species are destined for upscale food and supplement markets in developed, food-secure countries, such as Japan, the European Union, and the United States, suggesting that, in aggregate, high seas fisheries play a negligible role in ensuring global food security.

INTRODUCTION

To address high seas conservation and governance issues, the United Nations (UN) will start negotiations on a legally binding instrument to protect biodiversity in marine waters beyond national jurisdiction in September 2018 (*1*). Among the proposed conservation suggestions is the use of area-based management tools, in which fishing and other extractive activities could be prohibited. The prospect of closing any ocean area to fishing can raise many concerns, including negative impacts on food security. To understand potential trade-offs between conservation actions on the high seas and food security outcomes, it is necessary to assess the contribution of high seas fisheries to global food security.

The UN defines food security as "the condition in which all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (*2*). Currently, more than 800 million people remain affected by severe food insecurity, and recent increases in the prevalence of civil conflicts and the severity of natural disasters due to climate change have exacerbated this problem in certain parts of the world (*3*). Seafood (defined here as both marine and freshwater species) provides more than a third of the global population with 20% of their animal protein intake (*4*); many researchers and nongovernmental organizations suggest that it is especially important for assuring food security in less developed countries (*5*–*7*) and in coastal indigenous communities (*8*). Marine fish and invertebrates from both wild capture fisheries and aquaculture are predicted to be increasingly important protein sources as the global population grows to 9 billion by 2050 (*5*, *9*, *10*).

Between one-quarter and one-third of the world's marine catch is caught by small-scale coastal fisheries (*11*), which play a role in addressing food security at a local level. However, fisheries are not just contained to the coasts. As inshore fish populations have been sequentially overfished and depleted, the development of industrial and technologically advanced fishing gears, storage, and processing capabilities has enabled vessels to travel farther offshore in pursuit of fish (*12*), and industrial fishing currently occurs in more than half of the global ocean (*13*). As fisheries have industrialized and markets have become globalized, those who rely most on fish for food are often marginalized through lack of capital and restrictions on accessing fishing grounds or purchasing fish (*14*). However, markets may allow the fish caught far offshore by industrialized fleets to feed those who are food-insecure, and so it is often assumed that high seas fisheries make an essential contribution to global food security [for example, (*15*)]. But is it true?

The "high seas" are the area beyond national jurisdiction as defined by the 1982 UN Convention on the Law of the Sea and represent almost two-thirds of the ocean surface. Areas of ocean adjacent to shore—that is, the 200 nautical miles that extend from the coastline—are the exclusive economic zones (EEZs) of countries. While the pelagic environment is lower in biological productivity compared to nearshore areas, the high seas are habitat for migratory, high-trophic fish species, such as tuna and some sharks, and long-lived species, such as orange roughy and toothfish. Thus, high seas fisheries can exert a high degree of top-down control in the open ocean at both the species and community level (*16*).

To assess the contribution of the high seas catch to global food security, we determined (i) the contribution of the high seas catch relative to other sectors of seafood production, (ii) the main high seas fishing countries, (iii) the species composition of the high seas catch, and (iv) the primary importing countries and associated markets for those species. We used annual catch statistics from the Sea Around Us reconstructed fisheries database (v. 47), aquaculture and freshwater production estimates from the UN and Food and Agriculture Organization (FAO) (*4*), and import and export data from the FAO FishStat database (v. 3.01).

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RESULTS

High seas catch by volume

Between 2009 and 2014, the total landed catch on the high seas was an average of 4.32 million metric tons annually. This volume represents

4.2% of the annual marine catch (102 million metric tons) and 2.4% of all seafood production, including freshwater fisheries and aquaculture (178 million metric tons; Fig. 1).

High seas catch by species

Thirty-nine fish and invertebrate species accounted for 99.5% of the high seas catch identifiable to the species level during the time period sampled (Table 1). Only one of those species, Antarctic toothfish, was caught exclusively on the high seas (3700 metric tons annually) and represented 0.11% of the total high seas catch. The remaining species are "straddling" and/or highly migratory species (that is, caught both on the high seas and within EEZs). The top three species caught on the high seas were all tunas: skipjack (967,000 metric tons annually), yellowfin (563,000 metric tons annually), and bigeye (336,000 metric tons annually). The tunas (these species plus albacore and the three bluefins) collectively accounted for 61% of the total high seas catch by volume. Other main species groups were non-tuna pelagic fishes (26%), pelagic squids (7%), billfishes (3%), demersal fishes and invertebrates (2%), and krill (1%) (Table 1).

High seas catch by producers and consumers

Ten fishing countries were responsible for 72% of the total high seas catch between 2002 and 2011 (Table 2). China and Taiwan alone accounted for one-third of the world's total high seas catch, while Chile and Indonesia had the third and fourth largest catches, followed by Spain. Despite having the largest high seas catch by volume, fish from the high seas account for only 5% of China's total domestic catch. Catch from the high seas contributed to ≤6% of the total national catch for half of the top 10 fleets: China, Japan, India, Indonesia, and the Philippines; only for Ecuador and Taiwan did high seas catches account for more than one-third of their domestic landings (Table 2).

Current traceability standards do not allow disaggregation of imported seafood into spatial jurisdictions (that is, caught on the high seas versus in an EEZ). However, imports of species caught on the high seas are available, and Japan was the top importer of all three globally traded bluefins (93% for southern, 58% for Atlantic and Pacific), as well as bigeye (75%), and the secondary importer of yellowfin (20%) and both toothfishes (22%). Thailand was the top importer of skipjack (63%), yellowfin (21%), and albacore (30%), and Spain was the secondary importer of albacore (19%). The United States imported the majority of both toothfishes (48%) and all of the krill

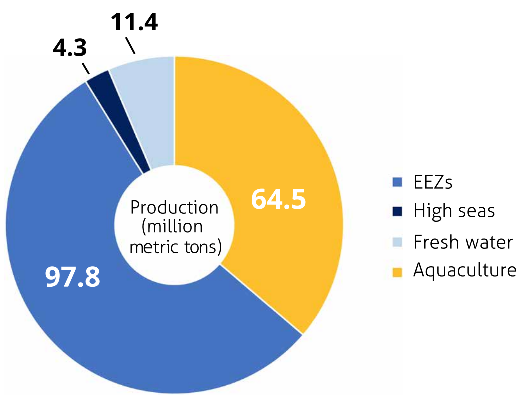

Fig. 1. Average contribution (million metric tons) of seafood-producing sectors, 2009–2014. The high seas catch represents 2.4% of total global production. Data: FAO 2016 and Sea Around Us.

and was the secondary importer of southern bluefin (2%). With the exception of South Korea importing almost all of the globally exported chub mackerel and Pacific saury, all other primary importers of species caught on the high seas were from the European Union (EU) (for example, Denmark, France, Italy, Spain, and the Netherlands). Further details of these trade flows—and additional trade of affiliated processed products—are available in Fig. 2 and table S2 and are discussed below.

DISCUSSION

High seas fish catch and global food security

High seas fisheries contribute an estimated 4.3 million metric tons (2.4%) to the global seafood supply. In 2014, these fisheries were valued $7.6 billion, yet they are enabled by an estimated $4.2 billion in annual government subsidies (*17*). We found that only one species, Antarctic toothfish, is caught on the high seas and nowhere else; the remaining species are also caught in EEZs.

Antarctic toothfish, along with its close relative, Patagonian toothfish, is usually consumed under the pseudonym "Chilean sea bass." Our results indicated that citizens in the United States are the main consumers of these fish, which is consistent with other work that found that the Unites States imported roughly 70,000 metric tons of toothfish between 2007 and 2012 (four times as much as the secondary importer Japan) (*18*). Some toothfish are certified by the Marine Stewardship Council eco-certification program, which notes that "this fish's fine quality meat means it is considered to be luxury seafood" (*19*). A 5-lb (2.3-kg) frozen portion currently retails through New York City's Fulton Fish Market website for $170 (*20*)—an equivalent portion of fresh chicken costs $7.35.

The remaining species caught on the high seas are also caught within national waters. Japan catches Pacific bluefin tuna within its EEZ and on the high seas and imports most of all three bluefin species caught by other countries [fish that were recently selling for $33/kg at Tokyo's Tsukiji Market (*21*)]. Japan is also the primary importer of bigeye tuna, which is used as an alternative to bluefin in sashimi (the fresh/frozen tuna market). Similar to the large tunas, the billfishes have relatively fatty and oily flesh and are usually sold as steaks. Italy is the world's top importer of billfish species, followed by Spain and Japan. From March 2017 to 2018, the average price for frozen swordfish at the Mercamadrid fish market in Madrid, Spain was $11/kg, while fresh swordfish fetched nearly triple at $31/kg (*22*).

Dwarfing the fresh/frozen market, however, is canned tuna. Two-thirds of all tuna caught globally is canned; almost all of this is skipjack, although yellowfin and albacore also contribute to this supply (*23*). As our analysis showed, Thailand is the main importer of these species, which is unsurprising given that Thailand processes many types of seafood and is the top global exporter of canned tuna, supplying about one-quarter of all products to the market (*23*, *24*). Canned tuna is the least expensive form of tuna available and is heavily consumed in the EU and North America (30 and 19%, respectively), while African and eastern European nations consume the least (3 and 1.6%) (*23*). Egypt, Australia, Japan, and Canada are the top importers after the EU and the United States, but current microtrends in the global tuna market suggest stagnation or decline in the import of canned tuna in all places, except the EU, where imports by five of the top six canned tuna–consuming countries (that is, Spain, Italy, France, UK, Germany, and the Netherlands) increased in 2017 (*25*).

Table 1. Species caught on the high seas, 2002–2011. Data: Sea Around Us.

Species	Family	Average annual high seas catch (10^3 metric tons)	Proportion of total catch from the high seas (%)
Skipjack tuna	Scombridae	966.6	35
Yellowfin tuna	Scombridae	562.5	34
Bigeye tuna	Scombridae	335.7	64
Chilean jack mackerel	Carangidae	307	22
Argentine shortfin squid	Ommastrephidae	149.5	25
Blue whiting	Gadidae	130.8	10
Chub mackerel	Scombridae	113.1	10
Albacore tuna	Scombridae	104.5	42
Japanese anchovy	Engraulidae	96.6	6
Jumbo flying squid	Ommastrephidae	83.8	7
Pacific saury	Scomberesocidae	81.7	9
Swordfish	Xiphiidae	64.7	52
Antarctic krill	Euphausiidae	37.4	24
Japanese jack mackerel	Carangidae	28.9	9
Northern prawn	Pandalidae	27.8	8
Flathead grey mullet	Mugilidae	23.3	13
Frigate tuna	Scombridae	17.1	7
Narrowbarred Spanish mackerel	Scombridae	14.6	3
Atlantic cod	Gadidae	11.3	1
Southern bluefin tuna	Scombridae	11.1	48
Kawakawa	Scombridae	10.6	4
Greenland halibut	Pleuronectidae	7.6	7
Shortfin mako shark	Lamnidae	7.6	18
Striped marlin	Istiophoridae	6.5	53
Pacific bluefin tuna	Scombridae	5.3	21
Patagonian toothfish	Nototheniidae	4.8	17
European anchovy	Engraulidae	4.5	0
Black marlin	Istiophoridae	4	24
Indo-Pacific sailfish	Istiophoridae	4	11
Antarctic toothfish	Nototheniidae	3.7	100
Wellington flying squid	Ommastrephidae	3	39
Patagonian grenadier	Merlucciidae	2.4	1
Indo-Pacific king mackerel	Scombridae	2.1	1
Atlantic bluefin tuna	Scombridae	2	5
Silver seabream	Sparidae	2	7
Blue marlin	Istiophoridae	1.4	27
Atlantic sailfish	Istiophoridae	1.3	24
Roundnose grenadier	Macrouridae	1.2	17
Bullet tuna	Scombridae	1.1	5

Although canned tuna is not considered a staple item in food-insecure countries, its price is comparable to other animal proteins (that is, canned tuna and canned chicken both retail for as little as \$1.50 per 5-oz tin online through Walmart), which suggests that it probably does help meet the nutritional and caloric needs of some low-income households in countries where it is sold. Nearly two-thirds of the world's tuna is caught in the western and central Pacific Ocean, where fishing predominately occurs in the EEZs of Pacific Island countries (*26*). In this region, the skipjack population is currently believed to be at

Table 2. Top high seas fishing fleets based on retained catch volume, 2002–2011. Data: Sea Around Us and FishStat (see table S3). Y, yes; N, no; NA, not applicable.

Fishing country	Average annual high seas catch (10^3 metric tons)	Contribution to global high seas catch (%)	High seas fleet contribution to total domestic catch (%)	Prevalence of severe food insecurity (% of population)*	Primary or secondary exporter of high seas species?	High seas species exported
China	714	17.0	5.3	<0.5 ± 0.07	N	NA
Taiwan	503	12.0	42.7	0.8 ± 0.62	Y	Skipjack, albacore, southern bluefin, bigeye, yellowfin, Pacific saury, marlins, and swordfish
Chile	340	8.1	7.4	3.7 ± 1.22	Y	Patagonian and Antarctic toothfish and jack mackerels
Indonesia	277	6.6	5.8	3.3 ± 1.86	Y	Frigate tunas and kawakawa
Spain	260	6.2	17.9	1.5 ± 1.12	Y	Pacific and Atlantic bluefin and swordfish
South Korea	254	6.1	11.9	0.9 ± 0.82	Y	Chub mackerel, skipjack, bigeye, squids, and seabream
Japan	231	5.5	5.1	0.6 ± 0.57	Y	Albacore and Pacific saury
Ecuador	185	4.4	32.3	8.7 ± 2.50	N	NA
India	128	3.0	3.6	12.4 ± 2.43	Y	Spanish and king mackerel
Philippines	119	2.8	5.3	12.0 ± 2.11	N	NA
Total	**3011**	**71.7**	—	—		

*Values from (*46*). These estimates were determined using a new method for estimating national food insecurity [FIES (Food Insecurity Experience Scale)] and are for 2014. For reference, the highest rate of severe food insecurity is 63.9% (Liberia) and the lowest is ≤0.5% (Azerbaijan, Bhutan, China, Israel, Switzerland, Sweden, and Thailand).

a healthy level of abundance, and the catch is considered sustainable (*27*); however, climate change is predicted to shift the distribution of this species (*28*, *29*). Furthermore, there are uncertainties around yellowfin population structure in this ocean (*30*). With these uncertainties in mind, ensuring the long-term health of these populations through effective management is of paramount importance not only because of the amount of food they provide but also because EEZ-caught tuna plays a vital role in assuring the economic and nutritional well-being of small island developing states in the Pacific Ocean (*31*).

Not all species caught on the high seas are destined for direct human consumption. Chilean jack mackerel, blue whiting, and anchovies are common targets of directed "reduction fisheries" (that is, used for fishmeal), of which almost all is used in aquaculture. About 70% of all farmed fish species require fish-based feed (*32*), although reduction species are also used in the production of feeds for terrestrial livestock and domestic pets, as well as fish oils and nutritional supplements. Trade data pointed to the Netherlands as the primary global importer of blue whiting, jack, and horse mackerels, although they likely re-export these fish to other EU countries (such as, Denmark, Norway, and Iceland) to turn into fishmeal (*33*). Norway is the world's leading producer of farmed salmon (about 1.2 million metric tons annually) (*34*), followed by Chile (*25*), a nation that is also a top producer of fishmeal for aquaculture (*35*). Most of the fish caught by Chile are likely retained domestically for the fishmeal industry. In 2017, the United States imported 24% of the fresh and frozen Atlantic salmon fillets produced by Norway (Japan and France were secondary and tertiary markets with 10 and 8%, respectively) and 30% of the fresh and frozen fillets produced by Chile (followed by Brazil and Japan, 17 and 16% each) (*25*). Advances in feeds, including more plant-based proteins, may eventually reduce the reliance on fishmeal for livestock and aquaculture (*36*).

Norway operates the biggest fishery for Antarctic krill in the Southern Ocean (*37*). The primary destination of these invertebrates has typically been the fishmeal industry, but because of the high fatty acids in krill oil, the past decade has seen an increase in the krill supplements marketed as "essential oils" that improve brain function (*38*). Globally, there are three main manufacturers of krill oil products: Neptune (Canada), Aker Biomarine (Norway), and Enzymotec (Israel). Krill supplements are not food but "nutraceuticals" and are another product sold in developed countries (*39*), and a 1-month supply retails online for $20 to $40 in the United States.

Additional high seas fisheries

The results presented have focused solely on catches and seafood reported in global catch and trade databases. However, some fish catches and discards may be illegal, unregulated, and/or unreported,

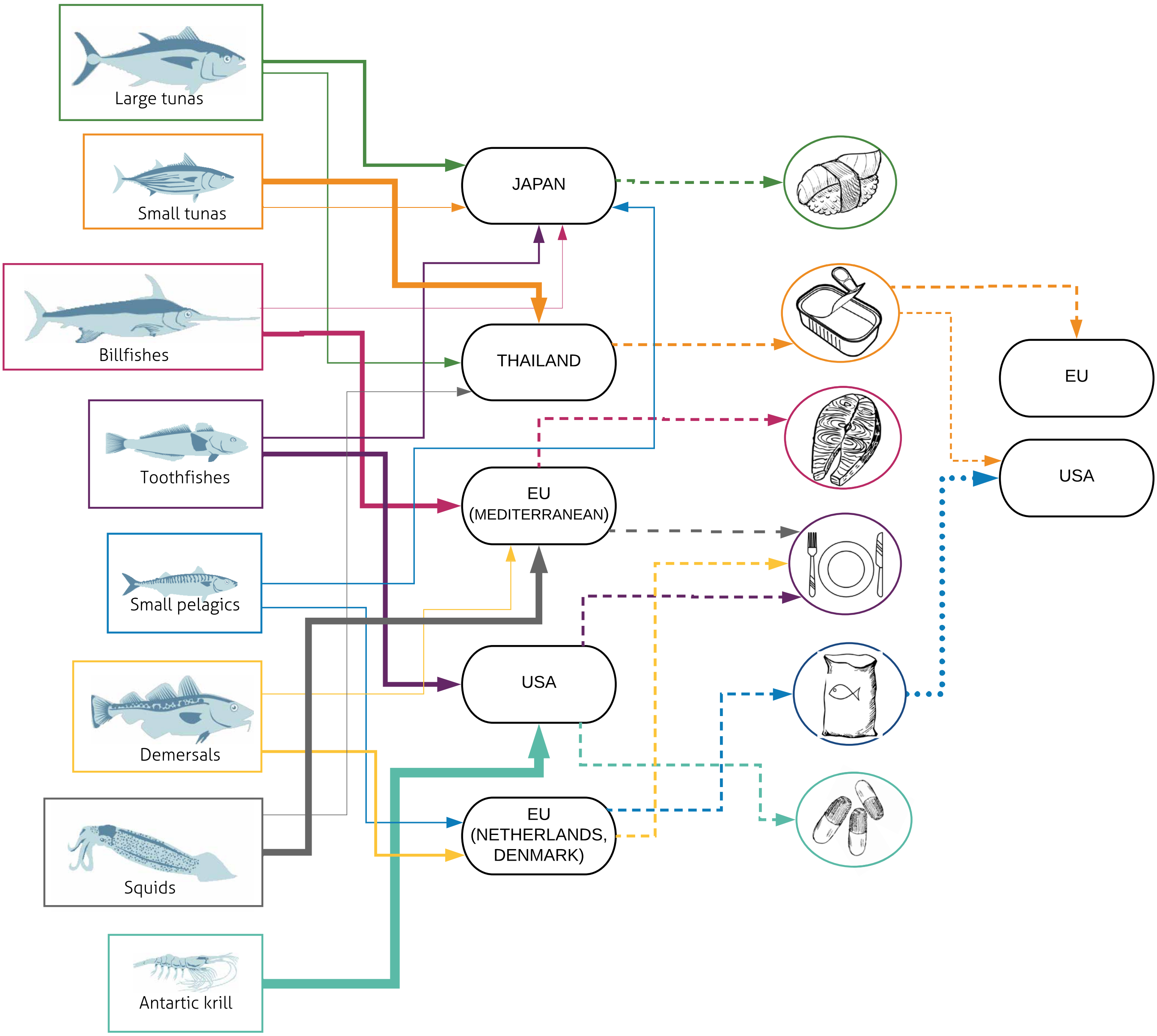

Fig. 2. Imports of species caught on the high seas. Solid arrow width proportional to destination's share of total global imports for each species group (fresh, frozen, unprocessed form), and dashed arrows indicate likely form of consumption in primary importing country or, if applicable, processed product produced. Primary and secondary importers of processed products indicated by weighted dashed lines based on market share of imports (based on information in the literature). Data: FishStat (see table S2).

such as documented cases in previous decades of undocumented toothfish and southern bluefin (*40*, *41*). Sharks were not considered target species in this analysis (see Materials and Methods), and they are routinely discarded at sea to make space for higher-value species often after removing their fins. While shark meat is of low commercial value, shark fins are one of the world's most expensive animal products but are consumed for status, not for calories (*42*). Spain, Taiwan, Indonesia, the United Arab Emirates, Singapore, and Japan are the biggest producers, while Hong Kong has traditionally been the world's primary importer and, along with the Chinese market, the largest consumer (*43*). After a series of conservation measures, a recent review suggested that Hong Kong's imports of shark products declined by 50% since 2007 (*44*), although loopholes in trade legislation and under-reported exports have potentially allowed the shark fin trade to continue (*45*).

Heterogeneity of consumption within countries, indirect contributions to food security, and food waste

Most of the top countries fishing on the high seas are food-secure (95% or more of their citizens are considered food-secure), with the exception of Ecuador, India, and the Philippines (Table 2). In addition, the top importers of high seas–related species (in no particular order: the Netherlands, United States, Japan, Spain, France, Denmark, and Thailand; see table S2) all have a low prevalence of severe food insecurity at the national level (that is, less than 2% of the population) (*46*). However, data are not available to analyze the role of seafood at the household level. Even within a food-secure country, access to food is not uniform, and many people may struggle to meet their caloric and nutritional needs. For example, the United States is one of the top importers of multiple species in this analysis, and the second most food-secure country in the world by some metrics (for example, https://foodsecurityindex.eiu.com/Index). However, more than 3 million Americans (1.2% of the population) are severely food-insecure because they cannot access food that meets their nutritional and caloric requirements and/or food preferences (*46*). Thus, although products derived from species caught on the high seas may be on the market, the prices of these products suggest that they are not financially accessible to these Americans, in the same way that bluefin tuna is likely not accessible to the 612,000 people in Japan (0.5% of the population) considered severely food-insecure (*46*).

There is also the notion that the high seas contribution to food security may be indirect—that sales of a relatively small quantity of high-value seafood by developing countries can generate revenue to allow those countries to import lower-value seafood to alleviate national food insecurity (*47*) or purchase replacement foods (*48*). While we do not have the data to support or refute the notion of "trickle down" food security, we know that the countries catching most of the fish on the high seas are not considered food-insecure (Table 2), although the relatively few people doing the actual fishing on high seas fishing vessels very well might be (*49*).

In addition, the export of high seas–related species for trade revenue may have unanticipated consequences. Evidence from Pacific Island countries, which caught tuna in nearshore waters for local consumption for centuries (*50*, *51*), shows that, as tuna has become a primary export commodity (*51*), there has been a decline in the consumption of local plants and fish in favor of less nutritious imported foods (for example, canned meat and fish, cereal, instant noodles, and soda); these nations now have some of the highest rates of obesity in the world (*52*). Recent local initiatives are focused on improving access to tuna for direct consumption, not only ensuring its continued supply for export (*53*). The global problem of food insecurity is more a problem of food availability given that one-third of all food produced globally is lost or wasted, including seafood (*54*). Putting this in perspective, retaining less than one-fifth of the seafood currently wasted as discards, in postharvest handling, or in poor supply chain practices would be the equivalent of the high seas catch.

CONCLUSIONS

The discussion of access to the high seas will inevitably lead to concerns about how closing areas to fishing could affect global food security. Here, we show that only one species of toothfish is caught exclusively on the high seas, that the high seas catch contributes less than 3% to the global seafood supply, and the vast majority of the marine life caught on the high seas is destined for upscale markets in food-secure countries. On the basis of the available data, high seas fisheries do not make a direct or crucial contribution to global food security.

MATERIALS AND METHODS

Study design

Two large global data sets were used for these analyses: the Sea Around Us fisheries database (v.47, obtained 13 December 2017) and the FAO FishStat database (v.3.01, obtained 11 January 2017). The Sea Around Us database includes reported and reconstructed marine fisheries catch over time since 1950 [for database rationale and methodology, see (*55*)]. FishStat is a global fisheries landings and trade database based on nationally reported figures since 1950, and it is the most comprehensive publicly available set of this kind. Data for aquaculture production and freshwater capture fisheries were obtained from the 2016 FAO State of World Fisheries and Aquaculture report (*4*). We defined "seafood" as all fish and invertebrates consumed by humans, regardless of whether they originate in fresh or salt water or are caught or farmed. See table S1 for an overview of data sources and analyses.

Data analysis

We analyzed the relative contribution of the world's four primary seafood sectors: (i) capture fisheries in national waters (EEZs), (ii) capture fisheries in the high seas, (iii) capture fisheries in fresh water, and (iv) aquaculture (both marine and fresh water combined). Sea Around Us data of capture fisheries landings in EEZs and the high seas and FAO data (*37*) were used for freshwater landings and aquaculture production values. To get a sense of the most recent trends, we used the period of 2009–2014.

Our second analysis determined (i) the primary high seas fishing countries and (ii) key species caught on the high seas. We identified the top fishing fleets (by catch volume) and the key species caught between 2002 and 2011 using the Sea Around Us database. This time frame was chosen as these were the most recent years with trade information in FishStat (v. 3.01, obtained 11 January 2017). On the basis of these data, a total of 395 different species (for example, "bigeye tuna" and "Atlantic cod") and taxonomic groups (for example, "unidentified marine fishes," "deep-sea crabs," and "unidentified pelagic fishes") were caught on the high seas during this time. From this, we extracted the 243 species-specific entries for fish and invertebrates. Because the reconstructed Sea Around Us data used in this analysis include all forms of catch (including nontargeted species that are caught as bycatch), we assumed that not every one of the 243 species were targeted catch and that some would have been caught incidentally as bycatch in certain fisheries. To account for this, we refined this list into "targeted species" by (i) removing any species with an average annual catch of ≤1000 metric tons and (ii) removing any species with a discard/total catch of ≥10%. From these filters, 39 species remained for the subsequent analysis of trade (table S2). As the Sea Around Us data also include estimates of capture fisheries catch within EEZs, these values were used to compute the proportion of a species' total catch that is from the high seas.

Our third analysis used the FishStat database to determine the primary importing and exporting nations of the high seas species identified in the preceding analysis. Here, we defined "primary" importers as those nations with the highest percentage (by volume) of a given species as an imported product. "Secondary" importers are those with the second highest. Unless otherwise specified, import statistics for fresh and frozen, unprocessed product forms (that is, "salted," "dried," "processed," and "prepared" products were not included) for each species were obtained from this database. We also identified which high seas fishing countries had exports of the high seas species identified in the preceding analysis. Trade data were not disaggregated between EEZs and the high seas. Therefore, it was not possible to determine what proportion of a traded species or product was originally caught on the high seas. For the purpose of this study, the assumption was no difference in the importers of EEZ or high seas products of a given species, and the data presented represent imports of the total reported catch for those species. This assumption was made on the premise that the international seafood market predominantly differentiates products based on flag state (fishing country) rather than the geographic location of the catch.

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/4/8/eaat8351/DC1

Table S1. Data sources and associated analyses.

Table S2. Species caught on the high seas and associated primary and secondary importers from 2002 to 2011.

Table S3. Species caught on the high seas and associated primary and secondary exporters from 2002 to 2011.

REFERENCES AND NOTES

1. United Nations, *Intergovernmental Conference on an International Legally Binding Instrument Under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction* (United Nations, 2018).
2. United Nations, *Interim Report of the Special Rapporteur on the Right to Food* (United Nations, 2012).
3. FAO, IFAD, UNICEF, WFP, WHO, *The State of Food Security and Nutrition in the World 2017: Building Resilience for Peace and Good Security* (FAO, 2017) pp. 1–132.
4. FAO, *The State of World Fisheries and Aquaculture 2016* (FAO, 2016); www.fao.org/3/a-i5555e.pdf.
5. C. Béné, G. Macfadyen, E. H. Allison, *Increasing the Contribution of Small-Scale Fisheries to Poverty Alleviation and Food Security* (Food and Agriculture Organization of the United Nations, 2007).
6. B. Belton, S. H. Thilsted, Fisheries in transition: Food and nutrition security implications for the global South. *Glob. Food Sec.* **3**, 59–66 (2014).
7. L. C. L. Teh, D. Pauly, Who brings in the fish? The relative contribution of small-scale and industrial fisheries to food security in Southeast Asia. *Front. Mar. Sci.* **5**, 1–9 (2018).
8. A. M. Cisneros-Montemayor, D. Pauly, L. V Weatherdon, Y. Ota, A. Global Estimate of seafood consumption by coastal indigenous peoples. *PLOS ONE* **11**, e0166681 (2016).
9. C. Béné, M. Barange, R. Subasinghe, P. Pinstrup-Andersen, G. Merino, G.-I. Hemre, M. Williams, Feeding 9 billion by 2050—Putting fish back on the menu. *Food Secur.* **7**, 261–274 (2015).
10. M. D. Smith, C. A. Roheim, L. B. Crowder, B. S. Halpern, M. Turnipseed, J. L. Anderson, F. Asche, L. Bourillón, A. G. Guttormsen, A. Khan, L. A. Liguori, A. McNevin, M. I. O'Connor, D. Squires, P. Tyedmers, C. Brownstein, K. Carden, D. H. Klinger, R. Sagarin, K. A. Selkoe, Sustainability and global seafood. *Science* **327**, 784–786 (2010).
11. R. Chuenpagdee, L. Liguori, M. L. D. Palomares, D. Pauly, Bottom-up, global estimates of small-scale marine fisheries catches (Fisheries Centre Research Reports, University of British Columbia, 2006); https://open.library.ubc.ca/collections/52383/items/1.0074761.
12. W. Swartz, E. Sala, S. Tracey, R. Watson, D. Pauly, The spatial expansion and ecological footprint of fisheries (1950 to present). *PLOS ONE* **5**, e15143 (2010).
13. D. A. Kroodsma, J. Mayorga, T. Hockberg, N. A. Miller, K. Boerder, F. Ferretti, A. Wilson, B. Bergman, T. D. White, B. A. Block, P. Woods, B. Sullivan, C. Costello, B. Worm, Tracking the global footprint of fisheries. *Science* **359**, 904–908 (2018).
14. T. McClanahan, E. H. Allison, J. E. Cinner, Managing fisheries for human and food security. *Fish Fish.* **16**, 78–103 (2015).
15. E. Poloczanska, Keeping watch on the ocean. *Science* **359**, 864–865 (2018).
16. G. Ortuño Crespo, D. C. Dunn, A review of the impacts of fisheries on open-ocean ecosystems. *ICES J. Mar. Sci.* **74**, 2283–2297 (2017).
17. E. Sala, J. Mayorga, C. Costello, D. Kroodsma, M. L. D. Palomares, D. Pauly, U. Rashid Sumaila, D. Zeller, The economics of fishing the high seas. *Sci. Adv.* **4**, eaat2504 (2018).
18. E. Grilly, K. Reid, S. Lenel, J. Jabour, The price of fish: A global trade analysis of Patagonian (*Dissostichus eleginoides*) and Antarctic toothfish (*Dissostichus mawsoni*). *Mar. Policy* **60**, 186–196 (2015).
19. Marine Stewardship Council, *Toothfish* (Marine Stewardship Council, 2017); www.msc.org/cook-eat-enjoy/fish-to-eat/toothfish.
20. Fulton Fish Market, *Chilean Sea Bass (Frozen, Wild, Chile)* (Fulton Fish Market, 2018); https://shop.fultonfishmarket.com/frozen-chilean-sea-bass.html.
21. Tokyo Metropolitan Government, *Tokyo Central Wholesale Market Monthly Statistics* (Tokyo Metropolitan Government, 2017); www.shijou-tokei.metro.tokyo.jp.
22. Mercamadrid, *Pez Espada (Estadísticas)* (Mercamadrid, 2018); http://www.mercamadrid.es/estadisticas/.
23. A. Hamilton, A. Lewis, M. A. McCoy, E. Havice, L. Campling, *Market and Industry Dynamics in the Global Tuna Supply Chain* (Pacific Islands Forum Fisheries Agency, 2011).
24. FAO, *GLOBEFISH Highlights: A Quarterly Update on World Seafood Markets* (FAO, 2016).
25. FAO, *GLOBEFISH Highlights: A Quarterly Update on World Seafood Markets* (FAO, 2018); www.fao.org/3/I8626EN/i8626en.pdf.
26. K. Seto, Q. Hanich, The western and central pacific fisheries commission and the new conservation and management measure for tropical tunas. *Asia Pacific J. Ocean Law Policy* **3**, 146–151 (2018).
27. International Seafood Sustainability Foundation, *Status of the World Fisheries for Tuna: February 2018* (International Seafood Sustainability Foundation, 2018); https://iss-foundation.org/knowledge-tools/technical-and-meeting-reports/download-info/issf-2018-02-status-of-the-world-fisheries-for-tuna-feb-2018/.
28. P. Lehodey, I. Senina, B. Calmettes, J. Hampton, S. Nicol, Modelling the impact of climate change on Pacific skipjack tuna population and fisheries. *Clim. Change* **119**, 95–109 (2013).
29. J. D. Bell, A. Ganachaud, P. C. Gehrke, S. P. Griffiths, A. J. Hobday, O. Hoegh-Guldberg, J. E. Johnson, R. L. Borgne, P. Lehodey, J. M. Lough, R. J. Matear, T. D. Pickering, M. S. Pratchett, A. S. Gupta, I. Senina, M. Waycott, Mixed responses of tropical Pacific fisheries and aquaculture to climate change. *Nat. Clim. Chang.* **3**, 591–599 (2013).
30. P. M. Grewe, P. Feutry, P. L. Hill, R. M. Gunasekera, K. M. Schaefer, D. G. Itano, D. W. Fuller, S. D. Foster, C. R. Davies, Evidence of discrete yellowfin tuna (*Thunnus albacares*) populations demands rethink of management for this globally important resource. *Sci. Rep.* **5**, 16916 (2015).
31. J. D. Bell, V. Allain, E. H. Allison, S. Andréfouët, N. L. Andrew, M. J. Batty, M. Blanc, J. M. Dambacher, J. Hampton, Q. Hanich, S. Harley, A. Lorrain, M. McCoy, N. McTurk, S. Nicol, G. Pilling, D. Point, M. K. Sharp, P. Vivili, P. Williams, Diversifying the use of tuna to improve food security and public health in Pacific Island countries and territories. *Mar. Policy* **51**, 584–591 (2015).
32. T. Cashion, P. Tyedmers, R. W. R. Parker, Global reduction fisheries and their products in the context of sustainable limits. *Fish Fish.* **18**, 1026–1037 (2017).
33. EU Fishmeal, *EU Fish Meal: Production* (EU Fishmeal, 2018); www.eufishmeal.org/production/.
34. T. Ytrestøyl, T. S. Aas, T. Åsgård, Utilisation of feed resources in production of Atlantic salmon (*Salmo salar*) in Norway. *Aquaculture* **448**, 365–374 (2015).
35. T. Cashion, F. Le Manach, D. Zeller, D. Pauly, Most fish destined for fishmeal production are food-grade fish. *Fish Fish.* **18**, 837–844 (2017).
36. N. Pelletier, D. H. Klinger, N. A. Sims, J.-R. Yoshioka, J. N. Kittinger, Nutritional attributes, substitutability, scalability, and environmental intensity of an illustrative subset of current and future protein sources for aquaculture feeds: Joint consideration of potential synergies and trade-offs. *Environ. Sci. Technol.* **52**, 5532–5544 (2018).
37. S. Nicol, J. Foster, The fishery for Antarctic krill: Its current status and management regime, in *Biology and Ecology of Antarctic Krill*, V. Siegel, Ed. (Springer International Publishing, 2016), vol. 7, pp. 387–421.
38. J. M. Kwantes, O. Grundmann, A brief review of krill oil history, research, and the commercial market. *J. Diet. Suppl.* **12**, 23–35 (2014).
39. M. Urch, *China Committed to Becoming a World Leader in Krill Oil Production* (SeafoodSource, 2016): www.seafoodsource.com/commentary/china-committed-to-becoming-a-world-leader-in-krill-oil-production.
40. T. Polacheck, Assessment of IUU fishing for Southern Bluefin Tuna. *Mar. Policy* **36**, 1150–1165 (2012).
41. D. J. Agnew, The illegal and unregulated fishery for toothfish in the Southern Ocean, and the CCAMLR catch documentation scheme. *Mar. Policy* **24**, 361–374 (2000).
42. S. Clarke, E. J. Milner-Gulland, T. Bjørndal, Social, economic, and regulatory drivers of the shark fin trade. *Mar. Resour. Econ.* **22**, 305–327 (2007).
43. K. H. Shea, A. W. L. To, From boat to bowl: Patterns and dynamics of shark fin trade in Hong Kong—Implications for monitoring and management. *Mar. Policy* **81**, 330–339 (2017).
44. World Wildlife Fund, *Hong Kong Shark Fin Imports Down 50%* (World Wildlife Fund, 2018); https://sharks.panda.org/news-blogs-updates/latest-news/hong-kong-shark-fin-imports-down-50.
45. S. C. Clarke, S. J. Harley, S. D. Hoyle, J. S. Rice, Population trends in Pacific Oceanic sharks and the utility of regulations on shark finning. *Conserv. Biol.* **27**, 197–209 (2012).
46. C. Cafiero, M. Nord, S. Viviani, M. E. Del Grossi, T. Ballard, A. Kepple, M. Miller, C. Nwosu, *Voices of the Hungry: Methods for Estimating Comparable Prevalence Rates of Food Insecurity Experience by Adults Throughout the World* (FAO, 2016).
47. F. Asche, M. F. Bellemare, C. Roheim, M. D. Smith, S. Tveteras, Fair enough? Food security and the international trade of seafood. *World Dev.* **67**, 151–160 (2015).
48. S. M. Garcia, A. A. Rosenberg, Food security and marine capture fisheries: Characteristics, trends, drivers and future perspectives. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* **365**, 2869–2880 (2010).

49. International Labour Office, *Caught at Sea: Forced Labour and Trafficking in Fisheries* (International Labour Office, 2013); www.ilo.org/wcmsp5/groups/public/---ed_norm/---declaration/documents/publication/wcms_214472.pdf.
50. J. D. Bell, M. Kronen, A. Vunisea, W. J. Nash, G. Keeble, A. Demmke, S. Pontifex, S. Andréfouët, Planning the use of fish for food security in the Pacific. *Mar. Policy* **33**, 64–76 (2009).
51. R. Gillett, M. I. Tauati, *Fisheries of the Pacific Islands: Regional and National Information* (FAO, 2018).
52. K. E. Charlton, J. Russell, E. Gorman, Q. Hanich, A. Delisle, B. Campbell, J. Bell, Fish, food security and health in Pacific Island countries and territories: A systematic literature review. *BMC Public Health* **16**, 285 (2016).
53. J. D. Bell, J. Albert, S. Andréfouët, N. L. Andrew, M. Blanc, P. Bright, D. Brogan, B. Campbell, H. Govan, J. Hampton, Q. Hanich, S. Harley, A. Jorari, M. Lincoln Smith, S. Pontifex, M. K. Sharp, W. Sokimi, A. Webb, Optimising the use of nearshore fish aggregating devices for food security in the Pacific Islands. *Mar. Policy* **56**, 98–105 (2015).
54. FAO, *Global Food Losses and Food Waste: Extent, Causes and Prevention* (FAO, 2011).
55. D. Pauly, Rationale for reconstructing catch time series. *EC Fish. Coop. Bull.* **11**, 4–10 (1998).

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