Distant Water Fishing Atlas - Methods

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Last updated on September 2, 2021

1. Introduction

This document contains a detailed account of the materials and methods underlying the "Distant Water Fishing Atlas" toolkit created by the Environmental Market Solutions Lab (emLab) at the University of California, Santa Barbara (UCSB). This interactive web-based application was created to explore patterns of subsidized distant water fishing effort in support of the fisheries subsidies reforms being negotiated by the World Trade Organization (WTO) between 2017 - 2021.

All data and code for the Distant Water Fishing Atlas toolkit is available at https://github.com/emlab-ucsb/subsidy-atlas (hereafter referred to as the "project repository"). All analysis was done using R version 3.6.2 [1], and the Distant Water Fishing Atlas toolkit was built using the *shiny* [2] package. The toolkit is hosted on the web at http://www.dwfsubsidyatlas.org/.

2. Data Sources

Fisheries subsidies data for this analysis came from two datasets obtained directly from their creator(s) and used with permission. We also use three spatial datasets, one delimiting political land boundaries, one delimiting countries' Exclusive Economic Zones in the ocean, and one delimiting the statistical regions used by the Food and Agriculture Organization (FAO) of the United Nations. The following datasets are described in section 2.1:
- Estimates of global fisheries subsidies from Sumaila et al. [3];
- Estimates of global small-scale fisheries subsidies from Schuhbauer et al. [4];
- Exclusive Economic Zone boundaries from Marine Regions [5];
- Country administrative unit and subunit boundaries from Natural Earth Data [6];
- Statistical area boundaries from the FAO [7].

The code used to process the data, as well as the raw data itself are included in the project repository (where possible).

This analysis also leverages satellite-derived estimates of global fishing effort from Global Fishing Watch (GFW) [8-9]. An aggregated version of the GFW data is freely available to download at https://globalfishingwatch.org/, but this analysis draws on higher-resolution data that was available to the authors as part of a research collaboration between emLab and GFW. All code used to process the raw data is included in the project repository, but the raw data is hosted on Google's BigQuery cloud data system and is not publicly accessible.

2.1. Datasets

2.1.1. Updated estimates and analysis of global fisheries subsidies (Sumaila et al. 2019)

Sumaila et al. [3] identified and compiled published information on financial transfers provided to the fishing sector by governments and estimated the likely magnitudes of fisheries subsidies (in 2018 $USD) in countries for which this information was not available. They assign subsidies to one of 13 categories based on many factors including the policy objective of the subsidy, the description of the subsidy program, scope, coverage, and duration, sources of funding, the administering authority, annual magnitude, recipients, and mechanisms of transfer [10]. Each category is associated with one of the three

subsidy types first described by Sumaila et al. [11]: beneficial ("good") subsidies, capacity-enhancing ("bad") subsidies, and ambiguous ("neutral") subsidies. This work builds upon the estimates previously presented in 2009 $USD by Sumaila et al. [10]. These data were provided to us directly by their creators.

By definition, beneficial subsidies are those that lead to investment in natural capital assets (maximize economic rents). In the context of fisheries, these types of subsidies often aim to increase the growth of fish stocks via conservation, allow for improved monitoring of catch rates, or enhance fisheries management to achieve biologically or economically optimal use of the resource. Subsidies included in the following three categories are considered to be "good" subsidies: 1) fisheries management programs and services, 2) fishery research and development (R&D), and 3) Marine Protected Areas (MPAs).

Capacity-enhancing subsidies are those that lead to disinvestments in natural capital assets. In the fisheries context, "bad" subsidies allow for fishing capacity to develop beyond the point that would be sustainable in the long term by artificially increasing profits. This overcapacity can then compound overexploitation problems such as overfishing. Subsidies included in the following seven categories are considered to be "bad" subsidies: 1) fuel subsidies and tax exemptions, 2) boat construction, renewal, and modernization, 3) fishing port construction and renovation, 4) price and marketing support (processing and storage infrastructure), 5) fishery development projects and support services, 6) foreign access agreements, and 7) non-fuel tax exemptions.

Ambiguous subsidies are those that may lead to either investment or disinvestment in the fishery resource, often depending on the specific mechanisms of the subsidy program. Subsidies included in the following three categories are considered to be "neutral" subsidies: 1) fisher assistance programs, 2) vessel buyback programs, 3) rural fishers' community development programs.

2.1.2. The Global Fisheries Subsidies Divide Between Small- and Large-Scale Fisheries (Schuhbauer et al. 2020)

Schuhbauer et al. [4] identified and compiled published information on financial transfers provided to small-scale fisheries by governments and estimated the likely magnitudes of small-scale fisheries subsidies (in 2009 $USD) in countries for which this information was not available. They use the same subsidy types first described by Sumaila et al. [11].

The data used in this analysis are the published values from [4] in 2018 $USD. These estimates were provided to us directly by their creators and are based upon the global subsidy estimates published in [3].

2.1.3. Exclusive Economic Zone boundaries (Marine Regions)

Marine Regions is an integration of the VLIMAR Gazetteer and the VLIZ Maritime Boundaries Geodatabase. The VLIMAR Gazetteer is a database with geographic, mainly marine names such as seas, sandbanks, seamounts, ridges, bays or even standard sampling stations used in marine research. The geographic cover of the VLIMAR gazetteer is global but initially focused on the Belgian Continental Shelf and the Scheldt Estuary and the Southern Bight of the North Sea. Gradually more regional and global geographic information was added to VLIMAR and combining this information with the Maritime Boundaries database, representing the Exclusive Economic Zones (EEZs) of the world, led to the creation of marineregions.org [5]. Marine Regions is managed by the Flanders Marine Institute.

This analysis uses v11 of the World EEZ maritime boundaries database (released on November 18, 2019). Some of the boundaries included in the Marine Regions database were developed or modified by the Sea Around Us and provided to Marine Regions for incorporation [20].

2.1.4. Country administrative unit and subunit boundaries (Natural Earth Data)

Natural Earth [6] is a public domain map dataset available at 1:10m, 1:50m, and 1:110 million scales. Natural Earth was built through a collaboration of many volunteers and is supported by NACIS (North American Cartographic Information Society).

This analysis uses version 4.1.0 of the 1:50m cultural vector administrative units and subunits data.

<u>2.1.5. FAO Statistical Areas for Fishery Purposes</u>

For statistical purposes, 27 major fishing areas have been internationally established to date. These comprise:
- eight major inland fishing areas covering the inland waters of the continents,
- nineteen major marine fishing areas covering the waters of the Atlantic, Indian, Pacific and Southern Oceans with their adjacent seas.

This analysis uses the high seas portions of the nineteen major marine fishing areas (7).

2.2. Global Fishing Watch

Very few estimates of total fishing effort exist on a global scale, but GFW is a novel way of tracking fishing behavior in near real time on an individual vessel level [8-9]. GFW has processed more than 22 billion automatic identification system (AIS) positions broadcast by fishing vessels across the world. Designed to help vessels avoid collisions, AIS broadcasts a vessel's identity, position, speed, and turning angle to nearby vessels, and these transmissions are also picked up by satellite- or land-based receivers allowing companies to store and distribute this information. GFW has identified more than 80,000 unique fishing vessels ranging in length from 6 - 146 m. GFW used data on 45,441 marine vessels listed on official fleet registries to train a convolutional neural network (CNN) to identify vessel characteristics. This model can use the behavior of vessels (as broadcast by AIS) to identify six classes of fishing vessels and six classes of non-fishing vessels with 95% accuracy and can predict vessel length, engine power, and gross tonnage.

As it only includes fishing vessels with AIS systems onboard, GFW does not represent the total global fishing effort. The International Maritime Organization (IMO) requires all vessels greater than 300 tons traveling in international waters to have AIS, though certain countries also require smaller vessels to use the device [9]. There is great uncertainty regarding the total number of active fishing vessels in the world, but Kroodsma et al. [8] estimated that the number of vessels with AIS comprised approximately 56% of all vessels larger than 24 m, 9% of vessels 12-24 m, and only 0.2% of vessels under 12 m. They also estimated that vessels with AIS likely contributed between 26% - 34% of the global fishing effort (kW hours expended) of all vessels in the world, with that value increasing to 50% - 70% for all vessels fishing more than 100 nautical miles from shore (halfway to the EEZ boundary).

The number of vessels with AIS has been increasing greatly since the period covered by the aforementioned study (representing the period between 2012 - 2016) [9], so it is likely that the 2018 data used in this analysis represents more than 34% of global fishing effort of all vessels in the world, and more than 70% of fishing effort for vessels fishing more than 100 nautical miles from shore (both high-end estimates for the period between 2012 - 2016). For more information on the coverage of the GFW dataset, refer to the supplementary information in [8].

3. Data Processing & Analysis

The objective of the Distant Water Fishing Atlas toolkit is to allow users to explore patterns of distant water fishing activity and estimates of distant water subsidies globally. Here we briefly describe the processing of the raw data sources discussed above and note how these datasets were combined to produce estimates of distant water fishing subsidies.

3.1. Country naming, political entities, and dependencies

Our use of the word "countries" refers to countries, territories and areas without distinction. The naming of countries varies widely across the data sources used in our analysis, and we recognize that this is often intentional and political. Nonetheless, for this analysis we have tried to use the country names recognized

by the WTO for display purposes whenever possible. Our use of a particular name is not meant to convey any opinions regarding the sovereignty or status of any country, territory, or area.

It is important to note that the EU as a political entity is a Member of the WTO, in addition to many of the individual countries that make up the EU. EU countries are often represented at the WTO by the EU delegation -- rather than by their respective delegations -- which is the case for the fishery subsidies negotiations [12]. For the purposes of this analysis we consider the EU to be comprised of the following 28 countries (all data used in this analysis is from 2018 or before): Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, and the United Kingdom.

3.2. Data processing

The general processing of the three spatial datasets discussed in section 2.1 is performed in three separate scripts found in *.../scripts/global/* in the project repository. Those three files are *00a_eez_polygon_wrangling.Rmd, 00b_land_polygon_wrangling.Rmd*, and *00c_fao_regions_polygon_wrangling.Rmd.*

The general processing of the two fisheries subsidies datasets discussed in section 2.1 is performed in a single script in the same folder *../scripts/global/01_data_srangling.Rmd.* These datasets were imported into R where country names were standardized using ISO-3 character codes, and data was converted to a "tidy" format (one row for each data entry) using the *tidyverse* [13], *janitor* [14], *countrycode* [15], and *readxl* [16] packages.

3.3. Vessel list

Creation of the global vessel list from GFW is performed and detailed in *.../scripts/global/02_vessel_list_global.Rmd* in the project repository. As previously mentioned, an aggregated version of the GFW data is freely available to download at https://globalfishingwatch.org/, but this analysis draws on higher-resolution data that was available to the authors as part of a research collaboration between emLab and GFW. All code used to process the raw data is included in the project repository, but the raw data is hosted on Google's BigQuery cloud data system and is not publicly available. The *bigrquery* [17] package was used to access the BigQuery data.

3.3.1. Identifying "good" fishing vessels

The raw data used to create the GFW dataset may include transmissions from anything in the ocean with an AIS transponder. Therefore, we take a number of steps to identify and extract data only originating from sources that are truly fishing vessels. We first remove all transmissions from objects that are likely fishing gear (buoys, nets, etc.), rather than vessels. Then, we apply a number of filters to remove transmissions associated with non-fishing and inactive vessels, as well as vessels that may be spoofing their positions. We use the following criteria (suggested to us directly by GFW staff in a research partners training) to identify our list of Maritime Mobile Service Identity (MMSI) numbers corresponding to "good" fishing vessels:

- MMSI number must be on the best fishing vessel list created and maintained by GFW;
- MMSI number cannot be used by 2+ vessels with different names simultaneously;
- MMSI number cannot be used by multiple vessels simultaneously for more than 3 days;
- MMSI number has not been found to be offsetting its position;
- vessel class can be inferred by the neural net (i.e. it is an active vessel);
- MMSI number was active for at least 1 day and fished for at least 1 hour in a year;
- MMSI number is associated with fewer than five ship names.

Finally, we cross reference our list of good MMSI numbers with a list of manually identified vessel IDs that are not fishing vessels created by GFW and exclude any vessel identifiers on that list.

3.3.2. Extracting fishing effort and vessel characteristics

Once we create our list of "good" fishing vessels, we then extract the number of hours spent fishing by each vessel in every EEZ and on the high seas in a given year. To isolate only valid fishing activity, we apply a number of filters:

- The fishing activity must have occurred during a valid segment as identified by GFW;
- The fishing activity must have occurred during a segment with more than 10 positions that was not concurrently overlapping with another, longer, segment for the same MMSI;
- The vessel performing the fishing activity must appear on the list of "good" fishing vessels created previously.

We then sum the total number of hours each vessel on our list of "good" fishing vessels spent fishing in each EEZ, or in each FAO region (if the fishing activity occurred on the high seas). Hereafter, the areas in which vessels fish are referred to as "EEZ/FAO region", with the understanding that FAO regions are only used on the high seas.

We extract many different characteristics for each vessel including flag state, vessel class, total length (m), gross tonnage (gt), engine power (kW), ship name, call sign, and IMO number. We then calculate fishing effort in units of fishing kilowatt-hours (kWh), by multiplying the hours spent fishing by the engine power of the vessel. Expressing fishing effort in kWh (as opposed to just hours) allows for a more comparable metric of fishing effort across vessels with different gear types and/or sizes [21-22].

GFW relies upon three different methods to assign vessel class, total length, gross tonnage, and engine power [8]. First, self-reported characteristics ("likely") are those reported by fishing vessels with AIS. However, the identity characteristics broadcast by a vessel's AIS must be manually entered, so vessels engaging in illegal, unreported and unregulated (IUU) fishing may choose to alter their identity to avoid detection, or there is potential for human error. Second, "known" characteristics are those that appear on vessel registries (such as the EU's vessel registry or the Consolidated List of Authorized Vessels). Third, GFW used data on 45,441 marine vessels listed on official fleet registries to train a CNN model) to identify vessel characteristics. This model can use the behavior of vessels (as broadcast by AIS) to identify six classes of fishing vessels and six classes of non-fishing vessels with 95% accuracy and can predict vessel length, engine power, and gross tonnage. "Inferred" fishing vessels are those identified using the CNN. Whenever possible, known designations are considered first, followed by likely designations, and then inferred, to assign the best characteristics to each vessel. The flag state, ship name, call sign, and IMO number we use are those most frequently broadcast by the vessel.

3.3.3. Allocating subsidies

In order to estimate the subsidies associated with each of the vessels in our fishing effort database, we first calculate subsidy rates by flag state. These rates-- expressed in terms of $USD/kWh -- are then used to proportionally allocate subsidies based on the total fishing effort expended (in fishing kWh) by each vessel (same as the method used to allocate subsidies by [18]).

We calculate subsidy rates and perform allocations only by flag state. Additionally, we only use the proportion of total subsidies reported by Sumaila et al. [3] associated with industrial fisheries in the calculation of subsidy rates to be applied to vessels in the GFW dataset. The proportions of subsidies associated with industrial fisheries for each country were obtained by subtracting out subsidies for small-scale fisheries as determined by the unpublished updated estimates from Schuhbauer et al. [4]. All subsidy estimates shown in the tool only include subsidy types characterized as "capacity-enhancing".

3.4. Distant water fishing

As the focus of this tool is on distant water (including high seas) fishing, we need to extract vessels engaging in these activities from our global vessel list. Extraction of distant water fishing activity is performed and detailed in *.../scripts/global/03_distant_water_fishing.Rmd* in the project repository.

We remove activity from our global vessel list that should not be classified as distant water (or high seas) fishing. This isn't a comprehensive classification, as most industrial fishing vessels fish across multiple jurisdictions (i.e., within the EEZ of their flag state, on the high seas, or in the EEZ(s) of other coastal states). Therefore our distant water fishing database may not include all activity associated with certain vessels.

The identification of high seas fishing activity is straightforward. Defining what counts as distant-water fishing is somewhat more complicated as many countries have fishing agreements with one another. We base our definition of distant-water fishing on that used by Cabral et al. [19]. By classifying fishing activity as "distant water", we are not making any assumptions about the legality of the activity. Many countries have agreements with one another relating to distant water fishing.

When any of the following conditions are met, that fishing activity is NOT considered to be distant water fishing:

- The fishing activity is occurring outside of the jurisdiction of any country (i.e., on the high seas) [NOTE - This is included in the tool, but is presented separately];
- The flag state of the vessel is the same as the administering state of the EEZ in which it is fishing (or one of the administering states in the case of joint regime and disputed areas);
- The sovereign flag state of the vessel is the same as the administering state of the EEZ in which it is fishing (or one of the administering states in the case of joint regime and disputed areas);
- The flag state of the vessel is a member state of the EU, Norway, Svalbard and Jan Mayen, or Iceland, and the EEZ in which it is fishing is administered by a member state of the EU, Norway, Svalbard and Jan Mayen, or Iceland (e.g., a French flagged vessel fishing in Spain's EEZ);
- The sovereign of the vessel's flag state is a member state of the EU, Norway, Svalbard and Jan Mayen, or Iceland and the EEZ in which it is fishing is administered by a member state of the EU, Norway, Svalbard and Jan Mayen, or Iceland (e.g., a vessel flagged to the Azores fishing in Spain's EEZ).

Our definition of distant water fishing does include "sovereign fishing". Even if the vessel and EEZ in which it is fishing share a sovereign state, we still consider this activity to be distant water fishing (though this does not mean that it is foreign distant water fishing). Therefore, when either of the following conditions are met, we DO consider the activity to be distant water fishing:

- The flag state of the vessel is also the sovereign of the administering entity of the EEZ in which it is fishing (e.g. a US flagged vessel fishing in the EEZ of Palmyra Atoll).
- The sovereign country of the vessel's flag state is also the sovereign of the administering entity of the EEZ in which it is fishing (e.g. a Puerto-Rican flagged vessel fishing in the EEZ of Palmyra Atoll).

3.4. Connectivity analysis

Creation of the connectivity plot data is performed and detailed in *.../scripts/global/04_connectivity_analysis.Rmd* in the project repository. The purpose of this analysis is to show the origins (by flag state) of vessels engaging in distant water (or high seas) fishing activity in each EEZ and high seas FAO region.

3.5. High-resolution fishing activity

Creation of the high resolution binned effort data used to make the effort and subsidy maps displayed in the toolkit for each EEZ and high seas FAO region is performed and detailed in *.../scripts/global/05_eez_hi_res_data.Rmd* in the project repository. The purpose of this script is to extract raw fishing activity from GFW that meets the distant water fishing criteria identified above and bin it by 0.1 degree latitude/longitude.

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