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The NGA and Illegal, Unreported, and Unregulated Fishing

Enabling Efficient Intervention Through Informed Prioritization

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About this project

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Executive Summary

In June 2022, the Biden Administration published a "Memorandum on Combatting Illegal, Unreported and Unregulated Fishing and Associated Labor Abuses", which put the issue of illegal, unreported and unregulated (IUU) fishing on the radar of all federal agencies. That memo is a 'call to arms' for all federal agencies to use their resources to address IUU-fishing activities. IUU fishing is a complex problem. The complexity underscores the need for international cooperation and for prudent resource allocation by all appropriate federal agencies.

Among the responses to date of the National Geospatial Intelligence Agency (NGA) was reaching out to Carnegie Mellon University's Heinz College to sponsor this capstone project examining IUU generally, and ways that NGA and its partner agencies may contribute to ameliorating IUU-related problems.

Our research focused on the legal environment surrounding IUU fishing (Chapter 2) and on providing information on the global fishing fleet (Chapter 3), a discussion of what motivates IUU-fishing behavior with a case study of one important fishery (Chapter 4), analysis on the IUU support fleet (Chapter 5), analysis of some international treaties and policies that aim to deny ports to participants in IUU-fishing activity (Chapters 6-8), and the European Union's market-denial "carding" system (Chapter 9).

An overall conclusion is that the challenge of IUU should not be approached only through a "cops and robbers" lens of trying to detect and "arrest" fishing boats that are violating rules. There are far too many fishing vessels (2.4 million powered vessels) to catch enough to make their risk of capture very high, and many are crewed by poorly paid workers who are easily replaced. A more promising approach is to focus on the much smaller number of support vessels. There are various types of support vessels, but we pay particular attention to those also known as reefers or refrigerated containers ships, which collect catch from fishing vessels and carry the catch to ports for sale.

Even though there are fewer support vessels (approximately 1,500 at sea at any time), matters of jurisdiction limit the U.S. or other nations' ability to stop and seize those vessels. In general, nations can only enforce fishing laws within their Exclusive Economic Zone (EEZ), which extends 200 nautical miles from shore. Generally speaking, on the high seas, only the nation to which a ship is flagged may take enforcement action, and various nations lack the will and/or means to aggressively enforce laws against ships flagged to them. That is partially but not primarily because some nations serve as "flags of convenience".

Three broad options for increasing enforcement are (1) Negotiating additional international treaties, (2) Developing bilateral agreements whereby officials from one nation can ride on craft belonging to a second nation, so that the first (typically poorer) nation is able to enforce its laws

more effectively, and (3) Creating circumstances in which ports can either be closed to IUU vessels or can seize IUU vessels that do dock there.

Our analysis of the current legal environment focused on two types of international agreements that appear promising: the Port States Measures Agreement (PMSA) and Regional Fisheries Management Organizations (RFMO). The PSMA is aimed at preventing fishing vessels engaged in IUU-fishing from using designated ports in states that have ratified the agreement. RFMOs are agreements among both local "coastal" states and other nations (distant fishing water nations) to manage and set catch limits on species that do not exist within one nation's EEZ. Among the objectives of RFMOs is to regulate fishing vessel's activities on the open water within that RFMO. One of the most important aspects of RFMO agreements is that they authorize and incentivize enforcement by the signatory nations. These agreements appear to have seen moderate success in changing support vessel behavior, but their effects may be hampered because not all nations have ratified and enforced them.

We developed some tables that may be of use as the U.S. decides how to allocate its scarce diplomatic capital in ways that encourage additional nations to join these international protocols. For example, we show how when Mauritania joined the PSMA, the frequency with which its ports were used to support a certain aspect of IUU declined sharply, but violations in nearby Guinea-Bissau rose at the same time, suggesting there may have been displacement. But given the relatively high rate of adoption of PSMA agreements in the region overall, inducing Guinea-Bissau and perhaps a handful of other countries to join and enforce the PSMA agreements might make a material difference.

We invested less time studying two other agreements which might nonetheless hold promise. Fishing Convention C188 and the Cape Town Agreement (CTA) regulate the treatment of workers and the safety of vessels, respectively. To the extent that rogue firms that fish illegally cut corners on cost by violating multiple types of good business practices, enforcing C188 and CTA provisions may be an indirect way to bring enforcement pressure to bear on IUU vessels – what might be termed an "Al Capone" strategy – since it can be difficult to catch vessels for fishing violations themselves.

The nature of the IUU problem and the most promising solutions varies around the world. Time and other limitations precluded analyzing all regions in depth, so we chose to make a case study of one of the FAO's major fishing areas – Region 87 – which is the eastern portion of the South Pacific RFMO (SPRFMO). Region 87 covers the waters off the west coast of South America. The coastal nations of Peru, Ecuador, and Chile are among the SPRFMO's 16 member nations, as are the United States, the European Union, and several major fishing nations (China, Korea, Russia).

Our goal was to see what insights could be obtained by thinking of IUU-fishing vessels or companies as rational actors who engage in IUU-fishing activities if their expected profits exceed their expected costs. It is surmised that actors engaging in IUU fishing activities could significantly

decrease their labor and vessel costs by violating any of various rules. Further, the variability of punishments imposed on the fishing crews and/or vessel owners caught for IUU fishing within Region 87 could be making punishment a less effective deterrent. Through its surveillance capabilities, the NGA may be able to increase the enforcement efficiency within the SPRFMO. However, the NGA should be aware that improving enforcement efficiency in Region 87 may not be enough because the states that have the legal authority to impose punishments must structure their laws to impose sufficient and consistent penalties.

The next research area focused on the activity of support vessels. These large carrier ships meet (or "encounter") fishing vessels to provide supplies and conduct transshipment of catch. For our analysis, we utilized data from Global Fishing Watch and Sea Vision. Global Fishing Watch used machine learning techniques to classify support vessel's behavior into two different types of meetings: tracked meetings and dark meetings. Dark meetings are ones in which the vessel meeting with the support vessel turned off its AIS transponder.

We used these data both to create a prototype of a tool that NGA may want to use and to investigate relationships among these vessels. The prototype tool is a dashboard which can display general vessel information, its recent suspicious activity, and up-to-date geolocation information. This dashboard can provide close to real-time location information through SeaVision. However, the IUU-fishing activity would have a 72-hour delay due to restrictions on Global Fishing Watch's data.

One insight gleaned from investigating support vessels' meeting patterns was our ability to identify potential networks of support vessels working together or with the same fishing vessels. The motivating idea is that just as there are many fishing vessels for each support vessel, there may be multiple support vessels operated by one corrupt company or ownership group. Because of the use of front companies, it may not always be easy to see which support vessels are part of the same "team". However, by looking for indirect connections between support vessels, we can start with one support vessel that is known to be "bad" and then discover what other support vessels move in the same circles as the "bad" vessel, and so may merit additional investigation.

As a proof of concept for this approach, we used advanced network analysis to identify the network of an infamous Chinese-flagged support vessel named Yong Hang 3. We began by finding all the fishing vessels that met with the Yong Hang 3 in recent months. Then we identified any other support vessels that met with the fishing vessels that met with Yong Hang 3's. These other vessels are not known to have done something wrong, but it is known that they met with fishing vessels that met with a known bad actor. This let us create a network with a node for each support vessels and arcs indicating the strength of the association between two support vessels, with an edge weight that measured the number of fishing vessels which met with both of those support vessels.

The definition of an edge might be enhanced to note the sharing of other attributes, such as visiting the same ports, being flagged to the same nation, or having a captain or crew from one vessel serve on the other.

The identification of Yong Hang 3's network opens the door for further intelligence exploitation efforts and network analysis in order to more properly understand the main actors within the IUU fishing realm. Network analysis of support vessels may allow the NGA to enhance its ability to prioritize its own surveillance operations and/or provide intelligence assessments to enforcement agencies and diplomatic partners (United States State Department) in order for them to apply pressure on the nation-states that are conducting or hosting the most egregious IUU-fishing activity.

Contents

Tables

Figures

Abbreviations

CBD	Convention on Biodiversity
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMS	Convention on Migratory Specie
Compliance Agree.	The Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas
CFV	Commercial Fishing Vessel
EEZ	Exclusive Economic Zone
FSA	Fish Stock Agreement
GFW	Global Fishing Watch
FoC	Flags of Convenience
IC	Intelligence Community
IUU	Illegal, Unreported, and Unregulated
LOA	Length Overall
NGA	National Geospatial Intelligence Agency
PSMA	Port State Measures Agreement
RFMO	Regional Fisheries Management Organization
SPRFMO	South Pacific Regional Fisheries Management Organization
UN	United Nations
US	United States
USCG	United States Coast Guard
USG	United States Government

Chapter 1. Introduction

Illegal, Unreported, and Unregulated, (IUU) fishing is a broad term describing practices within the fishing industry that do not adhere to international and national laws and regulations. As IUU fishing has become more widely recognized as a serious problem, the causes and consequences have gained attention in academia, policy, and the media. Research has shown that IUU fishing can lead to depleted fish stocks and other harmful environmental impacts (National Intelligence Council, 2016; Widjaja et al., 2020). It is also associated with illegal labor practices (EJF, 2019; McDonald et al., 2021; Selig et al., 2022) and other criminal behavior (Witbooi et al., 2020). IUU fishing also has negative economic impacts (Temple et al., 2022) (Temple et al. 2022). By depleting fish stocks, IUU fishing makes it difficult for governments and fishermen to sustain long-term economic benefits from their natural resources. It can also rob law-abiding fisherman of potential profits (Daniels et al., 2016).

Although it is known that IUU fishing is harmful, it is extremely difficult to quantify just how harmful it actually is. Many sources claim to have an estimate of the size of IUU fishing; however, most of these sources derive their estimates from a single publication, *Estimating the Worldwide Extent of Illegal Fishing*. In Appendix A, we explain the limitations of this study and show that many contemporary estimates of IUU fishing on the global level are not necessarily up to date or reliable.

Further exacerbating the IUU fishing problem is the fact that the countries, companies, and fishers involved in this illicit industry naturally try to avoid detection and punishment. These perpetrators can often be completely unknown, or they can be known but difficult to catch and punish. This is partially due to the complex legal framework governing international maritime industries which can make it difficult to discern which actors are breaking which laws and who is legally permitted to intervene to stop the illegal behavior.

Techniques such as using support vessels can essentially "launder" illegal catch by mixing it with legal catch and then package all of the catch together at sea, far away from prying eyes. Even in scenarios where a vessel is clearly engaged in IUU fishing, it can be difficult to stop because powerful actors with large and protected fishing fleets sometimes take advantage of smaller nations' inability to patrol and protect their sovereign waters. Or they operate on the open seas, outside of EEZs, where often only the nation to which a vessel is flagged has jurisdiction to enforce the law.

The difficulties of stopping IUU fishing are many, but the United States (US) has a vested interest in reducing IUU fishing. As a significant importer of seafood, the US wants to ensure that its imports are not tied to harmful environmental practices or abhorrent labor abuses. Additionally, the US wants to protect the livelihoods of law-abiding US fisherman who are negatively affected when illegal, cheaper, fish products enter the market. However, the US cannot eliminate IUU

fishing alone. The global fishing industry is large and includes numerous, diverse actors who are under the jurisdiction of many different states. Additionally, the international laws governing the seas largely prohibit unilateral intervention. Finally, even if the US were to commit to consuming only domestic catches, the global seafood market, both licit and illicit, is enormous and the negative impacts of IUU fishing would continue even if the US were to exit it completely. Therefore, the US must work with partners and the larger international community to combat IUU fishing.

The Biden Administration has emphasized the need for the US to combat IUU fishing. This commitment is captured by a 2022 Presidential Memorandum which called on all executive departments and agencies to "work toward ending forced labor and other crimes or abuses in IUU fishing; promote sustainable use of the oceans in partnership with other nations and the private sector; and advance foreign and trade policies that benefit U.S. seafood workers" (House, 2022). As one of the agencies called on to combat IUU fishing, the National Geospatial Intelligence Agency (NGA) has a unique opportunity to engage their specialized assets to help the US and the international community counter IUU fishing. The advanced surveillance capabilities of NGA could be used to identify IUU fishing before, during, and after it occurs, contributing to more efficient intervention as well as providing evidence of the crime. In order to effectively utilize NGA capabilities, the agency must first understand the IUU fishing environment which is a complex space bounded by varied international and domestic laws and regulations. The NGA must understand the major actors in the IUU fishing industry as well as the practices that make IUU fishing so difficult to detect. Finally, the NGA should be aware of what data is valuable and how it can be used to identify and track suspected IUU fishing behavior.

Chapter 2 summarizes the most important international laws and treaties governing the international fishing industry. The review identifies the legal status of 193 countries in regard to nine treaties, analyzes the roles and limitations of international treaties, and identifies how these policies and legal frameworks can be improved

Chapter 3 describes aspects of the global fishing fleet and identifies the states who are major players in the global fishing industry. This section also describes the way in which flags of convenience enter the fishing industry and the most common fishing vessels and associated characteristics.

Chapter 4 analyzes a particular case study off the coast of South America and draws conclusions as to what factors within that case study are motivating IUU fishing behaviors. We discuss to what extent the findings from this case study can be applied to the global IUU fishing industry and if the findings can inform NGA actions in combatting IUU fishing.

Chapter 5 examines how support vessels interact with fishing vessels, and proposes a dashboard allowing users to track support vessels that are most vulnerable to U.S. jurisdiction.

Chapter 6 identifies a number of countries in Africa that can make viable partners for the USG to counter IUU-fishing based on economic, political, enforcement, and fisheries indicators.

Chapter 7 examines ports as a potential focal point of intervention and expands on Port States Measures Agreement (PSMA), focusing on the country's capabilities to execute the treaty.

Chapter 8 measures the efficacy of PSMA by examining if it had impact on the number of port visits by support vessels in a country or PSMA-designated ports.

Chapter 9 introduces a market-denial measure developed by the EU with its carding system as a tool to rein in illegal fishing.

Chapter 10 summarizes the findings in this research and provides key takeaways to help inform NGA's future efforts to combat IUU fishing.

Chapter 2. Legal Environment

There are many international treaties and conventions governing the sea, management and conservation of fish resources, and underwater ecosystems. This section describes nine international treaties that are relevant to the management of international waters and fish stocks. General frameworks that are not legally binding such as declarations, action plans, and international guidelines are not included in this law review. The review identifies the legal status of 193 countries in regard to nine treaties, analyzes the roles and limitations of international treaties, and identifies how these policies and legal frameworks can be improved.

Not all countries sign or ratify every international treaty. On average, each of these 193 countries is legally bound by 4 out of the 9 treaties. This limits the effective power of these treaties in two respects. Most obviously, a country which does not sign a treaty is not bound to follow it, but also, each convention requires a certain number of signatories before it enters into force for any of the countries. Furthermore, signature is only a first step; signing by itself does not establish the consent to be bound. "The signature qualifies the signatory state to proceed to ratification, acceptance, or approval. It also creates an obligation to refrain, in good faith, from acts that would defeat the object and the purpose of the treaty" (UN Library, n.d.). In this review, the legal terms ratification, accession, acceptance, approval, and succession are treated as though they are legally binding. The United Nations Treaties Collection states that these terms have the "same legal effect as ratification" and express "the consent of a state to be bound by a treaty" (UNTC, n.d.).

We begin and spend the most time on the United Nations Conference on the Law of the Sea (UNCLOS), which is sometimes referred to as the "Constitution of the Oceans", and two agreements that figure prominently in the analysis we pursue in other chapters of this report: (1) The Port States Management Agreement (PSMA) and (2) Regional Fishing Management Organizations (RFMOs). We then more briefly discuss other pertinent treaties.

In each case we report rates of treaty ratification, with full details provided in Table 1. Our analysis shows the proportion of countries that have ratified UNCLOS and what can be considered primarily "environmental conventions" is higher than the proportion ratifying the "fishing conventions".[1] We pay particular attention to treaty ratification rates for so-called Flag of Convenience (FoC) nations. All vessels are required to be flagged to some country, and most are flagged in the vessel owners' country. However, some countries sell the right to flag vessels with that country and entice "customers" by offering favorable tax treatment and/or lax rules. Unsurprisingly, vessels with such a "Flag of Convenience" (FoC) include some bad actors in the

[1] Fishing conventions in this chapter refer to Compliance Agreement, UN FSA, and PSMA that directly aim at regulating or providing guidance on fishery industry and the role of flag and port states. Environmental conventions refer to CBD, CMS, and CITES that are the treaties designed to conserve biodiversity and ecosystem while protecting certain marine species under their framework.

IUU world. Hence, we might suspect that FoC countries have low rates of treaty ratification, but that is not necessarily the case.

Table 1. Ratification Rates of Nine Treaties

Category	Treaty	Global	FoC Countries
General	UNCLOS	85%	91%
Fishing convention	Compliance Agreement	22%	31%
	UN FSA	46%	47%
	PSMA	37%	47%
Environmental convention	CITES	94%	94%
	CMS	68%	59%
	CBD	99%	97%
New treaties	C188	10%	3%
	CTA	8%	6%

However, the 32 countries offering a Flag of Convenience (FoC)[2] have relatively high ratification rates across the nine treaties studied here. Globally, the ratification rates of UNCLOS are 85%, environmental convention is 87%, and fishing convention is 35%. FoC countries' ratification rates of UNCLOS are 91%, environmental convention ratification is 83%, and fishing convention ratification is 42%.

Although it appears surprising that FoC countries such as Liberia and Panama are ratifying relevant treaties, signing a treaty and assiduously enforcing its provisions are not the same thing. Rather, their signing may merely demonstrate the degree to which these states pay attention to ongoing trends of international regulation. Although the international treaties establish flag states' obligation and standards towards IUU-fishing, FoC countries are aware that many loopholes exist in legal frameworks, and that they would like to appear cooperative. They are aware that they won't be called out for not regulating the vessels flagged to their countries.

Recognition of this led to a turning point in the principal approach taken by international treaties. International treaties changed focus from increasing the responsibility of flag states to empowering the roles of port states so that they can regulate and exercise jurisdiction over all vessels entering their ports, including vessels flagged to FoC countries.

[2] FoC countries included in this analysis are Antigua and Barbuda, Bahamas, Barbados, Belize, Bolivia, Cambodia, Cameroon, Comoros, Cyprus, Equatorial Guinea, Georgia, Honduras, Jamaica, Lebanon, Liberia, Malta, Mauritius, Moldova, Mongolia, North Korea, Palau, Panama, Sao Tome and Principle, Sierra Leone, Saint Kitts and Nevis, Saint Vincent, Tanzania, Togo, Tonga, and Vanuatu (ITF undated). Among the ITF's list of FoC, those that are not countries are not counted in the analysis.

Summary of Key Treaties

UNCLOS or the "Constitution of the Ocean"

The convention stemming from the 1973 third United Nations Conference on the Law of the Sea (UNCLOS III) was adopted in 1982 and entered into force in 1994. UNCLOS III lays down a "comprehensive regime of law and order in the world's oceans and seas establishing rules governing all uses of the oceans and their resources" (IMO, 2022). It incorporates customary rules for the uses of the oceans and at the same time introduces "new legal concepts" (IMO, 2022). UNCLOS III scaled down sovereign rights through several zones, including EEZ and established the International Seabed Authority to control "all mineral-resources-related activities" on the seabed of parties to UNCLOS III (ISA, n.d.).

Currently, 168 out of 193 countries (85%) are party to UNCLOS III, and out of the 32 (FoC) countries we identified, 29 have ratified UNCLOS (91%). On the other hand, the U.S. did *not* ratify UNCLOS based on the argument that the U.S. might have to surrender sovereignty to the International Seabed Authority (ISA) if did so. However, in practice, the U.S. accepts and complies with all the treaty provisions without ratifying it.

UNCLOS defines an EEZ as extending 200 nautical miles from shore. Within a country's EEZ, that state has "the right to explore and exploit, and the responsibility to conserve and manage, both living and non-living resources" (*WTO Glossary*, n.d.). As a practical matter, that gives the coastal state the right to enforce both its domestic laws and the laws of any international treaty, to which they are a party, within those waters. As 15% of countries have not ratified UNCLOS, not all countries declare EEZ boundaries under the authority of UNCLOS, and some states declare EEZ under the authority of their domestic law. This is mainly due to territorial disputes with neighboring nations. Major coastal countries that are non-party to UNCLOS include the US, Peru, Venezuela, and Eritrea but their sea territory is subject to customary international law. Due to the non-ratification of UNCLOS in these countries, part of their sea such as the Caribbean Sea, Red Sea and South Pacific Ocean are affected by the non-ratification of UNCLOS.

Previous Fishing Conventions that Laid a Foundation for PSMA

The Compliance Agreement and the UN Fish Stock Agreement (FSA) played a key role in codifying the role of flag states in international fishing treaties. The Compliance Agreement strengthens the role of the flag state because it requires a flag state's "control over its vessels to ensure compliance with international conservation and management measures" (FAO, 2022b). FSA sets out principles for the conservation and management of straddling fish stocks[3] and highly migratory fish stocks and "establishes that such management must be based on the precautionary approach and the best available scientific information" (United Nations, 2001). Out of three fishing

[3] Straddling fish stocks are "stock of fish such as pollock, which migrate between, or occur in both, EEZ of one or more state and the high sea" (UN Atlas of the Oceans, undated)

conventions studied in this review, it is notable that the ratification rate of the Compliance Agreement is the lowest at 22% and progress towards increasing signatories remains quite stagnant. However, it laid the foundation for integrating the role of flag states in later agreements.

Port State Management Agreement (PSMA)

The PMSA is referred to as the first binding international agreement to specifically target IUU fishing. PSMA's objective is to "prevent, deter, and eliminate IUU fishing by preventing vessels engaged in IUU fishing from using ports and landing their catches" (FAO 2022b). PSMA reduces the incentive of such vessels to continue to operate by providing coastal states the authority to inspect suspicious vessels and share information with flag states and RFMOs. It also blocks fishery products derived from IUU fishing from reaching national and international markets. The provisions of the PSMA apply to fishing vessels seeking entry into the port of a state which is different than their flag State (FAO, 2022a). As of 2022, 37% of countries are legally bound by PSMA. The treaty entered into force in 2016, but its implementation is still in the early stages. Under PSMA, countries should "designate" ports that carry the mandate of PSMA. However, many countries haven't yet designated ports. Currently, out of 36 coastal African countries, only 13 designated ports that would fall under the mandate of PSMA. This suggests that while PSMA has been signed by many African nations, in practice, it may be having much less of an impact than may be thought. Below in section 5, we will show how "displacement" may happen when one country joins PSMA while there are other nearby countries who don't join PSMA.

Out of 32 FoC countries, 47% are legally bound by PSMA, including Liberia and Panama. The agreement is designed to prevent ships engaged in IUU fishing from using services at ports mandated under PSMA. The fact that FoC countries' approval rate on these agreements is higher than the global average may imply that even FoC countries wish to be more empowered to inspect the vessels entering their ports.

An article from Pew Charitable Trust in 2019 noted that "critical gaps" exist in the current IUU enforcement structure, but the article argued that the gaps can be closed or narrowed by two specific measures, namely penalizing FoC countries for inappropriate behaviors or by further strengthening the role of port states for their inspection and regulation over IUU fishing (Pew Charitable Trust, 2019).

Regional Fishery Management Organizations (RFMO)

There are currently 17 RFMOs covering various geographic areas. Under the UN FSA, RFMOs can regulate highly migratory and straddling fish stocks. One of our hypotheses was that RFMOs would impact the behavior of support vessels in the EEZ of a country joining an RFMO. We looked at support vessel activity around three countries that joined RFMOs between 2012-2022. Liberia joined the International Commission for the Conservation of Atlantic Tuna (ICAAT), Somalia joined the Indian Ocean Tuna Commission (IOTC), and Peru joined the Inter-American Tropical Tuna Commission (IATTC). The dark meetings of support vessels were not

influenced by the entrance of Peru and Liberia to RFMOs, but the dark meetings of vessels in Somali waters decreased significantly after Somalia joined the IOTC. This suggests that sometimes RFMOs could reduce instances of suspicious support vessel events, possibly pushing these actions into other waters not under the jurisdiction of an RFMO. Below in Section 4 and 5, we will further discuss the impact of legal instruments on a regional scale.

Other Relevant Treaties

Environmental Conventions as a New Approach to Countering IUU-fishing

In addition to treaties specific to IUU, there are also general environmental conventions whose provisions may constrain IUU. There is a debate over the effectiveness of these environmental treaties, but they provide legal frameworks to conserve biodiversity and protect endangered species. CITES, CBD, CMS extend their mandates to the protection of marine and coastal fish resources and thus can serve as a legal framework for regulating non-compliant parties. Among them, CITES protects 154 fish species (out of 38,700 species in total that are protected by CITES against over-exploitation). As of 2022, 42 countries are subject to the suspension of all trade in specimens of one or more CITES-listed species (CITES, 2022). Despite weakness caused by the lack of enforcement, the environmental treaties such as CITES can provide a rationale to strengthen counter IUU-fishing activities. Note that the ratification rates of the three environmental conventions are slightly higher at global level (87%) than at FoC countries (83%).

"Three Treaties to End IUU-fishing"

Pew Charitable Trust (2018) claims that three treaties (PSMA, C188, CTA) can put an end to IUU-fishing. We have already discussed the PSMA, so here we describe the other two. All three are more recent international efforts to empower port states to counter IUU fishing, efforts spurred in part by recognition that flag nations do not always enforce the law against the vessels they flag. The Work in Fishing Convention 188 (C188) sets standards for decent working and living conditions on fishing vessels and allows countries that have ratified it to enforce its requirements on foreign fishing vessels entering their ports and to conduct labor inspections. C188 ensures fishers have sufficient rest, occupational safety and medical care, and have the social security protection as other workers. If any complaint is received or there is evidence that a vessel doesn't conform to the C188 standards, the country can take necessary legal measures to rectify the conditions (ITF 2007).

The Cape Town Agreement (CTA) was adopted in 2012 by IMO but hasn't entered into effect because the minimum number of ratifications has not been reached[4]. Parties to the CTA are required to establish safety measures for fishing vessels flagged to their country such as requiring

[4] CTA will enter into force once 22 states with a total of 3,600 eligible vessels ratify it.

certain radio communications, lifesaving and navigational equipment, and creating emergency procedures. CTA allows port states to carry out safety inspections of all vessels entering their ports. If this treaty entered into force, it would "empower states to carry out safety inspections that could be aligned with fisheries and labor agencies, to ensure responsible labor and environmental practices are in place" (Pew Charitable Trust, 2018). These three treaties are designed to empower a port state to carry out necessary safety and labor related inspections, and apply port state measures, even when vessels are flagged to non-parties of these treaties.

The US might consider using its diplomatic power to advance the ratification of C188 and CTA and to assist parties to exercise authority under PSMA, in hopes that might have an impact on IUU-fishing.

Chapter 3. Fishing Fleet

The IUU fishing industry is complex. There are numerous fishermen and vessels operating in different parts of the world and catching all kinds of aquatic animals. The variability in the IUU landscape is significant. One person in a small wooden canoe can violate domestic fishing laws and thus be an IUU fisherman. Indeed, some artisanal fishermen use very harmful methods, including fishing with dynamite. However, many of the more important cases of IUU fishing involve sizable commercial ships capturing large quantities of fish with each voyage. As previously mentioned, we do not know the size of IUU fishing on a global scale and the lack of reliable data and the complex legal environment can make it difficult to discern what countries, companies, and vessels are contributing most to the IUU fishing problem. So our focus on the major actors in the fishing industry follows more from a common sense assumption than from data proving they are the best target.

It is possible to identify major fishing actors because international registration laws require maritime vessels to be registered to a specific country. Vessels of a certain size must be registered to a state, and those vessels are then permitted to fly the flag of that state. Individual countries determine the conditions under which a ship can be registered in the country. Once registered in a country, the state of registration, often called the "flag state", has jurisdiction and enforcement responsibility over that vessel whether the vessel is in the state's waters or in international waters. According to UNCLOS "there must exist a genuine link between the State and the ship" and such links might include requiring a certain percentage of the crew to be citizens of the flag country. Some countries interpret the text of UNCLOS liberally and this has led to FoC being used by vessels looking to circumvent the law.

Flags of Convenience (FoC)

A flag of convenience describes the registration of a vessel to a country without a genuine link in order for the vessel to take advantage of lax enforcement. This can also be described as a state having an "open registry" meaning states have low standards for determining what the genuine link is between their country and a vessel. When "flagging out" a vessel owner can take advantage of "minimal regulation, cheap registration fees, low or no taxes, and freedom to employ cheap labour from the global labour market" (International Transportation Workers' Federation, n.d.). The implicit understanding between the vessel owner and the FoC state is that the country likely has no intention, or even ability, to enforce regulations on their vessels, especially when the vessels are operating far away from the flag country. Running an open registry can generate financial benefits for a nation. For example, Liberia is estimated to generate around $18 million a year from the taxes and fees earned on selling flags of convenience. Some even suggest this is a low estimate and that 25% of the Liberian governments annual budget is earned from selling flags of convenience (Alam, 2021).

On the other hand, $18 million is a tiny sum compared to estimates of the annual cost of IUU or the cost of enforcement; e.g., one U.S. Coast Guard cutter costs the taxpayers on the order of $500 million. Hence, if the existence of FoC were a major enabler of IUU and those registration revenues were a primary motivator of the FoC countries, it would seem worth investigating whether existing FoC countries could be induced to stop their practices in exchange for increases in foreign aid of equal or greater value. There could be complications, such as preventing a new country from becoming an FoC. But the fact that the rewards to the flagging countries appear to be rather modest suggests investigating such options – something we did not have time to do.

FoC allow vessel owners to essentially pay a fee in order to behave in ways that are illegal in most countries but are perfectly legal – or illegal but not enforced – under the jurisdiction of their FoC state. Flagging your vessel to a FoC state can provide benefits that you otherwise would not be able to access. In the global merchant fleet, FoC states have jurisdiction over a significant number of vessels but interestingly, the influence of these states is far less obvious in the fishing fleet.

Global Fleet Numbers

Our data collection attempts to provide perspective on the global maritime environment, and it reveals some expected patterns and some unusual patterns. According to the United Nations database on flagged vessels[5], in 2022 the global merchant fleet consisted of roughly 100,000 flagged vessels. These vessels include cargo ships, oil tankers, bulk carriers, container ships, and "other"[6] types of vessels. Roughly 52% of the global fleet (as measured in number of vessels) is flagged to 10 states. Some of the states with the highest number of vessels make sense because they are an archipelago (Indonesia and Japan) or have large populations and big economies (United States and China). However, of these 10 states, 3 of them, Panama, Liberia, and the Marshall Islands, have open registries and fleet sizes that are disproportionate to the size of their population and economy. These three FoC countries account for a little over 16% of the global merchant fleet.

Fishing Fleet

Focusing exclusively on fishing vessels, the world has roughly 4.3 million fishing vessels[7]. Of these, the powered fishing vessels are likely most important because they are capable of capturing larger quantities of fish more efficiently than unpowered vessels, although the destruction of whaling stocks by 19th century sail-driven whalers demonstrates that even

[5] See the provided Excel workbook entitled "Fleet Snapshot and Law Review Deliverable" for more information as well as the data sources

[6] "Other" was the category name used in the UN database

[7] This number far surpasses the UN count for total number of world vessels because many of these vessels are small enough to not require registration, e.g. the individual in a wooden canoe.

unpowered vessels can be a problem. Global Fishing Watch (GFW), an organization that develops and publicly shares ship tracking data in order to combat IUU fishing, estimates that motorized vessels over 24 meters in length are responsible for over 50% of global catch (Global Fishing Watch, 2022a). According to 2020 estimates from the United Nations, about 45,000 vessels (or 1.8% of the global fishing fleet) were powered vessels over 24 meters in length. If these estimates are correct, that means only 2% of vessels are responsible for over 50% of total capture production.

In 2020, the UN estimated the world total of powered fishing vessels to be around 2.4 million. In 2019, roughly 20% of the world's powered fishing vessels were flagged to China and another 20% were flagged to Indonesia[8]. This is not surprising as China is the top global consumer of seafood and Indonesia is an archipelago state where the population gets at least 20 percent of the average per capita intake of animal protein from seafood (FAO, 2022c). The next 8 countries account for about 38% of the global powered fishing fleet, meaning that the top 10 countries account for about 78% of the global powered fishing fleet.

Organizing countries by the number of fishing vessels flagged to that country is one way to identify the major actors in the global fishing industry. However, other metrics reveal different major actors within the industry. For example, when organizing countries by the proportion of global capture production[9] we see that China and Indonesia remain as the top two countries, accounting for 15% and 8% respectively. The next 8 countries listed account for about 37% of global capture production meaning the top 10 countries account for about 60% of global capture production see Table 2 below.

[8] The UN reported aggregate estimates of the global fleet size in 2020, but 2019 was the most recent year for which the United Nations reported country-level data.

[9] Capture production refers to what we typically think of as fishing, namely the capture and removal of aquatic animals from the water. "Total fishery products" or other equivalent terms refer to capture production plus also aquaculture, which is a type of aquatic farming. Aquaculture "farms" are mostly contained and as such, easier to monitor and protect. IUU fishing practices mostly apply to capture production.

Table 2: Major Fishing States by Capture Production and Fleet Size

% of Global Capture Production		% of Global Powered Fishing Fleet	
China	14.9%	China	19.7%
Indonesia	8.1%	Indonesia	19.3%
Peru	7.1%	Japan	9.5%
Russian Federation	6.0%	Philippines	7.7%
United States of America	5.4%	India	6.0%
India	4.7%	Nigeria	3.3%
Vietnam	4.2%	Cambodia	3.3%
Japan	4.0%	United States of America	3.2%
Norway	3.1%	South Korea	2.7%
Chile	2.3%	Mexico	2.7%

SOURCE: Author analysis. See the included Excel workbook "Fleet Snapshot and Law Review Deliverable".

Aside from China and Indonesia, the major countries according to capture production differ from the major countries according to the number of powered fishing vessels. Some countries are included in both lists but sit at different spots. For example, Japan has the third highest number of powered fishing vessels but is the 8th largest in terms of proportion of global capture production. Peru on the other hand does not even rank within the top 10 for number of powered vessels but is the third largest in terms of global capture production[10]. Interestingly, Russia is 4th in terms of global capture production but 49th according to the number of powered fishing vessels. This could mean that Russia obscures the size of its powered fishing fleet, and so the UN has to estimate the number of vessels.

Interestingly, far fewer fishing vessels than merchant vessels are flagged to FoC states. We identified 38 countries that are considered to have an open registry (International Transportation Workers' Federation, n.d.) and these countries account for 28% of the global merchant fleet but only 7.6% of the global powered fishing fleet. Cambodia is the only country with an open registry that appears in the top 10 countries when categorized by global capture production or number of powered fishing vessels. Cambodia accounts for about 3.3% of the global powered fishing fleet. This does not mean that FoC are absent from the global fishing industry. FoC may not appear frequently on flagged fishing vessels, but they do appear to enter the fishing industry through their registration of support vessels which will be discussed in Chapter 5.

[10] This is likely because Peru can fish significant quantities of Anchovia (the genus of anchovy type fish) right off its own coast which allows their fishing fleet to be highly efficient.

As previously mentioned, we focused our analysis on powered vessels because they are capable of capturing large quantities of fish. Within the category of powered vessels, we can further drill down into categories of ships by the size and type of vessel.

Fleet Snapshot – Commercial Fishing Vessel Overview

According to GFW, commercial fishing vessels (CFV) are vessels that are 24m length overall (LOA) or longer. As previously mentioned, these types of fishing vessels make up 2% of the global fleet but are responsible for over 50% of the global catch (GFW, 2022). Additionally, our research has shown that CFVs primarily conduct two types of trips. The first occurs when a CFV leaves its port, conducts its fishing operations, and returns to port in order to sell its catch on the open market. The second kind occurs when the CFV leaves port and conducts its fishing operations, meets with a support vessel, and unloads the catch onto the support vessel – perhaps multiple times – before returning to port. The overall functionality of support vessels will be covered in Chapter 5.

In a 2021 The United Nations FAO report entitled "Review of the Techno-Economic Performances of the Main Global Fishing Fleets" the authors identified and analyzed eight different types of CVFs that are commonly used in commercial fishing. Although the global fleet consists of many different vessels, we have provided descriptions of these eight types of CFVs because they are prominent vessels used for commercial fishing. They are small bottom trawler, medium bottom trawler, large bottom trawler, pelagic trawler, purse seiner, longliner, gillnetter and jigger fleet.

The table below provides the vessel length, engine power in kilowatts (kW) and mechanical horsepower, tonnage and the type of fish typically caught by the eight most prominent commercial fishing vessels.

Table 3: Commercial Fishing Vessel Characteristics

Type of Vessel	Vessel Length	Engine Power in kW	Engine Power in Mechanical Horsepower	Tonnage (tons)	Type of Fish Typically Caught
Small Bottom Trawler	14 – 22m	104 – 456	139 – 611	19 – 138	Rockfish, cod, ocean perch, flounder and sole
Medium Bottom Trawler	25 – 35m	112 – 1,480	150 –1,984	337– 1,843	Rockfish, cod, ocean perch, flounder and sole
Large Bottom Trawler	43 - 66m	67 – 2,464	626 – 2,464	337 – 1,843	Rockfish, cod, ocean perch, flounder and sole
Pelagic Trawler	25 – 66m	2,250	3,017	1,480	Seabass, mackerel and herring
Purse Seiner	18 – 87m	85 – 3,853	114 – 5,167	47 – 2,714	Small sardines to large tuna. Estimated they are responsible for over 60% of total tuna caught
Longliner	22 – 63m	329 – 1,185	441 – 1,589	75 – 1,165	Sablefish, halibut, tuna, swordfish and marlin
Gillnetter	12 – 34m	100 – 225	134 – 301	25 – 160	Salmon, cod, haddock, rockfish, tuan, and sturgeon
Jigger Fleet	10 – 25m	150 – 550	200 - 737	10 – 110	Squid

Source: FAO Fisheries & Aquaculture

Two important characteristics of a vessel type are the gross tonnage and engine power. These two characteristics closely relate to the total amount of catch that an individual CFV can "hold" (UN FAO, 2021). Additionally, these two characteristics largely dictate the distance and duration of a single "trip" for the individual CFV without refueling at sea.

According to a paper titled *Modeling Fuel Consumption of Fishing Vessels for Predictive Use* (Davie et al., 2015), an increase in fuel price negatively affects fuel consumption, especially for larger vessels. This study was conducted on Irish fishing vessel economic data collected between 2003 and 2011. The authors found two general trends across their predictive fuel consumption analysis. First, more fuel was used by vessels of greater size which directly relates to the overall weight of the vessel. Second, there are differences in fuel consumption based on gear type. It was concluded that dredge gears, a fishing method that drags nets along the seabed, are the most fuel-

demanding fishing method because it generates greater drag resistance as the boat is in motion. Pelagic trawlers were the second most fuel-demanding fishing method identified, which can be partially attributed to the high volume of catch and weight of the catch and also because pelagic trawlers typically need to travel longer distances for their catch.

Fuel conception is also heavily dependent on speed, since beyond the lower ranges of speeds, hull resistance tends to increase roughly as the cube of the vessel's speed.

The overall approach to commercial fishing and so also vessel type varies depending on the target species that the crew wishes to catch and by the geographic area of operation. It is important to understand the differences between the types of commercial fishing vessels in order to best understand how certain vessels operate during their fishing operations. For example, the speed of a commercial fishing vessel is different for all of the vessels discussed above. The speed, engine power and gross tonnage correlate to the duration that a fishing vessel can conduct its fishing operations. Further, a shorter the duration increases the likelihood that the fishing vessel will need to meet with a support vessel for fuel. Therefore, by understanding the geographic region of operation, mainly the type of catch, and the speed of the vessel the NGA can better ascertain possible indicators of illegal fishing actors and activity.

Chapter 4 Motivating Forces for IUU Behavior

Chapter 3 attempted to show what the global fishing fleet looked like, but we are much more concerned with what the illegal fishing industry looks like. One way to pursue this is to attempt to understand what could motivate a captain, crew, or company to fish illegally instead of legally. In this chapter, we attempt to illustrate how illicit actors might be affected by changes in the illegal fishing environment

Literature Review

As one economist recently told us, citing Gary Becker's 1968 work *Crime and Punishment: An Economic Approach* is like citing the Bible as it is the seminal publication which models crime and punishment in economic terms. Becker theorizes that criminals can be modeled as utility maximizing rational actors who engage in illegal activity if the expected payoff is greater than for other activities that they could legally pursue. His theory posits that criminals will respond to changes in the probability of apprehension and the size of punishments as these factors influence their expected payoff (Becker, 2000). This premise was the foundation for many subsequent works at the intersection of economics and criminology. In our analysis, we follow Becker's idea that varying apprehension and punishment can influence criminal behavior.

Building on Becker, Polinsky and Shavell, in their 2000 work, *The Economic Theory of Public Enforcement of Law*, examine how societies should allocate resources to apprehend rule breakers and what types of punishments should be inflicted upon those who are caught (Polinsky & Shavell, 2000). Their conclusions reveal insights that can be applied to IUU fishing. Since large sections of the ocean can be very difficult to police, countries will need to make resource allocation decisions on where to patrol. Furthermore, states with small or unsophisticated navies and coast guards will struggle to police effectively the areas of the ocean in which they choose to allocate resources. According to Polinsky and Shavell, imposing very high sanctions on IUU fishing actors could be an effective solution because "sanctions that are substantially in excess of harm are needed for proper deterrence when the probabilities of enforcement are significantly less than one". The authors also provide information on choosing between fines and imprisonment as a sanction. They note that imprisonment is a costlier sanction than a fine, but that imprisonment might be needed to counter criminal activity.

Much of the literature on economics and criminality discusses catching and imposing a cost on the perpetrator of the crime. However, it is also worth discussing how this approach can be counterproductive in some criminal industries. Caulkins et al. find that victim-level interventions in human trafficking can paradoxically lead to an increase in the number of victims. The research shows that when human traffickers view people as an asset that generates value then they can make decisions that essentially ignore the probability of having that victim be apprehended. The research

states, "When replacement costs are so low relative to revenues per victim, victim-level interventions may actually increase the number of HT [human trafficking] victims: if the interventions reduce by half the average time an individual is trafficked, then traffickers must obtain two people to provide the same volume of activity" (Caulkins et al., 2019). Similar insights could possibly be applied to low-level fisherman crewing an IUU fishing vessel. These laborers are often the victims of human trafficking and as such, a higher-level actor in the operation might not care if these people are apprehended because the cost of recruiting a new crew could be low compared to the potential revenues generated from IUU fishing. If this is the case, then enforcement against vessels crews might have no effect on IUU fishing while also indirectly leading to more victims of labor trafficking.

One unresolved question is how to view ships' officers in this regard. It is not entirely clear whether the officers are the key decision makers whose incentives can be manipulated to reduce IUU or whether they are just higher-paid crew members with the real drivers of decisions to break laws resting with shore-bound executives of companies that own a fleet of ships. If it were more the latter, then in order for the bite of punishment to fall on the key decision makers, those punishments might need to take a different form, such as seizing catch and vessel or imposing fines or cease and desist orders on the ownership group.

IUU Fishing Actor Equation

From this literature, we derived a simple equation that can help us think about which factors are motivating IUU fishing practices. By examining the disaggregated factors that influence behavior we hope to identify where and how the US can best allocate resources to intervene in IUU fishing internationally. Our equation assumes that IUU fisherman are profit-maximizing rational actors. Therefore, when the profit from illegal fishing (P_i) minus the profit from legal fishing (P_l) is greater than the probability of being caught (P_c) multiplied by the cost of being caught (C_c) then IUU fishing will occur[1]. This can be thought of as the benefit from illegal fishing outweighing the expected cost of illegal fishing. See the equation below.

$$P_i - P_l > P_c * C_c$$

Revenue from Fishing Operations

Revenue is measured as the price of the fish being sold multiplied by the quantity sold. The price of the fish is determined by the type of catch pursued and this price can vary greatly. For example, a Red Seabream costs $58 per kg while a European Seabass costs $5 per kg (FAO, 2022c). The price will also depend on the market you are selling into. Consumer preferences for quality and type of fish will determine how valuable the catch is. The quantity of fish being sold will depend on the vessel being used. Larger, more sophisticated vessels can efficiently catch and store more fish. However, selling fish often means returning to port which costs time and money (primarily in fuel costs). Some crews are able to increase their revenue by engaging in

transshipment with support vessels which allows the crew to produce more catch in a given time period. Transshipment will be discussed in much more detail in Chapter 5. Tracking and Targeting the Support Fleet

Cost of Fishing Operations

Table 4 below provides definitions for each type of fishing cost.

Table 4: Fishing Costs Defined

Type of Cost	Definition
Labor Cost	Personnel costs; labor wages
Running Cost	Energy costs (fuel, lubricant, oil and filters). Harbor dues, ice, bait, salt, fish-selling costs and packaging materials
Vessel Cost	Gear replacements, repair and maintenance, vessel repair, other non-variable costs (insurance), fishing licenses, permits and the purchase of fishing rights (quotas)
Capital Costs	Depreciation (of the vessel, engine, equipment, and gears lasting more than three (3) years), interest and amortization of intangible assets
Operating Costs	Labor Costs + Running Costs
Vessel Owner Costs	Vessel Costs + Capital Costs

SOURCE: Anrooy et al. 2021

Labor costs largely depend on the location from which the vessel recruits its crew, not where the vessel operates. Crew recruited from an area where there are few economic opportunities or labor protections in place are more likely to accept smaller wages. Hence, long-distance fishing fleets enabled by support vessels expose local fishing communities to labor competition from around the world.

Vessel costs do not include the costs of purchasing the vessels; that is captured under the "capital costs" category. The vessel cost category does include maintenance and repair, but at least in some fisheries, the perhaps greater share of this cost category is related to the leasing of quota and other fishing rights. That has implications for IUU enforcement.

Some crews conducting IUU fishing activities are essentially "poaching" and do not obtain these rights. Those crews are likely able to eliminate substantial parts of this cost category and thereby obtain a competitive advantage over law-abiding vessels. In our case study, that cost category might account for on the order of 17% of total costs.

On the other hand, IUU can also involve licensed vessels exceeding their quotas. In that case, the high costs of obtaining quota and fishing rights could work to law enforcement's advantage, if it represents a valued asset that is relatively easy to seize and forfeit when violators are caught.

Capital costs could have interesting dynamics for illegal vs. legal fishing vessels that we will describe but did not have time to quantify with empirical data. On the one hand, vessels used for IUU fishing are criminal assets that may be vulnerable to seizure, giving an incentive for IUU fishing operations to use vessels that are relatively old and/or not well maintained (so that their replacement is lower if they are seized). On the other hand, we conjecture that it may be harder to obtain repair and maintenance services from ports for IUU vessels than for legal vessels because IUU vessels are, in essence, the scene of a crime and a seizable asset. We are unclear how difficult it is for IUU vessels to enlist the services of a 'shady' repair yard, or how that is affected by PSMAs. The overall assumption is that the vessel costs of a vessel conducting IUU-fishing activities would likely be higher when compared to vessels who are not conducting IUU-fishing activities, but that is something that bears further investigation.

Probability of Being Caught

In order to catch an IUU fishing vessel, the enforcer must have the physical capability, legal authority, and willingness to apprehend and prosecute the rule breaker. A country's physical capability depends on their investment into the Navy or Coast Guard in proportion to the size of their jurisdictional area. The United States has one of the largest EEZ's in the world measuring roughly 11.4 million square kilometers. This EEZ is protected by the US Coast Guard which has about 1,800 surface vessels and 200 aircraft at its disposal (United States Coast Guard, n.d.). However, many nation states do not have maritime enforcement capabilities close to the level of the United States, which renders enforcement difficult.

If a country has the capability to intervene, it still must have the legal authority. Countries have the right to enforce laws against vessels within their EEZ. However, EEZ's can be very large, making it difficult to successfully surveil and protect the entire area. Outside of a country's EEZ, surveillance, patrolling, and enforcement become more difficult and matters of jurisdiction become more complicated. Different international and RFMO rules apply in the areas beyond an EEZ and enforcement against vessels flagged to a different country is difficult. Even if you know where a vessel is, some international regulations could prevent you from "catching" the vessel or imposing a punishment on the guilty parties when the vessel is outside your jurisdiction.

Finally, a country must be willing to prosecute a bad actor even if they are able and authorized to apprehend them. This can be a nontrivial matter as some small nations might be apprehensive about prosecuting the crew of a more powerful nation fearing some sort of diplomatic or financial retribution. However, if the ability, authority, and willingness are all in place, then punishments can be imposed on IUU fishing actors.

Cost of Being Caught

Apprehension is just one step in combatting criminal behavior. Once the actor is caught, they can be punished in different ways including fines, vessel seizure, industry blacklisting, and imprisonment, at least in theory. In practice, as previously discussed, the legal landscape in IUU fishing is complicated. Varying international and domestic laws result in the imposition of different penalties for IUU fishing activities, but they are not always swift or substantial. Nor do they always fall on the key actors (e.g., if sanctions fall on crew, but crew are not the key players).

To the extent that vessels that flout fishing laws may also be cutting corners in other ways, an IUU actor may also be subject to penalties for violating labor, trade, environmental, or other laws.

Understanding the costs of being caught for IUU fishing requires a legal understanding of the domestic and international laws applicable in each scenario, and how things play out in practice since it is the norm in all sorts of criminal justice processing that actual sentences are often not the same as the statutory maximum.

Case Study – Region 87

Attempting to quantify these variables on the global scale would be very difficult. Therefore, we decided to apply this methodology to a particular case and then reflect on how the case could be applied to other regions. We chose to focus on the UN identified Region 87 which is an area of ocean on the west coast of South America. This region extends from the coastlines of Ecuador, Peru, Chile, and western Columbia (to include their EEZs) into the Pacific Ocean and is covered by parts of the South Pacific Regional Fishery Management Organization (SPRFMO) and the Inter-American Tropical Tuna Commission (IATTC). In 2020 the region produced over 8.4 million metric tons of capture production

Region 87 is an attractive case because there are only three primary coastal nations in the region, Peru, Ecuador, and Chile which are all party to the Port State Measures Agreement, meaning that the nations are committed to preventing IUU fishing by trying to stop illegal catches from landing in their ports.

Additionally, the region is relatively close to the United States which makes USCG patrols in the region feasible. There is recent evidence to suggest that the US might be willing to pursue such actions in the region. In 2021, Ecuador requested USCG assistance in patrolling near the Galapagos Islands to deter a large Chinese flagged fishing fleet (Sinclair 2021) and in August of 2022 the USCG conducted its first counter IUU fishing operation under the authority of the South Pacific Regional Fisheries Management Organization (SPRFMO) (DVIDS, 2022).

After identifying Region 87 as our case study, we decided to further narrow our focus to a particular vessel and catch type. This was done because as Chapter 3 noted, fishing vessels and catch types are diverse and each one will have a different cost and revenue structure. We decided

to focus on pelagic trawlers fishing for mackerel in the region because large amounts of mackerel (estimated to be between 5-10% of total capture production) are fished in the region, and all three primary coastal nations fish for mackerel.

Pelagic Trawler Costs

The following analysis of the cost and revenue structure for a pelagic trawler draws heavily on information obtained from a Food and Agriculture Organization (FAO) report (Anrooy et al., 2021)[11] that studied six segments of pelagic trawlers[12] from Senegal, Bangladesh, Denmark, Norway, Turkey and the United Kingdom. The analysis did not include any South American pelagic trawler fleets, so we were forced to assume that there are broad similarities between the pelagic trawler fleets analyzed in the report and those in our Zone 87 case study.

The sum of all costs for pelagic trawlers are largely dependent upon the vessel length. For vessels with a length between 28m and 56m, the total costs range from $586,300 - $5.9 million USD per year, on average for all fleet segments studied from 2018 – 2020 (Anrooy et al., 2021). Typically, the highest cost component for a pelagic trawler is running costs (40% of total cost), followed by labor costs (24%), capital costs (19%), and vessel costs (17%). So Operating Costs account for 64% of overall fishing costs.

Based on the UN FAO report, labor costs in absolute values vary from as low as $42,900 to the highest average labor cost of $2.6 million on a per ship per operational time basis. Overall, the wide range of costs is most associated with an increase in the pelagic trawler vessel size.

Expected Pelagic Trawler Revenues

The average revenue for a pelagic trawler also depends on geographic fishing region, targeted catch type and their stock status, and the gross tonnage of the fishing vessel (Anrooy et al., 2021). The average revenue per year obtained by pelagic trawlers ranged from $305,500 - $12.2 million USD for vessels with lengths of 28m - 66m, with lower revenues for smaller vessels (Anrooy et al., 2021). Other factors that drive revenues are the efficiency of the fishing crew, the type and quality of fishing equipment, and the type of fishing product being caught. The efficiency of the fishing crew depends on many factors including knowledge about the areas in which their target catch is likely to be. The type and quality of fishing equipment used directly ties into a crew's ability to be efficient in catching their desired target product. The type of fishing product being targeted and caught will affect the vessel's revenue because most fishing crews will target a

[11] Countries include Bangladesh, Brazil, Chile, China, Denmark, France, Germany, India, Indonesia, Italy, Japan, Norway, the Republic of Korea, Peru, Senegal, South Africa, Spain, Turkey, United Kingdom of Great Britain and Northern Ireland, and the United States of America

[12] The information presented in the report is partly based on annual data and information programs conducted by fisheries agencies in Denmark, France, Germany, Italy, Japan, Norway, the Republic of Korea, Spain, the United Kingdom of Great Britan and Northern Ireland, and the United States of America.

product that is selling for a higher market price. Overall, these factors equally affect legal versus illegal fishing vessels.

Pelagic Trawler Profit

The six pelagic trawlers fleets studied by the FAO (Anrooy et al, 2021) had net profit margins which ranged from 12% - 36%, with an average of 24% (Anrooy et al, 2021). For reference, in most industries a 10% net profit is considered a worthwhile endeavor. Return on Investment was the last financial measure used to measure the financial success of the pelagic trawler fleet. The report found that 66% of the pelagic trawler fleet segments studied by the FAO had a return-on-investment percentage above 10%.

Increased Demand for South American Mackerel

As noted, revenues depend on prices which depend on demand and supply, and there is an interesting recent history of demand for the South American mackerel.

The jack mackerel species is found in the south-central zone of Chile. In the early 2000s it was fished heavily and dangerously overexploited. However, through the conservation efforts of the South Pacific Regional Fisheries Organization (SPRFMO) it has recovered and is currently in high demand across the world (SeafoodSource, 2022). That recovery has now brought increased harvesting, by legal and illegal fishing, potentially placing the fishery in danger again. Indeed, one can even interpret the sequence of events as a case in which the conservation-induced recovery made the fishery a large and appealing enough target to attract the attention of the large distant-water fishing fleets that conduct some of the most damaging forms of IUU.

Before describing the sequence of events, it is worth getting a sense as to the nature and scale of this fishery. "Mackerel" is not a single species. Rather, it is a category of fish. The Chilean jack mackerel, for instance, is a rather ordinary fish (typical length is about 2 feet long) that concentrates around upwellings but migrates into the open ocean – and outside of coastal states' EEZs. Historically, when smoking and salting were the principal means of preservation, it was not highly valued, but the advent of canning and refrigeration technologies made it more desirable in international markets.

After the first bout of overfishing, the conservation efforts by the SPRFMO permitted an increase in the jack mackerel catch to 297,000 metric tons in 2015 and 581,000 metric tons in 2022 (source: same as above). In 2021 Chile exported 227,342 metric tons of frozen jack mackerel with a total value of $245.9 million USD and 15,062 metric tons of canned jack mackerel earning $33.6 million USD (SeafoodSource, 2022). These numbers imply export revenues of about $1,100 per metric ton of frozen jack mackerel and $2,200 per metric ton of canned jack mackerel. Prices paid to the fishing vessels are presumably lower than the export price of processed fish.

Worldwide market prices for mackerel have remained consistent in recent years due to there being an international market. Prior to 2019, a kilogram of mackerel was going for $1.64 USD in

2017 and $1.47 USD in 2018. In 2022, the approximate price range for Mackerel is between $1.47 – 1.64 per kilogram. The average price for a ton of Mackerel is the United States is $1,641 USD (Wamucii, 2022)

The recent boom in jack mackerel exports from Chile coincided with major companies in the European market starting to source jack mackerel from Chile due to the continued overexploitation and decline of mackerel stocks in the Northeast Atlantic (MSC International, 2022).

However, this explosion of demand for jack mackerel from the South Pacific creates a market opportunity for IUU-Fishing activities. According to Chile's National Fishing and Aquaculture Service, crews and nation-states responsible for conducting IUU-Fishing activities have caused $397 million in losses and have collapsed the country's fishing stock by 70% from its former high since 2018 (BRINK, 2022).

The growing demand for jack mackerel in world markets coupled with the increase of supply due to the conservation efforts of the SPRFMO may have unintentionally created an environment that is ripe for IUU-Fishing actors to operate. The possibility that this illegal market has grown out of conservation and sustainability efforts, mostly by the Chilean government, should not be lost. The increase of illegal fishing activities in the South Pacific RFMO can also be tied to this increased European demand for sustainable seafood products.

Probability of Being Caught in Region 87

We believe it is unlikely that the countries in Region 87 will be able to generate a reasonable probability of apprehension given their current resources, size of their jurisdictions, and fishing activity in those jurisdictions. Table 5 shows the number of maritime enforcement vehicles that each of Region 87's three coastal countries have available, as well as the area that each vessel would have to patrol in order to police the entire EEZ[3], with the U.S. included as a benchmark.

Table 5: Enforcement Resources Compared to Enforceable Area

Country	EEZ Size (square kilometers)	Naval Surface Enforcement Vessels	Enforcement Aircraft	Square km per vessel	Square km per aircraft
United States	11.4 million	1,800	200	6,333	57,000
Ecuador	1.1 million	15	28	73,333	39,285
Peru	900,000	38	14	23,700	64,285
Chile	3.7 million	14	11	264,000	336,363

SOURCE: Multiple Sources. Vividmaps.com, Ecuadorian Navy website, Peruvian Navy website, Chilean Navy website

It is also important to consider how much fishing activity is occurring in an area. Patrolling large areas of ocean is even more difficult when those areas contain a lot of fishing vessels. Table 6 shows the quantity of fishing activity that each country is responsible for policing.

Table 6: Enforcement Resources Compared to Fishing Activity

Country	Naval Surface Enforcement Vessels	Enforcement Aircraft	Number of Powered Fishing Vessels[13]	Capture Production in 2020 (metric tonnes)	Average Annual Fishing Hours in the EEZ[14]	Percentage of Fishing Hours Accounted for by Home Country
Ecuador	15	28	10,700	550,000	27,444	85.7%
Peru	38	14	4,200	5.6 million	95,370	86.1%
Chile	14	11	13,500	1.7 million	79,154	98.0%

SOURCE: Multiple sources. GFW export, Ecuadorian Navy website, Peruvian Navy website, Chilean Navy website, "Fleet Snapshot and Law Review Deliverable"

Jurisdiction Under SPRFMO

Each RFMO includes different member states, conservation techniques, and legal authorities. Region 87 benefits from the South Pacific Regional Fishery Management Organization (SPRFMO) which allows for a higher probability of bad vessels being caught as compared to unmanaged international waters. The SPRFMO is a 16 member RFMO that that is "committed to the long-term conservation and sustainable use of the fishery resources of the South Pacific Ocean" (SPRFMO, n.d.) and covers the international waters in Region 87 and other waters extending across the Pacific to Australia. The SPRFMO allows member countries to board and inspect suspicious vessels if those vessels are flying the flag of a country which is party to the 1995 UN Fish Stocks Agreement. China has signed the agreement, and Japan and the Republic of Korea have ratified it. So, some of the important long-distance fishing powers are parties to the FSA. The inspecting country must notify the flag country of the potential violations and the flag country is responsible for responding to any violations that have been discovered. If the flag state does not respond to a notification from the inspecting state and a serious violation has occurred[6], then the inspecting state can bring the boarded vessel to a nearby port. The Agreement still gives significant

[13] This number indicates the powered fishing vessels registered in each country.
[14] This is a three-year average of all fishing activity captured by Global Fishing Watch monitoring systems from 2019 to 2021. Hours are measured by the total time GFW systems determine a vessel to be fishing. The numbers are rounded in the table.

authority to the vessel's flag state, but the structure of the SPRFMO does give some jurisdictional power to member countries

Costs of Being Caught in Region 87

We relied on media reports from environmental organizations to illustrate some of the costs imposed on various rule breakers in the region. These reports are helpful, but not comprehensive. A more dedicated research effort would be needed to quantify the magnitude of punishments actually imposed.

In 2018, the Fuzhou Hong Long Distance Fishing Company had its fishing license revoked by China after Ecuador accused the company of illegal shark fishing near the Galapagos Islands. Ecuadorian authorities seized a Chinese flagged vessel in 2017 and sentenced 20 of the ship's crew to four-year prison sentences in Ecuador (Godfrey, 2018). In this instance, the fishing company not only lost its crew, vessel, and catch, but they were barred from generating any future profits as long as they remained blacklisted.

Other high-profile incidents have been much less successful. In 2016, the Peruvian government imposed a $7 million fine on the largest factory fishing vessel in the world for fishing and pollution violations. The vessel, which has changed names and flag states frequently, was impounded by the Peruvian government but was eventually released when the owning company agreed to pay a reduced $1.8 million fine (White, 2018). This vessel was detained by Peru again in 2018 and the country attempted to prosecute the owners of the vessel. Successful conviction could have led to a prison sentence of 3-5 years (SeaShepherd, 2018); however, the ship was released without facing any punishment and has since been renamed and reflagged (White, 2018).

Although we cited one successful prosecution by Ecuadorian authorities, the country is considered to be lacking when it comes to IUU enforcement. In 2019 the European Union issued Ecuador a "yellow card" which is essentially a warning to reform IUU practices or risk being banned from accessing EU markets. The EU cited Ecuador's "lenient approach towards infringements" which is "neither depriving the offenders from the benefits accruing from IUU fishing, nor deterrent [*sic*]" (Holland, 2019). Review of this yellow card status is expected in December 2022. The United States issued a similar rebuke in the congressional "Improving International Fisheries Management" report which stated, "The United States is particularly concerned with Ecuador's failure to fully investigate allegations of noncompliance" (NOAA, 2019).

Additional Important Factors

China's Distant Water Fleet

Complicating enforcement in Region 87 is China's recent and public incursions near the Galapagos islands with their sizable Distant Water Fleet (DWF). Since roughly 2020, China has been sending huge fishing fleets to the oceans near South America to capture large quantities of

fish. The fleets became so unmanageable that Ecuador requested USCG assistance to help intervene, which pushed the large Chinese fleet further south near Chile (Sinclair, 2021). In 2022, the USCG, responding to growing Chinese presence in the region, completed its first intervention under the jurisdiction of the SPRFMO. While attempting to board Chinese vessels suspected of questionable fishing practices, multiple vessels attempted to flee, and one vessel maneuvered in a way that resulted in a near collision with a USCG cutter (Goodman, 2022). Addressing China's overwhelming presence in the region is important, but it also forces states to decide how to allocate scarce resources that are needed to police other IUU fishing activity in the region.

Costs in Other Parts of the World

Since we could locate so few instances of major enforcement actions in Area 87, we cite here some cases from other areas. From 2019 to 2020 a Chinese fishing vessel in Ghana was fined twice and impounded after it was discovered to be using illegal nets. However, the vessel was eventually released and relicensed to fish in Ghana without paying its fine (Chase, 2020). In 2016, Argentina imposed a more kinetic punishment on an IUU vessel caught fishing in Argentina's EEZ. When confronted, the vessel tried to ram Argentinian authorities which led to a chase eventually culminating in Argentinian authorities firing on the vessel resulting in the vessel's sinking. The company which owned the vessel has a reputation for IUU practices and has previously paid heavy fines for their impounded vessels (White, 2016). In 2016, the Government of Spain successfully prosecuted a number of individuals involved in IUU fishing and imposed roughly 5 million euro in fines as well as barring the guilty parties from fishing activities and made them ineligible for public subsidies for a period of time (EJF, 2017).

Lockett (2022) describes the results of a three-month patrol by one USCG Cutter in in 2021 within the North Pacific RFMO that produced some sanctions. For example, one of 15 boarding operations resulted in the Fishery Agency of Taiwan fining an operator over $200,000, suspending the operator's license for a month, and listing the vessel as a high-risk vessel subject to more attentions. It also fined the captain for $40,000, suspended their certification as a fishing vessel officer for a month, and revoked their fishing vessel crew identification (Lockett, 2022). This is evidence of how the USCG can operate within a RFMO in order to increase the probability and severity of catching IUU-fishing vessels. However, during the same patrol one Russian and ten vessels flagged to the People's Republic of China refused to be boarded, which is itself a serious regulations violation and shows the extent to which enforcement is much easier when the flag nation cooperates.

Indonesia

Indonesia's offers an example of an aggressive approach to countering IUU fishing. It also shows that what ultimately drives criminal behavior is perceptions of enforcement risks, not the actuarial risk itself. In 2014 Indonesia prohibited foreign fishing in Indonesian waters for one year. They created a special enforcement task force that aggressively pursued violators of the 1-year moratorium. This task force increased the probability of being caught and also resulted in

deportation or imprisonment of the crew as well as vessel seizure. However, Indonesian authorities added another deterrent. They very publicly blew up the seized vessels and advertised this deterrent internationally (Tennesen, 2018). The results were incredible. One study estimates that Indonesia's efforts reduced fishing by 25% overall including a 90% reduction in fishing from foreign vessels (Cabral et al., 2018). Indonesia has shown that perception of enforcement matters, and it can be effective to publicly and dramatically show what happens to IUU fishing vessels when they are caught. Furthermore, Indonesian government passed legislation that specifically targets those who own the vessels operating illegally. The policy includes criminal sanctions for corporate and beneficiary owners of vessels that are engaged in illegal fishing activities including jail time (Gokken, 2018).

Conclusion

Our working hypothesis is that rational actors will engage in IUU fishing if the expected profits exceed the expected costs. Our analysis has shown that pelagic trawlers operating legally typically produce healthy returns on investment. When these vessels operate illegally, they have the potential to significantly decrease labor costs (by paying workers under the table or simply not paying workers) and vessel costs (since they do not purchase things like insurance or fishing permits). Running costs such as fuel, ice to preserve fish and packaging materials are likely similar between legal and illegal fishing operations. Engaging in transshipment events can significantly decrease running costs because it allows vessels to minimize non-fishing fuel use and does not require the fishing vessel to preserve the catch on board. These cost-saving measures make transshipment events economical. Chapter 5 will examine how these transshipment events can be used to efficiently identify suspected IUU activity.

As for the other key terms in the equation, our brief analysis of enforcement profile in Region 87 suggests that its coastal nations have a lot of territory to police and relatively few resources to do the policing. Furthermore, China's significant presence in the region can draw resources away from the normal patrolling. When vessels are caught, the punishments appear to vary greatly. A more detailed analysis would be needed to understand the likely punishment imposed for various violations. If these fishermen or companies believe there is a good chance that they may be caught and then not face any punishment, then they might be more willing to engage in IUU behavior.

Even though we were not able to quantify these variables as precisely as we would have liked, there are still valuable conclusions that we can draw. Since NGA is an intelligence agency, it would most reasonably combat IUU fishing by attempting to increase the probability that a vessel would be caught. This could occur by creating actionable intelligence that an enforcement arm could act on or by helping identify smaller problem areas within a country's EEZ. However, increasing the probability of being caught can only do so much. The cost of being caught must also be sufficient and consistent. Right now, punishments in Region 87 appear somewhat arbitrary; however,

powerful, known, and consistent punishments, such as the destruction of vessels in Indonesia, could perhaps produce better results.

Before spending resources on increasing the probability of catching IUU actors, NGA should understand the punishment mechanisms in the areas being assisted. If NGA helps catch more bad actors but those actors face insufficient punishment, then the NGA could be spending resources inefficiently. If the United States intends to help other countries become more efficient at catching bad actors, then they should also attempt to help those countries structure their punishments against those actors in order to maximize effectiveness.

Chapter 5. Tracking and Targeting the Support Fleet

Motivation for Targeting Support Vessels

Fishing vessels might seem to be the natural target for enforcement, but there are challenges, including sheer numbers. As discussed in the previous Chapter, there are approximately 2.4 million powered fishing vessels worldwide, and the best (albeit weak) guesses are that perhaps 20% of fishing is IUU. That suggests there may be on the order of half a million powered fishing vessels engaged in IUU, so each illegal fishing vessel may only represent a very small fraction of the total amount of IUU.

Furthermore, individual fishing vessels can be hard to track because – depending on the vessel's flag state's regulation – the use of a transponder (which is a kind of positioning device installed on vessels to send location data automatically to permit easy tracking of location) is often not required or enforced. Tracking fishing vessels through non-transponder means, such as satellite images, is more difficult and may be less comprehensive. This is because although geostationary satellites can "hover", other satellites orbit the earth and so only take pictures of a particular location infrequently.[15]

Therefore, instead of tracking individual fishing vessels, this chapter explores the potential of shifting attention towards so-called support vessels that work as intermediaries between fishing vessels and ports. A support vessel's primary function is to supply fishing boats with fuel, food, labor, and other necessities, while in turn receiving the fishing vessel's latest catch. Because of their size and gear, support vessels can receive, process, and freeze catches from dozens of fishing boats before returning to port.

In their role as "middlemen" between fishing boats and the ports, support vessels allow fishing vessels to maximize their time in the fishing grounds, rather than in transit, thus cutting the fuel costs of returning to the shore and allowing for more distant and prolonged fishing voyages. Additionally, support vessels can mask where the fish was caught by packaging legal and illegal catches together, allowing illegally caught fish to enter the market unseen. Opportunities for abuse are enhanced by the fact that support vessels are often subject to looser regulation and monitoring than fishing vessels are.

We have found in data that fishing vessels frequently turn off their transponder, a practice referred to as "going dark", before meeting with a support vessel which helps obscure the origin and legality of caught fish. "Going dark" can prevent would-be trackers from detecting and

[15] "Drone" or UAV surveillance technology has been advancing rapidly. We did not come across literature describing IUU surveillance or enforcement via UAVs, and we did not look into such capabilities, but we would not rule out the possibility that there may be circumstances in which UAVs working in conjunction with surface enforcement assets might offer opportunities.

analyzing a vessel's location and movements which, in turn, impedes intervention. Richer data sources such as satellite images and radar data can help track these fishing vessels, yet their use for accurate tracking has not been successful on a larger scale. The absence of surveillance capabilities and thus accountability emboldens fishing vessels to stay dark for longer times and enter restricted zones.

In our research, we found the average length of a support vessel to be 84 meters (276 feet) and weigh an average of 11,000 tons. Generally, under national and international law, larger vessels are subject to stricter regulations and frequent checks from various enforcement arms. Therefore, due to their size, support vessels are required by the law of their flag countries and fisheries organizations to keep their transponder on at any time. In practice, we find that support vessels indeed keep their transponder consistently turned on, allowing us to capture their activity during "meet-ups" with fishing boats. By focusing on tracking support vessels, we are able to focus our attention on fewer vessels that exhibit suspicious behavior.

One challenge is that support vessels may primarily operate in the open ocean where the responsibility for enforcement falls primarily on the flag state (see Figure 1). However, the data we have collected (which will be discussed in detail in the following sections) suggests that 60% percent of support vessels are flagged to FoC states, including Panama (22% of total support vessels), Bahamas (8%), and Liberia (7%), where enforcement is unlikely. Many of the remaining vessels are flagged to Russia (15%), China, and South Korea (both 3%). Nevertheless, enforcement is possible under the jurisdiction of international law.

In this section, we present a data pipeline that allows for real-time identification of the worst support vessels involved in the IUU industry and highlights vessels operating where US enforcement is possible. It will be complemented by an analysis of which policies appear to have been effective or ineffective in reducing suspicious activity in the past and recommendations concerning concrete steps for US might consider for diplomatic efforts.

Data Sources

Our analysis relies primarily on the public vessel tracking tool provided by Global Fishing Watch and the US government's boat tracking tool SeaVision.

Global Fishing Watch

Global Fishing Watch was collaboratively founded by Oceana, an international ocean conservation organization, SkyTruth, a technology firm that uses satellite imagery and data to protect the environment, and Google, whose tools and contributions help process big data (Global Fishing Watch, n.d.). The data provided for our analysis stems from the "Carrier Vessel Portal" that contains a data on support vessels' activities.

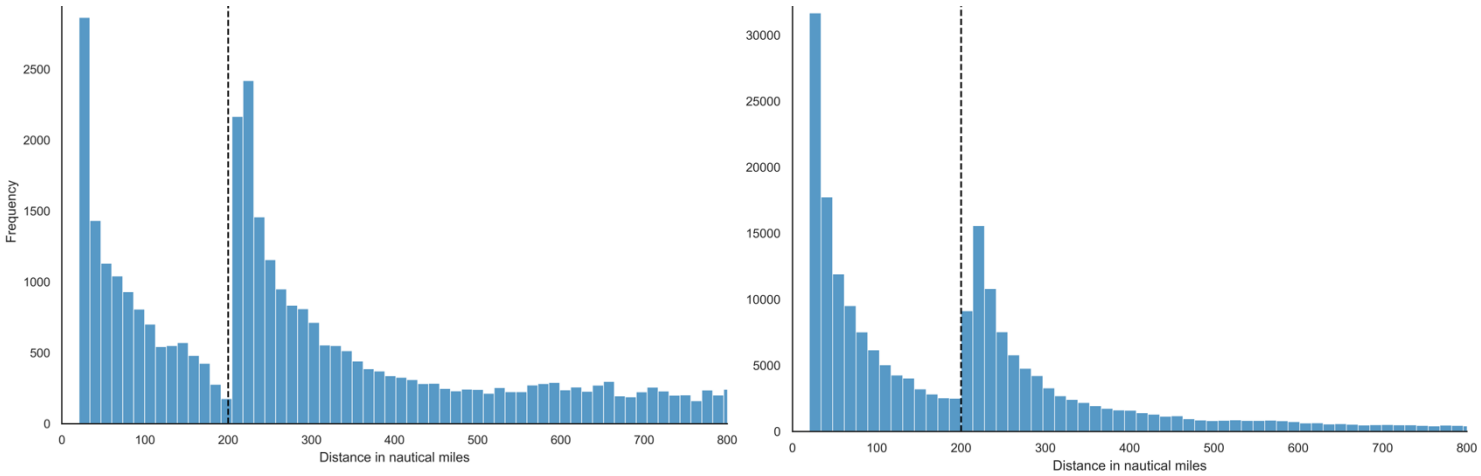
Using machine learning techniques based on vessel's movement patterns (Global Fishing Watch, 2022b), GFW can classify support vessels' behavior into two different events: tracked meetings and dark meetings. Additionally, the tool is able to detect when a support vessel reaches port, which allows us to record the distance from suspicious activities to ports.

- **Tracked meetings** also referred to by GFW as "encounters" or "likely transshipments": Tracked meetings are meetings of support vessels with fishing vessels where *both* parties keep their transponder or other tracking devices on. The algorithm defines a "meeting" as an instance when the transponders of the two vessels remain within a 500-meter (0.3-mile) distance of each other for at least two hours and neither vessel is moving at a speed of more than two knots. On top of precise vessel and location information, GFW provides data on whether the meeting was authorized by the respective management organization (17% of cases), partially authorized (24%), or whether they were not able to find evidence of authorization (59%).
- **Dark meetings** also referred to by GFW as "loitering" or "potential transshipments": Dark meetings are meetings where only the support vessel has its transponder turned on and the fishing vessel is "dark". If one of the previously identified vessels is travelling at a speed less than two knots for two hours, GFW assumes that a dark meeting between a support and fishing vessel has taken place. In the tool's display component, the activity is also marked by a distinct "zigzag" of the support vessel's path that is indicative of meetings, as opposed to a linear path indicating that the vessel is trying to get from point A to point B. These meetings are most likely with fishing vessels but may also include cases of weapon, drug, and human trafficking (Global Fishing Watch, 2016).

> *"Some transshipment is legal, but mostly the transfer of fish from one vessel to another is restricted to ports where it can be tightly monitored. Even offshore, it is expected that legal transshipment be done with observers present. Of course, far offshore it is hard to monitor" (Global Fishing Watch, 2016).*

Given the apparent effort of the second vessel to conceal its identity and activity, we consider dark meetings as a proxy for suspicious and potentially illegal fishing activity.

Figure 1: Distance from shore during tracked meetings (left) and dark meetings (right)



The location pattern of dark meetings is suggestive. Using data provided by Global Fishing Watch, Figure 1 plots the number of dark meetings worldwide since 2012 as a function of distance from shore. Recall that EEZs extend 200 nm from shore. The spike in the number of meetings just outside the border of Exclusive Economic Zones suggests that dark meetings are intentionally conducted just outside of an area where a third party could enforce regulations. If the transshipments were completely legal, then there would be no incentive to intentionally stay outside of an EEZ.

Nevertheless, there are some structural caveats with GFW's data based on its tracking software. Firstly, the data is mainly based on AIS (automatic identification system) transponders, so it is unable to track fishing vessels that do not carry AIS. As reported by GFW, only 2% of the fishing vessels in the world have an AIS transponder, but those vessels account for half of the fishing activities all over the world (Global Fishing Watch, 2016). Global Fishing Watch is mitigating this by integrating national Vessel Monitoring Systems (VMS) data to match encounters as some of the vessels only reported the VMS. To be more specific, Global Fishing Watch is receiving VMS data from key countries such as Panama and Belize, known Flag of Convenience countries, as well as Indonesia, Chile, and other Latin American countries, which enables a more comprehensive coverings in terms of vessel activities in those regions. The data from VMS systems is contained in GFW's final processed dataset that is used by this project.

Secondly, there is a 72-hour time lag in GFW's data, meaning that the latest data a user can see on GFW is 3 days old. In our analysis, GFW is therefore solely used for historical activity analysis, while real-time services such as SeaVision (see below) are used for up-to-date location tracking.

Thirdly, as mentioned above, we concentrate on dark meetings. However, it's possible that some of the dark meetings were falsely identified because of broken transponders, loss of data, or other non-IUU-related circumstances. We performed a verification of a subset of the labelled events using other sources and were able to confirm that most of both types of meetups are correctly classified by doing spot checks and cross-references with other activity tracking data sources. Still, false positives can occur when vessels have paths that closely resemble that of a support vessel. For example, we identified false positives when observing a close-to-shore construction project in Alaska and an Italian cargo vessel with engine problems in the Atlantic Ocean. Furthermore, we removed roughly a quarter of dark meetings attributed to vessels that are registered as fishing vessels and whose movement was more suggestive of fishing activity than transshipment. We also removed vessels with less than ten dark meetings. Nevertheless, we find these classifications to be rare overall and, more importantly, easily verifiable and discoverable by the human eye when investigating one vessel further.

SeaVision

SeaVision allows real-time tracking of the highly suspicious support vessels and provides actionable information such as the direction they are heading. SeaVision, operated by the United States Department of Transportation, provides real-time situational awareness of maritime events that allows users to track the vessels' travel for the past 90 days. A user is able to extract detailed information regarding each unique Maritime Mobile Service Identities (MMSIs), a global identification number for vessels, which includes information on the registered owner, flag, registered port, and more. We also use the latitude and longitude of the "real-time" position data to identify whether a vessel is within an Economic Exclusive Zone (EEZs), as well as its distance to the nearest US territory. Those features help us craft more comprehensive profiles for vessel activity pattern to identify suspicious events to establish the ultimate data pipeline that merges and processes various data sources to provide actionable policy recommendations.

There are some limitations on the SeaVision data as well. First, SeaVision only allows us to query data for the past 90 days, so we could not use it to study the long-term historical patterns of those suspicious fishing vessels, nor could we identify events that happened earlier than 3-month ago. However, the most crucial information we extract from SeaVision is the real-time positional data for a given MMSI including its location, heading direction, distance to ports, etc. Based on this, the 90-day historical limitation had minimal impact on our analysis due to the fact that we only utilize the most recent records from SeaVision for each vessel.

Creating Actionable Intelligence

Methodology

We designed a data pipeline that can allow us to easily access a support vessel's information, meetings with other vessels, and whether the specific vessel can be considered suspicious according to one specific definition of suspicious. Our end-to-end pipeline is capable of quickly downloading and integrating the latest datasets from Global Fishing Watch and SeaVision to include data on meetups, port visits, and the vessel profiles. The pipeline is designed to aggregate data from multiple data sources and do preprocessing. One output from the pipeline is a table that contains the support vessels' basic information and the statistical data about their meetups, port visits, and a basic prediction of their future driving directions and potential meetups based on the historical statistics from the data. The process will be replicable and scalable.

The datasets use two types of IDs to distinguish a specific support vessel:

- IMO – the unique ID of a vessel when it is produced.
- MMSI – register ID; One vessel might have more than one MMSI over time.

Each vessel in the dataset will be recorded with a unique IMO number that does not change throughout its lifetime, even if the vessel is sold to another entity. The MMSI number also identifies the specific vessel, but it acts more like a "register number" since each vessel can obtain more than one MMSI number over the vessel's lifespan. The MMSI might change as a result of the vessel's owner, a change of regulation, or other potential reasons.

In this pipeline, we group vessels based on MMSI number because a change of MMSI might relate to a transition, such as a change in the vessel's ownership, which might dramatically change the behavior of the vessel, so it is better to analyze one vessel with different MMSI separately. In addition, the IMO numbers are partly missing in both the SeaVision and Global Fishing Watch datasets. The output table of the pipeline contains three types of information: vessel information, prior activity, and current location.

Table 7 below shows the columns we have in the output:

Table 7: Pipeline Output Columns

Vessel Info	Activity	Location
Name	Overall meet-ups	If at port
Call Sign	Dark meeting	If in EEZ
Flag	Authorized tracked meeting	If in US water
Registered owner	Unauthorized tracked meeting	If in US allied waters

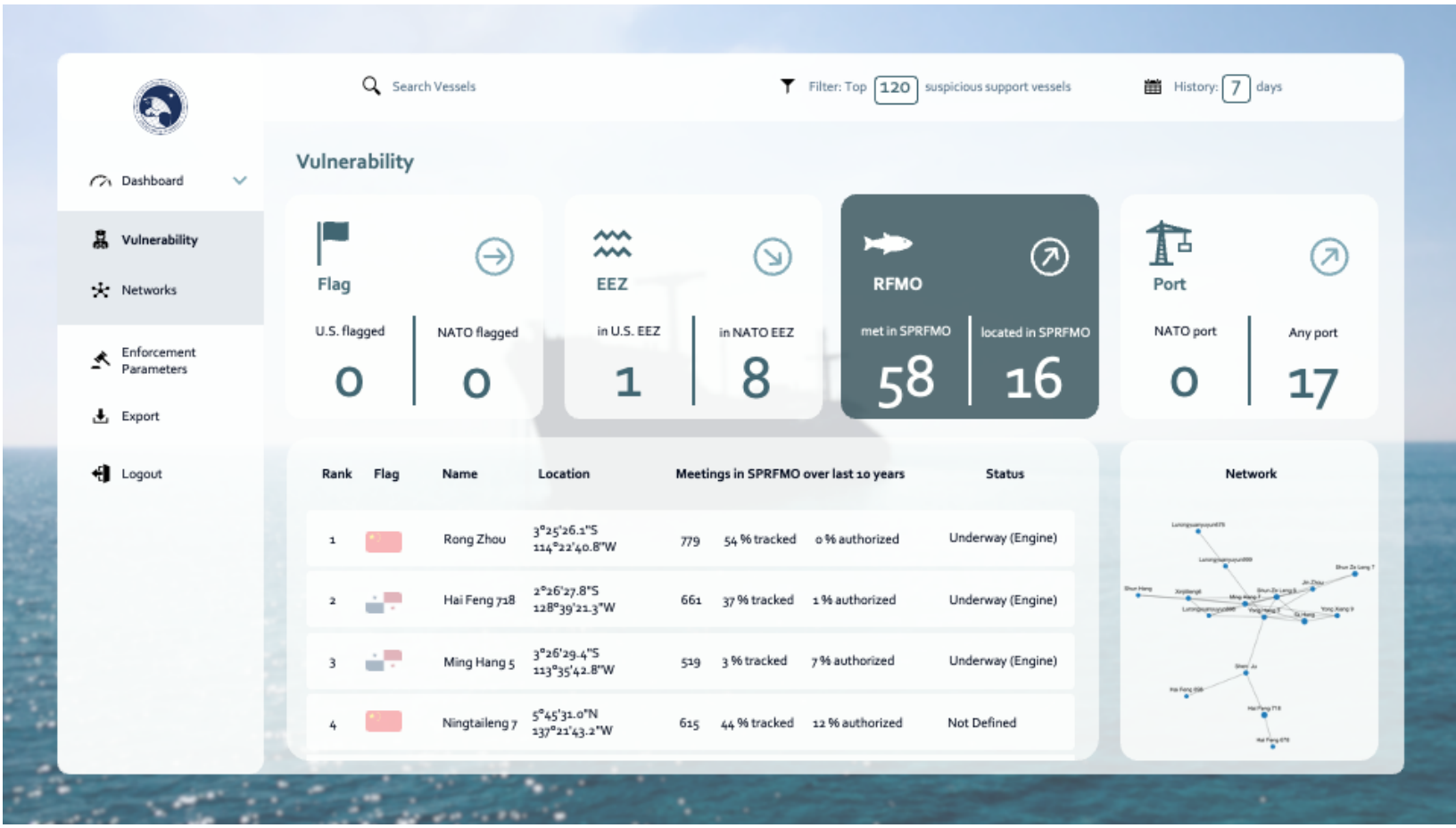
Year built	Meet-ups in last 6/12 months	If in RFMO
Length	Location of meet-ups	If in ride-along RFMO
Dead Weight	EEZ/RFMO Analysis	Distance from US
Current latitude/longitude	Frequent/last port visit	Direction prediction
	Prediction of future meet-ups	

Output

Having generated these variables, our data is structured to be a foundation for a dashboard that could take the form of Figure 2 and Figure 4 below. The unit of analysis is one support vessel that is uniquely identified by its MMSI number. A possible dashboard based on the back-end calculations described above could show general vessel information, its recent IUU activity, and up-to-date location data. While suspected IUU activity would have a time lag of 3 days, location data from SV would generally be less than one hour old.

A primary value is the functionality of filtering and sorting support vessels by both an approximate measure of the severity of their suspected IUU-related behavior (e.g., number of dark meetings) and also by indicators that reflect the US government's ability to take enforcement action against that vessel, given the vessel's flag and location.

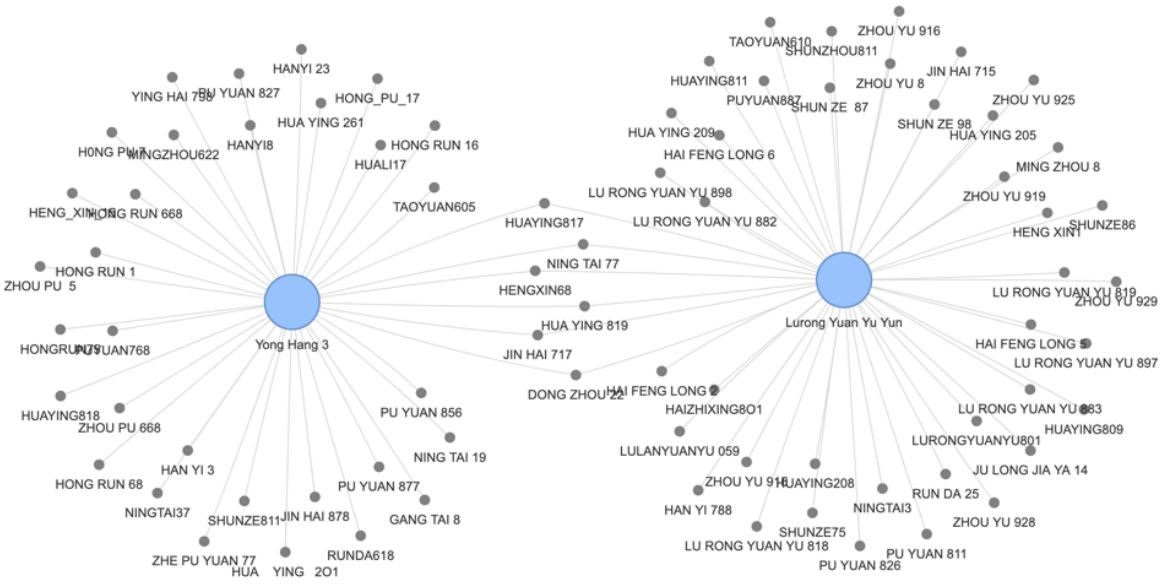
Figure 2: Possible dashboard design for support vessel tracking



In the bottom table of Figure 2, each row represents one support vessel. However, in order to guide enforcement prioritization, it may be valuable to see whether any given vessel is part of a network of vessels whose behaviors and movements are related. For example, since some sanctions fall on corporate owners, it may be more valuable to take action against a vessel that is part of a fleet of bad actors, as opposed to a vessel whose own actions are similar but which is an independent operator.

To illustrate an approach to identifying an example network, we looked at one support vessel, Yong Hang 3 (see left blue node in Figure 3), and all fishing vessels that it met in the last six months (grey nodes). These meetings include only tracked meetings, as we do not know who each vessel met during a dark meeting. Having found the fishing vessels within Yong Hang 3's known network, we then searched for other support vessels that met with these same fishing vessels. We assume support vessels to be in the same network if they are supplying the same fishing vessels. In this case, six fishing vessels were met by both Yong Hang 3 as well as another support vessel called "Lurong Yuan Yu Yun".

Figure 3: Example of mapping connections between two support vessels.



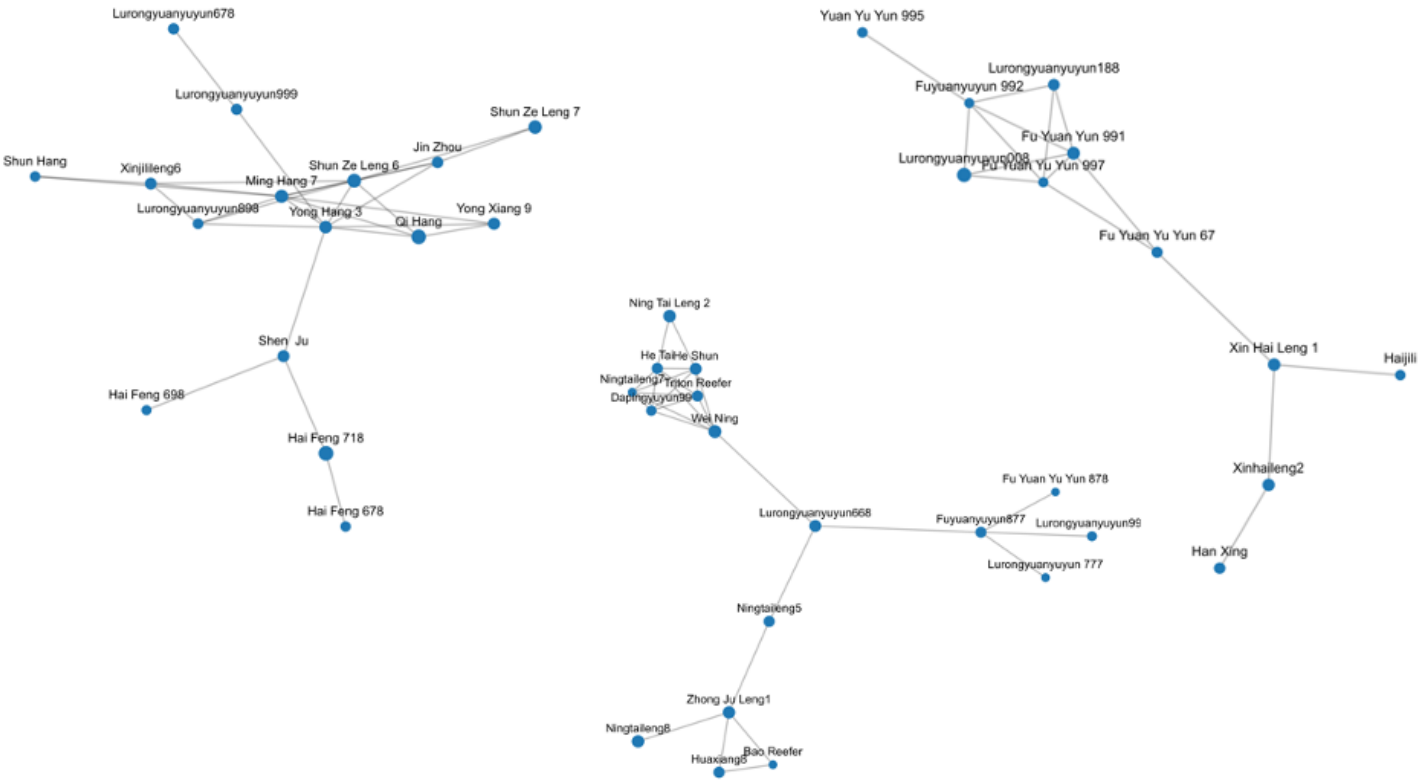
Source: Author analysis based on Global Fishing Watch tracked meeting data

Repeating this process for all pairs of support vessels allows one to create a network map showing relationships among all support vessels. Figure 4 shows the resulting networks of support vessels in 2020. Each node represents one support vessel, sized by its number of dark meetings. Each line connecting two support vessels indicates that both of those support vessels met (in an open not a dark meeting) with some of the same fishing vessels. The thicker the line, the more fishing vessels they both met with.

Figure 4 shows three large clusters of support vessels that appear to move in the same circles. We can see a few things from this figure. For one, it is not the case that all of the "bad" support vessels (those with the largest circles, indicating the most dark meetings) cluster together in one network. There are also many things we can't tell from this particular figure. For example, Figure 4 does not indicate whether clusters are driven by geography (e.g., one community of fishing vessels in a given area is shared by all support vessels operating in that area, both good and bad) or by flag nation. Such distinctions could be made by refining the graph, e.g., using different colors to plot support vessels flagged to different nations.

Hence, Figure 4 should be viewed as a proof of concept of a general approach to mapping support vessel networks, not as providing any specific insight.

Figure 4: Networks of support vessels in 2022



Source: Author Analysis based on 2022 Global Fishing Watch data

Key Metrics

As mentioned, the pipeline aims to provide information about two key concepts: (1) The severity or suspiciousness of the vessel's behavior and (2) Its vulnerability to enforcement action by the United States. We discuss metrics pertinent to these concepts here.

Severity of suspiciousness of the vessel's actions

Both dark meetings and meetings that are tracked but non-authorized can be indicators of possible IUU activity. While the former is a more conclusive sign of suspicious behavior, incorporating tracked but unauthorized meetings can add additional information. Also, even dark meetings are not conclusive proof of illegal behavior; e.g., the vessel's transponder may have failed, although failing just at the time of meeting with a support vessel would seem like quite a coincidence. Tracked meetings include cases where the fishing vessel did not have or did not use an AIS transponder, yet Global Fishing Watch was able to obtain national Vessel Monitoring

System (VMS) data from the respective government. Some of the tracked meetings have authorization (17%) but for most Global Fishing Watch was not able to find evidence for authorization (58%). The lines between tracked and dark meetings are blurry. In recent years, the behavior of vessels involved in either of these have become increasingly similar in at least some respects. For example, the distance from shore of each of these meetings are very similar as seen in Figure 1**.** The separate indicators of dark and unauthorized-tracked meetings can be combined in various ways to create a summary measure, including doing beyond the simple counts. For example, one may incorporate the location of each meeting into the ship's severity ranking – in particular, whether most of its meetings have occurred inside or outside of EEZs or, perhaps most tellingly, just barely outside of an EEZ.

Enforceability

Identifying suspicious behavior is only half the battle; taking effective action is also a challenge. Indeed, inasmuch as almost all support vessels have multiple dark encounters with fishing vessels, finding which support vessels are violators may be more like shooting fish in a barrel than finding a needle in a haystack. So the second half of the data pipeline is also important, namely the ability to gather and integrate information concerning the vessel's flag and, more importantly, its location relative to various enforcement opportunities (EEZs, RFMOs, and ports) which may indicate whether there are opportunities for the U.S. or another state to take action against the vessel.

Flag

Regardless of location, a vessel's flag state has the authority to enforce regulations against the vessel which include violations of international fishing laws. So in principle, if a suspicious support vessel were flagged to the U.S. or a cooperating nation, that might make it vulnerable to enforcement action. However, our analysis shows that in 2022, almost half of support vessels are flagged to so-called Flags of Convenience states, many of which are unable or unwilling to enforce any laws against their vessels. The remaining vessels are primarily flagged to China (26%) and Russia (21%), which likely would not welcome U.S. participation in enforcement action against their vessels.

In the list of the top 400 most suspicious support vessels in 2022, ranked by number of dark and unauthorized tracked meetings, there are just three vessels flagged to a NATO member: one to Turkey (rank 98) that has not been active since June and two to Italy (rank 328 and 372) who appear to be false positives in the Global Fishing Watch database. No US-flagged vessel has had a dark meeting in 2022. We conclude that enforcement based on flags does not offer a viable path for the United States to reduce IUU activity.

Exclusive Economic Zones

Nations have certain rights to enforce national and international law against vessels operating within their EEZ. This section considers several scenarios under which this might permit action by the U.S., and ways our pipeline could identify those opportunities. Based on our analysis, meetings of fishing vessels and support vessels in US territory are very rare, and IUU fishing violations there tend to be small-scale operations that account for a negligible share of global IUU fishing.

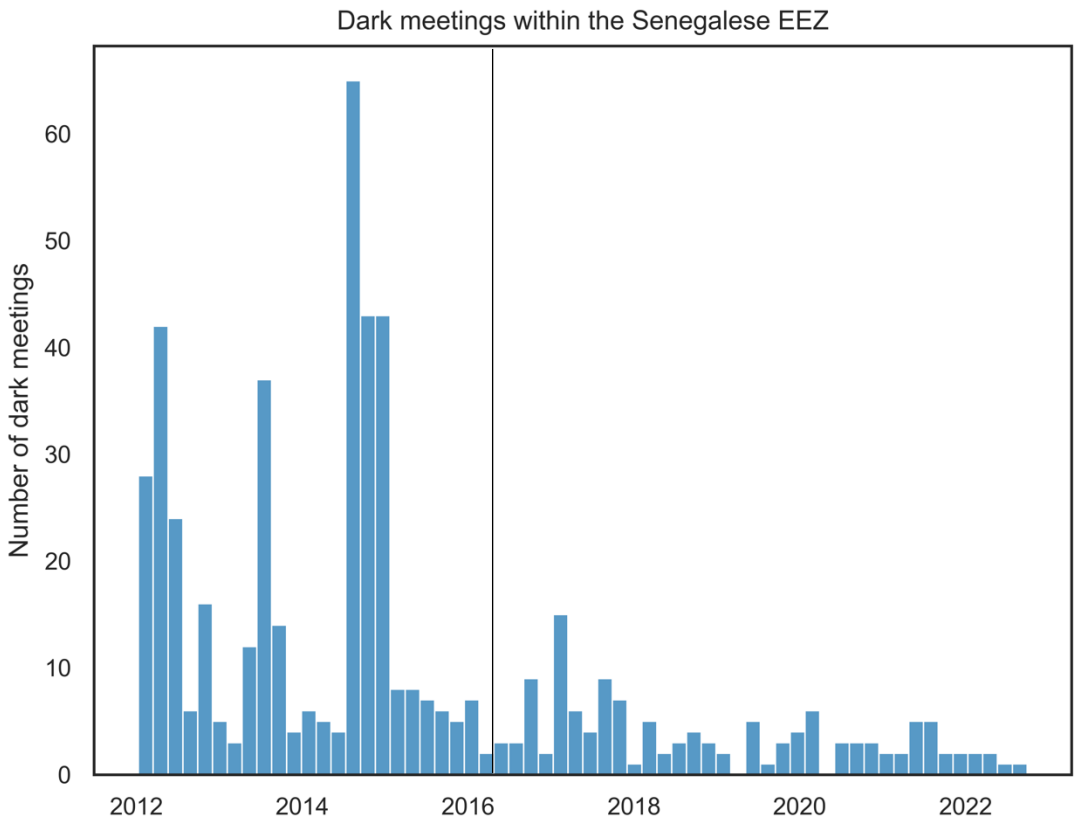
Though illegal activity is unlikely to occur in US waters, some of the most active support vessels cross US territory on their way to or from port. Guam, a US territory in the Western Pacific and home to a USCG post, frequently sees support vessels cross through its EEZ. Indeed, as of the time of writing "Ming Hang 5" was within Guam's EEZ (from 30 Nov to 1 Dec 2022). This support vessel is ranked 70th in our records of dark meetings and most often travels between Zhoushan, China and fishing areas just outside and potentially within Ecuador's and Argentina's EEZs. Whether merely passing through Guam's EEZ provides an opportunity for U.S. enforcement action under international law is unclear to us. We are not experts in international maritime law. However, our dashboard can rank vessels by their distance from U.S. waters and could serve as an early warning tool to predict when some of the worst IUU actors are about to enter US jurisdiction.

Another option would be for the U.S. to enter into agreements with other countries to help them enforce their laws within their EEZs. One limit to this approach is that support vessels – at least the bad actors – appear not to spend much time in EEZs. Of the top 500 support vessels, only six are currently (December 2022) within an EEZ, and most of those are in Somalia's EEZ where they may not need to fear enforcement.[16] Nevertheless, some of the worst support vessels do still sometimes enter Exclusive Economic Zones as seen in Figure 1 above which shows dark meetups as a function of the distance from shore.

Furthermore, U.S. support of other nation's patrols has shown to be an effective tool to drive illegal fishing away from Exclusive Economic Zones, in at least some cases. One promising example is a 2016 collaboration between the United States and Senegalese coast guards in patrolling Senegal's EEZ.[17] Figure 5 shows the monthly dark meetings in the Senegalese EEZ before and after the operation, where time 0 on the horizontal axis indicates when the joint patrols were launched. While there had been large spikes of suspicious activity prior to the joint patrol operation, there has so far not been a noticeable amount activity since then. It is uncertain whether this is a causal effect of the operation or whether it coincided with other changes in law enforcement by Senegal.

[16] Although Turkey donated several patrol vessels to Somalia in 2020, and China and Somalia are planning joint naval patrols in Somali waters, that is not much to patrol a coastline that stretches more than 3,000 kilometers.
[17] https://www.africom.mil/article/30988/first-phase-of-amlep-closes

Figure 5: Dark meetings within the Senegalese EEZ

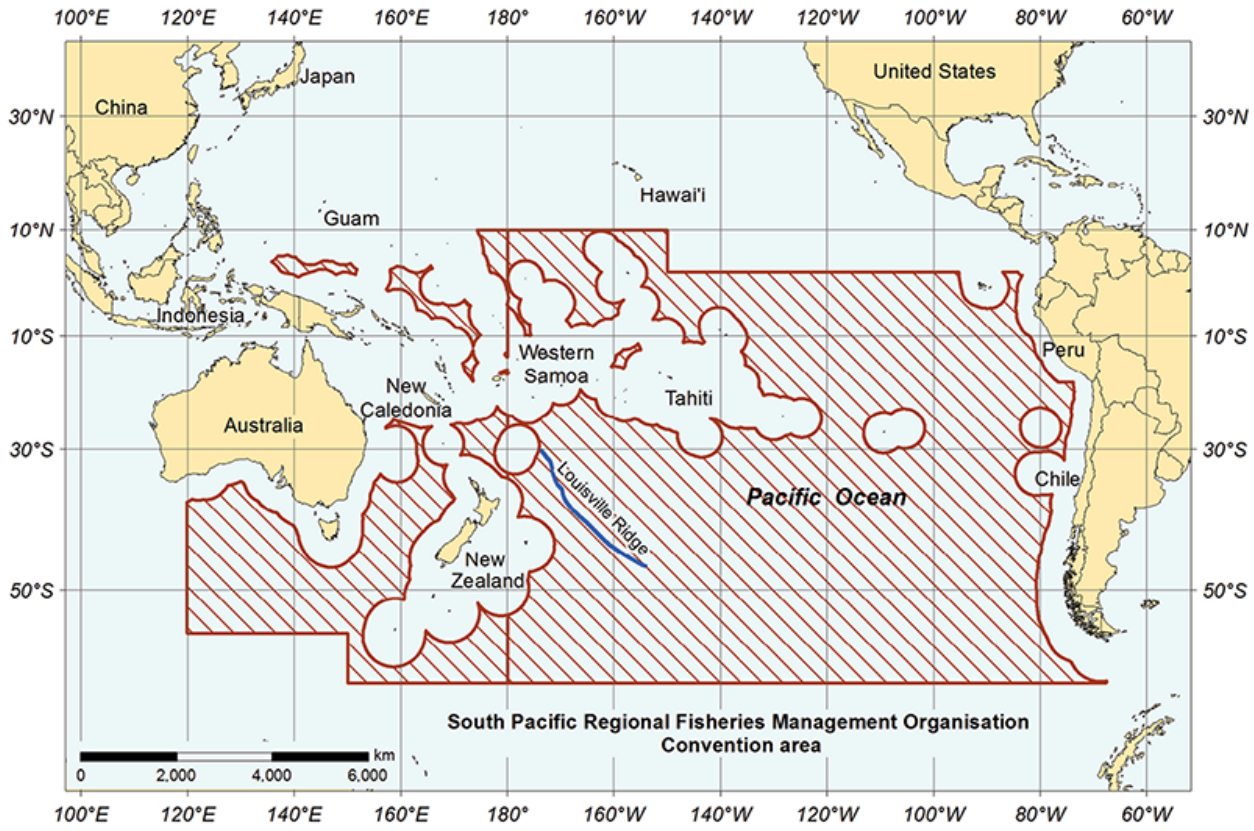


Regional Fishery Management Organizations (RFMO)

EEZs only extend 200 nm from the coast, so support vessels can generally remain outside an EEZ and still be within 20 hours sailing time for fishing vessels operating within the EEZ if those fishing vessels have a cruising speed of 10 knots. However, not all water that is outside of EEZs is simply "open seas" where only the flag nation has enforcement powers.

The world's ocean is divided into several, frequently overlapping, RFMOs that offer some powers to regulate certain fishing activity by parties other than a vessel's flag nation. The international law surrounding these management organizations is complex and interwoven with other bilateral and multilateral agreements. However, there is reason to believe that RFMOs can sometimes provide effective open-sea enforcement opportunities for the United States. As described in our law review in Chapter 2, fishing and support vessels are subject to the regulations agreed upon by the signatories of the RFMO.

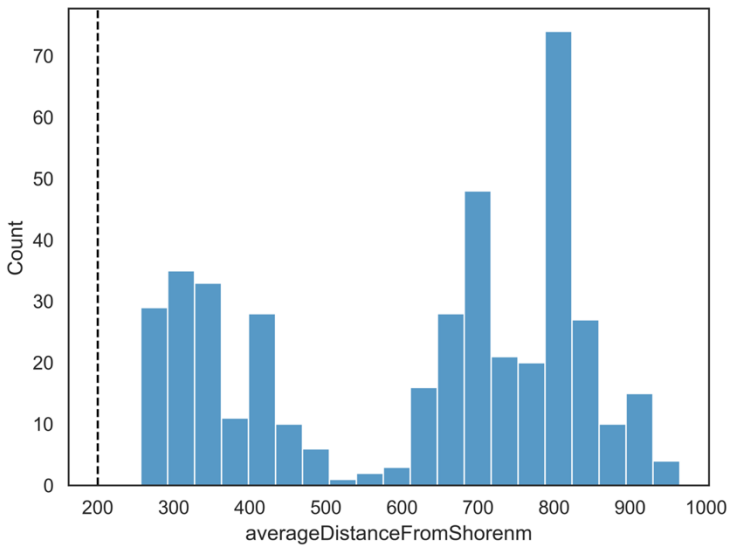
Figure 6: South Pacific Regional Fisheries Management Organization (SPRFMO)



Source: https://www.agriculture.gov.au/agriculture-land/fisheries/international/south-pacific-rfmo

As discussed in Chapter 4, in 2022 the United States partnered with Ecuador to patrol an area in the SPRFMO (see Figure 6) just outside its EEZ around the Galapagos Islands. One of the vessels that fled during the attempted boarding was "Yong Hang 3", a Panama-flagged support vessel that makes our list of the top 100 most-active IUU-suspected vessels. It is part of a large network of vessels that are active in the SPRFMO and are suspected of illegal squid fishing. Since its registration in January 2019, Yong Hang 3 has had 944 suspicious meetings with fishing vessels, of which 45% were tracked meetings and 55% were dark meetings. Consistent with our hypothesis of dark meetings as a proxy to suspicious behavior, we see that its dark meetings were far more likely to occur within an Exclusive Economic Zone than its tracked meetings (Figure 7).

Figure 7: distance from shore during Yong Hang 3's tracked meetings (left) and dark meetings (right)



Source: Global Fishing Watch Data from 2019 to 2022

Our network analysis can provide additional detail to Yong Hang 3's action. Using our network tool, Yong Hang 3 can be located in a network of very similar support vessels, all flagged to Panama or China and active in the SPRFMO around Ecuador's EEZ. Their 90-day transponder history is shown in Figure 9. Figure 8 shows Yong Hang's network for the year 2022, where every connection indicates at least 10 fishing vessels that were met by both support vessels. We see that while Yong Hang is a major actor in this network, it is not located in its center. It is too early to draw conclusions about the long-term effects of the USCG August 2022 incident; however, it may serve as a form of deterrence for future illegal behavior in the SPRFMO, just as the intervention off the coast of Senegal has led to apparently lasting reductions in activity there.

Figure 8: Network of Yong Hang 3 in 2022

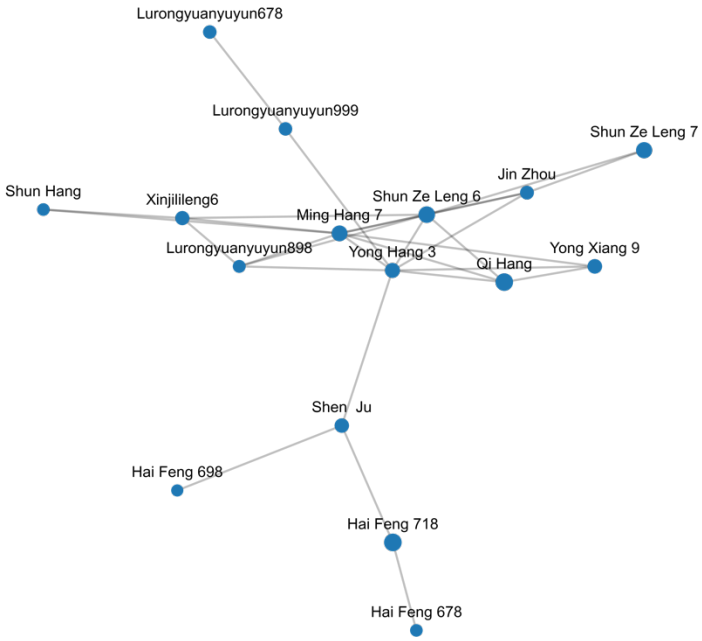
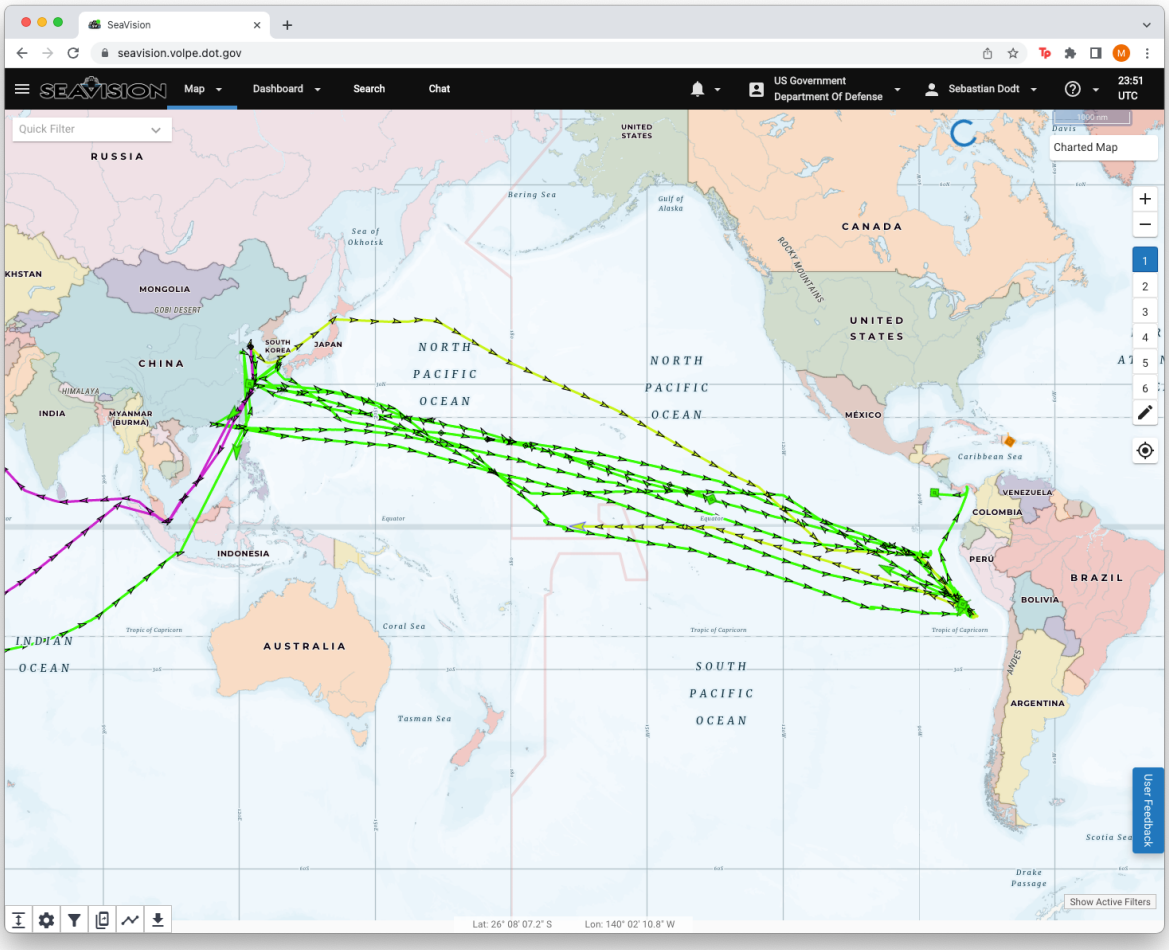


Figure 9: 90-day location history of all vessels in Yong Hang 3's network (Aug - Nov 2022)



Source: SeaVision. Each green and purple line is a different support vessel.

Port

Finally, our data can identify support vessels that are headed to or are currently docked at a port where the United States has opportunities to act or to exert diplomatic pressure. A user could filter by vessels currently at port and whether those ports belong to a strategic ally of the United States (e.g., NATO members), a friendly nation (e.g., South Korea, Colombia), or a country were US diplomacy would have little impact (e.g., China, Russia). The overwhelming majority of port visits of support vessels are in Asia, where US influence is decreasing, yet we will discuss in the next chapter how policy changes could enable an environment that makes illegal activities more costly or risky.

Chapter 6. Potential Partners for Diplomatic Cooperation

Motivation

One of the basic challenges the United States faces in trying to combat international IUU is the matter of jurisdiction. Even when the US has solid proof of wrongdoing, in most waters the US simply does not have the legal right to "arrest" perpetrators (e.g., stop and seize a vessel). The US has enforcement powers only if a vessel is within its EEZ, flies a US flag (which account for only 5.4% of the global fishing fleet), or flies a flag of a country that has a diplomatic arrangement in place with the US.

One of the diplomatic arrangements that can extend the jurisdiction of US enforcement powers are bilateral agreements called "bilateral shiprider agreement" (GAO, 2021). Under these agreements, a law enforcement official from the partner country is allowed to "ride along" on the US vessel in order to assist the nation with law enforcement activities within its jurisdiction[18]. This can help a partner nation that lacks the financial, intelligence, and/or naval resources to enforce its laws against IUU within its EEZ. Since there are extensive problems with IUU fishing around Africa and many African nations struggle with competing demands for their limited resources, one plausible way for the US to expand its efforts to combat IUU is by forming further bilateral partnership with one or more African nations.

Description of the two matrices

This section develops two matrices that are intended to help prioritize strategic diplomatic efforts. There is a row for each of the 36 African countries that is not landlocked (and so has an EEZ), and columns for multiple variables that might indicate the viability of that country as a potential partner.

[18] The U.S. already has some agreements, notably with Cape Verde, Cook Islands, Fiji, Kiribati, Nauru, Palau, Senegal, Sierra Leone, Gambia, Tonga, Tuvalu, and Vanuatu (GAO, 2021).

Table 8: Prioritization Matrix (Raw data)[19]

	Economic Indicator		Fishing Indicator		Political Indicator		Enforcement Indicator	
Country	GDP per capita ($)	Fisheries production (t)	Dark meetings within EEZ	Treaties signed	Corruption index	Relation-ship with US	Military enforcement	Distance from USCG
Algeria	3,765	105,392	211	4	2	1	6	4
Angola	2,137	402,700	1,519	7	2	1	3	1
Benin	1,428	79,233	291	7	2	1	1	2
Cameroon	1,661	300,064	862	4	1	2	1	2
Congo	2,213	71,085	470	6	2	1	3	2
Côte d'Ivoire	2,578	113,660	1,118	5	2	1	2	2
Comoros	1,494	17,603	1	3	2	1	1	2
Djibouti	3,363	2,272	2	4	2	1	1	2
DR Congo	2,213	3,590	62	3	1	3	3	1
Egypt	3,876	2,038,997	79	4	3	3	10	5
Equatorial Guinea	8,462	6,438	208	2	1	1	1	2
Eritrea	642	5,643	19	1	1	1	1	1
Gabon	8,017	29,058	262	5	2	1	3	1
Gambia	835	56,235	44	6	2	1	1	2
Guinea	1,774	360,646	770	6	2	1	1	2
Guinea Bissau	813	60,158	3179	4	1	1	1	2
Ghana	2,445	370,370	1400	7	3	3	4	2
Kenya	2,006	114,681	4	7	2	3	6	3
Liberia	673	16,392	351	5	2	2	1	5
Libya[s]	6,018	32,347	112	3	1	1	3	4
Mauritania	1,723	720,854	2129	6	2	1	2	2

[19] There are many pertinent attributes for which we as a student team cannot provide reliable values. We nonetheless include columns for those concepts as placeholders, in hopes that if the concept underlying these matrices proves useful, they can be filled in by other parties later. For example, the NGA may have knowledge of ways that its satellites offer greater or lesser coverage for some nation's EEZs than others or have greater or lesser past history of sharing the results of NGA analysis with certain nations. Likewise, the State Department certainly has a much richer understanding of the strength of current and past bilateral relationships with the United States than we were able to glean from public sources during this semester.

Madagascar	514	118,220	163	5	2	1	5	1
Morocco	3,496	1,459,925	521	7	3	1	7	4
Mozambique	500	403,582	94	6	2	3	2	2
Namibia	4,729	457,433	591	6	3	1	3	1
Nigeria	2,085	1,114,560	869	4	2	3	6	2
São Tomé and Príncipe	2,449	4,276	212	5	2	1	1	2
Seychelles	13,306	87,000	59	6	3	1	1	1
Senegal	1,606	517,160	598	6	3	2	2	2
Sierra Leone	515	202,188	423	3	2	1	1	2
Somalia	445	30,000	52	3	1	3	2	4
South Africa	6,994	448,272	279	7	4	3	3	1
Sudan	764	50,770	19	3	2	2	1	4
Togo	2,380	18,764	136	6	2	1	1	2
Tunisia	3,924	128,371	51	3	3	2	1	4
Tanzania	1,135	486,277	6	4	2	3	1	2

Table 8 reports data elements as numbers or other "natural units" as reported in the source documents we consulted. Those numerical values can be hard to interpret. For example, in 2012 - 2022 Gambia had a sum of 44 known dark meetings and a combined of 56,235 tons of fish capture and aquaculture, but the significance of these numbers is not easily discernible.

The second matrix converts the data from the first matrix into categorical scores and adds coloring so that it can be understood more easily. Whereas the original matrix lists nations alphabetically, the "at a glance" matrix could be sorted to prioritize the most promising nations at the top of the table. There is no one single or correct way to aggregate the columns into an overall partner suitability score, so the ordering is approximate. The coloring scheme is that of a form of "stoplight chart", with green meaning good or favorable, white meaning bad or unfavorable, and intermediate shades used for intermediate values. When all the attributes in a row are green, it suggests that the country has highly favorable economic, political, and military attributes that would make the country a viable partner for the US to work with to counter IUU fishing.

Table 9: Prioritization Matrix ("at-a-glance matrix")

	Economic Indicator		Fishing Indicator		Political Indicator		Enforcement Indicator	
Country	GDP per capita	Fish market size	Dark meetings within EEZ	Treaties signed	Corruption index	Relationship with US	Military enforcement	Distance from USCG
Algeria	2	2	3	3	2	2	3	4
Angola	2	3	5	4	2	2	2	1
Benin	1	1	3	4	2	2	1	2
Cameroon	1	3	4	3	1	3	1	2
Congo	2	1	3	4	2	2	2	2
Côte d'Ivoire	2	2	5	3	2	2	1	2
Comoros	1	1	1	2	2	2	1	2
Djibouti	2	1	1	3	2	2	1	2
DR Congo	2	1	1	2	1	4	2	1
Egypt	2	5	1	3	3	4	5	5
Equatorial Guinea	5	1	3	2	1	2	1	2
Eritrea	1	1	1	1	1	2	1	1
Gabon	5	1	3	3	2	2	2	1
Gambia	1	1	1	4	2	2	1	2
Guinea	1	3	4	4	2	2	1	2
Guinea Bissau	1	1	5	3	1	2	1	2
Ghana	2	3	5	4	3	4	2	2
Kenya	2	2	1	4	2	4	3	3
Liberia	1	1	3	3	2	3	1	5
Libya[s]	4	1	2	2	1	2	2	4
Mauritania	1	4	5	4	2	2	1	2
Madagascar	1	2	2	3	2	2	3	1
Morocco	2	5	4	4	3	2	4	4
Mozambique	1	3	1	4	2	4	1	2
Namibia	3	3	4	4	3	2	2	1
Nigeria	2	5	4	3	2	4	3	2
São Tomé and Príncipe	2	1	3	3	2	2	1	2

Seychelles	5	1	1	4	3	2	1	1
Senegal	1	4	4	4	3	3	1	2
Sierra Leone	1	2	3	2	2	2	1	2
Somalia	1	1	1	2	1	4	1	4
South Africa	4	3	3	4	4	4	2	1
Sudan	1	1	1	2	2	3	1	4
Togo	2	1	2	4	2	3	1	2
Tunisia	2	2	1	2	3	3	1	4
Tanzania	1	3	1	3	2	4	1	2

Note: On a scale of 1 – 5, 5 being the most favorable and 1 being the least favorable. For instance, Corruption Index is reversed from original source; when corruption is high, the number is small. In case of Dark Meetings within EEZ, high number of dark meetings is considered favorable for the prioritization, because more assistance is needed when the number if big.

Source: GDP per capita (World Bank, 2022), Fish market size (FAO, 2022b), Dark meeting (GFW), Treaties signed (UNTC, undated), Corruption index (Global Risk Profile, 2022), Relationship with US (ForeignAssistance, 2022), and Distance from USCG (USCG, undated)

In Table 9, we group the attributes into four bins for indicators related to fishing, political climate, economics, and practicalities of enforcement potential.

Each matrix describes the economic, political, and military environment surrounding IUU-fishing for 35 coastal countries in Africa. Economic indicators are meant to show the extent to which the country has economic capabilities to tackle problems relating to IUU-fishing. All other things being equal, we expect that a bigger GDP per capita indicates a greater capability to partner effectively with the U.S. One could argue the opposite. One could argue that a poorer nation is either in greater need of assistance and/or is more easily motivated by U.S. aid and entreaties.

The present coding considers large domestic fish production (fish market size) to be a favorable indicator. The logic is that if a nation depends on fishing, it has greater incentive to conserve those fishing resources, so they can continue to provide jobs, food, and economic benefits for generations to come. Again, one could make an argument for the opposite coding. Perhaps nations with large domestic fishing industries have powerful domestic political stakeholders who would resist foreign (i.e., US) "interference" within their EEZ.

Fishing indicators use 10-year averages of numbers of dark meetings within each country's EEZ obtained from GFW as proxy to estimate the potential size of IUU-fishing, while the number of treaties ratified out of 9 treaties is taken as a measure of their willingness to address IUU-fishing. Political indicators show the extent to which each country appears to be politically capable and willing to address IUU-fishing with the U.S. The lower the corruption index and better the relationship with U.S., the better the environment is. Enforcement indicators include the degree of military enforcement and distance from USCG as proxies to measure the actionability from each country's and U.S. government's perspective. Enforcement indicator includes the number of navy

bases in each country collected from Wikipedia. If no detailed information is found on Wikipedia, the country is counted as having the least capacity in terms of military enforcement. Distance from USCG was measured from the USCG liaison offices in Liberia, Italy, and Saudi Arabia and the United States Africa Command (AFRICOM) headquarter in Germany. East and North African countries are relatively found closer while South African countries are found far from the USCG.

Interpreting the results

When all attributes are green, it suggests that the country has favorable economic, political, and enforcement profiles which could make the country a viable partner for US cooperation on IUU fishing. This first group of countries includes Algeria, Ghana, Kenya, Nigeria, and Morocco, the ones with the most favorable conditions across all 4 indicators. Two North African countries are selected mainly due to the large number of dark meetings (as more attention is needed), economic capability, and their close distance from USCG station in the Mediterranean.

The second-tier countries are Mauritania, Liberia, Angola, Mozambique, Namibia, Senegal, South Africa, and Tunisia. These countries have one or two unfavorable conditions, but their overall scores are as high as the first group. Most of these countries have unfavorable scores because of their GDP per capita, level of military enforcement, and/or distance from USCG stations. Some unfavorable conditions might be improved with US assistance. For instance, the low level of GDP per capita in Sub Saharan African countries may imply that they lack adequate financial and human resources to enforce the mandate of PSMA. Foreign aid providing assistance to strengthen port state control can improve the specific unfavorable condition. Strategies that can be considered include the reinforcement of diplomatic partnership, information sharing, secondment of USCG liaison officers, and the Africa Maritime Law Enforcement Partnership (AMLEP) program. The USCG liaison office currently based in Liberia may perhaps serve as a pilot to strengthen partnership with the countries.

Finally, the countries with the most unfavorable conditions in this matrix include Eritrea, Comoros, Madagascar, Gambia, Djibouti, Somalia, and Sudan.

Chapter 7. Ports as a Potential Focal Point for Intervention IUU

Chapter 5 noted that while one's first instinct might be to target IUU fishing boats, an alternate strategy is to focus on their support vessels, of which there are far fewer. However, actually taking enforcement against illegal support vessels can be difficult when they remain in the high seas. Chapter 6 described a different general strategy, which is U.S. partnerships with specific nations, e.g., to assist in enforcement of their laws within their EEZs. Here we discuss a third approach, which is focusing on ports, notably by promoting adoption of the Port State Measures Agreements. There are opportunities for taking action in and through ports that are not available on the open seas.

The Port State Measures Agreement, or PSMA in short, is one of the key international treaties that aims to tackle IUU fishing. It has captured a lot of governmental, academic, and public interest. This chapter goes in-depth about the PSMA's intention and a state's capability to implement it. The ensuing chapter, an extension of this, graphically displays some metrics suggestive of the potential effects of PSMA adoption as an instrument for reducing suspicious activity. It will conclude with some policy options and pointers for further studies.

The PSMA was drawn up following realization of the enormous challenges in combating IUU-F on the high seas. The PSMA approach enables port states to deny entry to or require vessels suspected of engaging in IUU-F to dock for inspection. The port state can further detain a vessel after port inspection furnishes evidence of offenses. In this case, the port state communicates its decision to the flag of the State of the vessel, coastal states, and Regional Fishery Management Organizations (RFMOs). Usually, RFMOs prepare a list of suspicious vessels, which they regularly communicate with other port states that are their members. Once the port states have information on suspicious vessels, they use the information to deny such vessels entry (FAO, 2022a).

This port-denial approach increases the cost of illegal fishing as it increases their operational costs and time finding alternate ports. If enough ports follow the agreement, and port nations share information on suspicious vessels, in principle, this will prevent illegal caught fish from entering the market supply chain. The PSMA strategy relies on the following assumptions:

1. Port states possess the capabilities to monitor and survey vessels in and around their EEZ, through sea patrols, coast guards, satellite tracking systems, or other useful mediums.
2. Port states have legal mechanisms in place to deal with situations surrounding suspicious vessels. They have the required personnel and resources to implement the mechanisms.
3. Information sharing on suspicious vessels between port states is strong.
4. Most (almost all) port states are a part of this agreement. Each port within the state receives sufficient monitoring and surveillance.
5. The governance and monitoring at the port are robust, and the port actors are not corrupted.

6. Illegal actors' do not adapt in ways that negate the intended effects.

The final assumption is perhaps challenging. The literature has shown that illegal actors do change their behaviors in light of constraints. For example, to evade port surveillance, vessels may transship their catches onto other, local artisanal vessels. They also change their names.

The Port States Country Resources and Governance Table

That list of assumptions necessary for the PSMA approach to function raises questions as to whether enough of the port states can meet those criteria. This section introduces a reference table that provides a quick visual reference as to the various states' capabilities in this regard. The table has a row for each country and multiple indicator columns that are color-coded, with green indicating values that are favorable to the state being able to fulfill its obligations under a PSMA, and red indicating potential warning signs.

We next describe the indicators captured in those columns. A country's ability to board and inspect a vessel involved in suspicious activities within its Exclusive Economic Zone (EEZ) depends on the size of the EEZ it has to patrol and the resources it possesses for conducting that patrol. The resources can be multifaceted, ranging from the size of its coast guard to the sophistication of its tracking system. In the table below, we use GDP as a rough proxy for a country's ability to monitor and inspect vessels. Similarly, the ratio of EEZ size to GDP is the amount of area a country must patrol per a million dollar of its GDP. For example, with each million dollars of its GDP, Australia must look after 55.13 KM^2 of EEZ.

Contrarily, Albania has a small EEZ area and a moderate GDP leading to one of the smallest EEZ/GDP ratios, meaning that for every million dollars of GDP it must cover a smaller EEZ area than other countries.

The farthest right column in the table gives the nation's corruption perception index (CPI) on a 0 – 100 scale (Transparency International, 2021). The higher the number, the better the perception of the country in handling corruption. If a country has a high EEZ/GDP per million (dark red color) and a low CPI score (formatted with red color), it denotes a country that has the worst combination of variables. The country may therefore be most vulnerable to illegal fishing and/or least able to fulfill its duties under a PSMA. Some of the African countries that are inflicted by this 'worst combination' are Somalia, Madagascar, and Mozambique.

Table 10: EEZ, GDP, and corruption index.

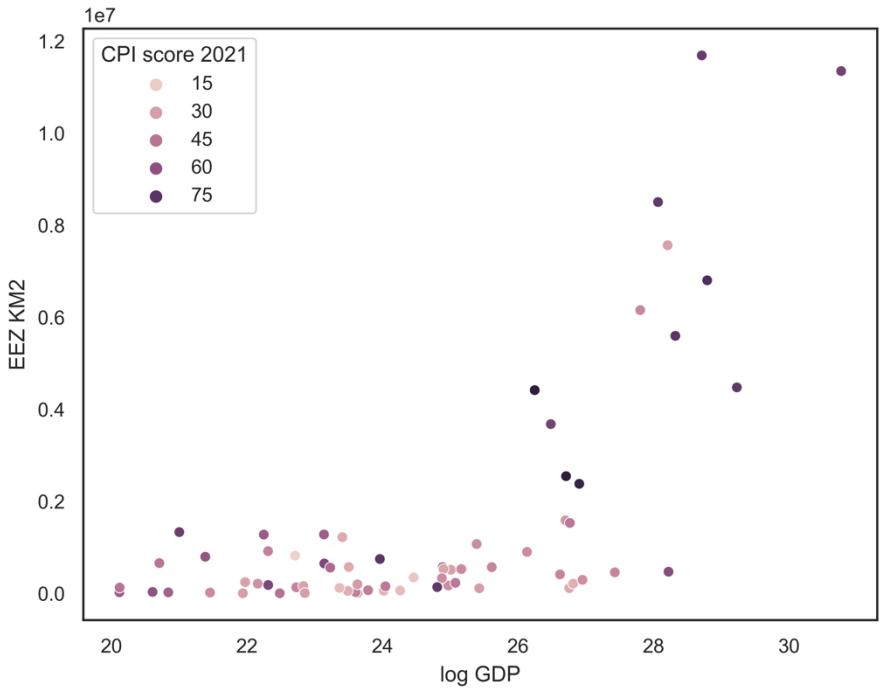
Country	GDP (in millions)	EEZ KM2	EEZ/GDP	Corruption Perception Index (CPI) 2021
Albania	18260	13,691	0.75	35
Angola	72547	518,433	7.15	29
Australia	1542660	8,505,348	5.51	73
Bahamas	11209	654,715	58.41	64
Bangladesh	416265	118,813	0.29	26
Barbados	4901	186,898	38.14	65
Benin	17786	33,221	1.87	42
Cabo Verde	1936	800,561	413.48	58
Cambodia	26961	62,515	2.32	23
Canada	1990760	5,599,077	2.81	74
Chile	317059	3,681,989	11.61	67
Costa Rica	64282	574,725	8.94	58
Cuba		350,751		46
Côte d'Ivoire	69765	176,254	2.53	**36**
Denmark	397000	2,551,238	6.43	88
Djibouti	3371	7,459	2.21	30
Dominica	546	28,985	53.12	55
Ecuador	106166	1,077,231	10.15	36
Eritrea		77,728		22
Fiji	4592	1,282,978	279.39	55
France	2940000	11,691,000	3.98	**71**
Gabon	18269	202,790	11.10	31
Gambia	2078	23,112	11.12	37

Source: For port states data, visit https://www.fao.org/port-state-measures/background/parties-psma/en/ . For EEZ data, visit http://iilss.net/exclusive-economic-zoneeez-map-of-the-world/. For GDP per capita, visit https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.KD. For corruption perception index, visit https://www.transparency.org/en/cpi/2021.

The following graph plots the size of each country's EEZ in square kilometers against its Log of GDP. Each dot represents a country. The color of the dot represents the country's corruption perception score (CPI): darker color means the country is less corrupted, whereas a fainter color represent that the country is more corrupted. The most vulnerable country would be indicated by

a faint dot in the upper left (much area to patrol, few resources to do it, and saddled with corruption). Dark dots in the lower right would be the least vulnerable.

Figure 10: Scatterplot of Exclusive Economic Area versus the Log of GDP



Each dot represents a country, and the dot color represents the country's corruption perception.

Port State Requirements vs Port State Capacity

The PSMA requires its party states to adhere to a minimum standard for certain measures that combat IUU fishing. For example, the state can ask more information from the captains of foreign-flagged vessels seeking entry at the port. The state can also ask vessels to dock for inspection. If the inspection produces evidence that the vessel was engaged in IUU fishing, the state must follow a certain protocol guided in the PSMA articles. However, not all countries will possess enough resources to enforce all the PSMA port state standards. Drawing upon the research and analysis by Pew Trust, we have generated sample capacity-requirement table of PSMA States (The Pew Charitable Trusts, 2017).

The PSMA outlines 24 articles that deal with different aspects of the process such as "integration and coordination at the national level," "exchange of information", and "designation of ports" among others. From these 24 articles, the Pew Trust identified 43 PSMA requirements for port states to adhere to effectively administer this agreement (The Pew Charitable Trusts,

2017). The table below shows several sample Articles, PSMA requirements borne out of the articles, and the capacity of three countries from three continents to adhere to the requirements.

Table 11: Three PSMA countries' performance against PSMA State requirements.

Articles of PSMA	Port State Requirement	Port State Capacity		
		Canada	Ghana	Ecuador
Article 5 (Integration and coordination at the state level)	Domestic legislation to empower the implementation of PSMA	✓	X	✓
Article 6 (Cooperation and Exchange of Information)	State to participate in international organizations, FAO, RFMOs, and other fisheries bodies of relevance to the State.	✓	✓	✓
Article 6 (Cooperation and Exchange of Information)	Domestic legal provisions in place to enable international, regional, and bilateral information sharing about vessels and compliance information.	✓	N/A	N/A
Article 7 (Designation of Ports)	Port(s) designated as appropriate for foreign vessels	28	2	16
Article 7 (Designation of Ports)	Information about designated ports available (e.g., stated in license documentation, on the government website, or advertised through other media).	✓	N/A	N/A
Article 7 (Designation of Ports)	Fisheries inspectors are available at designated ports to carry out inspections.	✓	✓	✓
Article 11 (Use of Ports)	Legal mechanisms in place to deny a vessel that has engaged in IUU fishing the use of the port for landing, transshipping, packaging, or processing of fish, etc.	✓	X	X

Source: https://www.canada.ca/en/fisheries-oceans, Bello (2021), https://www.fao.org/port-state-measures/en/, https://www.gsa.gov.gh/fish-inspection/

The information on how a PSMA country is fairing against various PSMA state requirements is scattered. For example, data on the number of designated ports were derived from the FAO database, whereas the data on the domestic legislations was obtained by visiting governmental and

non-governmental sites. This necessitates a centralized and standardized database that possesses information on countries' performance vis-à-vis different PSMA parameters.

The PSMA is complicated and different countries will have varying ability to implement effectively all the requirements. Understanding how the agreements articles translate to requirements can help policymakers understand which countries can adhere to this agreement and which countries need assistance. Further analysis can provide a strategic view of each PSMA country to identify areas of strength and weakness in implementing this agreement.

Chapter 8. Assessment of PSMA Effects

The previous chapter tried to assess which countries may be capable of meeting the obligations required for a PSMA strategy to work. This chapter looks at whether PSMA implementation appears to have had any effect in places that have adopted the PSMA.

The two chapters complement each other. This chapter can only look at local effects: Was there a reduction in suspicious activity after a state adopted PSMA measures? But PSMA as a global strategy is vulnerable to a Maginot Line effect. If one state closes its ports to IUU vessels, but its neighbor next door does not, then the PSMA strategy may fail to curtail global IUU because it might merely displace IUU from one country to its neighbor.

So success of a PSMA strategy overall requires "success" in terms of both Chapters 7 and 8. There needs to be a local effect when a capable country implements the PSMA and a sufficiently large proportion of all countries must be able to implement the PSMA provisions with teeth.

The PSMA ratification as an instrument

How has the PSMA affected the number of ships at a port? One of the goals of the PSMA agreement is to discourage illegal vessels from visiting ports that are under PSMA jurisdiction. The previous chapter listed minimum steps, including strict monitoring and inspection, that a port state country must abide by under this treaty. Such measures should in theory decrease the number of illegally operating vessels arriving at 'stringent' ports.

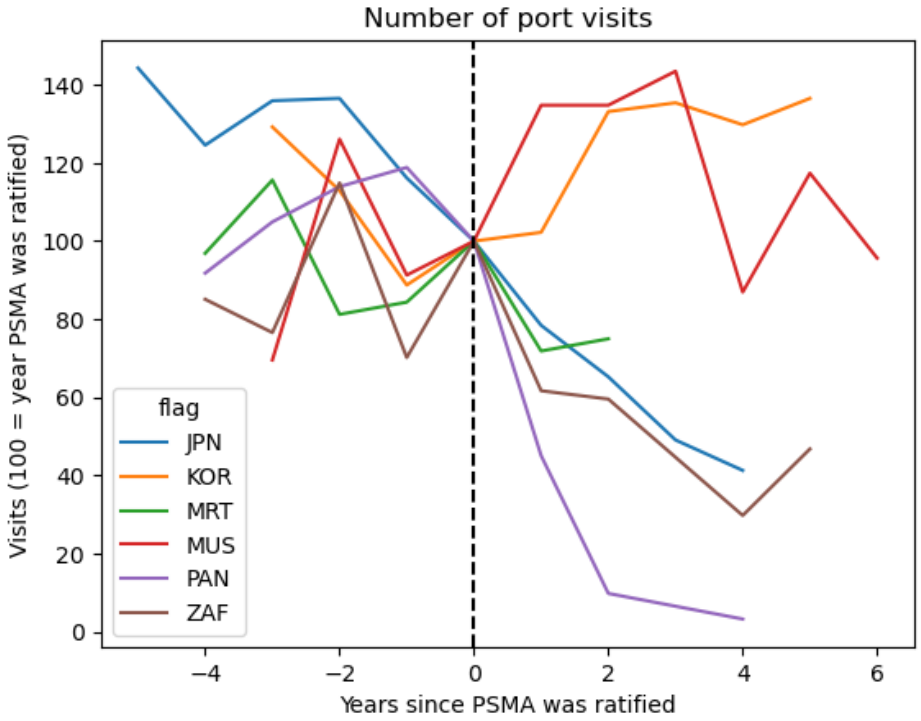
It is an empirical question, however, whether that goal is being met, and we examine one indicator of that here. While we do not know the identity of every vessel participating in IUU-F, Chapter 5 identified suspicious support vessels, the 'middlemen' between fishing vessels and ports. Using Global Fishing Watch data, we can count the number of times each of those vessels visited any given port between 2013 and 2021. So, for example we can plot the number of such visits per year to the Japanese ports in the years before and after 2017, when Japan joined the PSMA (see figure below).

It is hard to draw inferences from what happened at a single port before and after implementation, because there is no control group and there may have been simultaneous circumstances. However, we can aggregate data from multiple ports that implemented the PSMA in different years by measuring time not in terms of calendar year but rather in years before and after that port became subject to the PSMA. That reduces the chance that any one unmeasured third factor could have accounted for any trend change observed at the time of implementation. Figure 11 does that for all ports in 6 countries, with the number of visits normalized for all countries to be 100 in the year before implementation.

Hence, Figure 11 shows the extent to which the number of suspicious support vessels visiting ports covered by the PSMA decreased after the countries ratified PSMA. The interpretation is not clear cut. There appears to have already been a pre-existing downward trend, albeit irregular, in at least some countries, so a simple before-and-after comparison cannot rule out the possibility that other factors were contributing to subsequent reductions, making it difficult to identify the sole impact of the PSMA on the outcome.

Superficially, however, one might take Figure 11 as offering suggestive evidence that the PSMA led to reductions in visits to Japan and South Africa, but there was little effect or even perhaps a perverse effect in Korea and Mauritius.

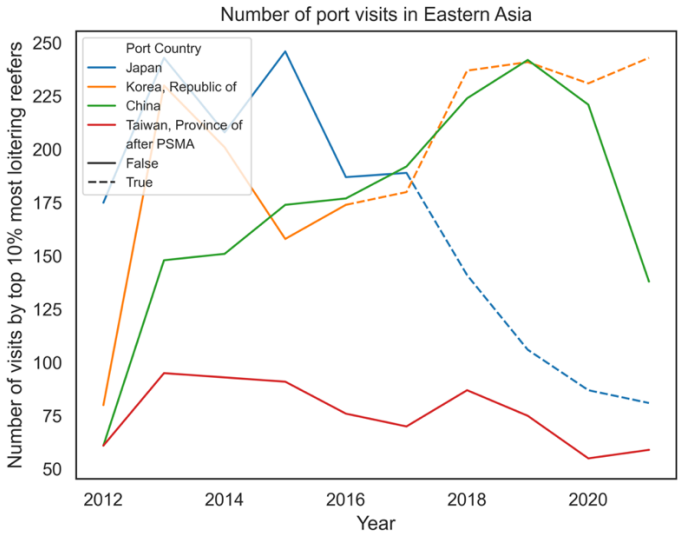
Figure 11: The number of port visits by support vessels fell in 4 out of 6 countries that attracted highly suspicious vessels after the PSMA ratification



Source: Global Fishing Watch data

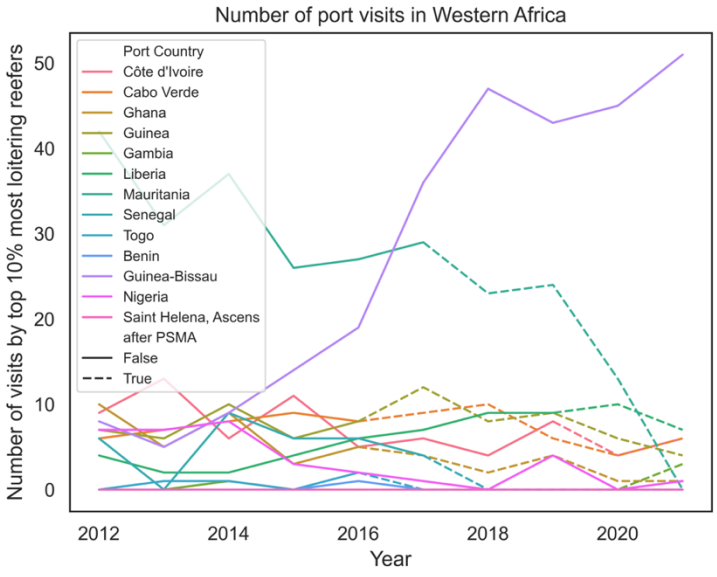
The next figure, which focuses on visits to East Asian countries, suggests that Japan's joining the PSMA dramatically reduced visits, but the same was not true in the case of South Korea.

Figure 12: Port visits in Eastern Asian states before and after the PSMA ratification



Dotted lines represent years in which the PSMA had already been ratified.

Figure 13: Port visits in Western African states before and after the PSMA ratification



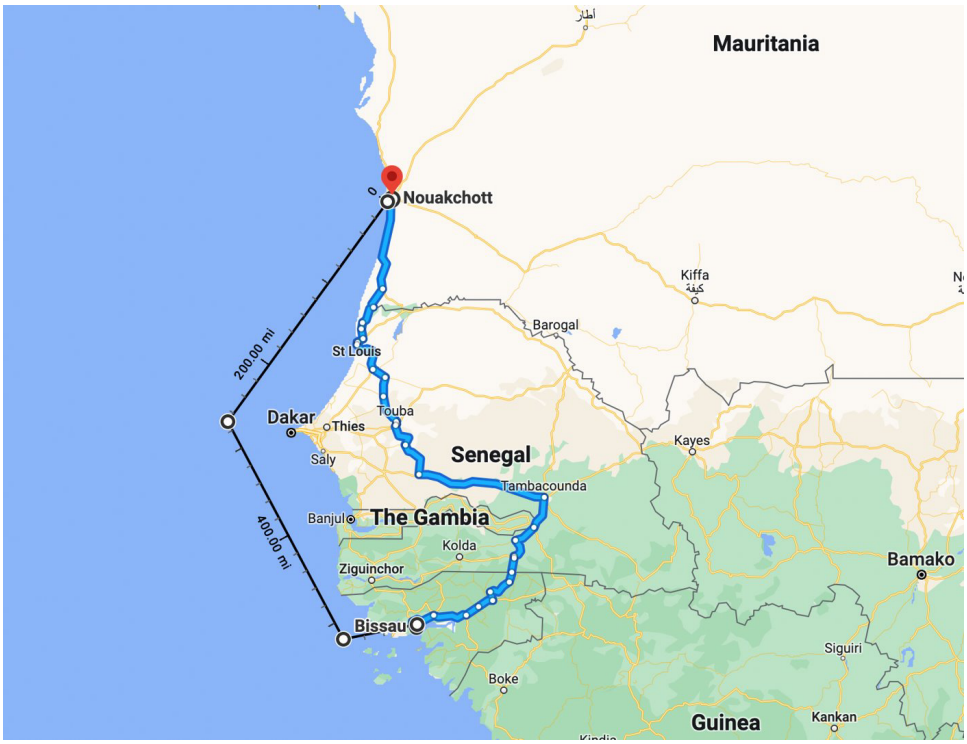
Dotted lines represent years in which the PSMA had already been ratified.

One potential limitation on the effectiveness of PSMA as a tool for combatting IUU-F is displacement, meaning vessels participating in IUU-F simply shifting their activity from ports covered by the PSMA to other ports that are either not covered, or which are nominally covered but in fact are not enforcing its provisions, either because the country lacks the capacity, or its relevant officials have been corrupted. The PSMA may fail to protect fisheries if vessels engaging in IUU-F can simply go around the participating PSMA ports to dock at other ports that do not participate.

For example, although Mauritania has ratified the PSMA, so its port of Nouakchott is not available – at least in theory – to IUU-F vessels, its neighbor Guinea-Bissau has not ratified the PSMA, so its ports remain accessible to IUU-F vessels. Since the port of Bissau is only 500 miles away from Nouakchott, that may mean that Mauritania ratifying the PSMA has not by itself created great hardship for IUU-F vessels.

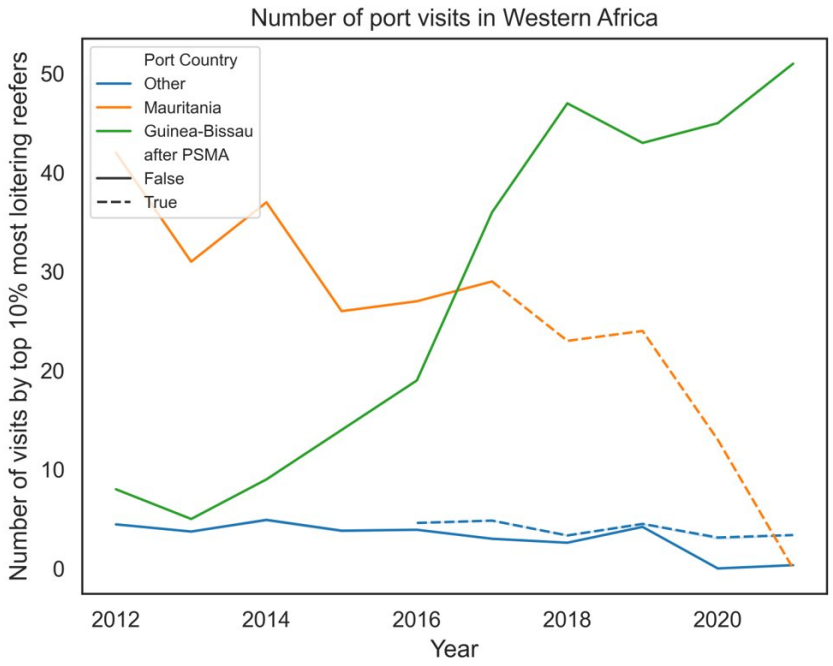
Table 9 in Chapter 6 provides a prioritization matrix of African Countries. One of the attributes in the matrix is a fishing indicator called "Dark Meetings within EEZ." Both Guinea-Bissau and Mauritania had scores of 5 on this indicator, meaning the two countries face the highest number of dark meetings in their EEZ. Other matrix attributes also place Guinea-Bissau as more vulnerable compared to Mauritania. For example, Guinea-Bissau has lower GDP per capita and higher corruption compared to Mauritania, making the former a potential target for bad actors to re-route their vessels towards it once Mauritania ports become stringent.

Figure 14: The distance between two ports Nouakchott (Up), Mauritania (PSMA Party) and Bissau (Down), Guinea-Bissau (Not a PSMA Party)



The graph below encapsulates the number of port visits by the top 10% of support vessels ranked by dark meetings to Mauritania and Guinea-Bissau over the years. Following its PSMA ratification in 2017, Mauritania saw a decline in port visits. However, during the same time, the number of port visits by suspicious support vessels increased in Guinea-Bissau, suggesting potentially that Bissau ports became more desirable for suspicious support vessels.

Figure 15: Port visits in Western African states before and after the PSMA ratification



Dotted lines represent years in which the PSMA had already been ratified.

Assuming that PSMA has had some impact on discouraging 'bad' ships from entering ports, it is important to track where 'bad' (support) vessels go after they are denied entry. If a port becomes inaccessible, bad actors will prefer to go to nearby but less stringent ports because it costs less in time and fuel, and they can land their catch at or near the same market. However, if even nearby ports become more stringent then the bad actors will have to move to a port further away, perhaps even in a different country, causing their costs to rise and exposing them to other vulnerabilities, including fluctuating foreign exchange, uncertain fish prices, and the cost of establishing/maintaining a new network of downstream vendors not to mention the chance that they are caught in transport.

Differences between PSMA designated ports and non-designated ports

The designation requirement for ports under PSMA create a quasi-natural experiment, and it can be a subject of future study. Under PSMA, each country must "designate" a certain number of ports where foreign vessels can land their catches (Pew Trusts, 2017). This divides a country's ports into two categories: designated and non-designated. PSMA requires the state to have more inspectors at the PSMA designated ports, causing heterogeneity in monitoring and surveillance across ports. For a given country, before the PSMA ratification, an average port would receive

both foreign and domestic support vessels. However, after the country ratifies the treaty and assigns designated ports, we assume the following changes. Foreign-flag bearing vessels engaged in fishing or fishing-related activities, including supporting vessels, would choose designated ports, whereas domestic vessels would choose designated and non-designated ports. Non-designated ports, post-ratification, would receive fewer overall vessels because foreign vessels that earlier went there would have to dock at designated ports by law. We can make three hypotheses. First, the number of port visits to increase in designated ports following the PSMA ratification. Second, the number of port visits to decrease in non-designated ports post-ratification. Third, the *total* number of foreign vessels in designated ports post-ratification to be less compared to the sum total of foreign vessels in all ports before the PSMA ratification because of extra surveillance and inspection at designated ports.

Japan and South Korea are two East Asian countries that ratified PSMA. As per our analysis, they are also the two topmost countries that attract the top 120 worst support vessels to their shores every year. PSMA appears to be have had an effect in Japan but not South Korea based on the following plots of the number of port visits in designated versus non-designated ports in both countries.

Figure 16: Port visits in designated and non-designated ports around PSMA ratification in Japan.

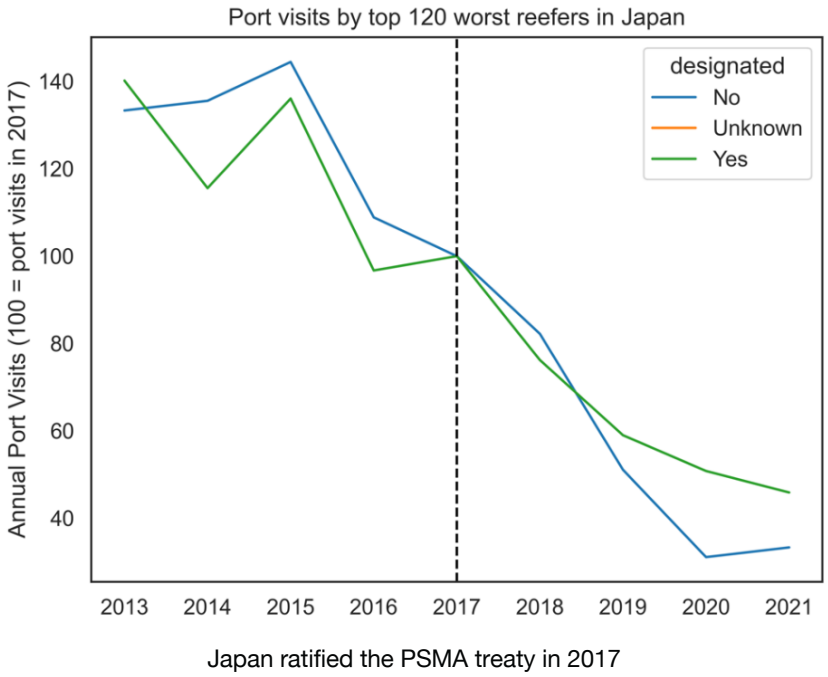
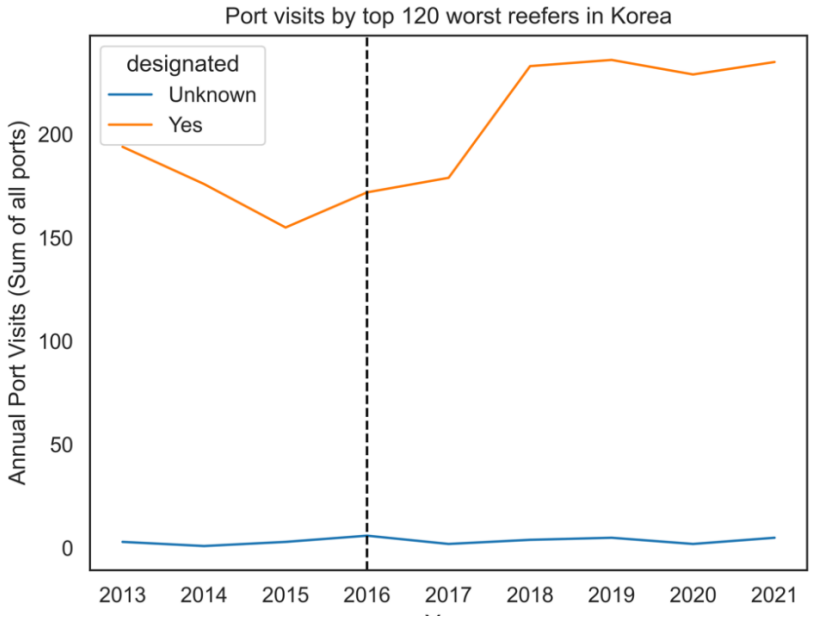


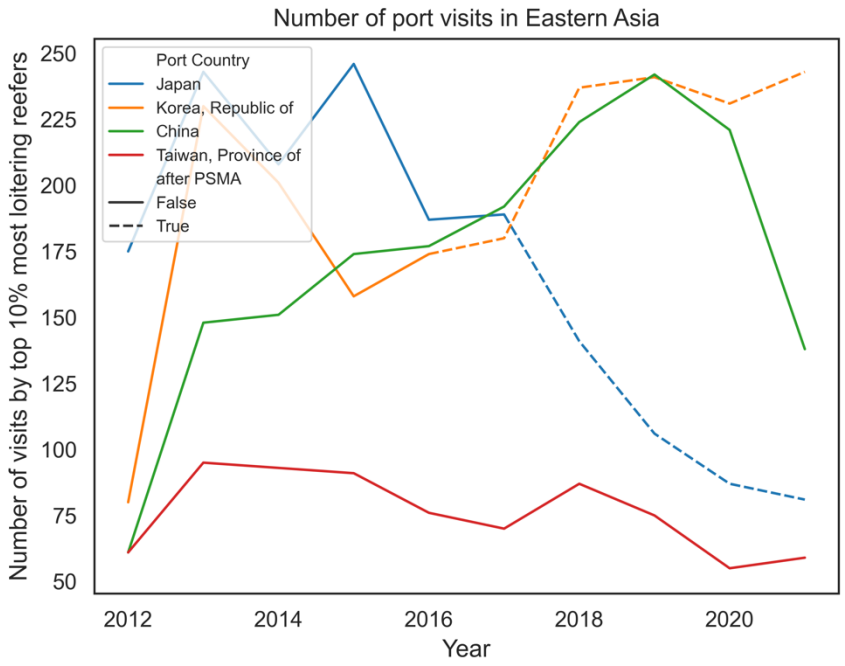
Figure 17: Port visits in designated and non-designated ports around PSMA ratification in South Korea.



From the graphs, we can make the following observations:

- In Japan, there is a reduction in port visits after PSMA is ratified in both the types of ports. We expected the number of port visits to decrease in non-designated ports, but had expected the number of port visits to increase in designated ports because foreign-flag bearing vessels (engaged in fishing) have to be routed to them because of the new law.
- In South Korea, the number of port visits in designated ports increased consistent with our hypothesis. However, the increase in port visits in the 'newly' designated ports is greater than the decrease in visits to non-designated ports, of which there were very few even ex ante. It may be that some of the increase is displacement from Japan.

Figure 18: Port visits in Eastern Asian states before and after the PSMA ratification



Dotted lines represent years in which the PSMA had already been ratified.

Concluding Thoughts

When PSMA members met in 2022, about 1/3rd of the members said they had denied vessels entry or use of ports (Bryce, 2022), yet this does not reveal if those actions were effective in combatting IUU fishing because it is not clear how onerous it is for IUU fishing vessels to seek alternate ports.

This brief analysis cannot provide definitive evidence concerning what if any actions related to PSMAs would be productive, but a few possibilities can be mentioned as potentially worthy of further thought.

1. Encourage more port states to be a member of PSMA. The rationale for this is that if there are non-PSMA states (such as Cameroon), the support vessels will have alternative ports to land their catches. Currently, only 56% of the total potential port states are PSMA members. Major states such as Brazil, with a large EEZ area, are not a part of the agreement, offering illegal vessels alternate and potentially less-stringent ports to land their catches.
2. The analysis above warrants further research into the effect of the PSMA. Further analysis of the correlation between the number of port visits by support ships and the number of designated ports may shed light on whether more and sturdy checkpoints can slow down

IUU-F. Generally, richer countries tend to have a greater number of designated ports. For example, Australia has 59 designated ports. Japan has 47, and South Korea has 31 (FAO, 2022). Contrarily, low-income countries have fewer designated ports. For example, Ghana has 2 and Nigeria has 1. Rich countries have more resources to hire more inspectors and pursue monitoring and surveillance.

3. PSMA articles lay out requirements and obligations for port states. While there are funds and capacity-building programs aimed at helping developing countries to combat IUU-F, it is important to understand that some of the requirements laid out by PSMA articles mandate a change in domestic legislation and institutional reforms, which may be too ambitious (FAO, 2022). PSMA implementation in developing countries may need to be looked at as a long-term strategy, and more short-term innovative policies to combat IUU-F should be thought of and adopted.

Chapter 9. The EU Strategy for Denying Markets to IUU Fish Catch

Another strategy for combatting IUU-F could be a market-denial measure for illegally sourced fish. Even though NGA may not have any direct role in enacting trade policies, we found this trade strategy worthy of discussion. The European Union, the world's topmost importing bloc of fish and fish-related products, leverages its consumer power to shape the behavior of exporting nations. It uses a carding system that categorizes nations into three bins: 'red,' 'yellow,' and 'green' as with cards in football (American soccer). For example, if the fish-exporting country abides by international marine norms and possesses strong monitoring and tracking systems against IUU fishing, the country receives a green card from the EU, allowing it access to the European Union market. However, suppose the fish-exporting country does not abide by some of the international regulations. In that case, the EU imposes a "yellow" card and initiates a 6-month consulting process to help the country enact necessary reforms to combat IUU fishing. If the country's track record against IUU fishing remains the same, the EU imposes a 'red' card on the country, banning all fisheries-related imports from that source (EJF Staff, 2022). The EU issued its first yellow card to a state in 2012, and since then, it has issued cards to over 30 countries in five geographical regions (EU IUU Fishing Coalition, 2022).

Effectiveness

The 'yellow' cards have triggered a series of reforms in the recipient countries. For example, Thailand received its yellow card in 2015. Prior to the year, Thailand had a flawed control system and a patchy legal framework on fishery management. Furthermore, the country's catch certificates, and processing statements were ambiguous and hindered traceability efforts. After the 'yellow card' and the fear of loss of access to the EU market, the Thai government 'adopted new fisheries laws and regulations in line with international best practices,' increased penalties for people engaged in IUU-F, established a new control system, and enhanced the landing and processing traceability (European Court of Auditors, 2022). The EU delisted Thailand in 2019 following all these reform measures.

Other countries such as Ecuador, Philippines, Sri Lanka, and Belize also stepped up to enact reforms or undertake measures to improve traceability (Bello, 2021). For example, the Ecuador and Philippines changed their national fisheries codes, established strong sanctions against legal violations, and focused on data collection and monitoring. Similarly, Sri Lanka and Belize worked on their catch documentation performance.

Shortcomings of the Carding system

Notwithstanding this success, there are loopholes that diminish the impact of 'yellow' and 'red' cards. First, it is important to note that the EU only deals with the 'market' economy which rules out the possibility of issuing a card to China (Congressional Research Service, 2019). Since

China eludes the carding system, not scrutinizing its validation and catch certificates means that there are chances that illegal fish products may be entering the EU market. For example, during 2018-19, of the 24,000 catch certificates received by Portugal, 11% of them were validated by China (EJ Foundation, 2022).

Second, most countries that have received any cards from the EU are not major players in the fishery market. Most are small countries with little trade relationships with the EU. Hence, while the EU maybe shaping their behaviors, these states don't contribute substantially to IUU-F. The table below shows a country's current card status, if they are a 'flag of convenience' state, and its trade ties vis-à-vis the EU.

Table 12: Countries' card status and their fish export percentage to EU

Exporting Countries	Current Card	Country is a flag of Convenience State	Fishery Products Trade Volume in (Euro) (in Millions) [2021 figures]	% Total of Country's Export to EU
Belize	Green	Yes	17	18.4
Panama	Yellow	Yes	35	3.5
Ecuador	Yellow	No	1,404	40.8
Curacao	Green	Yes	< 1	
Trinidad and Tobago	Yellow	No	0	0
Saint Vincent and the Grenadines	Red	Yes	~ 0	~ 0
Saint Kitts and Nevis	Yellow	Yes	~ 0	~ 0
Liberia	Yellow	Yes	Not included (0)	Not included (0)
Sierra Leone	Yellow	Yes	0	0
Guinea	Green	No	0	0
Ghana	Yellow	No	91.3	3.87
Togo	Green	Yes	0	0
Cameroon	Yellow	Yes	0	0
Comoros	Red	Yes	0	0
Sri Lanka	Green	No	132	5.1
Thailand	Green	No	197	0.9
Cambodia	Red	Yes	0	0
Viet Nam	Yellow	No	944.77	2.08
Philippines	Green	No	191	2.3

Taiwan*	Green	No	26	0.1
Republic of South Korea	Green	No	131.9	0.205
Papua New Guinea	Green	No	197	20.9
Solomon Islands	Green	No	53.47	71.47
Vanuatu	Green	Yes	0	0
Kiribati	Green	No	0.25	61.9
Tuvalu	Green	No	0	0
Fiji	Green	No	4	13.9

Source: European Union Trade Data, OEC.WORLD

Third, many of the EU-carded countries are also 'flag of convenience' states (see Table 12). The vessels from these flags of convenience can re-flag and still export the fishery products to the EU under a different country's banner. Similarly, a vessel from a non-carded country can go to the EEZ of a carded country and still engage in fishing (European Court of Auditors, 2022).

Concluding Thoughts

This brief review does not provide sufficient basis for making any specific recommendations, but we mention this denial of market strategy as an alternative (or complement) to the other strategies discussed in chapters above. To the extent that it holds appeal, the US could join the EU-only carding system to expand its influence on exporting nations by having bans affect a larger share of potential markets (as also suggested by researchers such as Sumaila et al., 2020). Or the US could develop its own similar system.

Chapter 10. Concluding Thoughts

Summary

IUU fishing is a serious global issue that the international community is increasingly trying to address. Unfortunately, this is extremely challenging as the global fishing industry is massive and very interconnected. Additionally, the laws and treaties that govern the seas and maritime resources are varied and can be difficult for states to enforce. Territorial disputes, legal loopholes, and competition for resources further complicate this issue. Combating IUU fishing requires an international effort and countries will need to decide how to efficiently allocate resources towards this effort. The ocean is large, and the bad actors are many, so understanding how to allocate a state's resources in this fight is imperative.

The United States has a large, advanced coast guard and strong judicial institutions which enables them to police and enforce laws in their jurisdictional waters effectively. However, many other countries struggle to effectively counter IUU fishing in their jurisdictional waters and the international community faces capability and legal barriers in countering IUU fishing on the high seas. The United States has an opportunity to leverage enforcement (cutters, aircraft, personnel), intelligence (surveillance, data analysis, tracking), and diplomatic (international treaties, RFMO's, bilateral agreements) assets to assist the international community in solving the IUU fishing problem.

Takeaways

Enforcement Assets

- States have a scarce number of enforcement vehicles (naval surface and aircraft) that must patrol and surveil vast areas of jurisdictional waters
- These jurisdictional areas also have a lot of fishing activity occurring within them and it is difficult to discern a legal fishing operation from an illegal one
    - Leveraging intelligence assets can narrow the focus to the vessels most likely engaged in IUU
- Physical enforcement assets must be combined with legal authority and willingness to apprehend and prosecute an IUU fishing operation

Intelligence Assets

- Narrowing surveillance and tracking effort to support vessels greatly reduces the number of vessels the NGA needs to focus on.
    - We estimate there are 2.4 million powered fishing vessels but only 1800 support vessels currently operating in the world

- There are characteristics such as the number of dark meetings, and distance from an EEZ boundary that can further narrow this list of support vessels allowing for increased attention to be paid to vessels most likely to engage in suspected IUU fishing.
- Network analysis allows us to identify support vessels that operate within the same organization and locate key actors.
- The location of support vessels is a key indicator to determine vulnerability to US jurisdiction.

Diplomatic Assets

- There are many international treaties that govern jurisdiction, travel, conservation, and trade of the world's oceans and waterways
    - International treaties are evolving in a way that empowers port states with legal foundation to inspect and regulate foreign-flagged vessels
- RFMO's, multilateral, and bilateral treaties can help authorize US jurisdiction in areas it otherwise would not be permitted
- The United States should expend diplomatic capital to encourage other states to create and impose sufficient and consistent penalties on guilty actors.
    - There are useful metrics which can help the US prioritize the most impactful partnerships

Appendix A. Limitations of Conventional Understanding of the Scale of IUU Fishing

Illicit activities are difficult to measure because they are naturally hidden, but IUU fishing can be particularly challenging because of varied international laws, territorial disputes, and the fact that these events are occurring around the world and at sea, sometimes thousands of miles away from any monitors. Although a review of news stories and scientific literature might suggest that the global scale of IUU fishing is known, this is not the case. Only a few studies estimating the global scale of IUU fishing can be found. Of these, one in particular provided what has become the de facto standard estimate purporting to measure the scale of IUU fishing. That estimate comes from a 2009 paper written by David Agnew and colleagues entitled "Estimating the Worldwide Extent of Illegal Fishing" (Agnew et al., 2009). The study provided the first estimate of the global size of IU[20] fishing, but the methodology was not without weaknesses, and the data used are now two decades old, dating from 2000 - 2003. Despite this, the results from this research are still often cited by important publications as accurate estimates of IUU fishing, with few if any cautions. Understanding the origins of these oft-cited figures helps one understand their limitations.

Agnew Paper

In 2009, David Agnew and a team of researchers published a study that claimed to be the first to estimate the size of illegal and unreported (IU) fishing at a global level (Agnew et al., 2009). The research team used scientific literature and country-specific reports to generate a point estimate as well as a lower and upper bound of the total tonnes of illegal catch in different regions from 2000 to 2003. The regional estimates were aggregated to calculate a global IU fishing estimate. They concluded that between 11 and 26 million tonnes of IU fish were captured per year from 2000 to 2003.

Note: The authors use the term "worldwide" in their title, but they focus on 54 EEZs and 15 high seas regions which comprise 75 percent of the global catch.

The authors' corresponding estimate that the dollar value of this catch was between $10 and $23.5 billion compounds all of the uncertainty concerning quantities with additional uncertainty concerning price or valuation. Agnew et al. used a single price per tonne of fish in the given year

[20] The authors chose to only attempt to estimate illegal and unreported (IU) catches and disregarded fishing discards and artisanal unregulated catches. Even though this distinction is clearly stated in the publication, the estimates provided are almost always cited by other sources as a measure of IUU fishing. Therefore, even if this estimate was perennially accurate, it would still be an underestimate when it is wrongfully used as an estimate for IUU fishing since it excludes unregulated catches.

and multiplied this value by the estimated tonnes of illegal catch to create a lower and upper bound on the dollar value of illegal catches.

The price per tonne of fish was taken from the 2005 United Nations Food and Agriculture Organization's Yearbook of Fishery Statistics, but the citation did not provide a page number indicating where the price per tonne could be found so it is unclear exactly where the price came from and why it was used. However, dividing the lower and upper bounds of IU catch value by the lower and upper bounds of total IU catch estimates results in a single price per tonne of fish estimate of $909 per tonne for the lower bound and $904 per tonne for the upper bound. The Yearbook of Fishery Statistics provides a price per tonne of fish across many fish species. These prices are then used to estimate a world price per tonne of fish which, for 2003, was $900 per tonne. We do not know if the authors used this price, but since it comes from 2003 which is the latest year of data used by Agnew et al. and it is the closest listed number we can find to the $909 or $904 price range we calculated above, we think it is possible that this was price per tonne of fish used by Agnew et al. to generate the dollar value estimate.

It is unclear how the Yearbook of Fishery Statistics calculation was made; however, there is significant variability in seafood prices and so using any single price per tonne may be problematic. For example, the document shows that lobster prices were as high as $9,100 per tonne, but a category called "miscellaneous freshwater fishes" was valued as low as $395 per tonne.

There is also the question of whether the IUU haul should be valued at its eventual retail price, or whether it makes more sense to value the IUU catch at the wholesale or dockside price that the perpetrators are paid. Deciding how to correctly value the catch will depend on what you ultimately want to measure. Estimating the economic loss from IUU fishing would likely require the use of a different price value than trying to calculate an IUU fisherman's net revenue.

Since this publication was the first to provide an estimate of IU fishing on a global scale and few other estimates have followed, it has been cited widely in subsequent research. Google scholar shows Agnew's paper has been cited 1171 times, while the next most cited publication was cited 347 times, and most other publications did not reach 100 citations[21]. Not only is this paper cited frequently, but it or its estimates are cited in high profile policy documents such as the 2020 US coast Guard Strategic Outlook (United States Coast Guard, 2020) document aimed at addressing IUU fishing and President Obama's 2014 memorandum entitled "Comprehensive Framework to Combat Illegal, Unreported, and Unregulated Fishing and Seafood Fraud" (Office of the Press Secretary, 2014). President Biden's recent memorandum on IUU fishing does not cite the size of the IUU market. This could signal a recognition by the Biden Administration that the Agnew estimate is no longer current. Organizations such as the United Nations FAO and Global Fishing

[21] This is the result of a Google scholar search of "Illegal Fishing". Similar search terms such as "IUU Fishing" and "IUU Fishing size" return different publications, but no publications as displayed on google scholar have come close to being cited as frequently as the David Agnew paper.

Watch have recently commented on the prevalence and accuracy of the Agnew estimate, as will be discussed below, but the estimates still dominate the topic of IUU fishing.

The 1 in 5 estimate and other variations

Academic literature, policy documents, and media often claim that up to 1 in every 5 fish caught has been caught illegally. This estimate is used by Global Fishing Watch (Global Fishing Watch, undated) a Pew article discussed below, the US Coast Guard (United States Coast Guard, 2020) and many other sources. Although the 1 in 5 estimate is not explicitly stated in the Agnew paper as such, it may be derived from Agnew et al.'s Table 2 which is entitled "Trends in regional estimates of illegal fishing, averaged over 5 year periods 1980–2003". The column for 2000-2003 calculates the global percentage of IU catch to be 18% of reported catch, which is quite close to 20% or 1 in 5.

The 18 percent estimate was calculated by taking the simple average of all regional IUU midpoint estimates, meaning the average of the upper and lower bounds in each region. This calculation weights each region equally, but equal amounts of fish are not captured in each region. For example, both back in 2003 and more recently in 2020, the Pacific Northwest accounted for a quarter of all capture production, whereas the Atlantic Northwest accounted for one-tenth as much. Hence, it does not make sense that Agnew et al. would weight the Pacific Northwest's region illegal fishing proportion (33%) no more heavily than the Northwest Atlantic's proportion (9%) when averaging them together into the composite 18% figure

Table 13: Capture Production by Region

FAO major fishing area	2003	2020	% total 2003	% total 2020
Pacific, Northwest	19,875,238.0	19,153,023.1	24.9%	24.3%
Pacific, Western Central	10,896,839.0	13,260,369.9	13.7%	16.8%
Pacific, Southeast	10,554,397.0	8,401,489.1	13.2%	10.7%
Atlantic, Northeast	10,271,103.0	8,311,198.3	12.9%	10.5%
Indian Ocean, Eastern	5,333,893.0	6,593,803.8	6.7%	8.4%
Indian Ocean, Western	4,400,836.0	5,625,904.2	5.5%	7.1%
Atlantic, Eastern Central	3,553,971.0	4,948,546.2	4.5%	6.3%
Pacific, Northeast	2,901,710.0	2,862,965.7	3.6%	3.6%
Atlantic, Southwest	1,986,869.0	1,702,103.4	2.5%	2.2%
Pacific, Eastern Central	1,788,105.0	1,694,448.1	2.2%	2.2%
Atlantic, Northwest	2,337,510.0	1,538,473.9	2.9%	2.0%
Atlantic, Southeast	1,736,635.0	1,363,741.9	2.2%	1.7%

Atlantic, Western Central	1,724,517.0	1,248,348.7	2.2%	1.6%
Mediterranean and Black Sea	1,479,277.0	1,187,038.6	1.9%	1.5%
Atlantic, Antarctic	127,330.0	449,491.9	0.2%	0.6%
Pacific, Southwest	731,490.0	431,887.8	0.9%	0.5%
Indian Ocean, Antarctic	13,167.0	10,262.0	0.017%	0.013%
Pacific, Antarctic	2,051.0	1,834.5	0.003%	0.002%
Arctic Sea	0.0	420.0	0.000%	0.001%
Totals - Tonnes - live weight	79,714,938.0	78,785,351.1		

SOURCE: United Nations Food and Agriculture Organization FishStatJ Database Table "FAO Regional capture fisheries statistics" (size 9)

Sometimes it appears that there are multiple, independent, consistent estimates when more than one ultimately traces to the same source. In 2017, Pew Charitable Trusts published an article (Pew, 2017) with a title that used the 1 in 5 estimate. It also cited the Agnew estimate stating that $23.5 billion worth of illegal seafood is caught each year, and cited a second source, an article from *The Atlantic*, which claimed that 1,800 pounds of seafood were illegally caught each second. All three numbers (1 in 5, $23.5B and 1,800 pounds per second) come from the same source. The 1,800 pounds per second figure can be created using simple arithmetic (26 million tonnes caught per year divided by 31,536,000 seconds per year is 0.824 tonnes per second, or 1,800 pounds caught per second). Thus the Pew article appeared to provide 3 different estimates of the size of IUU fishing, but they all ultimately came from the Agnew publication.

Another possible example comes from Global Fishing Watch, which is a highly respected source of information on IUU. Their website says "The most often cited report estimates the total IUU catch in 2003 to have been between 11 million and 26 million tons of fish. Some experts suggest that 10 to 30 percent more fish are being taken from the ocean than what is accounted for by legal fishing" (Global Fishing Watch, undated) without giving a source for the "some experts", The 11 – 26 million tons matches Agnew et al. if we ignore the switch from tonnes to tons, and the 10 to 30 percent could be just the 1 in 5 figure wrapped in a +/- 10 percentage point error band.

This memo is not meant to be a critique of Agnew et al.'s research. That paper attempted to accurately generate the first estimate of something that is incredibly difficult to calculate. However, the research was published in 2009 and used data from 2000-2003 so even a perfect estimate made at the time would be outdated now, and it was a reasonable first attempt not a definitive final word on quantities even in that earlier time frame. It is risky to think that the Agnew estimates can be applied to the global fishing environment today. The prevalence of these estimates over time make them appear more reliable and current than they actually are. Additionally, mathematically modifying these estimates in ways not included in the original research risks further distorting these estimates.

FAO and GFW Responses

Global Fishing Watch (Cutlip, 2016) and The United Nations Food and Agriculture Organization (FAO) (FAO, undated) have recognized that the current de facto estimate of IUU fishing might no longer be reliable. In 2016, the FAO commissioned a "study of IUU fishing studies, in order to compare the strength of studies since 2009 in estimating IUU fishing… and to determine whether FAO should work to provide guidance for the future estimation of IUU fishing, at the national, regional or global level". The FAO noted that it might not be efficient to conduct another global estimation study and instead suggested that the FAO might create technical guidelines for states and RFMO's to conduct their own studies in the hope that standardizing estimation methodology could allow for regional studies to be aggregated into a global estimate (FAO, 2016).

Other Global Estimates

A few other global IUU fishing estimates are available, but ones we found appear all to be connected to some degree to the University of British Columbia's Sea Around Us initiative, which was launched in 1999 in partnership with Pew Charitable Trusts, and two of Agnew's co-authors (Reg Watson and Tony Pitcher) were affiliated with the University of British Columbia Fisheries Centre.

For example, a 2020 paper by Sumaila et al. estimates that "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" (Sumaila et al., 2020), but Sumaila sits on the Sea Around Us Advisory Board.

One important publication directly from the Sea Around Us initiative is a 2016 paper by Daniel Pauly (longtime director of the Sea Around Us Project and described as the world's most-cited fisheries scientist) and Dirk Zeller (executive director of Sea Around Us, now faculty at the University of Western Australia). They attempted to reconstruct how many fish are caught in fisheries over time and compare those estimates to what is reported to official sources. They conclude that actual catches could be 53% higher than reported catches (Pauly and Zeller, 2016).

Hence, even new/separate estimation efforts may draw on a common tradition.

Conclusion

Estimating the global scope of an illicit activity is incredibly difficult especially when some of that activity is taking place in the middle of the ocean. Agnew's publication provided what, at the time, was likely a reasonable estimate of the size of IU fishing globally. Since this was one of the only estimates available, researchers, policymakers, and the media used this estimate liberally to show that IU fishing was a significant problem. Unfortunately, repetition of this publication's

estimate has made it seem that there is an accurate estimate of global IU fishing. The world does not know the magnitude of global IUU fishing and it is problematic to continue citing Agnew's estimates without understanding its limitations.

Appendix B. Handbook for Fishing Fleet Excel Workbook

We gathered data on various components of the global fishing environment and are including that data in an Excel workbook entitled “Fleet Snapshot and Law Review Deliverable”. The workbook has three tabs each containing data on a different area. The tabs are “Fleet Snapshot”, “Law Review”, and “Common Vessel Types”

Fleet Snapshot – This Excel sheet shows data on different variables for a specific country. The data was gathered from multiple sources and these sources can be found in the comment box of each column header. The data is not all from the same year, but all data is from within three years of each other. The comment boxes will also indicate the year that the data is from. The Excel sheet is currently sorted alphabetically by country but can be sorted on any column to reveal the most prevalent actors according to each metric.

Law Review – The excel shows the ratification status of 193 countries with regards to nine international treaties as retrieved from various sources such as UNTC and the website of each convention. As each website and treaty use different country names, it required data cleaning process. First, 193 countries were converted into 3-digit ISO country code on Python using Pandas. One tab contains the list of countries joining each treaty and a main tab was created referencing the status from each tab.

Appendix C. Documentation of Data Pipeline

The code used for the analysis in Chapter 5 can be found in the following GitHub repository: github.com/sebdodt/illegal_fishing_dashboard

It contains the following:

- All code used to generate the figures and graphs as well as additional quantitative analyses that has not been featured in this report
- A pipeline that receives data from *Global Fishing Watch* and *SeaVision* to produce the back-end infrastructure of a dashboard. The dashboard is described in detail on page 47 above. Its goal is to show the activity and location of the most suspicious support vessels and provide actionable intelligence on their vulnerability to U.S. enforcement.

Bibliography

Alam, M. A. (2021, February 12). The Flag of Convenience: A case study of Liberia's Shipping Industry. *Maritime Study Forum*. https://www.maritimestudyforum.org/the-flag-of-convenience-a-case-study-of-liberias-shipping-industry/

Anrooy, R. van, Carvalho, N., Kitts, A. W., Mukherjee, R., Eijs, S. van, Japp, D., & Ndao, S. (2021). *Review of the techno-economic performances of the main global fishing fleets*. Food and Agriculture Organization of the United Nations.

Becker, G. S. (2000). Crime and Punishment: An Economic Approach. In N. G. Fielding, A. Clarke, & R. Witt (Eds.), *The Economic Dimensions of Crime* (pp. 13–68). Palgrave Macmillan UK. https://doi.org/10.1007/978-1-349-62853-7_2

Bello, M. (2021). *Ecuador on the Frontier of a Changing Ocean: Understanding the Impacts of Illegal, Unreported, and Unregulated Fishing on Ecuador's International Economic Relations*. Wilson Center. https://www.wilsoncenter.org/publication/ecuador-frontier-changing-ocean-understanding-impacts-illegal-unreported-and

BRINK. (2022). *Fishing in Dangerous Waters: A New Flashpoint for Latin America and China*. BRINK – Conversations and Insights on Global Business. https://www.brinknews.com/fishing-in-dangerous-waters-a-new-flashpoint-for-latin-america-and-china/

Cabral, R. B., Mayorga, J., Clemence, M., Lynham, J., Koeshendrajana, S., Muawanah, U., Nugroho, D., Anna, Z., Mira, Ghofar, A., Zulbainarni, N., Gaines, S. D., & Costello, C. (2018). Rapid and lasting gains from solving illegal fishing. *Nature Ecology & Evolution*, *2*(4), 650–658. https://doi.org/10.1038/s41559-018-0499-1

Caulkins, J. P., Kammer-Kerwick, M., Konrad, R., Maass, K. L., Martin, L., & Sharkey, T. (2019). A call to the engineering community to address human trafficking. *Bridge*, *49*(3), 67–73.

Chase, C. (2020, August 24). *Previously-fined Chinese vessel given Ghanaian fishing permit, despite lack of payment | SeafoodSource*. SeafoodSource.Com. https://www.seafoodsource.com/news/environment-sustainability/previously-fined-chinese-vessel-given-ghanaian-fishing-permit-despite-lack-of-payment

CITES. (2022, June 8). *Countries currently subject to a recommendation to suspend trade*. https://cites.org/eng/resources/ref/suspend.php

Congressional Research Service. (2019). *China's Status as a Nonmarket Economy (NME)*. https://sgp.fas.org/crs/row/IF10385.pdf

Daniels, A., Gutierrez, M., Fanjul, G., Guerena, A., Matheson, I., & Watkins, K. (2016). *Western Africa's missing fish: The impacts of illegal, unreported and unregulated fishing and under-reporting catches by foreign fleets*. Overseas Development Institute.

Davie, S., Minto, C., Officer, R., Lordan, C., & Jackson, E. (2015). Modelling fuel consumption of fishing vessels for predictive use. *ICES Journal of Marine Science*, *72*(2), 708–719. https://doi.org/10.1093/icesjms/fsu084

DVIDS. (2022, August 3). *Coast Guard conducts counter-illegal, unreported and unregulated (IUU) fishing operations*. DVIDShub.Net. https://www.dvidshub.net/image/7415287/coast-guard-conducts-counter-illegal-unreported-and-unregulated-iuu-fishing-operations

EJ Foundation. (2022). *The EU Forced Labour Products Ban: How to Ensure Effective Enforcement*. Environmental Justice Foundation. https://ejfoundation.org/resources/downloads/Briefing-EU-Forced-Labour-Products-Ban-September-2022-v2.pdf

EJF. (2017, April 27). Learning lessons from Spain's experience of prosecuting nationals for involvement in illegal, unreported and unregulated (IUU) fishing. *IUUWatch*. http://www.iuuwatch.eu/2017/04/learning-lessons-spains-experience-prosecuting-nationals-involvement-illegal-unreported-unregulated-iuu-fishing/

EJF. (2019). *Blood and Water: Human Rights Abuse in the Global Seafood Industry*. Environmental Justice Foundation. https://ejfoundation.org/resources/downloads/Blood-water-06-2019-final.pdf

EJF Staff. (2022, March 21). *EU Scheme to Tackle Illegal, Unreported, and Unregulated Fishing Brings Positive Results and Empowers Nations, New Report Finds*. Https://Ejfoundation.Org/News-Media/Eu-Scheme-to-Tackle-Illegal-Unreported-and-Unregulated-Fishing-Brings-Positive-Results-and-Empowers-Nations-New-Report-Finds-2#:~:Text=The%20EU%27s%20%27carding%20scheme%27%20%E2%80%93,Enforcement%20measures%20in%20several%20carded.

EU IUU Fishing Coalition. (2022). *EU Carding Decisions*. https://www.iuuwatch.eu/map-of-eu-carding-decisions/

European Court of Auditors. (2022). *EU Action to Combat Illegal Fishing* (pp. 22–30). https://www.eca.europa.eu/Lists/ECADocuments/SR22_20/SR_Illegal_fishing_EN.pdf

FAO. (2022a). *Agreement on Port State Measures (PSMA)*. https://www.fao.org/port-state-measures/en/

FAO. (2022b). *Study on The Implementation Of The 1993 FAO Compliance Agreement*. Food and Agricultural Organization. https://www.fao.org/3/cc1871en/cc1871en.pdf

FAO. (2022c). *The State of World Fisheries and Aquaculture 2022*. FAO. https://doi.org/10.4060/cc0461en

GAO. (2021). *Combating illegal fishing: Clear authority could enhance U.S. efforts to partnership with other nations at sea* (United States Government Accountability Office Report to Congressional Requesters). https://www.gao.gov/assets/gao-22-104234.pdf

Global Fishing Watch. (n.d.). *Transshipment*. Retrieved 20 September 2022, from https://globalfishingwatch.org/transshipment/

Global Fishing Watch. (2016, August 23). Rendezvous at Sea: What is Transshipping? *Global Fishing Watch*. https://globalfishingwatch.org/fisheries/rendezvous-at-sea-what-is-transshipping/

Global Fishing Watch. (2022a). Commercial Fishing—Satellite Monitoring. *Commercial Fishing*. https://globalfishingwatch.org/commercial-fishing/

Global Fishing Watch. (2022b). What is an encounter in the carrier vessel portal? *Global Fishing Watch*. https://globalfishingwatch.org/faqs/what-is-an-encounter-in-the-carrier-vessel-portal/

Godfrey, M. (2018, March 2). *China blacklists firm in Galapagos shark-catching scandal | SeafoodSource*. SeafoodSource. https://www.seafoodsource.com/news/business-finance/china-blacklists-firm-in-galapagos-shark-catching-scandal

Gokken, B. (2018, May 31). *Indonesia targets illegal fishing vessel owners under new bill*. Mongabay Environmental News. https://news.mongabay.com/2018/05/indonesia-targets-illegal-fishing-vessel-owners-under-new-bill/

Goodman, J. (2022, November 1). *China fishing fleet defied U.S. in standoff on the high seas*. AP NEWS. https://apnews.com/article/taiwan-fish-pacific-ocean-oceans-china-810be144e62b695da2c6c0da65e9f051

Holland, J. (2019, October 31). *EU hits Ecuador with yellow card | SeafoodSource*. SeafoodSource.Com. https://www.seafoodsource.com/news/supply-trade/eu-hits-ecuador-with-yellow-card

House, T. W. (2022, June 27). *Memorandum on Combating Illegal, Unreported, and Unregulated Fishing and Associated Labor Abuses*. The White House. https://www.whitehouse.gov/briefing-room/presidential-actions/2022/06/27/memorandum-on-combating-illegal-unreported-and-unregulated-fishing-and-associated-labor-abuses/

IMO. (2022). *United Nations and the Oceans*. https://imo.libguides.com/c.php?g=659467&p=4655217#:~:text=The%20United%20Nations%20Convention%20on,the%20oceans%20and%20their%20resources.

International Transportation Workers' Federation. (n.d.). *Flags of Convenience*. ITFGlobal.Org. Retrieved 30 November 2022, from https://www.itfglobal.org/en/sector/seafarers/flags-of-convenience

ISA. (n.d.). *About ISA*. https://www.isa.org.jm/about-isa

Lockett, M. S. (2022, July 10). *Coast Guard announces penalties against fishing vessels*. Juneau Empire. https://www.juneauempire.com/news/coast-guard-announces-fines-levied-against-illegal-fishing-vessels/

McDonald, G. G., Costello, C., Bone, J., Cabral, R. B., Farabee, V., Hochberg, T., Kroodsma, D., Mangin, T., Meng, K. C., & Zahn, O. (2021). Satellites can reveal global extent of forced labor in the world's fishing fleet. *Proceedings of the National Academy of Sciences*, *118*(3), e2016238117. https://doi.org/10.1073/pnas.2016238117

MSC International. (2022). *Major brands look to South America as European governments put health of fish stocks at risk*. MSC International - English. https://www.msc.org/media-centre/press-releases/press-release/major-brands-look-to-south-american-jack-mackerel

National Intelligence Council. (2016). *Global Implications of Illegal, Unreported, and Unregulated (IUU) Fishing*. United States Government. https://irp.fas.org/nic/fishing.pdf

NOAA. (2019). *Improving International Fisheries Management: 2019 Report to Congress*. NOAA. https://media.fisheries.noaa.gov/dam-migration/improvingintlfisheriesmgmt_2019_report_final.pdf

Pew Charitable Trust. (2018). *The Cape Town Agreement Explained*. The Cape Town Agreement Explained | The Pew Charitable Trusts (pewtrusts.org)

Pew Charitable Trust. (2019). *How to End Illegal Fishing: The Role of the Flag State*. https://www.pewtrusts.org/-/media/assets/2019/08/theroleoftheflagstate_factsheet_v3.pdf

Pew Trusts. (2017, November 13). *Up to 1 in 5 Fish Sold Is Caught Illegally—And Other Surprising Illegal Fishing Facts*. PewTrusts.Org. http://pew.org/2zGMZTo

Polinsky, M., & Shavell, S. (2000). An Economic Theory of Public Enforcement of Law. *Journal of Economic Literature*, *XXXVIII*, 45–76.

SeafoodSource. (2022). *Chilean jack mackerel recovery leading to increased competition with European species | SeafoodSource*. https://www.seafoodsource.com/news/environment-sustainability/chilean-jack-mackerel-recovery-leading-to-increased-competition-with-european-species

SeaShepherd. (2018, May 31). Largest Fish Factory Vessel in the World Arrested and Seized—Sea Shepherd Conservation Society. *Largest Fish Factory Vessel in the World Arrested and Seized*. https://seashepherd.org/2018/05/31/largest-fish-factory-vessel-in-the-world-arrested-and-seized/, https://seashepherd.org/2018/05/31/largest-fish-factory-vessel-in-the-world-arrested-and-seized/

Selig, E. R., Nakayama, S., Wabnitz, C. C. C., Österblom, H., Spijkers, J., Miller, N. A., Bebbington, J., & Decker Sparks, J. L. (2022). Revealing global risks of labor abuse and illegal, unreported, and unregulated fishing. *Nature Communications*, *13*(1), 1612. https://doi.org/10.1038/s41467-022-28916-2

Sinclair, M. (2021, January 25). The national security imperative to tackle illegal, unreported, and unregulated fishing. *Brookings*. https://www.brookings.edu/blog/order-from-chaos/2021/01/25/the-national-security-imperative-to-tackle-illegal-unreported-and-unregulated-fishing/

SPRFMO. (n.d.). *South Pacific Regional Management Organisation*. SPRFMO.Int. Retrieved 30 November 2022, from https://www.sprfmo.int/

Sumaila, U. R., Zeller, D., Hood, L., Palomares, M. L. D., Li, Y., & Pauly, D. (2020). Illicit trade in marine fish catch and its effects on ecosystems and people worldwide. *Science Advances*, *6*(9), eaaz3801. https://doi.org/10.1126/sciadv.aaz3801

Temple, A. J., Skerritt, D. J., Howarth, P. E. C., Pearce, J., & Mangi, S. C. (2022). Illegal, unregulated and unreported fishing impacts: A systematic review of evidence and proposed future agenda. *Marine Policy*, *139*, 105033. https://doi.org/10.1016/j.marpol.2022.105033

Tennesen, M. (2018, August 6). *Blowing Up Illegal Fishing Boats Helps Indonesian Fishers*. Scientific American. https://www.scientificamerican.com/article/blowing-up-illegal-fishing-boats-helps-indonesian-fishers/

UN Library. (n.d.). *What is the difference between signing, ratification and accession of UN treaties?* https://ask.un.org/faq/14594

United Nations. (2001). *The United Nations Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks*. https://www.un.org/depts/los/convention_agreements/convention_overview_fish_stocks.htm

United States Coast Guard. (n.d.). *The Coast Guard: America's Oldest Maritime Defenders | GoCoastGuard.com*. Gocoastguard.Com. Retrieved 30 November 2022, from https://www.gocoastguard.com/about-the-coast-guard/learn-the-history

Wamucii, S. (2022). Page Analysis. *Selina Wamucii*. https://www.selinawamucii.com/insights/prices/united-states-of-america/mackerel/

White, C. (2016, March 16). *Argentina sinks Chinese-flagged vessel suspected of illegal fishing | SeafoodSource*. SeafoodSource.Com. https://www.seafoodsource.com/news/environment-sustainability/argentina-sinks-chinese-flagged-vessel-suspected-of-illegal-fishing

White, C. (2018, July 9). *Factory fishing vessel Damanzaihao leaving Peru after detention | SeafoodSource*. SeafoodSource.Com. https://www.seafoodsource.com/news/supply-trade/factory-fishing-vessel-damanzaihao-leaving-peru-after-detention

Widjaja, S., Long, T., & Wirajuda, H. (2020). *Illegal, Unreported and Unregulated Fishing and Associated Drivers*. World Resources Institute. http://www.oceanpanel.org/iuu-fishing-and-associated-drivers

Witbooi, E., Ali, K.-D., Santosa, M. A., Hurley, G., Husein, Y., Maharaj, S., Okafor-Yarwood, I., Quiroz, I. A., & Salas, O. (2020). Organized crime in the fisheries sector threatens a sustainable ocean economy. *Nature*, *588*(7836), 48–56. https://doi.org/10.1038/s41586-020-2913-5

WTO glossary. (n.d.). https://www.wto.org/english/thewto_e/glossary_e/exclusive_economic_zone_eez_e.htm