

SOCIAL SCIENCES

Illicit trade in marine fish catch and its effects on ecosystems and people worldwide

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Illegal, unreported, and unregulated fishing is widespread; it is therefore likely that illicit trade in marine fish catch is also common worldwide. We combine ecological-economic databases to estimate the magnitude of illicit trade in marine fish catch and its impacts on people. Globally, between 8 and 14 million metric tons of unreported catches are potentially traded illicitly yearly, suggesting gross revenues of US\$9 to US\$17 billion associated with these catches. Estimated loss in annual economic impact due to the diversion of fish from the legitimate trade system is US\$26 to US\$50 billion, while losses to countries' tax revenues are between US\$2 and US\$4 billion. Country-by-country estimates of these losses are provided in the Supplementary Materials. We find substantial likely economic effects of illicit trade in marine fish catch, suggesting that bold policies and actions by both public and private actors are needed to curb this illicit trade.

INTRODUCTION

Illegal, unreported, and unregulated (IUU) (1) fishing is global in nature, but more widespread in certain regions (2–3). This implies that IUU fishing is an important negative driver that needs to be tackled by both the global community and individual countries if we wish to secure sustainable and inclusive benefits from renewable marine resources (4). In the absence of truly effective national, regional, and international institutions, policies, and actions, and in the presence of international noncooperation, IUU fishing is undermining the ability of coastal countries to achieve the Sustainable Development Goals of the United Nations that the world has agreed upon (5). IUU fishing has the potential to exacerbate the detrimental effects (6) and losses that global illicit trade in marine catch has on individuals, societies, and governments, as well as nature.

The Global Agenda Council of the World Economic Forum defines illicit trade as trade that “involves money, goods or value gained from illegal and generally unethical activity. It encompasses a wide variety of illegal trading activities, including human trafficking, environmental crime, illegal trade in natural resources, various types of intellectual property infringements, trade in certain substances that cause health or safety risks, smuggling of excisable goods and trade in illegal drugs, as well as a variety of illicit financial flows” (7). For example, illicit trade in the arts involves people stealing, selling, forging, and trading artwork illegally.

We would like to stress that not all fisheries catches that are unreported can be assumed to be illegal. In many cases, small-scale, artisanal catches are simply not reported because there is no official or legal mandate to record and hence report such catches, or even if there notionally is such a requirement, no data collection system or resources are in place to record and report all artisanal catches in many coastal communities around the world (8–9).

Daniels *et al.* (3) identify two major potential channels through which illicit trade in fish is enabled. The first practice uses at-sea

transshipments, which involves offloading catches from multiple fishing boats onto large freezer and processing ships at sea. This makes proper and transparent accounting of the origin and legality of catches very difficult or even impossible to achieve. For example, transshipment activities account for about 16% of fish exported from West African waters, and about 35 transshipment vessels were seen in West African waters in 2013 (3). Most of these were likely operating under flags of convenience (9), making accountability and transparency even more challenging. The second practice that enables illicit trade in seafood relates to how fish is transported for exports (3). It is estimated that about 84% of fish exported out of West Africa are transported in large refrigerated containers that are generally subjected to far less stringent reporting and inspection requirements (3). A third mechanism for illicit trade, in addition to the two channels mentioned above, is transport of illegally caught seafood into nearby local and regional markets to satisfy domestic demand in fisheries that are export-dominated. These three pathways are direct enablers of “laundering” illegal (10) as well as unreported or underreported catches into illicit trade. It is worth noting that transshipment is also a major enabler of labor abuses and modern slavery at sea (5, 11).

Many species of fish (collectively referring to exploited finfish and aquatic invertebrates), including both demersal and pelagic species (12–13), are targeted by both foreign and domestic fishing vessels in the Exclusive Economic Zones (EEZ) of sovereign countries, sometimes illegally. Such catches are often processed aboard large foreign industrial transshipment vessels and directly shipped overseas without unloading and processing in host countries, thereby depriving local economies of revenue, income, jobs, and economic impacts (14). The global activities of many industrial fishing fleets, including so-called IUU vessels, as well as the prevalence of transshipment vessels to circumvent landing and processing in host countries have been considered analogous to international organized crime (15). Thus, by not landing, reporting, and processing fish in the host country in whose waters the fish were caught, before exporting them, substantial economic and food and nutritional security losses are incurred by the communities and countries whose waters are being exploited (16).

Here, we estimate the potential economic costs of likely illicit trade in marine fish catch of the world by focusing on the potential losses to the legitimate trade system and associated economy due to such illicit trade, in terms of catches and gross revenues. In addition, and to provide a broader picture of the economic effects of illicit trade in

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marine fish catch, we compute the potential economic impacts, household income impacts, and tax revenue losses that result from such illicit activities.

RESULTS

Catch and fisheries revenue losses

We find that between 7.7 and 14.0 million metric tons of unreported fish catches are potentially traded illicitly each year (Table 1). We provide in table S1 the range of catch losses for each of the 143 countries included in our study. These numbers show that a substantial amount of seafood is likely illegally and illicitly taken out of the legitimate food supply system of many countries, affecting the food security and livelihoods of millions. These levels of catch volumes being traded illicitly suggest that gross revenues of between US\$8.9 and US\$17.2 billion per year are being redirected out of the legitimate market through illicit trade (Table 1). Table S1 presents the range of revenue losses for each of the 143 countries included in our study.

Catch and gross revenue losses are not distributed equally across the various geographic regions. Rather, our analysis suggests that Asia, Africa, and South America suffer the biggest losses in catch due to likely illicit trade under both scenarios (Table 1). The unreported catches deemed to likely contribute to illicit trade from these three geographic regions, combined, account for around 85% of total catch losses to likely illicit trade globally (Table 1). The estimated losses to legitimate (formal) trade in gross revenue for these three geographic regions are between US\$7.3 and US\$14.0 billion per year, or around 82% of the global gross revenue loss to the legitimate trade

system (Table 1). With regard to revenue losses to legitimate trade, however, European waters account for a higher likely loss compared to South America (Table 1), which may be due to the higher prices that are obtained for the species targeted in Europe, as South American fisheries are dominated by the high catch volume but low-price Peruvian anchoveta (*Engraulis ringens*).

Economic, income, and tax impacts

The estimated average annual economic impact from the redirection of fisheries catches away from the legitimate (formal) trading system toward potential illicit trade (i.e., taking into account the economic multiplier for each country) suggests a potential economic impact of between US\$25.5 and US\$49.5 billion (Table 2). The average annual income impact, i.e., the seafood workers' incomes that are likely associated with potential illicit trade in seafood, is estimated to be between US\$6.8 and US\$13.3 billion (Table 2). Last, the estimated potential losses to governments' tax revenues, assuming that unreported catches and the associated illicit trade largely bypass the taxation system due to their unreported nature, amount to between US\$2.2 and US\$4.3 billion annually (Table 2). While some variation exists between the two scenarios modeled here for all three impact measures, the differences do not appear to be substantial (Table 2).

The effects of likely illicit trade in marine fisheries resources, in terms of economic and income impacts, are most pronounced in Africa and Asia (Table 2). Africa was estimated to experience between US\$7.6 and US\$13.9 billion and US\$1.8 and US\$3.3 billion losses annually in economic and income impacts, respectively, due to the redirection of catches from legitimate to illicit seafood trade (Table 2). A good proportion of this is due to unreported catches by large industrial fleets, most of which are foreign. Asia fairs even worse, with estimated economic and income impact losses of US\$10.3 to US\$20.3 billion and income impacts of US\$2.7 to US\$5.4 billion annually, representing 41% (the equivalent number for Africa is 28%) of overall global economic and income impacts of likely illicit seafood trade (Table 2). As to be expected, illicit seafood trade ultimately affects tax revenues for maritime African and Asian countries much more than other parts of the world, estimated to be US\$0.83 to US\$1.50 billion and US\$0.81 to US\$1.60 billion annually for these continents, respectively (Table 2). Combined, the potential tax revenue losses due to likely illicit trade in African and Asian marine resources account for 72 to 74% of global tax revenue losses due to illicit trade in seafood, amounting to between US\$1.6 and US\$3.1 billion annually.

Table 1. Annual catch and gross revenue losses. Estimated average annual catch and gross revenue losses to the legitimate (formal) international trading system due to likely illicit trade in marine fish catch over the past decade of total reconstructed catch data (2005–2014) for two scenarios of assumed fractions of unreported catches being redirected to illicit trade. Both scenarios assume that 50 to 80% of unreported industrial landed catches are being redirected to illicit trade, while the fractions of artisanal unreported landed catches range from 30 to 50% and 10 to 30% for scenarios 1 and 2, respectively.

Geographic region	Scenario 1		Scenario 2	
	Catch loss (t × 10 ³)	Gross revenue loss (US\$ × 10 ⁶)	Catch loss (t × 10 ³)	Gross revenue loss (US\$ × 10 ⁶)
Africa	2,153–3,465	3,325–5,358	1,959–3,271	2,944–4,977
Antarctic and sub-Antarctic	0.1–0.2	0.8–1.2	0.1–0.2	0.8–1.2
Asia	4,116–6,635	4,689–7,586	3,618–6,137	3,852–6,749
Europe	959–1,545	1,124–1,811	850–1,436	991–1,679
North America	339–552	780–1,271	241–454	562–1,052
Oceania	31–51	61–99	28–47	55–92
South America	1,104–1,777	679–1,106	1,000–1,673	481–908
Total	8,702–14,024	10,659–17,232	7,696–13,018	8,886–15,459

DISCUSSION

Illicit trade, including in fish and seafood products, poses economic and social risks to societies worldwide, as it circumvents established and agreed upon national and international rules of corporate and business responsibilities and behavior, economic activities, trade, and taxation (17). In the first instance, illicit trade and the associated illicit financial flows divert money from the legitimate economy, thus imposing losses to law-abiding citizens and businesses and depriving countries of legitimate national revenues (18). This deprives countries of urgently needed resources to provide services to their citizens. Second, illicit trade in fish and seafood products can contribute to the depletion of a region's fish catch if the catches that enter illicit trade (here, a fraction of unreported catches) are not accounted for during the scientific evaluations or assessments of stocks and the affiliated fisheries management actions.

Table 2. Economic impacts. Average annual economic, income, and tax revenue impacts of likely illicit trade in seafood over the past decade of total reconstructed catch data (2005–2014) for two scenarios of assumed fractions of unreported catches being redirected to illicit trade. Both scenarios assume that 50 to 80% of unreported industrial landed catches are being redirected to illicit trade, while the fractions of artisanal unreported landed catches range from 30 to 50% and 10 to 30% for scenarios 1 and 2, respectively.

Geographic region	Scenario 1			Scenario 2		
	Economic (US\$ × 10 ⁶)	Income (US\$ × 10 ⁶)	Tax revenue* (US\$ × 10 ⁶)	Economic (US\$ × 10 ⁶)	Income (US\$ × 10 ⁶)	Tax revenue* (US\$ × 10 ⁶)
Africa	8,612–13,877	2,061–3,322	939–1,513	7,626–12,892	1,826–3,086	832–1,406
Antarctica and sub-Antarctic	3.0–4.7	0.8–1.2	0.2–0.3	3.0–4.7	0.8–1.2	0.2–0.3
Asia	12,520–20,255	3,329–5,386	989–1,600	10,284–18,019	2,735–4,792	812–1,423
Europe	3,506–5,651	854–1,376	217–350	3,092–5,237	753–1,276	192–325
North America	2,747–4,473	952–1,550	209–340	1,978–3,703	686–1,284	150–281
Oceania	201–323	45–72	17–28	178–301	40–67	16–26
South America	1,392–2,267	380–619	185–301	987–1,862	270–509	131–247
Total	30,591–49,455	8,207–13,268	2,651–4,286	25,503–44,367	6,842–11,903	2,210–3,845

*Note that this table uses the variable tax rates by region. Each region has an average tax rate reported at <https://home.kpmg/xx/en/home/services/tax/tax-tools-and-resources/tax-rates-online/corporate-tax-rates-table.html>.

Table 3. Curbing illicit trade. Suggested options to curb illegal fishing and the associated illicit trade in marine seafood.

Focal area	Governments	Industry
Improve transparency	Mandatory Automatic Identification System (AIS)/Vessel Monitoring System (VMS) on all commercial fishing vessels	Publicly commit to 100% AIS/VMS coverage on all vessels
	Mandatory observer coverage using video monitoring systems	Publicly commit to 100% observer coverage
	Mandatory International Maritime Organization (IMO) ship identification number scheme to empower identification of beneficial ownership and vessel history	Publicly commit for all vessels
	Maintain a public database of all fishing records	
	Publish rules/regulations in plain language and on easily accessible platforms for public and industry utility	
	Reduce the number of countries registering vessels as flags of convenience	Publicly commit to avoid flags of convenience and flag hopping
		Publicly commit to whole-of-industry supply chain accountability
Policy	Ratify and enforce the 2012 Cape Town Agreement*	
	Ratify and enforce the 2009 Port State Measures Agreement†	
	Design and implement an international standard policy for transshipment practices	Publicly commit to rapidly phase out all transshipments
	Apply market sanctions to encourage all flag states to join relevant fisheries agreements	
	Require insurance companies to only insure vessels that are not on any IUU list and restrict fishing access to insured vessels	
		Full and transparent accounting of all species and locations fished by every vessel in annual shareholder and Annual General Meeting reports
Enforcement	Criminalize illegal fishing practices in all countries	
	Apply innovative approaches to monitor and enforce national waters, e.g., Tanzania/Sea Shepard partnership	
	Establish and strengthen inter-agency cooperation	
	Reduce corruption along the fisheries value chain	

*See Pew Charitable Trusts, “The Cape Town Agreement” (2017). †See (23).

This study suggests that as much as 7.7 to 14.0 million metric tons per year of unreported catches may be diverted to illicit trade systems globally. To put this into a more general perspective, the potential loss to the legitimate trade system of global marine fisheries catches due to likely diversion into the illicit trade network is equivalent to losing 12 to 22 million mature cows in weight annually. This represents a substantial amount of animal protein that may be traded illicitly.

It has been argued earlier in the literature that the social impacts of illicit trade of marine fish catch in Asia are substantial, resulting in food and nutritional insecurity, loss of jobs, and loss of income to local fishers and economies (19). Our study provides more comprehensive estimates supporting these claims, revealing large catch, revenue, economic, and income losses to the formal economies and governments in Asia and elsewhere.

Furthermore, overfishing of stocks due to illegal and unreported fishing can also reduce the benefit flow to those fishers that fish legally and transparently (20), and this affects their societies and countries negatively. While not all unreported fishing is illegal, unreported as well as illegal catches are often unaccounted for in the formal fisheries stock assessments that inform fisheries management actions in many countries. Basing such assessments on incomplete and especially underreported catch volumes and fishing effort due to unreported and/or illegal fishing activities can result in incorrect estimates of total fishing mortality in affected fisheries. This can result in erroneous management advice and action, leading to overfishing and reductions in stock productivity, which, in turn, reduces the obtainable yields that can be maintained. This ultimately leads to losses in revenue and employment in the fishing sector. Given that our estimates of economic impact of illicit trade do not explicitly capture this effect, the current estimate of losses is likely to be conservative.

Our estimates of the fraction of unreported catches that may enter the illicit trade network were based on estimates of such numbers in forestry product trade (21). We relied on this information to guide our estimates because illicit forestry trade is better documented compared to fisheries (21). Given that seafood is more transportable and easier to hide than forestry products, it is possible that illicit seafood trade may attract even higher fractions of unreported catches than were used here. Thus, this adds to the likely conservative nature of our estimates.

We have demonstrated here that the global illicit trade in marine fish catch may lead to losses to society that can be measured in billions of dollars each year. Given the wide range of likely impacts on fish stocks, peoples' livelihoods, jobs, and incomes, as well as the broader economic and government revenue impacts of illicit trade in seafood, tackling this issue is crucial and urgent. Just like other illegal and illicit trade activities (22), illicit trade in fish and seafood products makes a small number of operators and businesses rich, at the expense of the wider community and society. Substantially improved transparency and accountability, including whole-of-industry supply chain accountability, are urgently needed (Table 3). This transparency and accountability needs to run from "net to plate" and thus calls for improved accounting of fisheries catches and landings (17).

In addition to value and supply chain accountability and transparency, urgently required and applied policy options include ratification and enforcement of various existing international agreements (23), addressing fish laundering via transshipment operations, granting fishing access permission only to vessels that are insured by marine insurance companies that exclude any IUU-listed vessel through

transparent due diligence (24), and stepping up collaborative enforcement activities across all on-the-water activities between countries (Table 3) (24–26). Only through full accountability and public transparency can we ensure not only that fish resources are sustainably and legally caught and traded but that the benefits of this economic activity accrue to the people and governments of each country where fisheries occur.

MATERIALS AND METHODS

Global catches by reporting status and fishing sector

For our analysis, we used the globally reconstructed catch data of the Sea Around Us (12), freely available at www.searoundus.org, which complements the officially reported landings data reported by the Food and Agriculture Organization of the United Nations (FAO) on behalf of countries. These data provide comprehensive estimates of all unreported catches for all maritime countries from 1950 to 2014 (27). Reconstructed estimates of unreported catches are based on country-specific secondary data and information sources (i.e., peer-reviewed studies, grey literature reports, and local expert knowledge) that provide data in space and time on catches that are not included in official data records for various reasons, such as many small fishing vessels having little or no reporting requirements, or countries lacking financial or staff resources for monitoring and recording of catches. The data sources used in the reconstruction of catches were carefully vetted for reliability and then used to conservatively extrapolate, where necessary, to country-wide time series estimates of unreported catches. At the time of writing, more than 100 country reconstructions have been published in the peer-reviewed literature, with numerous more currently in the publication pipeline. The catch reconstruction approach, while initially misunderstood, e.g., (28) but see (29), is now well established and recognized as a useful approach to derive data that are complementary to official records (30, 31). While some details of earlier reconstructions were criticized (32), these concerns were addressed (33). Overall, the process and data sources used for reconstructing unreported catches are an open and ongoing process, and the Sea Around Us welcomes collaborations to continuously improve and refine these estimates.

Defining and estimating illicit trade in seafood

Following Sumaila (34), we defined illicit trade in marine fisheries resources as trade that involves money, goods, or value gained from a portion of the unreported fishing of stocks by foreign and domestic industrial fishing fleets, and a fraction of unreported catches by artisanal fishing vessels that catch fish for commercial purposes. Thus, we equated a fraction of "unreported" fisheries activities with illicit trade and argued that not reporting on catches can, but not necessarily has to, equate to potential illicit trade activities. This differentiation is particularly important to note in the case of small-scale artisanal, subsistence, and indigenous fisheries, which often may be legal and legitimate but whose catches are variously not reported or underreported in official statistics (8, 12). Furthermore, we excluded unreported catches by the noncommercial sectors, i.e., subsistence and recreational fisheries. This is because subsistence fishing is defined as primarily for self, family, and community consumption or local barter and exchange, while recreational fishing is defined as primarily for pleasure, and thus, most of the subsistence and recreational catches are deemed to not enter the market or trade networks (27). In the case of the artisanal sector (defined as small scale and commercial),

part of their catch, e.g., of highly valuable and often poorly monitored species such as tuna and sea cucumbers, are traded and sold in the international market, and therefore, some fraction of unreported catches of this sector can be assumed to potentially enter the illicit trade in marine resources.

We summarized average annual global landed catches and the associated landed value by reported and unreported components of the commercially focused artisanal and industrial sectors while combining the noncommercial subsistence and recreational sectors into a single “noncommercial” entry over the most recent decade with comprehensive data, i.e., 2005–2014 (Table 4). As indicated above, we excluded the noncommercial fisheries components (subsistence and recreational) from further economic analysis while recognizing that some catches from these sectors may still end up in trade networks. Note that we only used landed catch data and did not consider discarded catches. Discarding is a wasteful practice in terms of ecological impact on populations, habitats, and sustainability and carries substantial economic loss associated with it, in terms of forgone revenue options, as well as forgone protein benefits from discarded fish. We also excluded catches taken in the high seas, i.e., in waters beyond national jurisdiction, because they comprise less than 5 to 10% of total global catches (35), and the effects of illicit trade from these catches cannot easily be attributed to specific countries.

Furthermore, to remain conservative in our estimates, we assumed that only unreported catches may contribute to illicit trade. Although properly reported catches may end up entering the illicit trade system, we considered it more likely that much of the illicit trade originates from unreported catches, but recognized that this assumption requires further examination in the future. To remain even more conservative, we assumed that only 50 to 80% of unreported industrial catches contribute to illicit trade. Because of a lack of specific data on how much of the artisanal catch actually enters the international trade networks, and especially how much unreported artisanal catch may enter illicit trade, we proposed two scenarios regarding the fraction of unreported catch from the artisanal sector that may enter the illicit trade market. In scenario 1, we assumed that a range of 30 to 50% of unreported artisanal catch enters the illicit trade market, while in the more conservative scenario 2, we assumed a range of 10 to 30%.

We informed our assumptions of the percentage of unreported catches that may enter illicit trade networks on information from the forestry sector. The percentages we applied correspond to similar

estimates for illegal logging in tropical countries. The numbers applied cover 50 to 90% of the volume of all forestry outputs in these countries (5), which is comparable to our 50 to 80% of unreported industrial catches. The lack of data for artisanal operations in both fisheries and logging is often due to lack of regulatory frameworks for the small-scale sector, and according to Hoare (36), this is a key factor in high levels of illegality in small-scale logging operations. Hoare (36) estimated that 10% of the total timber production in Cameroon in 2000 was small scale and illegal but that this had grown to 50% by 2012. Although this estimate is specific for Cameroon, Hoare (36) also found high levels of illegal small-scale production in Brazil, Indonesia, Papua New Guinea, Republic of the Congo, Democratic Republic of Congo, and Ghana. Thus, we considered that our 10 to 30% and 30 to 50% ranges of unreported artisanal catches potentially entering the illicit trade could be considered conservative.

Quantifying the magnitude and impacts of illicit trade in economic terms

Economic losses

We used two measures to capture the basic direct economic losses to the legitimate (formal) economy of countries from likely illicit trade. The first is the quantity of unreported catches by industrial and artisanal fishing fleets, both domestic and foreign that is assumed to contribute to illicit trade. The second measure is the landed value of the fraction of unreported catch (i.e., the gross revenues) that is assumed to be traded illicitly.

The quantity of reported and unreported landed catches (Table 4; i.e., excluding discarded catch) is taken from the open-access Sea Around Us database (www.seaaroundus.org), which presents the data from a decade-long effort by ~400 international collaborators to complement officially reported catch statistics with the best and most comprehensive estimates of unreported catches of marine fish for every country in the world (12). We combined the assumed-illicit fraction of unreported landed catches (Table 4) with data from another decade-long effort by the Fisheries Economics Research Unit (<https://feru.oceans.ubc.ca/>) at the University of British Columbia and the Sea Around Us that compiled and estimated ex-vessel fish prices worldwide (37–38) to calculate both the landed value of these catches and the loss of gross revenues to the formal economy of each country and geographic region (table S1).

Table 4. Catches. Reported and unreported landed catch and associated landed value by fishing sector for all maritime countries in the world, averaged over the 2005–2014 period. Discarded catches are excluded.

2005–2014	Landed catch ($t \times 10^3 \times \text{year}^{-1}$)				Landed value ($\text{US\$} \times 10^6 \times \text{year}^{-1}$)			
	Industrial	Artisanal	Noncommercial	Total	Industrial	Artisanal	Noncommercial	Total
Reported	57,915	16,845	687	75,447	71,751	30,950	940	103,642
Unreported	14,385	5,031	3,389	22,806	15,999	8,865	6,374	31,238
Total	72,300	21,877	4,076	98,253	87,750	39,815	7,314	134,880
% Unreported	63	22	15		51	28	20	
Scenario 1: % Unreported as illicit	50–80	30–50	0		50–80	30–50	0	
Scenario 2: % Unreported as illicit	50–80	10–30	0		50–80	10–30	0	

Economic and income impact losses to the legitimate (formal) economy due to illicit seafood trade

To provide a broader picture of the likely loss to the formal economy due to illicit trade in marine resources, we computed three additional broad potential impacts: (i) economic, (ii) income, and (iii) tax revenue impacts as a result of illicit trade in fish catch as estimated here. Economic impacts capture the added value through the fish value chain generated from the revenues earned from fishing. This includes the impact on economic activities such as fish processing, boat building/maintenance, equipment supply, and the restaurant sector. To calculate this impact, we multiplied the estimated gross revenue losses (i.e., landed value of catch likely going to illicit trade) by the economic impact multiplier, which allowed us to capture the overall impact of likely illicit trade on the economy as a whole, for each coastal country reported by Dyck and Sumaila (39) (see table S1).

Income impact is a measure of the amount of household income that is generated through the fish value chain when a given quantity of fish is caught and sold in the market. We computed the income impacts of unreported fish catches likely entering the illicit trade system by multiplying the gross revenue losses (i.e., landed value of catch likely going to illicit trade) by the income multipliers of the fisheries sector, which measure the impact on household incomes, as reported by Dyck and Sumaila (39) see (table S1).

Tax revenue impacts of illicit trade in fishery resources are defined as the tax revenues that coastal country governments had to forego but could have earned if illicit trade in the marine resources did not exist, based on the fraction of their catches estimated to enter the illicit trade system. This was calculated by multiplying the corporate tax rate for each country [(40); see table S2] by the gross revenues from the fraction of unreported catches assumed to enter the illicit trade system estimated above. Where the individual country's corporate tax rate was not available, a regional average corporate tax rate was used.

The equations below summarize how we computed the above three impact indicators of the economic effects of illicit trade in marine fish catch

$$\text{Economic impact} = R * m \quad (1)$$

$$\text{Income impact} = R * w \quad (2)$$

$$\text{Tax revenue impact} = R * t \quad (3)$$

where R , m , w , and t represent the gross revenue, economic multiplier, income multiplier, and the tax rate, respectively. R (gross revenue or landed value) is given in Table 1, m and w are presented in table S1 based on Dyck and Sumaila (39), and each country's corporate tax rate, t , and the associated tax revenue loss for the country under scenarios 1 and 2 are presented in table S2. For clarity, we also presented all catch losses and revenue losses from our study and from previous estimates of illegal fishing by Agnew and colleagues (2), the Sea Around Us total landed catch (reported and unreported landings) and total landed value of commercial fisheries averaged over the same time period, and the FAO total landed catch averaged over 2005–2014 (table S3).

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at <http://advances.sciencemag.org/cgi/content/full/6/9/eaaz3801/DC1>

Table S1. Catch, the economic and income multipliers.

Table S2. Corporate tax rate and revenue by country.

Table S3. Economic losses.

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Acknowledgments: We thank all former and current Sea Around Us and Fisheries Economics Research Unit members for their contributions to the underlying databases to this work over the past two decades. **Funding:** This is a product of the Fisheries Economics Research Unit, the OceanCanada Partnership and the Sea Around Us at the University of British Columbia, and the Sea Around Us—Indian Ocean at the University of Western Australia. This work is supported by the Social Sciences and Humanities Research Council of Canada, the Oak Foundation, Marisla Foundation, MAVA Foundation, Paul M. Angell Family Foundation, David and Lucile Packard Foundation, Bloomberg Philanthropies, Oceana, and the Minderoo Foundation. None of the funders had any input, direction, or say on the topic, analyses, or manuscript. **Author contributions:** U.R.S., D.Z., and D.P. conceptualized and framed the study. U.R.S., L.H., Y.L., and M.L.D.P. extracted and prepared the various data being used. U.R.S. and L.H. conducted the data analyses. U.R.S., L.H., and D.Z. drafted the manuscript. U.R.S., L.H., D.Z., M.L.D.P., Y.L., and D.P. revised and edited the final manuscript. **Competing interests:** The authors declare that they have no competing interests. **Data and materials availability:** All data underlying the analyses are freely available via www.seararoundus.org or presented in the Supplementary Materials.

Submitted 5 September 2019

Accepted 6 January 2020

Published 26 February 2020

10.1126/sciadv.aaz3801

Citation: U. R. Sumaila, D. Zeller, L. Hood, M. L. D. Palomares, Y. Li, D. Pauly, Illicit trade in marine fish catch and its effects on ecosystems and people worldwide. *Sci. Adv.* **6**, eaaz3801 (2020).