ENVIRONMENTAL STUDIES

Tracking elusive and shifting identities of the global fishing fleet

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Illegal, unreported, and unregulated (IUU) fishing costs billions of dollars per year and is enabled by vessels obfuscating their identity. Here, we combine identities of ~35,000 vessels with a decade of GPS data to provide a global assessment of fishing compliance, reflagging patterns, and fishing by foreign-owned vessels. About 17% of high seas fishing is by potentially unauthorized or internationally unregulated vessels, with hot spots of this activity in the west Indian and the southwest Atlantic Oceans. In addition, reflagging, a tactic often used to obscure oversight, occurs in just a few ports primarily by fleets with high foreign ownership. Fishing by foreign-owned vessels is concentrated in parts of high seas and certain national waters, often flying flags of convenience. These findings can address the global scope of potential IUU fishing and enable authorities to improve oversight.

INTRODUCTION

Sustainable fisheries are increasingly recognized for their vital role for food supply and nutrition, economic development, and the well-being of millions of people around the world (*1*). Achieving sustainable fisheries has been challenged by illegal, unreported, and unregulated (IUU) fishing, which may account for as much as one of every five fish landed (*2*, *3*) with an estimated annual loss ranging from \$26 billion to \$50 billion to coastal and island states (*4*). IUU fishing has been known to target endangered species, use nonselective fishing methods, have high rates of bycatch of nontarget species, and be linked to human rights abuses (*5*–*7*). IUU fishing is also a potential source for conflicts (*8*–*10*), and the international community is increasingly focused on this global challenge (*8*, *11*, *12*).

An important element for abating IUU activity is to track the activity of all vessels at sea. Although this technology was unrealistic a decade ago, recent advances have put this tracking in reach. About 70,000 large commercial fishing vessels now broadcast their GPS positions via the automatic identification system (AIS), a transponder designed for safety at sea. These data include the majority of fishing vessels over 24 m long, allowing modern machine learning techniques to classify and monitor fishing activity globally (*13*, *14*).

Although AIS has helped reveal large-scale patterns of fishing activity (*15*) and economics (*16*), its use in combating IUU and assisting with fisheries management has been limited because AIS data alone do not provide complete vessel identity characteristics, and the detail they do provide can be manipulated. More robust information on vessel identity is generally found in vessel registries, but many states and fisheries management bodies do not publish registries, and for those that do, the information provided is often still limited, incomplete, inconsistent, or outdated. The Global Record of Fishing Vessels, Refrigerated Transport Vessels and Supply Vessels (Global Record) is an initiative that aims to provide a single access point for information on vessels used for fishing and fishing-related activities with the primary objective being to combat IUU fishing by enhancing transparency and traceability. Hosted by the Food and Agriculture Organization of the United Nations (FAO), it represents a powerful tool to address this implementation gap once it is fully populated (see section S1). The Global Record is currently in the first development phase and is not fully populated. As a result, comprehensive vessel information that links the activity of specific vessels to vessel characteristics, history of registration, license to fish, and vessel ownership is lacking in the public domain.

This vessel identity challenge is especially important because of the strong relationship between IUU activity and vessels that recurrently change their name, flag state, or owner (*17*). While there are legitimate reasons for a vessel to change its identity, vessels with multiple identity changes are more likely to have engaged in IUU fishing (*17*–*20*), and abusive reflagging, or "flag hopping," is one way that operators avoid oversight (*12*, *21*–*24*). One solution to tracking changes in identity would be to mandate a unique identifier for each fishing vessel hull, much as merchant vessels are often required to be assigned a unique, seven-digit International Maritime Organization (IMO) number that stays with a vessel even if other aspects of its identity change (*25*). Unfortunately, IMO numbers are required for only a subset of industrial fishing vessels, and no globally unique identifier for fishing vessels exists.

To address the gap in our collective ability to track changes in the identities, authorizations, and ownership of the commercial fishing fleet, we combine historical and current information from over 40 public vessel registries and use fuzzy logic to match it to a decade of vessel tracking data (see Supplementary Text, figs. S1 to S4, and tables S1 to S3) (*26*). For many of these registries, we obtained multiple versions, each corresponding to a different time range or temporal "snapshot," thus allowing analysis of how these registries change over time. These registries contain both fishing vessels and fishing support vessels, which include refrigerated cargo vessels that engage in transshipment and bunker vessels that assist with refueling at sea, hereafter referred to as support vessels (*27*). Although most of these registries provide incomplete information, in combination, they provide detailed, dynamic insight into the identities of the global fishing and support fleet. This information,

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combined with GPS data, can track vessels from shipyard to ship graveyard, reveal potentially unauthorized fishing activity, and reconstruct vessel history to map patterns of reflagging. Enhancing our understanding of vessel identity dynamics can support governments in tackling IUU fishing and better managing fisheries to protect one of the world's most economically and culturally vital resources.

RESULTS

Unidentified, unauthorized, unregulated fishing

From vessel registries and AIS data, we matched the identities of about 33,000 fishing vessels and 2000 support vessels, which account for approximately 40% of all fishing-related vessels using AIS (Fig. 1A). The vessels with matched identities accounted for about 74% of all fishing activity by vessels with AIS and for more than 90% of the activity by non-Chinese vessels with AIS. The Chinese fleet, which accounts for over half the global fishing vessels in AIS, had an overall low rate of matching (8%) due to a lack of information about the domestic fleet that does not leave Chinese waters. For the Chinese distant water fleet, however, which fishes in the high seas and other countries' waters, about 50% of the vessels could be matched to AIS (fig. S5).

Fishing by vessels broadcasting AIS but unmatched to registries, referred to here as "publicly unidentified" fishing activity, is concentrated in four regions of the world including East Asia, the Indian Ocean, South America, and West Africa (Fig. 1B). These regions lack publicly available information largely because few vessel registries are published (e.g., China, Republic of Korea, and Brazil) or identity information from AIS or vessel registries is incomplete (e.g., Sri Lanka and Australia). In contrast, fishing activity in much of the high seas and the waters around Europe and North America is matched to publicly available registries.

In 2021, on the basis of public records from regional fisheries management organizations (RFMOs) responsible for managing the high seas, about 17% of fishing hours on the high seas was conducted by vessel identities that were either not publicly authorized or were internationally unregulated (Fig. 1C). For general fishing, when a given vessel is not on the list of authorized vessels at a given time in any of the RFMOs whose convention area overlaps with the fishing position, we consider it "potentially unauthorized." If the vessel operated in one of the few regions of the high seas where no RFMOs regulate fishing, then we consider it "internationally unregulated." Whether fishing by some of these vessels was truly unauthorized cannot be known, as public records may be incomplete or outdated, and in some regions, fishing is simply not internationally regulated, such as in the squid fisheries of the Indian and Atlantic oceans (although the fishing may be unilaterally regulated by national authorities). In contrast, tuna fishing has been internationally regulated by RFMOs for up to 70 years, but fishing with unverifiable authorization is still three times more common in the convention area of the Indian Ocean Tuna Commission than in the other tuna RFMOs (figs. S6 and S7). Overall, in the west Indian and southwest Atlantic oceans, about 30 and 80% of the fishing, respectively, is not authorized in public records, which is three and eight times more common than in the rest of the high seas regions. Note that even if vessel identities are matched to authorization lists, the vessels are only potentially authorized, as we can verify only that they were authorized to fish in that region and cannot verify that they were compliant with regulations on target species or catch quantities.

History of vessel identity

In our analysis, a vessel identity is a collection of identity characteristics associated with a hull for a fixed period of time. A vessel hull is a collection of vessel identities that are all linked to the same physical entity and captures how a singular hull changes names, flags, ownership, and more over time. Of the roughly 35,000 unique hulls in our data, roughly 6000 changed identities in the past decade; about 200 hulls changed identities three or more times. Over a third of the hulls in our data have at least one identity that we successfully associated with the hull despite missing a listed IMO number, which is currently the only global unique identifier for vessels (fig. S8).

This tracking of identities reveals where ships are built and scrapped. Although most vessels may be built in East Asia, Europe, and North America, certain states outside these regions are known destinations for ship breaking, with India, Bangladesh, and Turkey being the most frequent destinations (fig. S14). The identity changes of one vessel, whose final name was "Ocean Star 96," are shown in Fig. 2. This vessel changed identity three times since 2012, with the final name identified near a known ship-breaking site in Bangladesh before it disappeared from our dataset. This vessel was photographed beached in Chattogram, Bangladesh, waiting to be dismantled (fig. S15). The vessel was also suspected to have engaged in unauthorized transshipment and forced labor (*28*).

Patterns of reflagging

Our analysis also reveals how hulls change identities, particularly with regard to changes in flag. Reflagging was much more common in support vessels (28% of vessels reflagged) than fishing vessels (3%). Although reflagging involved 116 flag states, 20% of the flag states were responsible for about 80% of all reflagging over the past decade (*26*), with most reflagging occurring in Asia, Latin America, Africa, and the Pacific Islands (fig. S9). Among those, Panama was the most active in flag changes (both as previous flag and destination flag, mostly for support vessels), while the Russian Federation was the top destination of second-hand vessels (Fig. 3, A and B, and figs. S10 and S11). Support vessels were more likely than fishing vessels to be reflagged with "flags of convenience" reported by the International Transport Workers' Federation (ITF).

Reflagging behavior is also more common for fleets with higher rates of foreign ownership (those flying flags different from the nationality of their owners). Foreign ownership and reflagging at the flag state level are positively correlated (Fig. 3C), and the 20 states with the highest rates of reflagging have percentages of foreign ownership over five times greater than all other flag states (55.1 versus 10.2%). Moreover, 18 of the states in the top 20 for either foreign ownership or reflagging (red squares in Fig. 3C) correspond to flags of convenience reported by the ITF as of October 2021 (table S4).

Fishing vessels with foreign ownership are concentrated in a few regions of the ocean (Fig. 3D), often with foreign-owned vessels flagged to the exclusive economic zone (EEZ) in which they fish. In the southwest Pacific, the vessels are often owned by entities in Chinese Taipei but flagged to other states, mainly Vanuatu (fig. S12). In the northwest Indian Ocean, including within the

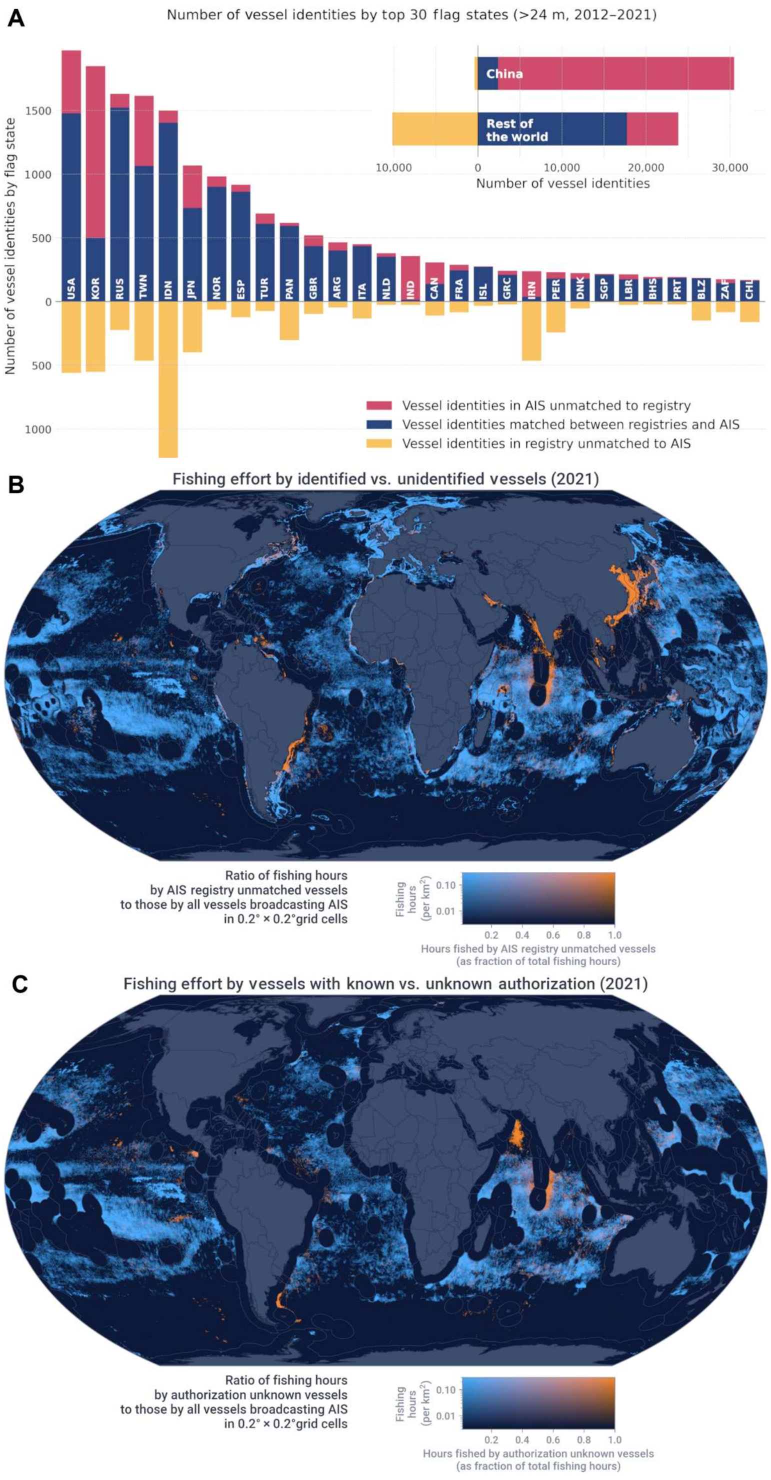

Fig. 1. Publicly unidentified and potentially unauthorized fishing. (**A**) For the top 30 flag states (in ISO-3166 country code, China being the first) during 2012–2021, number of fishing and support vessel identities estimated to be larger than 24 meters. Color codes correspond to (i) vessels identities matched between registries and AIS (blue), (ii) vessels identities present in AIS data but unmatched to registries (red), and (iii) vessels identities recorded in registries but unmatched to AIS data (yellow). These unmatched registry records (yellow) largely represent vessels unequipped with AIS devices but may also be due to discrepancies between identity fields in AIS and registries. See Fig. 3 for ISO-3166 country codes. (**B**) Fishing effort by vessels whose identity can be correlated to registry records. (**C**) Fishing on the high seas by vessels with known versus unknown authorization.

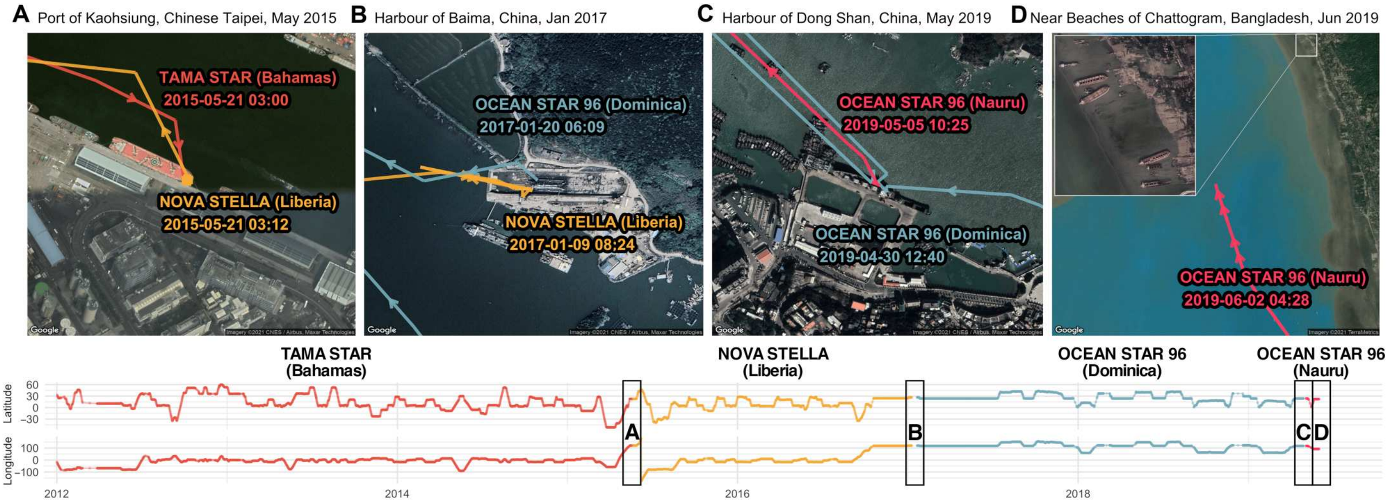

Fig. 2. Tracking changes of vessel identity. (**A** to **D**) Vessel identities associated with a hull with Vessel Record ID: IMO-8517358|IOTC-16188|WCPFC-11359 and four Google Maps providing geographical contexts of where the permanent changes in the identity of the hull take place, allowing for monitoring identity changes of individual vessels. AIS data also provide the vessel's track from January 2012 to June 2019, when the vessel beached at Chattogram, Bangladesh to be scrapped (fig. S15). Our data also indicate that the vessel was built in Toyama, Japan, in 1987.

Kenyan and Seychelles EEZs, tuna longliners are often flagged to the Seychelles but owned by Chinese Taipei nationals. In Argentina and the Falkland Islands (Malvinas), the owners of these vessels are largely based in Spain or China. In the West African EEZs, from Senegal down to Angola, Spanish nationals own the highest number of vessels, nearly all of them purse seiners, but here, most are not flagged to a West African state but instead to countries such as Curaçao, Belize, and Panama.

Most reflagging takes place in a few selected ports, with half of the reflagging occurring in just 10 port states (Fig. 4A). In some ports, most prevalent in East Asia, West Africa, and Eastern Europe, vessels reflag from one flag to another, neither of which corresponds to that port. This "foreign reflagging" occurs most commonly in Las Palmas de Gran Canaria (Spain), Busan (Republic of Korea), Zhoushan (China), and Kaohsiung (Chinese Taipei). The top port, Las Palmas, despite being in Spain, is used largely by non–EU-flagged vessels to reflag to non-EU flags. The foreign reflagging also has a higher tendency to occur in support vessels than fishing vessels (fig. S13). We also found that some ports are used more frequently by specific flags. For instance, while vessels using the port of Las Palmas reflag to a diverse set of foreign flag states, the vessels using the port of Busan primarily reflag to Russia (all vessel types), and vessels using the port of Zhoushan primarily reflag to Panama and Kiribati (mostly support vessels; Fig. 4, B to D). We also note that some reflagging occurs outside ports (>10 km from the nearest port in our database) and some even in the high seas. This relationship between reflagging and ports does not necessarily indicate the ports' involvement in reflagging but provides information about geographical patterns of reflagging practices.

Reflagging often occurs just before the vessel is to be scrapped. The most common flags of vessels to be scrapped are those of Russia, Panama, and the Bahamas, and the end points of their tracks correspond to major ship-breaking sites in India, Bangladesh, and Turkey (fig. S16). In many cases, the timing of reflagging suggests that the final flag was flown simply to enable the decommissioning and scrapping of the vessel. Of vessels that reflagged before being scrapped in these three states, half of them stayed with their last flag for less than 100 days and some as short as a week, and all were flags of convenience defined by the ITF. The average time these vessels held their last flags is about a month, in stark contrast to the four-year average for holding their immediate previous flags.

DISCUSSION

For monitoring global fishing fleets and addressing IUU fishing, the ability to track vessels when and where they change identities represents a major step forward. Although publicly available information is often limited, fragmented, and inconsistent, by collecting and consolidating disparate registries over time, we can improve data quality, fill existing data gaps, and help create a single reference for vessel history (figs. S3 and S4). Operators engaged in IUU fishing will then find it far more difficult to conceal past wrongdoing or avoid oversight. More specifically, this improved data can be useful in identifying individual vessels fishing without proper authorization records (the "I" part of IUU fishing) and/or operating in areas where no proper conservation and management measures exist (the second "U" part of IUU fishing).

The potentially unauthorized or internationally unregulated fishing vessels identified in this study deserve close attention. About one-sixth of high seas fishing can be categorized as such, and because of gaps in global adoption of AIS, the true amount of potentially unauthorized or internationally unregulated fishing may be even higher. The rates of questionable fishing are particularly high in the west Indian Ocean, which also scores poorly on management indicators (*29*), and the southwest Atlantic Ocean, which corresponds to the areas in which multiple nongovernmental organizations have recommended regional governance systems (*30*, *31*). While it is possible that some of this fishing may turn out to be authorized, our analysis can help authorities monitor areas at high risk of IUU fishing and optimize enforcement capacity.

The strong relationship between reflagging, foreign ownership, and flags of convenience also warrants further investigation, with

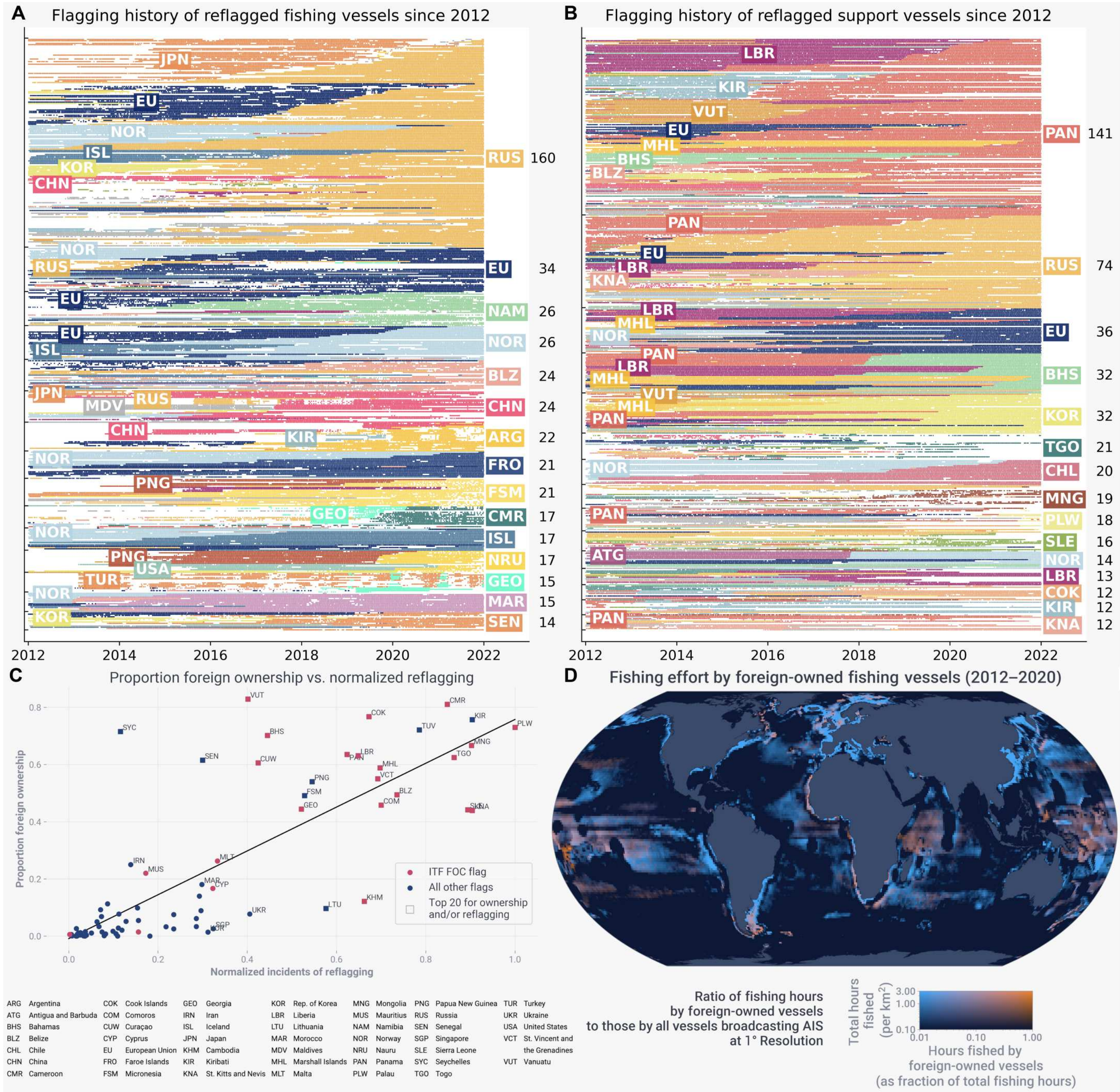

Fig. 3. Patterns of reflagging. As of 1 January 2022, flagging history of (**A**) fishing and (**B**) support vessels flying the top 15 flags each by the number of vessels. Each horizontal line with dots corresponds to a vessel hull, and each dot represents whether the vessel was active in a given week. Each dot is color-coded by flag that the vessel flies at a given time between 2012 and 2021. On the right are ISO-3166 country codes of the top 15 flags, and the numbers next to them indicate the number of vessel hulls. European Union Member States are grouped together under EU. (**C**) Regression analysis of the proportion of foreign ownership for a flag versus incidents of reflagging normalized by the number of distinct vessels (R^2 = 0.65). Only the top 50% of flags by the number of identities registered to that flag from 2012 to 2020 are included. Flags of convenience reported by the ITF are in red, and flags in the top 20 for either foreign ownership or reflagging are marked as squares. (**D**) Number of estimated hours fished by vessels with foreign owners as a proportion of the total fishing.

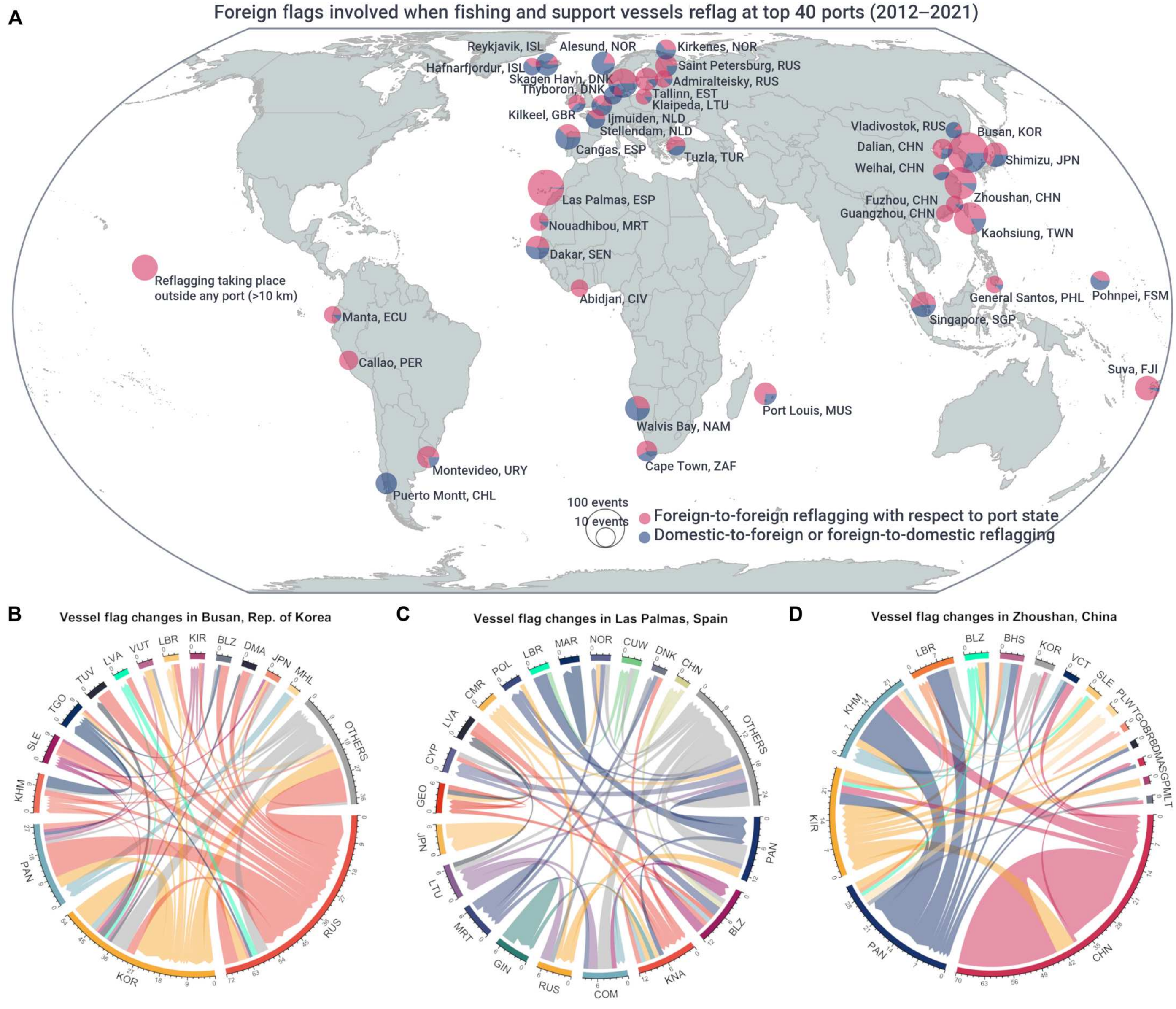

Fig. 4. Reflagging patterns at ports. (**A**) The top 40 ports where most reflagging practices involving at least one foreign flag are identified. The size of the circle indicates the number of instances. Blue represents reflagging instances involving one foreign flag and one national flag (either previous flag or destination flag), whereas red indicates reflagging between foreign flags with respect to the flag of the port. (**B** to **D**) Each diagram represents the flow of reflagging among flag states (from the previous flag to the destination flag with a weighted arrow) at the top three foreign reflagging ports (identity changes from national flag to national flag are included for comparison). See Fig. 3 for ISO-3166 country codes.

a focus on just a few ports and between vessels flagged to a small subset of states. This information is critical for port states, because, for all foreign vessels requesting port entry, nearly 100 states are required by the FAO Agreement on Port State Measures to collect and cross-check information on compliance with relevant conservation and management measures. High rates of fishing by foreign-owned vessels are not necessarily alarming when properly regulated and monitored, but in some regions, widespread fishing by vessels with foreign ownership suggests risks of IUU fishing (*32*), and targeted regulation of foreign-owned vessels may allow flag states to address IUU in a way that allows fish stocks to recuperate while limiting impacts to domestic fisheries (*33*). Transparency on IUU issues is further limited when the listed owners are shell companies, with the true owner that profits (the "beneficial owner") from the fishing being a different entity; as a result, the actual rate of foreign ownership is likely higher than presented here (*26*). Other problems arise when reflagging to flags of convenience just before delivering the ship to ship-scrapping sites in nations where regulations for environmental pollution are lax (*34*), raising concerns about the effectiveness of ship recycling regulations.

This study and its publicly available dataset can help flag states fulfill important responsibilities in the management of fishing vessels. FAO recommends that flag states follow rigorous registration procedures, for example, which requires verifying vessel history and beneficial ownership, exchanging vessel information with other states and making the procedure accessible and transparent (*35*). Flag states also have a responsibility to determine whether there are pending investigations or sanctions that may provide a motive for reflagging. It is also recommended that flag states identify a genuine link between the beneficial owner and the vessel's flag (*36*–*38*). Several international agreements also require a flag state to effectively exercise its jurisdiction and control over all ships flying its flag, whether foreign or domestically owned (*34*, *35*, *39*–*41*). Because our dataset complements a state's vessel monitoring system, which generally does not monitor vessels beyond its jurisdiction, our data can support flag states in all of these endeavors. Recent research also shows that combining authorities' proprietary data with AIS is beneficial to a country's effort to monitor vessels flying flags of convenience (*42*).

This analysis represents a new era in public monitoring of vessel identity and activity. A fusion of global open datasets, powered by big data processes (for this study, we processed more than 100 billion GPS positions and consolidated information about 200,000 vessel identities), enables us to learn patterns from the past decade and improve the management of the world's current and future oceans. However, this study has limitations including lack of public vessel registries (which has great disparity at the national level, although the high seas are relatively well covered by registries published by RFMOs; see table S1) and unequal AIS coverage (between large and small vessels; most of the vessels >24 m are equipped with AIS, while only a small fraction of vessels <24 m use AIS, and due to variation of satellite reception quality by region). Nevertheless, this study provides a global view of shifting identities of the global fishing fleet by focusing on vessels on international voyage, prone to reflagging, and likely to fish in the high seas (see section S8 on data representativeness). Further improvement will come with improved public registries including FAO's on-going global initiative of Global Record, increased sharing of those registries (*12*), more AIS-equipped vessels [particularly in Southeast and South Asia (*14*)], and fewer "dark vessels" that broadcast AIS only infrequently (see section S7 on caveats of the data and analysis) (*43*), but the activity of the world's commercial vessels can now be largely identified from the cradle to the grave. As more vessel information becomes available in the public realm, the easier it will be to demonstrate which vessels are compliant and which are rogue operators. Achieving transparency in global vessel identity and activity is an important step toward sustainable fisheries management and will drive fairer, smarter policies that protect fisheries and those whose livelihoods depend on them.

MATERIALS AND METHODS

Data collection

Information related to vessel identity from over 40 registries is available either in the public domain or from authorities and researchers, including registries from RFMOs, national registries, and lists curated by researchers (see sections S1 to S3 and tables S1 and S2). Each of the lists has been obtained regularly since early 2019 and supplemented, when possible, with historical data to provide snapshots of a registry and its vessels over time. Where available, we collected information on vessel identity, vessel characteristics, owner name, owner nationality, and fishing authorization.

The authorized period of fishing for a vessel is provided in most RFMO vessel registries. To compile the total authorized period of fishing for a given vessel, we used historical and regular (monthly, in general) snapshot information. For three RFMO registries that list only vessels authorized to fish at a given moment, we established an interpreted period of authorization since May 2019 by using the window of time in which a vessel appears consistently on the registry's monthly record. We considered a ship authorized if a gap shorter than three months occurred between two consecutive authorization periods, thus minimizing false positives, as a vessel is more likely to seek authorization continuously. Because vessels flagged to Chinese Taipei are not included in the authorized vessel list of the Indian Ocean Tuna Commission, we obtained that list of vessels from Chinese Taipei's fisheries administration.

We obtained owner information from sources that include some RFMOs and national vessel lists among others (see section S1). We also cross-checked owner information from the Global Integrated Shipping Information System (GISIS) that provides public information about vessels assigned an IMO number. We consider all the owner information in these sources registered owner information unless otherwise specified as beneficial owner information. In addition, Carmine *et al.* (*44*) provide the results of their extensive desktop research to manually determine likely beneficial owners of a few thousand vessels; we included their results. Our ownership analyses focus primarily on vessels that tend to operate on the high seas, as most of our ownership data are from those vessels.

Because the type of owner information in our data is inconsistently distributed, our analyses do not distinguish between registered and beneficial ownership. We assume, however, that the nationality of a beneficial owner is more likely different from a vessel flag than that of a registered owner. If a vessel is registered with a domestic owner, i.e., an owner in the same country as the vessel's flag state, then the beneficial owner, if different from the registered owner, could be either domestic or foreign. However, if a vessel is registered with a foreign owner, an owner in a country distinct from the vessel's flag state, then it is highly likely that the beneficial owner, if different from the registered owner, is also foreign, even if it may be in a different country than the registered owner. This assumption makes our analysis on foreign ownership conservative, as there might be more foreign ownership among beneficial owners.

Registry-AIS data match

Vessel records from each registry were then matched to identity information from AIS messages based on how close a set of identity fields from two sources were to each other (see section S2). Once matched to AIS records, multiple records from different sources were aggregated to produce a synthesized identity using the most representative information about each vessel. Through this process, identity information was cross-checked across multiple registries, any missing data were filled in, and outliers were removed to increase the accuracy (see section S3 and figs. S3 and S4).

The processed records of vessels were then categorized into vessels that were (i) both registered and matched to AIS, (ii) registered but not matched to AIS, or (iii) not in a registry but active on AIS (see section S4). We then analyzed the activity of the matched vessels using fishing effort inferred by machine learning techniques (*13*) and compared the fishing effort by vessels matched to registries to that by unmatched vessels. To analyze the compliance of fishing operations, we compared the fishing activity of individual vessels with their corresponding spatiotemporal authorization data (see section S5).

Authorization period identified

To determine whether fishing is authorized at a given time and space, we used authorization data from RFMO registries in conjunction with fishing activity data from Global Fishing Watch's public fishing effort dataset (https://globalfishingwatch.org/data-download/datasets/public-fishing-effort). For general fishing, when a given vessel is not on the list of authorized vessels at a given time in any of the RFMOs whose convention area overlaps with the fishing position, we consider it potentially unauthorized. If the vessel operated in one of the few regions of the high seas where no RFMOs regulate fishing, then we consider it internationally unregulated. Therefore, our analysis of fishing activity with unknown authorization encompasses both potentially unauthorized and internationally unregulated fishing without being able to distinguish between the two.

For fishing of specific species, such as tuna and squid, we selected only vessel classes that are relevant to the species and cross-checked with the authorization data from RFMOs that regulate that species. For instance, we chose only vessels that are classified as drifting longliners, tuna purse seiners, trollers, and pole and liners by the convolutional neural network model presented by Kroodsma *et al.* (*13*). Fishing activity by these vessels was then compared to the authorization data from five tuna RFMOs. When historical authorization data were unavailable, we used an interpreted period of authorization based on monthly registry records. As the resolution of authorization is a month in this case, we considered that the authorized period of a vessel that appears in an RFMO registry on the first day of a month may be from the start of the previous month to the end of the given month. This interpretation makes our analysis more conservative, as its true authorization period could be shorter than the interpreted period.

Identifying vessel hulls

We combined three approaches (see below) to identify a vessel hull and assign a temporary unique identity called Vessel Record ID. Once identities that are associated with the same hull were determined, we assigned a Vessel Record ID that concatenates, in alphabetical order, all identifiers that a given vessel is associated with. These identifiers come from IMO numbers, registry identity numbers assigned by RFMOs, and national vessel ID numbers. If a vessel has no known identifiers in our dataset, its AIS number is assigned to the vessel as a sole identifier.

IMO number

We first identified the IMO number associated with a vessel identity by compiling all registry sources to which the given vessel was registered. We accepted the IMO number only when these registry sources consistently indicate the same number. In addition, IMO numbers use a checksum scheme that allows us to filter out any false IMO numbers from the data (*45*). We further screened out false claims of IMO numbers (registering with an IMO number assigned to other vessels or broadcasting AIS messages with others' IMO numbers) by cross-checking vessel names and flags associated with a given IMO number provided on the public GISIS website.

Registry identity scheme

In addition to IMO numbers, existing identity schemes adopted by various RFMOs and national registers provide opportunities to find vessel identities that share the same hull. For instance, the Western and Central Pacific Fisheries Commission (WCPFC) assigns an ID number to a vessel registered to WCPFC, and the number remains unchanged even though the vessel changes its identity. By linking all vessel identities that share at least one ID number from a registry, we create a network of identities that point to the same vessel hull. To link multiple identities, we used about 15 registry sources that have an existing identity scheme.

Permanent AIS identity switching

The lifespan of vessel identity on AIS has discrete start and end points, and most of these points correspond to positions at port, indicating that the start and end messages of a given vessel identity on AIS occur when vessel operators change their identity on their AIS device while docking at port. By pairing the end of the lifespan of a vessel identity on AIS to the start of the lifespan of another vessel identity on AIS, we find a pair of two identities that are from the same hull. As many vessels start and stop their AIS signal near ports, we should find the right pairs of identities that switch AIS. We constrained the pairing in such a way that the end of an identity and the start of another identity coincide within 30 m of each other and with a time gap of less than two months (to capture the cases when a vessel turns off its AIS for some time until the transfer of identity is completed while sitting at port). For the distance constraint (30 m), we used instances of identity switching of a vessel at port with identities reporting the same IMO numbers to determine the distance threshold (fig. S8).

Identifying patterns of reflagging

Reflagging takes place between two consecutive vessel identities when a vessel changes its flag and therefore its identity. We used Vessel Record IDs to identify vessel identities that were associated with the same hulls and then established the temporal order of these identities by drawing on their AIS activity ranges, oldest to newest. With this information, we first analyzed how reflagging was practiced across regions. Most reflagging occurs in Latin America, Europe, Asia, the Pacific region, and Africa, and these reflagging instances were from a flag in one of these regions to a flag in a different region (fig. S9), while reflagging in Europe was more commonly from one European flag to another. At a country level, this practice of reflagging is concentrated in a few fleets, and our data demonstrate that the top 20 flag states are responsible for about 80% of the total reflagging events (2601 of 3381) in the past decade.

Flag-level reflagging metrics

Reflagging metrics at the flag state level were generated by first identifying all vessel hulls that had ever been registered under a given flag. Next, each hull was classified as having reflagged if it had ever changed to or from that flag. Hulls that never changed flags from their original flags according to our database were classified as never having reflagged. To determine the proportion of each fleet involved and not involved in reflagging, the number of reflagged and non-reflagged vessels was normalized by the total hulls ever registered with a given flag during the duration of this dataset. We next minimized the bias that small flag states can have when using proportional metrics by restricting our analysis to the top 50% of flag states by the number of identities registered to that flag state. That approach also puts focus on flags that represent a greater influence on the global fleet due to their larger size and would therefore have a larger impact from any management or oversight changes.

Flag-level ownership metrics

About three-quarters of the identities in our dataset have at least one owner with a known flag state. These vessels account for 48% of total fishing activity since 2012. In a subset of vessels for 2018, the spatial distributions of fishing activity differed between vessels with and without ownership information. Fishing for vessels with ownership information was more broadly distributed, while fishing for vessels without ownership information concentrated in the Western Tropical Pacific and parts of the Indian Ocean. Consequently, activity by vessels with known owners cannot necessarily be extrapolated to vessels without known owners.

Each identity was classified on the basis of the set of owner flags with which it was associated. To avoid misleading classifications, owner flags for territories were first substituted with the flag of the sovereign nation (e.g., a vessel flagged to Réunion but owned by an entity in France was classified as domestic, and vice versa, under this scheme). Because of discrepancies between registries, a few identities were associated with multiple owners, but the vast majority of the identities (99.9%) associated with only one owner flag. Ownership for each identity was then assigned as domestic if the owner flag and identity flag were the same and as foreign if they were different. Only 58 identities had a combination of foreign and domestic owners and were classified as foreign for the remainder of the analysis, as the nondomestic aspect of the ownership takes precedence as the variable of interest. If there was no known owner flag for an identity, it was classified as unknown. For each flag, the number of vessels with domestic, foreign, and unknown ownership was then summed and normalized by the total number of unique identities registered to a given vessel flag. For calculating flag-level ownership statistics, vessel identities with the same hull, ship name, international radio call sign, IMO number, and flag that used multiple Maritime Mobile Service Identities were counted only once.

Reflagging patterns at ports

We matched the reflagging events to specific ports around the world when the events occurred within 1 km from representative geolocations in a ports' database published by Global Fishing Watch (https://globalfishingwatch.org/datasets-and-code-anchorages/) (*6*). We counted all events of identity changes at a given port and categorized them into the following cases: (i) A vessel changes its identity at a port in the same state to which it is flagged, but it keeps the same flag (domestic to domestic). (ii) A vessel changes its identity at a port in the same state to which it is flagged, and it changes its flag either from or to a foreign flag (domestic to foreign or foreign to domestic). (iii) A vessel changes its identity at a port in a state other than it is flagged to, and it changes its flag from and to a foreign flag (foreign to foreign). We then combined (i) and (ii) to indicate the cases where at least one flag involved in the vessel's identity change is associated with the nationality of the port—domestic reflagging; category (iii) then represents the cases where both flags involved in the vessel's identity change are unrelated to the nationality of the port—foreign reflagging. Figure S13 illustrates the top 30 ports where most fishing and support vessels reflagged in the past decade.

Identifying scrapping sites

By combining vessel identity and tracking data, we could identify the location where a vessel permanently stopped broadcasting GPS signals without any more identity changes. Because a vessel may not broadcast a GPS signal while under maintenance or in the process of transferring ownership, we included only cases where a vessel stopped sending signals for more than six months, and no signal was ever broadcast since. We then mapped their last position to the port location data to determine where the vessel ended its life cycle.

The hot spots of these "destinations" are located at a few coastal areas in South Asia, especially Bangladesh, India, Pakistan, and Sri Lanka (fig. S14). Often, these locations lack port facilities, and these vessels are reported to be laid ashore waiting to be scrapped (*34*). In most cases, these vessels fly flags different from those of the coastal states where they are scrapped, with the most frequent foreign flags being from Russia, Panama, and the Bahamas.

Supplementary Materials

This PDF file includes:
Supplementary Text
Figs. S1 to S16
Tables S1 to S4

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