VISUALIZING FISHING EFFORTS

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Abstract. Much of the developing world relies heavily on fish consumption as a source of food security providing vital proteins and micronutrients. Yet, sustaining the world's fisheries has proved to be a complicated challenge made worse by widespread illegal, unreported, and unregulated fishing. Here, we utilize automatic identification system (AIS) messages tracking the location and fishing effort of vessels worldwide for the years 2012 through 2020 in order to visualize global fishing activity. We additionally layer on the world's existing marine protected areas thus, the result of our research provides not only a view of current fishing effort but also a planning tool for future conservation efforts.

1. Introduction. Fish serves as an essential source of protein and micronutrients, such as iron, zinc, vitamin A, and omega-3 particularly for developing countries in which food security is a primary challenge. An estimated 2 billion people suffer deficiencies in key micronutrients (WHO, 2007) which can lead to serious health issues such as anemia. For children and pregnant women, anemia poses a severe public health concern that is often borne disproportionately by low-income countries. In Sierra Leone for example, one in eight women die from pregnancy-related issues due primarily to deficiencies in micronutrients and protein (Petrossian and Clarke, 2020). As of 2017, fish consumption provided 17% of animal protein intake globally with these numbers exceeding 50% in some developing countries (FAO, 2020).

These vital fish stocks are in a critical state of decline with 90% of major marine fisheries subject to either severe overfishing or full exploitation (FAO, 2020). Historically, these issues were combated through traditional fisheries management methods such as gear restrictions, harvest limits, area closures, and access restriction which led to the creation of Exclusive Economic Zones (EZZ). EZZs comprise an area extending 370km from the coast in which the coastal State has full authority to manage its marine resources. However, traditional management approaches are often undermined by the practice of Illegal, Unreported, and Unregulated (IUU) fishing.

IUU fishing is a broad term that encompasses a variety of fishing activities. Illegal fishing usually refers to activities such as fishing without a proper license, fishing in closed areas, use of illegal gear, fishing above harvest limits, or fishing prohibited species. Unreported fishing is prevalent with vessels either not reporting catch or misreporting catch in order to forego harvest limits and taxes. Unregulated fishing refers to fishing on the high seas, outside of the EZZs, in international waters where there is limited regulation and enforcement of proper fishing practices. While unregulated fishing is not necessarily criminal, it has been found to be linked to other crimes such as human and drug trafficking as well as slavery (UNODC, 2011). IUU fishing is rampant with estimates of up to 14 million metric tonnes of catch annually resulting in an estimated loss of US$50 billion per year (Sumaila et al., 2020). Transshipments at-sea, which involves the offloading of catch from fishing vessels to refrigerated carrier vessels, has been identified as a major pathway through which IUU fishing is laundered (Daniels et al., 2016).

Coastal states combat IUU fishing through Monitoring, Control, and Surveillance (MCS) systems. Traditional MCS approaches include on-board observers, logbooks, and vessel patrols; however new technologies have emerged presenting states with an opportunity to enhance the effectiveness of MCS systems. Automatic Identification System (AIS) and Vessel Monitoring System (VMS) are satellite systems that can transmit the location of vessels. VMS was created specifically to combat IUU fishing but it was also designed so that only national authorities have access to the data which has resulted in a lack of transparency and availability for fisheries managers. AIS, on the other hand, was originally created as a collision avoidance tool and required for vessels of a certain size. Due to its nature, AIS data is available publicly. A 2018 study leveraged and trained the AIS data from 2012-2016 to identify vessel characteristics as well as vessel positioning and speeds indicative of fishing activity in order to quantify apparent fishing effort in space with 90% accuracy (Kroodsma et al., 2018).

Ineffective MCS systems have been found to be linked with country indicators such as poor governance and corruption (Doumbouya et al., 2017). One possible solution for these institution-poor regions is the creation of fully-protected marine protected areas (MPAs). A 2019 study found that MPAs not only serve to increase fish stocks but also fish catch in the boarding regions (Cabral et al., 2019). MPAs currently account for 7.7% of the ocean (IUCN, 2022) however, the extent of the conservation in these areas varies greatly. States can, for example, allow for commercial fishing activities within these protected areas. MPAs designed to fully or highly protect from marine extraction account for just 2.4% of the ocean (MCI, 2022).

2. Research Question and Relevant Literature. The trained AIS data resulting from Kroodsman et al.'s study is now publicly available through Global Fishing Watch. Data from a second study available on Global Fishing Watch (Miller et al., 2018) used AIS data to identify potential transshipment encounters. Encounters were estimated based on the distance between vessels, vessel speed, and loitering duration. Encounters are then matched against authorization records which are obtained through Regional Fisheries Management Organizations (RFMOs) in order to identify potential unauthorized encounters.

Our research project combines the vessel location and fishing effort data with unauthorized encounter data in order to create a global heatmap of monthly fishing activity. We then layer onto our map the FAO's defined major marine areas as well as the largest MPAs within each FAO area.

Can leveraging AIS data create a view of the world's current MPAs and overfished regions in order to inform policy maker and fisheries manager decisions regarding IUU fishing prevention and marine resource conservation?

3. Methodology. In order to understand how we approached the research question and consequently the type of project we developed, it is of fundamental importance to first analyze the problems and critical points of this project. Our objective was to create an intuitive user interface that quickly produces a heatmap of fishing effort over time depending on the user's selection of ocean area and year. In order to achieve this we had to deal with several categories of problems that can be divided into three macro-categories, corresponding to the python files: data processing, user interface, and map development.

3.1. Data Processing. Our project involved the use of an immense amount of heterogeneous data and so efficiency and execution time presented the biggest obstacle. Four different databases were used within the project:

- Vessel location and fishing effort
- Encounters
- FAO areas
- MPA areas

We obtained the first database from Global Fishing Watch; The database contains AIS data trained to detect fishing effort and vessel presence. The fishing vessels are identified by Global Fishing Watch through a neural network classifier, vessel registry databases, and manual review by experts. Fishing effort is identified through various vessel characteristics, vessel speed, and movement patterns. Vessel presence and fishing effort are binned into grid cells, so that the number of hours assigned to each vessel per location are calculated by assigning an amount of time to each AIS detection corresponding to the time of the previous position, and then summing all positions in each grid cell. Data was available in the form of daily csv files for the years 2012-2020. Each daily file contains information on approximately 100,000 vessels. For 9 years of data this results in over 320 million observations to analyze. To speed up processing time, we decided to first clean and consolidate this data and then export the results in a csv file that would then be imported by the main block of code (main.py). This way the cleansing process would not have to be repeated each time that the program is run.

The second database, also available from Global Fishing Watch, contains potential fishing and carrier vessel encounters. Encounters were estimated using vessel speed, distance, and loitering time. Encounters were then matched to a database of RFMO authorizations and classified as 'authorized' if a record was found for both the fishing and carrier vessel, 'partial' if a match was found for one vessel, and 'unknown' if no match was found. We use the 'unknown' encounters as a proxy indicator of IUU fishing activity. It is important to emphasize that while unauthorized transshipment activity may give an idea of the extent to which IUU fishing is being laundered, it does not necessarily establish illegal activity.

The third and fourth databases concern FAO major marine areas and MPA locations, which were obtained through FAO and Protect Planet website respectively. MPA data is provided in the form of a shapefile, which is a format used for storing geometric locations and attribute information of geographic features. The geographic locations cointained in the shapefile are represented by points, multi-points, polygons and multi-polygons. While points represent a single pair of coordinates, polygons define a planar Surface through one exterior boundary and zero or more interior boundaries, with each interior boundary defining a hole in the Polygon. A multi-polygon is a "MultiSurface" whose elements are Polygons; the boundary of the multi-polygon. The shapefiles also include dBASE tables (.dbf) that store additional attributes on the coordinates of the shapefiles. Data is supplied in the geographic coordinate system WGS84. While MPAs only account for 7.7% of the ocean, there are approximately 15,000 of these areas in existence today. Therefore the size of the shapefiles (1,000,000 kilobytes) was a challenge to consider while processing the database. Again we made the decision to separately clean this data and export new shapefiles. Before exporting the shapefiles, MPA areas are mapped to the corresponding FAO major marine area in which they lie.

3.2. User interface. We decided to implement a user interface that lists options for data year selection as well as map area to be viewed. We offer the user to select one year of data from 2012-2020 and any FAO major marine area or a global map view. Our intention was to be able to filter the databases based on the user's selection in order to reduce the amount of data to be processed for the map build. Given the amount of MPAs, we decided to load the FAO and MPA layers only when the user selects to view a specific FAO region and not offer these layers for the global view. In addition, we decided to only include the top 150 MPAs per FAO area by size to further reduce processing time.

3.3. Map Development. After the data has been cleansed of excess information and filtered by user selection, the final step of our program is the map creation. First, a base folium map must be created on which we will layer fishing effort, FAO areas, and MPAs. The base folium map is generated based on the user's area selection. If the user selects a global view a general base map will be created. If the user selects a specific FAO area we run a function to determine the center coordinates of the FAO area so that the resulting map will be centered and zoomed in on that specific area.

Once the base map has been generated, we layer on the nested list of vessel location, fishing effort, and unauthorized encounters by month to create a running heatmap. Finally, if the user has selected to view a specific FAO area, we layer on that region as well as the top 150 MPAs within the area.

Please see the appendix for a flow chart of our methodology.

4. Code Implementation. The project is hosted in a Github repository, which contains all the required files and instructions to run the code.
Please refer to the README for the adequate installation of the packages required.
The program runs in Python, version 3.9.2. and is structured using the following packages:

- Pandas - version 1.2.4
- Folium - version 0.12.1
- Geopandas - version 0.10.2
- Shapely - version 1.8.2.
- Pathlib2 - version 0.97
- Display from Template from jinja2 - version 2.11
- Datetime - version 4.4
- Matplotlib.pyplot - version 3.3.2

The code is structured in three separate files: one file to organize and clean the data (data_load.py), one file with the functions needed to plot fishing effort, MPA and FAO regions on the map (map_functions.py), and one main file that asks the user for a selection of area and year in order to create a HeatMap of the fishing effort and encounters.

We created an interactive map through the python library Folium, which allows for the creation of several types of Leaflet maps.

4.1. Data Processing. To process vessel location and fishing effort data, we first merge the daily csv files. Then we remove entries without fishing hours by excluding those vessels with a 0 in the field 'fishing hours'. We then aggregated the data by summing fishing hours over latitude, longitude, and month in order to reduce the amount of data to handle.

Encounter data is filtered to include 'unknown' encounters only. We then rename the latitude and longitude columns to match the vessel location data so that the same function to create a heatmap layer can be applied to both datasets at a later step.

To process the MPA data we load and merge the three shapefiles for both polygons and points shapefiles. From the larger dataset of World Protected Areas, we kept only MPAs by discarding those rows with an attribute of 0 in the field "Marine": a value of '0' indicates that there is very little to no marine component, '1' indicates that the site has substantial marine and terrestrial components and '2' indicates that there is very little to no terrestrial component. MPA areas are then mapped to their corresponding FAO major marine area using the function 'assign_FAO_area'. In order to call the 'assign_FAO_area' function, we must first import the FAO data that we obtained from the Food and Agriculture Organization of the United States website; the data are organized in the same way as the World Protected Areas. We selected only the 19 major marine areas for our purposes.

4.2. User interface. When creating our map, we allow the user to choose a global view or a specific major FAO area and year with the function 'user_menu'; this selection allows to focus the attention on a particular area and analyze the ships' movements since the map shows a heatmap of the fishing hours spent by vessels in a certain position and simultaneously allows to see the the boundaries of each MPA in the area. We created this user interface to be a menu of options and implemented some debugging checks against faulty user input.

4.3. Map implementation. In the module map_functions.py we defined a few functions to plot the vessels and regions of interest in our interactive map.

To create a heatmap with time lapse functionality, we used the folium plugin heatmapwithtime. This plugin requires input data to be of the form of a list of latitude and longitude weighted by frequency and not an absolute value. We therefore normalized the fishing hours field to be within an interval of 0 and 1. The 'lat_lon' function generates the list nested by month for both vessel location data and encounter data. Another issue that we came across with this plugin is that if you add more than one heatmap layer to your map a control bar is generated for each layer even if the layers are on the same time index. To solve this, we created a class 'HeatMapWithTimeAdditional'.

From the database of FAO areas, we extracted the center coordinates of each major FAO area to center the map on the selected FAO area by using the function 'get_FAO_center'. And we plot the boundaries of the selected area on the map using 'plot_FAO_areas' and 'plot_MPA'.

We decided also to create a static map (Figure 1) of all the Marine Protected Areas and the major FAO areas, using function 'map_of_MPA' to give a visualization of the total area covered by protected areas compared to the entire ocean surface. Only 7.7% of the ocean, an area corresponding to the size of North America, is under some kind of protection. More than 15,000 MPAs protect more than 27 million square kilometers of ocean according to the U.N.'s World Database on Protected Areas, which records marine protected areas (MPAs) submitted by countries.

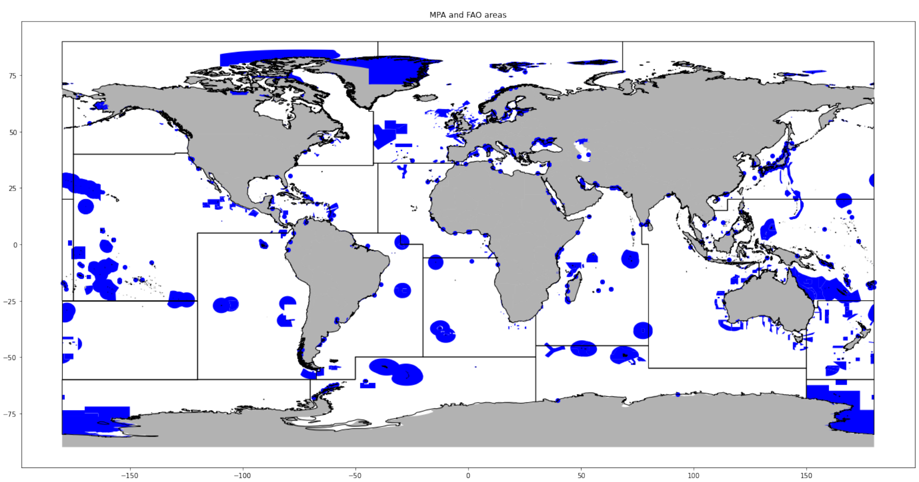

Fig. 1: FAO and MPA areas

5. Code maintenance. The outcome of this project's code implementation is the interactive maps, based on the data sets obtained from Global Fishing Watch, Protect Planet, and Food and Agriculture Organization of the United States. Therefore, proper maintenance and update are closely related to collection of up-to-date data and user interface options for new years of data. Updates of the data used to create the vessel map and MPAs are particularly important as the outcome of this project helps policy makers in establishing rule/protected areas only if the data provided to the user are up to date and hence allow for a timely and efficient analysis of the results. The different modules of the code are also uploaded in a public GitHub repository; , which allows the code to be stored adequately for further advanced and developments. All the code is appropriately commented and documented, with a corresponding README file, to ease the use from other parties.

6. Results. Through our research and code implementation, we were able to create an interactive map of fishing effort that provides additional views of fishing within MPAs and potential unauthorized transshipment events. Additionally, our program has been designed to allow for user flexibility to generate a global or region view and select which year of data they are interested in viewing.

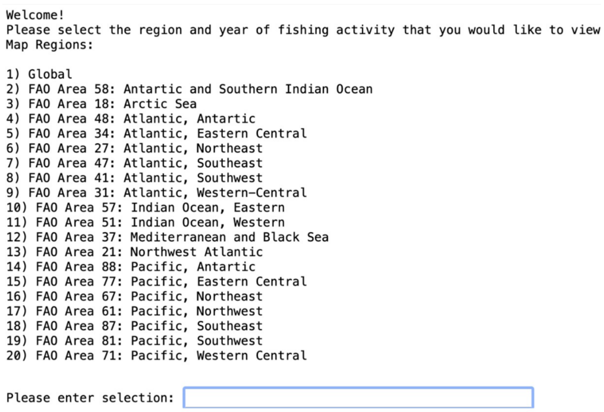

Fig. 2: Region Selection

Fig. 3: Year Selection

Figure 4 provides a glimpse of our program's global map for the year 2020 (frozen for the month of April). We can see here the intense levels of fishing activity off the coast of China, as well as many potential unauthorized transshipment events off the coast of Russia (indicated by the black spots).

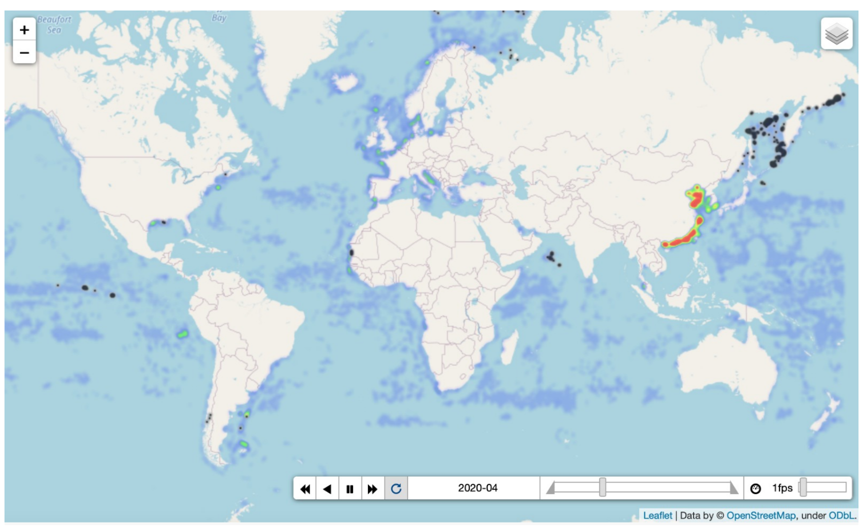

Fig. 4: Global Fishing Effort

To illustrate the ability of our program to provide users with a detailed view. Figures 5, 6, and 7 show a map of FAO areas 27, 61, and 71, respectively. The FAO areas have been shaded and outlined in blue while the MPA areas can be seen shaded and outlined in green.

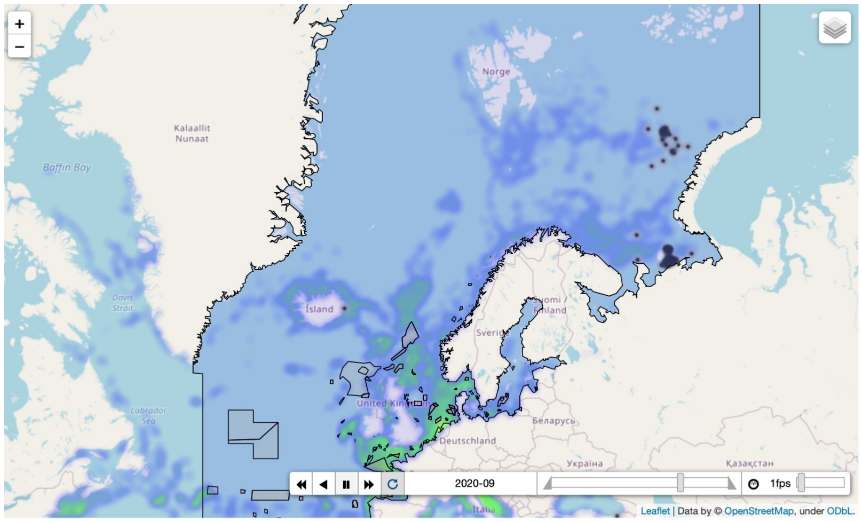

Fig. 5: FAO area 27

In FAO area 27 (between Northern Europe and Greenland), we can see little fishing activity occurring within the MPAs. However, if vessels are located within, it would be possible to obtain their MMSI identification number within the data to confirm whether or not they are in possession of the necessary permit. This may be useful for the authorities supervising the MPAs so that they can check whether these 'protected zones' are actually being respected.

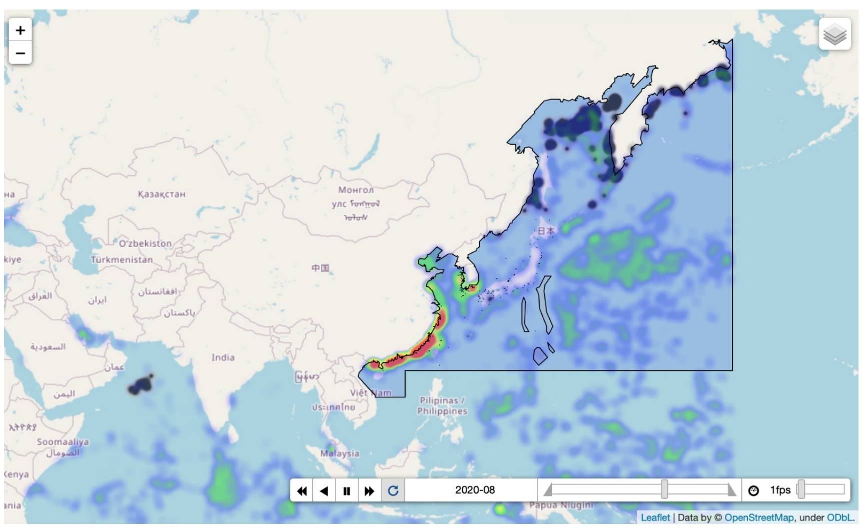

Fig. 6: FAO area 61

In FAO area 61 (east of China and south east of Russia), we can see two marked phenomena, high fishing activity off the coast of China and between China and Japan, this (phenomenon repeats frequently in different time periods) and concentrated 'unknown' transshipment events off the coast of Russia.

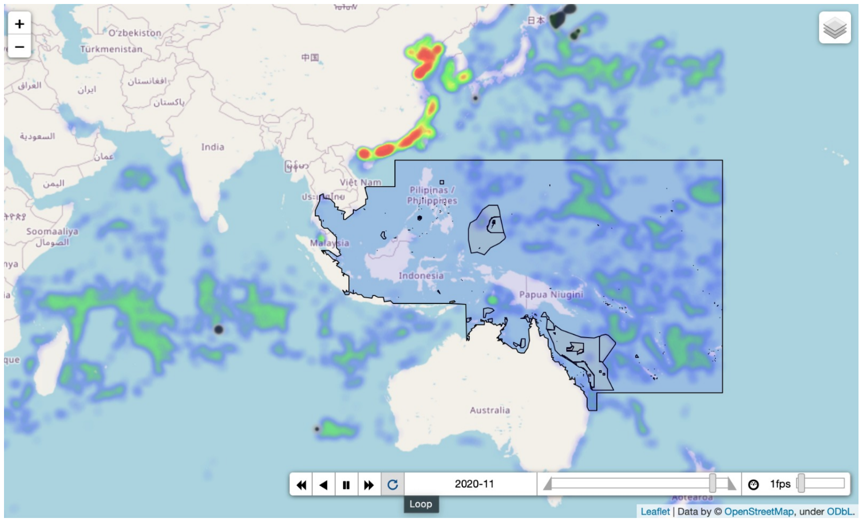

Fig. 7: FAO area 71

The map of FAO area 71 (north and northeast of Australia), allows us to see and emphasise the complexity and multiplicity of MPAs. This area contains many MPA areas (more then our illustrated in our map) often of extremely small sizes. This level of detail conveys the complexity of monitoring fishing activities in these conserved areas.

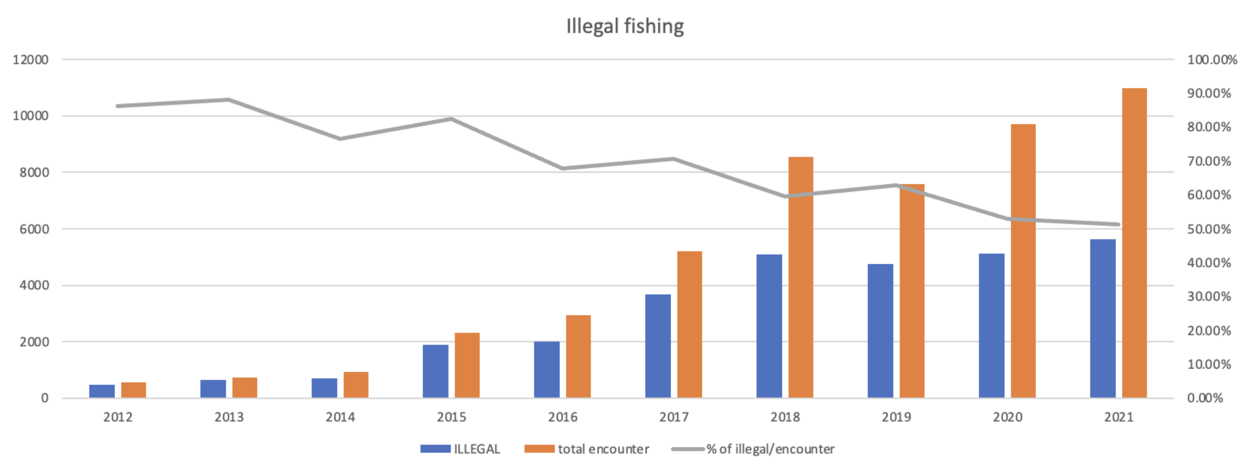

Fig. 8: Illegal fishing

Taking a closer look at the trasshipment events, we can see that in absolute terms, the recorded number of 'unknown' encounters is increasing. However, the percentage of 'unknown encounters' has been steadily decreasing. If 'unknown' encounters are truly a measure of IUU fishing laundering, this analysis is at odds with statistics provided by the major bodies responsible for monitoring and sanctioning illegal fishing which demonstrates a steady increase in IUU activity. As 'unknown' encounters are only a proxy measurement, we cannot say with certainty the measure of IUU fishing demonstrated by our map however, it can provide insight as to the ports that are most notorious for this type of activity.

7. Conclusions. Our interactive map has shown that it is possible to use publicly available AIS data to visually assess fishing activity. Policy makers can leverage this information in order to determine prime locations for new MPAs. And fisheries managers can use this information to target high volume areas for vessel patrolling in regions where IUU fishing is rampant. Additionally, ports in which potentially unauthorized vessel encounters occur most often can be determined in order to inform policy.

There are however some drawbacks to utilizing AIS data. First, it is possible for vessels to switch off their AIS signal as well as 'spoof' their signal which is when the positional messages are manipulated so that the vessel appears to be in a different location. Research has shown that these occurrences are rare but it is these vessels that are most likely to be those committing IUU fishing. For this reason, VMS data would be the preferred record of fishing activity as it cannot be manipulated or turned off. However, as the states alone have access and control over this data it is unlikely to become publicly available. Certain states are renowned for their ease of vessel registration and lack of monitoring. Flags from these states are known as 'flags of convenience'.

Additionally, not all vessels are required to register under a unique identification number. This can lead to vessel owners re-flagging, renaming, or changing ownership to keep their identities hidden and make it difficult to keep an accurate database of IUU fishing records associated with a particular fishing company. This is particularly common for vessels with flags of convenience.

Arguably the most important step towards deterring IUU fishing is the sharing of information. While it is unlikely that policies could be put in place globally to require unique vessel identification numbers and the sharing of VMS data, it is possible for states to join regionally to create a comprehensive database of fishing activity and IUU offenses leveraging both AIS and VMS data. We believe that the sharing of data, such as that produced by our project's map, is an important first step.

Appendix A. Program Flow Chart.

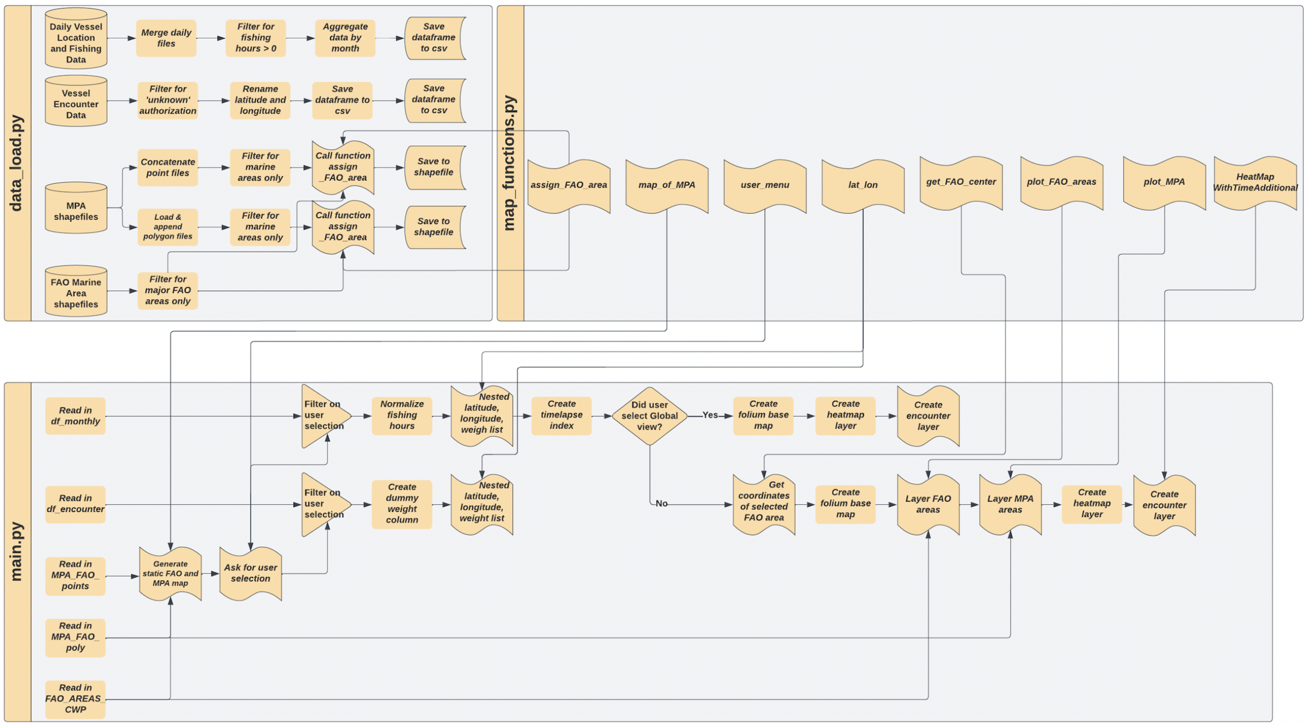

Fig. 9: Code Implementation Process

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