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Any Port in a Storm: Vessel Activity and the Risk of IUU-Caught Fish Passing through the World's Most Important Fishing Ports

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Any Port in a Storm: Vessel Activity and the Risk of IUU-Caught Fish Passing through the World's Most Important Fishing Ports

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Abstract
This study assesses the risk of fish from illegal, unregulated and unreported (IUU) sources passing through the world's most important fishing ports and explores the drivers of this risk.

Like previous studies it has attempted to rank ports and States based on landings and vessel visits reported by governments by using Automatic Identification System (AIS) positional data transmitted by fishing and fish carrier vessels to identify the locations of ports and rank them based on the frequency of visits by foreign-flagged and domestic-flagged vessels. It advances our thinking in that (i) the analysis includes an estimation of the hold capacity of fishing vessels and is therefore able to rank ports based on the total hold capacity of vessels visiting them and (ii) the profile and the frequency of vessel visits inform an assessment of the relative risks between different ports, and the implications for the implementation of the Port State Measures Agreement (PSMA). The study also assesses the accuracy and utility of AIS-derived data for determining IUU risk globally for all ports, notably by cross-referencing its findings with those of other studies.

The study develops a broad suite of indicators that quantify and aggregate the AIS-derived port visit information in conjunction with published and publicly available policy and regulatory information drawn from other sources, such as the compliance record with binding port State measures of regional fisheries management organizations, to raise a global port State IUU Risk Index. The comparison of achieved risk scores with national income, levels of corruption, and geography provides insights into factors driving (aggravating) or modulating (mitigating) risks of IUU-caught seafood passing through a Nation's fishing ports, and supports a view that States with weaker governance also face higher odds of visits by vessels likely to have engaged in IUU fishing (i.e. higher external risks).

Based on an in-depth assessment of 14 individual ports globally, appended as a supplement to this paper, the study finds that overall, and with the possible exception of mandatory advance request procedures for entering ports, the implementation of key provisions of the 2009 PSMA remains severely lacking. The two main areas for improvement are the posting of publicly available PSM-related information on national and/or FAO portals, and the formal designation of ports.

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1 INTRODUCTION

1.1 Background and purpose of this study

Fishing ports, the fishing vessels calling to them, and the transactions taking place in them have become the focus of increasing scrutiny coupled with work to develop the Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing, also known as the Port State Measures Agreement (PSMA), and its entry into force in June 2016. Since 2016, fishing ports have come to embody the latest statutory frontline in combatting illegal, unregulated and unreported (IUU) fishing. The centerpiece of port State action revolves around the principle that foreign vessels involved in fishing operations, visiting designated fishing ports, will be denied authorization to land their catch if that catch has been obtained by flouting national or international fisheries regulations – including, but not limited to those issued by regional fisheries management organizations (RFMOs).

While other fisheries-related national, regional and global data sets can be quite consolidated, complete and advanced – e.g. on the size of Exclusive Economic Zones (EEZs), the authorization regimes applying to them, RFMO membership of given States, etc. – knowledge and information about fishing ports, and the rules applying therein remains highly fragmented and, in many cases, limited. A comprehensive and up-to-date list of fishing ports, or designated fishing ports, does not exist. At a global level we do not know how many fishing ports there are of different sizes, and which classes of vessels they cater to.

Other important gaps in current port State related datasets and knowledge are the degree of exposure of port States to the risk of IUU fishing and of IUU products flowing through their ports, and related performance in combatting these phenomena. Given the very recent nature of the PSMA, this is not surprising.

This paper explores these issues in order to gain a better understanding of port State-related dynamics (numbers of ports, amount of traffic, etc.), port State exposure to IUU risks, and perceived performance in combatting IUU fishing.

The purpose of this study is twofold. Firstly, to assess the potential for using (remotely collected) Automatic Identification System (AIS) data to identify and characterize fishing port activities, thus enabling a possible long-term, cost-effective monitoring tool. Secondly, to establish how risk assessment methodologies can be applied to estimate IUU risks associated with port States and fishing ports, based upon a suite of internal and external indicators that are used to build a Port State IUU risk index.

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2 METHODOLOGY

2.1 Overall approach

The study builds upon an earlier assessment conducted by Poseidon Aquatic Resource Management Limited for Pew entitled 'Fish Landings at the World's Commercial Fishing Ports (Huntington *et al*, 2015) which ranked the world's top 100 ports by volume of commercial fish landed by industrial scale fishing vessels.

This new research differs in intent and approach from the previous study. Firstly, it is based on an entirely different methodology using global ship-based AIS data to pinpoint likely shore-side activity by fishing vessels - the latter covering both fish catching vessels and fish carrier vessels. Secondly it uses AIS-derived information on flag State, vessel type and vessel size to categorize activities by flag type (e.g. foreign and domestic), hold size, visit rates and temporal and spatial distribution characteristics. Thirdly it develops an innovative risk assessment methodology to determine the quality of port State response (expressed as internal risk and determined by governance indicators) and port State exposure to IUU risk (expressed as external risk and determined by the profile of fishing vessels visiting a State's ports). For each port State, the two risk components are combined to yield an overall Port State IUU Risk Index.

'Risk' is defined as the probability of IUU-related events to occur in ports of given port States and is qualitative in nature. Scores rating risk serve to rank States across this study, and do not embody a concise measure of probability. A high score merely signifies a "comparatively high risk", while a low score signifies a "comparatively low risk".

The study is global in scope. Over seven million vessel stopping events from 2017 have been analyzed to identify and characterize fishing vessel activities in over 3,000 ports and anchorages worldwide. This information was then used and complemented by a suite of fact-based indicators to characterize port State performance at the level of the individual State. The combination of both sets of data was the basis for the development of a global level port State IUU risk index, and related ranking.

It should be emphasized that this study is the first time such an approach has been used to assess IUU risk at port State level. The authors recognize that this process is based on machine learning algorithms which are at an early stage of development and implementation, and that improvements to methodology, efficiency, and elimination of errors associated with large volumes of AIS-derived data are likely to be beneficial in the future. An important part of our findings relates to the identification of current shortcomings in data and necessary further work.

2.2 Detailed Methodology

2.2.1 Global analysis

2.2.1.1 Fishing vessel tracking and analysis

AIS is a maritime collision avoidance system transmitted on marine Very High Frequency (VHF) radio. AIS transmissions provide information on the position, speed, course and identity as recorded by the transmitting vessel. The system is regulated by the International Maritime Organization (IMO) International Convention for the Safety of Life at Sea (SOLAS), and while mandatory on all passenger vessels and merchant vessels over 300 gross tons, fishing vessels are generally exempted from carriage requirements. Some flag States have required AIS on larger fishing vessels, but this is not the standard globally. Consequently, AIS does not provide 'the complete' picture of all vessel activity. However, its prevalence on larger fishing vessels makes it useful for this study, which looks especially at fishing vessels that may travel between countries and trigger the requirements of the PSMA. AIS is transmitted on VHF radio communication systems. These transmissions are line of sight, meaning the earth's curvature limits its horizontal reception. However, its vertical transmission is readily captured by commercial satellite arrays, extending the range of AIS to a near global footprint. This project utilized global AIS data captured by both exactEarth's exactView satellite constellation, and terrestrial antenna sourced data collected by exactEarth's terrestrial AIS partner FleetMon – for the calendar year 2017. All methods of capturing AIS data are limited by the fact that unless a station receives and records the transmission, there is no record. This combination of a global satellite constellation and terrestrial network was determined to be the most cost-effective combination with the widest reach of recorded position and identity reports, although it is not possible to record every AIS message broadcast in the world with current technology, despite multiple service providers operating in different regions across the world.

The starting point for the analysis was to identify all vessel stopping events within 12nm from shore around the world, which would capture all ports and anchorages commonly used by fishing vessels and fish carriers. Due to Global Positioning System (GPS) variation and a vessel's movement when alongside a quay or at anchor, a vessel never remains perfectly stationary. To account for this slight movement, an algorithm was developed that reviewed each vessel track for the 12-month study period and identified groups of consecutive transmissions where the distance travelled was less than 500m, at a speed of under 0.5 knots. Any group with a total time period under one hour was also discounted. Each one of these groups was labelled as a Vessel Stop Event and given a unique ID.

The analysis then developed an algorithm that converted the Vessel Stop Events into Port Visit Events. This was critical to avoid duplicate counting of multiple Vessel Stop Events by a single vessel within a given port as multiple port visits. When a fishing vessel arrives at a port, it may move between anchorages, transshipment events, the quayside or a dry dock. In this case, all individual internal port movements were grouped into one single Port Visit Event by using an algorithm to group Vessel Stop Events likely to be associated with a single port visit. The grouping algorithm created a new Port Visit Event if all the following criteria were satisfied:

1. The maximum distance moved since last Stop Event was more than 12 nautical miles;
2. The time since the last Stop Event was more than 6 hours;
3. The subsequent Stop Event was not brought about by an AIS irregularity.

An additional step was to create a new Port Visit Event when a vessel travelled more than 25 nautical miles between Stop Events occurring at the same port. Applying the grouping algorithm to the Vessel Stop Event data resulted in a total of 775,454 Port Visit Events.

2.2.1.2 Port Identification

A database of potential port locations was compiled based on algorithmically-identified worldwide concentrations of Vessel Stop Events. Locations of concentrations of stops were compared to the known port names and locations from the World Port Index, a dataset produced by the U.S. National Geospatial Intelligence Agency that includes the names and single point locations of major global ports[1]. In total, 2,961 of the ports algorithmically identified from AIS data were linked to the World Port Index records, and a further 106 ports were created and named manually. Regions and countries with high concentrations of ports that were not included in the World Port Index and with many fishing vessel visits were especially prevalent in eastern Russia, China, Japan, Antarctic, Iran, and South Korea.

Once all the 3,067 identified ports had been named, each port was given a radius to represent the port's area of jurisdiction. Radii were informed by the size documented in the World Port Index, or else a fixed standard radius of 5.5 kilometers was allotted (3.5 kilometers for European ports, due to their proximity to one and another). In general, port areas were coarsely defined, potentially encapsulating many different localized ports or landing places into a larger scale regional port area. An example of this is Hong Kong which – with a radius of 26 kilometers – encompasses many local ports which for the scope of this study were grouped under Hong Kong as a single port. Within each port's radius, a concave polygon was drawn around the vessel visits to determine the extent of vessel activity possibly associated with the port. Each polygon was reviewed and where they were inappropriate *i.e.* missed some vessel visits associated with the port, the radii were manually adjusted to capture all vessel activity that would likely be considered under the jurisdiction of the relevant port.

Some clusters of likely vessel port visits remained outside of the list of ports because the number of Vessel Stop Events was very small, or if there was no known port in the close vicinity likely to have jurisdiction over the observed activity as determined by a manual review of satellite imagery. Some of these clusters may represent coastal anchorages to help vessels avoid inclement weather or allow crew rest between fishing activities. Clusters were classified as unknown *ports* if they were within 400 meters of land and unknown *anchorages* if they were further offshore. These unknown ports and anchorages are relevant for understanding the implementation of the PSMA as they represent a risk if vessels are stopping in port State waters at otherwise unknown ports. Concentrations of unknown ports were found in Europe where AIS is mandated for vessels of 12m and up, and these vessels can easily cross borders within the EU to smaller unidentified ports.

[1] https://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_pageLabel=msi_portal_page_62&pubCode=0015

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Examples of unknown anchorages can also be found in places like eastern Russia, the Norwegian archipelago of Svalbard and Antarctica where fish carriers operate and transship in remote bays and anchorages.

2.2.1.3 Vessel identification and hold size estimates

59,906 fishing vessels and fish carriers that broadcast on AIS in 2017 for more than one day were identified. Fishing vessels were identified by either being on a list of fishing vessels such as RFMO authorization lists, or the vessel self-reporting as a fishing vessel on AIS. In total, 59,226 fishing vessels were included in the study. All the fish carrier vessels identified were either on an RFMO carrier list, identified as a fish carrier within a propriety identity database maintained by OceanMind, or listed as a fish carrier by IHS Markit[2]. From this list, any fish carriers that were identified as servicing fish farms were removed. This resulted in a total of 680 fish carrier vessels (also known as refrigerated fish carriers or "reefers") being included in the dataset of this study. The flag State of these fishing vessels and fish carriers was identified using the pre-fix of each unique Maritime Mobility Service Identity (MMSI) broadcast with every AIS transmission. The three-digit pre-fixes of these MMSIs are linked to a list of countries published by the International Telecommunications Union (ITU)[3]. Because MMSIs are manually entered into the transmitter, this results in a significant amount of human error on setup. Therefore many AIS transmissions have faulty or unknown identity information and MMSIs with 9% of unique MMSIs associated with fishing and fish carrier vessels having an unknown flag State. Unknown MMSI prefixes are frequently associated with fishing buoys or Fish Aggregating Devices (FADs). An effort was made to remove probable fishing buoy and FAD data from the data set, but some unknown MMSIs that were retained may not represent fishing vessels.

Unknown MMSIs represented 7.5% of Port Visit Events globally, and over nine in ten of these Port Visit Events occurred in China, likely representing domestic Chinese vessels. Because domestic-flagged Port Visit Events did not inform the risk analysis in this study, and these vessels are likely Chinese-flagged, the probability that these unknown MMSIs influenced any of the substantial findings and outcomes of the study is extremely low.

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[2] https://maritime.ihs.com/

[3] https://www.itu.int/en/ITU-R/terrestrial/fmd/Pages/mid.aspx

The study uses Port Visit Events by catching and fish carrier vessels to understand the fishing-related vessel traffic for each port over the course of an entire year. The initial analysis to identify Port Visit Events was expanded to consider the capacity of the vessels visiting the ports. The estimated refrigerated vessel hold size was used as an indicator to determine the capacity of fleets visiting ports.

A complete dataset of vessel hold capacity was not available and only a small number of RFMOs (ICCAT, WCPFC, IATTC and SPRFMO) publish the hold size of their authorized vessels. Known hold size data from 5,286 vessels was used to build independent power regression models, for each vessel type, to estimate vessel hold size based on a vessel's length. Power regression models were created for each of the following vessel types: fish carriers, longliners, purse seiners, trawlers, and others (obtained regression model formulae are shown in Appendix E; see supplementary material). When vessel length was not known, then hold size was taken as the average hold size of vessels with similar identity information, i.e. vessel type and vessel flag.

The following hierarchical rules were used to determine vessel hold size based on the information available for the vessel:

1. If vessel type and length were known: power regression analysis estimating hold size based on length;
2. If vessel type and flag were known: average hold size from the known data with the same vessel type and flag combination;
3. If vessel flag was known: average hold size from the known data for the same flag.

The ranking of ports based on the hold size associated with unique visits must also be considered in the context of the limitations of the data set. The ranking of ports based on aggregate hold size is of great interest because it represents the aggregate potential for the loading, unloading, or transshipment of fish by either fishing vessels or fish carriers, but should not be interpreted as an estimate of the volume of landings or transshipment in port. Some ports are primarily used as berthing/home ports, others embody a significant transit point that triggers port visit events (Panama), and others are merely used for anchoring visits while awaiting instructions to proceed to another location.

2.2.1.4 Port State IUU Risk Index and trend analysis

This study develops a port State IUU risk index. The index generates a score for IUU risk affecting port States globally and enables the ranking of port States by risk. The index is composed of two main risk components; internal risks and external risks. *Internal risk* provides a measure of the performance of the port State to address potential IUU risk, while the *external risk* component provides a measure of the exposure of the port State to potential IUU fishing operations and related transactions in its ports. The former relies primarily on published open-source data and information, such as the ratification of major international agreements and performance in RFMOs, while the latter is more grounded in AIS-based data sources such as vessel characteristics and movement data.

The straight arithmetic average of the scores of both risk categories yields the overall IUU risk index for any given port State. Given the inconclusive correlation between internal and external risk scores at the level of the port State, it appeared appropriate to assign the same weighting to both components, and to treat them as cumulative, rather than progressive.

Table 1. Indicators forming the Port State IUU Risk Index

Component	AIS-based	Weighting	Indicator name
General	yes	n/a[4]	1. Operates commercial ports in which fishing vessels do business
Internal	yes	3	2. Number of commercial fishing ports
	no	2	3. Party to the 2009 Agreement on Port State Measures
	no	2	4. Contracting Party (CP) or Cooperating Non-Contracting Party (CNCP) of an RFMO with a binding PSM resolution & transparent compliance monitoring
	no	3	5. Compliance record with binding RFMO port State conservation and management measures (CMMs)
	no	2	6. Transparency International Corruption Perceptions index of the port State
	no	1	7. Identification status of the port State - by the EU
	no	1	8. Identification status of the port State - by the USA
	no	2	9. Identification status of the port State - within any RFMO
External	yes	2	10. Port visits by foreign fishing vessels
	yes	3	11. Flag of Convenience (FOC) State fishing vessels entering ports (plus unknown MMSI)
	yes	3	12. Average flag State Governance Index of fishing vessels entering ports
	yes	3	13. IUU listed fishing vessels entering ports
	yes	2	14. EU carded flag State fishing vessels entering ports
	yes	2	15. US carded flag State fishing vessels entering ports
	yes	2	16. Average internal port State risk of fishing vessels entering ports[5]

The internal and external risk components are both made up of a number of indicators. Individual indicators may be conceived of as "risk factors" that either mitigate or aggravate risk of exposure to IUU and/or facilitation of IUU, depending on their relative or nominative presence or absence. Eight indicators make up the internal risk component of the Index, and seven make up the external risk component (see Table 1). Indicators are individually weighted as low, medium or high, determining their relative weight within each of the two risk components. A

[4] This indicator is not weighted. It is used to merely decide whether a country is included in the overall data set of countries assessed, or conversely, whether it is to be excluded.

[5] As calculated from indicators 1 to 9 in the same table.

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high weighting was assigned to indicators where a direct link to IUU fishing is given. An intermediate weighting was given to indicators where a more indirect, but strong and generally recognized correlation with IUU fishing exists. A low weighting was assigned to indicators where a direct link and/or a strong correlation is not given, but where port State related IUU fishing transactions would be expected to arise as a concomitant phenomenon.

Indicator scores are all divided into five tiers, ranging from 1 to 5 as full integers. 1 stands for “yes” and “very good”, while 5 stands for “no” and “very poor”. Care was taken to ensure indicators are symmetrically arranged, when not all five tiers are used (*e.g.* in yes/no type indicators). In this study, all indicators use 2, 3 or 5 tiers to assign scores. Overall, this implies that low Index scores provide for “low IUU risk”, and that high scores stand for “high IUU risk”. Table 1 also shows which indicators are based on AIS data. Overall, 9 out of 16 indicators are AIS-based, while seven are drawn from other fact-based sources.

One hundred and fifty-three independent coastal States were first selected as the object of this study. Only States in which AIS-fitted fishing vessels were detected to have entered ports were retained for scoring. This led to the elimination of 13 coastal States from the initial group of 153 States,[6] leaving 140 port States as the object of the more detailed analysis. Some of the coastal States that were eliminated, *e.g.* Barbados and Cambodia, are clearly port States, providing an early reflection of limitations of using AIS-determined data.

Data for all indicators are sourced from the most recently available full datasets – mostly 2017 – with possible minor variations between indicators.

A detailed description of individual indicators is provided in **Appendix A**, including notes on individual indicator methodology, where needed. Country scores for all indicators are provided in **Appendix B**.

[6] The 13 States eliminated from the analysis are: BRB, BLZ, BIH, KHM, DMA, ERI, HTI, HND, JOR, MCO, NIC, NIU, LCA (Note: consult the final table in **Appendix D** in supplementary material for a list of country names against alpha-3 country codes)

2.2.1.5 Risk analysis

Risk analysis is based on the computation of an internal risk score, an external risk score, and the combination of both, yielding an overall port State IUU risk index for every single port State covered by the study.

Since the study focuses on an assessment of IUU risks in light of the PSMA framework, and the PSMA regulates control of foreign vessel movements in and out of domestic ports, a focus on foreign fishing vessel movements is implied. Foreign vessel visits are an exclusive component of external risk, and the assessment of internal risk is not affected by the existence or absence of foreign vessel movements. However, external risk, and the external port State risk indicators can only be raised for ports into which foreign vessels have been found to enter. Out of the 140 coastal States which have been identified to operate fishing ports based on AIS data, a further three port States were identified as not having had any visits by foreign vessels in 2017; these are Bahrain, Comoros, and Saint Vincent and the Grenadines. In the global risk analysis, in which the external risk component plays a structural part, these three countries have been eliminated from that dataset. Also, 137 States obtain an overall port State IUU risk score based on the arithmetic average of both internal and external scores, while the overall IUU risk index score for the three countries with no detected foreign vessel visits is the same as their internal score. In the latter case, using an external score of 1 to compute an overall score based on an average between an actual internal and an artificial external score would have falsified the overall ranking by deflating those scores, rendering a risk score largely unhinged to the actual performance and exposure of those port States to IUU risks.

The internal, external and overall risk scores and index are compared to a range of factors, including indices external to this study (such as national income level and quality of governance), in order to establish how such specific factors correlate – or do not correlate – with port State IUU risk.

These comparisons have been graphed out, and statistical analysis was performed. To compare the means between two samples (e.g. the risk scores of port States having signed the PSMA against those that have not), a one-tailed two-sample t-test with equal variance was used, having established in all cases that variance in both samples was comparable. To test the significance of the correlation (i.e. causal effect relationship) between two variables (e.g. influence of internal port risk on external port risk), a simple linear regression analysis using the least squares

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method to fit a line through the set of observations was performed, having established in all cases that residuals were randomly distributed around the average, and verifying in all cases that the relationship was linear indeed – validating the appropriateness of simple linear regression analysis.

The significance level used in these tests, for the observed difference between sample means and/or the observed slope, is 0.05.

2.2.2 Data sources and robustness

Port State risk analysis was informed by an important number of indicators for which the vast majority of information and data used in the analysis was obtained from existing information sources outside of this study. The indicator sources used in the study fall into two categories, as follows:

1. AIS data
2. Published public-domain data sources hosted by international bodies

2.2.2.1 AIS and vessel identity data

AIS data are key to both the global and the deep dive analyses. Overall, larger vessels are inherently more likely to carry AIS transmitters and more powerful radio broadcasting equipment, being more likely to be detected by AIS receivers on satellites or terrestrial antennas. This creates a generic bias in the study, favoring the counting of port visits by larger vessels, which in turn are also more likely to operate in offshore and international fisheries. Given the focus of this study on identifying port visits by foreign-flagged vessels, this bias increases the confidence of the findings related to foreign visits, while under-estimating domestic port arrivals by smaller, local vessels.

Some countries and regions, for example USA and Europe, flag more fishing vessels operating on AIS because of regulations making AIS compulsory for given vessel sizes. In contrast, fewer vessels operate on AIS in the Indian Ocean, especially in proximity to Somalia, owing to the threat of piracy, or close to Yemen, due to detection risks relating to the conflict zone. In polar regions AIS coverage is superior as the majority of satellites are polar orbiting, increasing the visibility of vessels in these regions to AIS receiving satellites, hence increasing the frequency of observation of AIS transmissions in higher latitudes.

There are several regions generating generally poor AIS data owing to the limited number of terrestrial receivers and high traffic density. High traffic affects the collection of AIS from satellites due to the limited ability of the satellite to record and process transmissions during a single pass. Some of the regions affected by this issue include the Strait of Malacca and the English Channel. The combination of vessel traffic and interference from other radio transmissions is also suspected to interfere with the observation of transmissions in the South China Sea and in some waters adjacent to Russia.

The poor quality of some transmitted AIS data led to some data being excluded from the analysis. Poor data quality generally related to invalid positions, vessels transmitting on MMSIs shared with other vessels, and vessels transmitting insufficient identity information to distinguish them as catching vessels or fish carriers. AIS data quality issues are more common across the Asian region and exacerbated by the limited number of terrestrial receivers in this area.

Some invalid positions recorded among other valid positions on a vessel's track can contribute to a small percentage of instances where port visits may have been incorrectly assigned. Many of these instances were manually corrected and the algorithms refined to capture different permutations of vessel movement, but future endeavors of this nature should expect to invest significant time in the review and refinement of global analysis methods such as those used here to ensure that such invalid positions do not lead to inaccurate grouping of Vessel Stop Events or the mis-association of Port Visit Events with an incorrect port name.

The variable satellite coverage, AIS usage and AIS data quality imply that this analysis does not capture every fishing vessel in the world, even those fitted with functioning AIS transponders.

Finally, the use of AIS-derived data to identify the number of ports in States, may itself pose potential problems, for two main reasons:

1. AIS-derived data will not capture ports utilized by smaller vessels and/or domestic vessels which do not transmit on AIS;
2. In cases such as Thailand, individual ports (such as those of the Bangkok metropolitan area along the Chao Phraya river) are identified as a single port in this study using the AIS-derived data, while being counted (and factually embodying) separate, individual ports in reality.

Overall, it is expected that the impact of data quality issues will affect the global analysis less the deep dives, as effects at the global level will have the tendency to

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cancel out over larger areas, while it may have a more pronounced and immediate impact on the deep dive analysis results at the level of individual ports.

2.2.2.2 Published public-domain data

Open source public-domain data were used in the analysis, enabling the study to not look into countries individually, but to merely collect such information, assigning it to countries, and then assigning scores to it.

Such publicly hosted data are generally centralized – i.e. found in a single place – and generally cover all countries in the study, or alternatively, the countries to which given data sets apply (e.g. the parties of an RFMO, and their compliance standing; indicator 5 of the analysis). Such data (and their sources) are used in the following indicators:

- Ind. 3: countries having adhered to the PSMA agreement (held by FAO[7])
- Ind. 4: countries participating in an RFMO that has binding PSM rules and transparent compliance monitoring (RFMO websites)
- Ind. 5: countries presenting compliance issues with RFMO rules on PSM (RFMO compliance reports)
- Ind. 6 & 12: value of the Corruption Perceptions Index of flag and port States (produced by Transparency International[8])
- Ind. 7 & 14: countries carded by the EU under the EU IUU Regulation (Decisions published by the EU)
- Ind. 8 & 15: countries carded by the USA under the MSRA (biennial reports published by NOAA)
- Ind. 9: countries identified by RFMOs, with sanctions levelled against them (RFMO compliance reports)
- Ind. 11: countries listed as flag of convenience State (ITF Seafarers[9])

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[7] http://www.fao.org/fileadmin/user_upload/legal/docs/037s-e.pdf
[8] https://www.transparency.org
[9] https://www.itfseafarers.org/index.cfm

- Ind. 13: individual vessels identified on consolidated IUU vessel list (Trygg Mat Tracking[10])

Transparency international's CPI lacked scores for some countries. In the analysis where the CPI is used, those countries are eliminated from the sample. This leads to a smaller yet fully representative sample, does not affect the validity of the analysis, and is documented in the results.

Generally, datasets for 2017 were used to coincide with vessel movement analysis. Only where historic datasets could not be used (e.g. the IUU vessel list), the current dataset of 2018 was used. Such potential misalignment of data between years is viewed to have had no palpable impact on the global level analysis results. The period applying to the dataset is invariably referenced in the detailed indicator descriptions (in **Appendix A**, see supplementary material).

The good quality of these data overall is unquestionable and is determined by the processes applied by the individual organizations producing and hosting them. However, the discrepancy between style and content of RFMO compliance reports introduced the need for a certain amount of discretion in deciding whether individual States ought to be considered as being in default with given PSM rules or not. In some cases the EU is mentioned as being in default, rather than a specific EU member State. In such cases, all EU members with vessels active in that RFMO were negatively scored in their capacity as a port State – the approach constituting a conservative bias ensuring countries do not appear with better scores than they should have in reality.

[10] http://tryggmat.no/combined-iuu-vessel-list

3 RESULTS

3.1 Fishing Ports

3.1.1 Port numbers

This study identified 3,067 ports in the world utilized by fishing vessels and fish carrier vessels transmitting on AIS. The definition of ports was driven by the location of fishing vessel stops on AIS. The World Port Index (WPI) dataset formed the initial basis for naming the AIS-derived ports. This was complemented by 106 additional ports that were designated and researched to capture clusters of vessel stops on AIS that were not associated with a previously known port from the WPI. Pre-existing port information was of an inconsistent quality globally, with a significant number of additional ports identified in China, eastern Russia around the Sea of Okhotsk and Kuril Islands, and in western Russia and Norway relative to the rest of the world.

3.1.2 Global ranking of ports

The top 100 ports as classified by total number of vessel visits, total foreign vessel visits, domestic hold size, foreign fishing vessel hold size (harvester) and foreign carrier vessel hold size (reefer) are presented in **Appendix C**, with the top 15 ports based on number of vessel visits shown in the table below.

Table 2. **Top 15 ports based on total number of vessel visits**

Rank	Port	Country	Visits
1	Zhoushan	CHN	59,830
2	Wenzhou	CHN	20,874
3	Lanshan	CHN	11,579
4	Rizhao	CHN	9,501
5	Dongshan	CHN	9,406
6	Quanzhou	CHN	8,826
7	Xiamen	CHN	7,649
8	Qingdao	CHN	6,842
9	Shanghai	CHN	6,834
10	Shantou	CHN	6,032
11	Busan	KOR	5,585
12	Longyan	CHN	5,514
13	Zhuhai	CHN	5,408
14	Dalian	CHN	4,654
15	Shanwei	CHN	4,475

Fourteen of the top 15 ports in the world based on the total number of port visits are Chinese (Table 2). This is a consequence of the Chinese government's policy of heavily subsidizing commercial fleets, resulting in China having a disproportionately large domestic fishing fleet, the bulk of which is operating out of Chinese ports. This is likely also an underestimate because of the generally poor quality of both AIS data and AIS coverage around China. China also dominates the top 15 ports based on domestic hold size (see Table 4) with the domestic hold capacity estimated to enter Zhoushan port being an order of magnitude greater than the majority of ports in the same table. The dominance of China in terms of total port visits is not reflected in Table 3**,** Table 5 and Table 6 which examine foreign flagged vessel metrics, demonstrating that the activities at Chinese ports are dominated by domestic vessel movements.

For the purpose of this paper, all non-Taiwanese flagged vessel visits to Taiwan were considered foreign (including Chinese-flagged vessel visits) as were all Taiwanese-flagged visits to China. The legal status of the PSMA in Taiwan is complicated by the issue that Taiwan is not a member of the United Nations, under whose authority the PSMA is promulgated. This kind of unique relationship between different political jurisdictions was common in the analysis and required binary determinations which affect the interpretation and counting of "foreign"-flagged vessel visits. Kaohsiung is the main Taiwanese fishing port and is in the top 15 ports based on domestic, foreign fishing and foreign carrier vessels hold sizes. This demonstrates the prevalence of both large Taiwanese long line and purse seine vessels as well as Kaohsiung being used as an offload port frequented by the Korean and Chinese fleet on route to the Western and Central Pacific.

Busan (Republic of Korea) is the only port to feature in the top 15 ports across all five metrics assessed (Table 2 to Table 6). Busan is frequented by both domestic and foreign vessels. The diversity of foreign flagged vessel visiting Busan is limited, with Russian, Chinese and Panamanian flagged vessels representing 91% of the foreign visits.

Mid-ocean ports Majuro, Suva, Port Louis, Port Victoria and Pohnpei are frequented by foreign fishing vessels in terms of visit numbers as well as hold size of both fishing and carrier vessels (Tables 3, 5 and 6). These ports are much frequented for transshipment and/or unloading of tuna catches, notably because purse seine vessels in the Western Pacific Ocean and the Indian Ocean are not permitted by the relevant RFMOs (the Western and Central Pacific Fisheries

Commission and the Indian Ocean Tuna Commission respectively) to transship at sea.

Table 3. **Top 15 ports based on number of foreign vessel visits**

Rank	Port	Country	Visits
1	Busan	KOR	1,528
2	Majuro	MHL	1,168
3	Kirkenes	NOR	1,148
4	Nouadhibou	MRT	1,078
5	Suva	FJI	983
6	Port Louis	MUS	957
7	Vila Real De Santo Antonio	PRT	683
8	Manta	ECU	634
9	Dakar	SEN	614
10	Las Palmas	ESP	601
11	Castletown-Bearhaven	IRL	594
12	Hanstholm	DNK	549
13	Abidjan	CIV	502
14	Kaohsiung	TWN	492
15	Pohnpei	FSM	457

A number of European ports appear in Table 3. While EU-flagged vessel visits in fellow EU member ports may be treated as ‘domestic’ vessel movements rather than foreign movements for the purpose of EU controls, this study considers these as foreign visits, and the table captures all visits by vessels not flagged to the port State. European ports located closer to major fishing grounds are convenient landing sites for the EU fleet. We see this for Las Palmas in the Atlantic Ocean, Kirkenes in the Barents Sea, Hanstholm in the North Sea and Castleton-Bearhaven in the North Atlantic. The outlier in Table 3 is Vila Real De Santo Antonio, a small Portuguese port located on the Spanish-Portuguese border, dominated by Spanish fishing vessel visits.

Globally very few domestic carrier vessel port visits occur in domestic ports. This is primarily a result of fish carriers operating globally and receiving and landing fish in prominent transshipment and landing ports, irrespective of flag. Due to this, domestic carrier vessel and domestic fishing vessel data were aggregated in Table 4 overleaf; however, the dominant contributor was domestic fishing vessels.

Dakhla (Morocco) and Coronel (Chile) were the only ports outside of Asia to feature in the top 15 ports when ranked by domestic hold size.

Table 4. **Top 15 ports based on domestic hold size**

Rank	Port	Country	Total m^3
1	Zhoushan	CHN	12,549,704
2	Vladivostok	RUS	4,460,936
3	Wenzhou	CHN	2,863,021
4	Shanghai	CHN	2,498,576
5	Busan	KOR	2,096,918
6	Lanshan	CHN	1,404,034
7	Dalian	CHN	1,370,861
8	Rizhao	CHN	1,249,217
9	Quanzhou	CHN	1,247,898
10	Dongshan	CHN	1,206,586
11	Coronel	CHL	1,010,734
12	Petropavlovsk Kamchatskiy	RUS	974,505
13	Kaohsiung	TWN	956,518
14	Dakhla	MAR	951,304
15	Yantai	CHN	916,467

The top 15 ports based on foreign fishing vessel hold size are a combination of offload ports where fishing vessels transfer fish to fish carriers, and terminal ports where fish is offloaded for processing (Table 5 below). Las Palmas is the most important European port in terms of foreign fishing and fish carrier vessel offloads. The West African mainland ports of Tema, Abidjan, Walvis Bay and Nouadhibou are important ports in terms of both foreign fishing vessel and fish carrier vessel hold size. Dakar features in the top 15 foreign fishing vessel ports and Tema is ranked in the top 15 foreign fish carrier vessel ports.

Table 5. **Top 15 ports based on foreign fishing vessel hold size**

Rank	Port	Country	Total m^3
1	Majuro	MHL	943,000
2	Manta	ECU	761,748
3	Dakar	SEN	561,418
4	Busan	KOR	545,080
5	Nouadhibou	MRT	468,553
6	Kirkenes	NOR	381,074
7	Walvis Bay	NAM	375,292
8	Abidjan	CIV	335,405
9	Pohnpei Harbour	FSM	331,692
10	Port Louis	MUS	319,985
11	Cape Town	ZAF	232,970
12	Callao	PER	219,884
13	Las Palmas	ESP	217,222
14	Port Victoria	SYC	211,991
15	Montevideo	URY	199,120

Manta (a major tuna port), Callao (where small pelagics are mainly landed and Montevideo were the only South American ports to feature in the top 15 ports for foreign fishing vessel hold size (Table 5 above). Montevideo has been documented as a base of operations for domestic and foreign toothfish vessels operating in the CCAMLR area (Cajal, J. & García Fernández, J., 2002), with the port operating as a landing, transshipment, processing and re-exportation hub. This is likely to be the case for other major fisheries in the South-West Atlantic also.

Cristobal yields large volumes of foreign fish carrier traffic, a likely consequence of vessels waiting to transit through the Panama Canal (Table 6 below). The top 15 ports based on foreign fish carrier hold size are mostly terminal ports where fish carriers unload catches for processing, or where fish is transshipped from fishing vessels to carriers before transiting to such processing locations.

Table 6. Top 15 ports based on foreign carrier vessel hold size

Rank	Port	Country	Total m^3
1	Busan	KOR	4,152,292
2	Las Palmas	ESP	2,397,544
3	Dalian	CHN	1,943,959
4	Zhoushan	CHN	1,391,968
5	Kaohsiung	TWN	1,299,084
6	Abidjan	CIV	1,002,135
7	Majuro	MHL	912,474
8	Rabaul	PNG	908,397
9	Bangkok	THA	826,104
10	Pohnpei	FSM	816,970
11	Tema	GHA	808,808
12	Qingdao	CHN	754,417
13	Cristobal	PAN	687,137
14	Nouadhibou	MRT	686,089
15	Walvis Bay	NAM	624,869

Bangkok, which does not feature in the top 15 ports in any other metric, is frequented by fish carriers and receives a large proportion of global tuna, hence why it shows in the table above[11].

Taking all of the above tables together, most of the major regions are represented in the top 15 ports for foreign vessel visits, foreign fishing vessel hold size, and foreign fish carrier vessel hold size. There are five prominent East Asian ports (Busan, Kaohsiung, Dalian, Zhoushan and Qingdao), one South East Asian (Bangkok), four Pacific (Majuro, Suva, Pohnpei, Rabaul), two eastern South American ports (Manta, Callao), two western South American ports (Montevideo and Cristobal), five West African ports (Nouadhibou, Dakar, Abidjan, Walvis Bay, Tema and Cape Town), six European ports (Las Palmas, Castle-Bearhaven, Vila Real De Santo Antonio, Hanstholm, Kirkenes) and two East African ports (Port Louis, Port Victoria). The major areas missing are both the coastlines of North America and Middle East and Australasia. The lack of prominent American and

[11] Thailand absorbs in the order of 20-25% of the global commercial tuna harvest, mostly destined to processing and re-exportation as value-added products.

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Australasian ports is a likely consequence of a relatively uniform distribution of activity of a largely domestic fishing fleet.

3.1.3 Port State IUU risk analysis

The port State IUU risk index allows scoring and ranking of port States according to internal, external and overall risk. Furthermore, countries can be grouped and ranked by ocean basin, FAO region, Governance Index, or World Bank income group.

Figure 1 overleaf is composed of three graphs, showing the distribution of internal (A), external (B) and overall port State risk (C) across the range of tiers used for the indicator, and all 153 coastal States originally part of the study.

The global average internal risk score is 2.30 and ranges from a minimum of 1.21 for Grenada, to a maximum of 3.38 for Papua New Guinea and Russia. The global average external risk score is 2.48 with individual country scores between 1.76 for Antigua and Barbuda, and a maximum of 3.41 for Russia and Venezuela. The global average for the overall risk score is 2.40, with a minimum of 1.55 for Grenada, and a maximum of 3.39 for Russia – with both countries representing the best performer on one hand, and the worst performer on the other, across the port State IUU risk index.

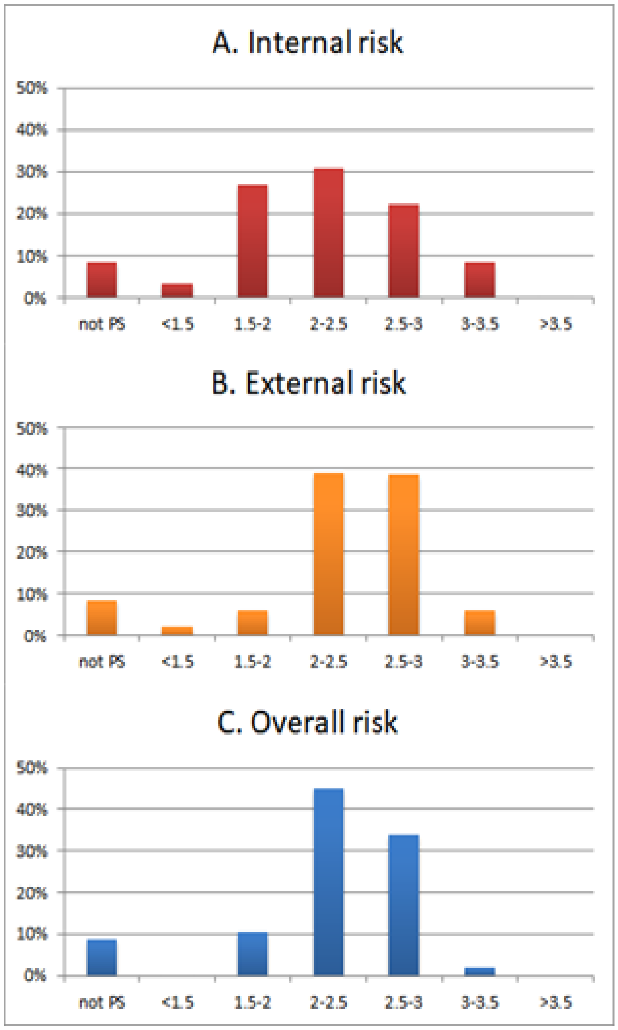

Figure 1: Distribution of port State IUU risk scores (n=153)

It can be seen in Figure 1 that internal risks are distributed more evenly across the spectrum of scores between 1 and 3.5, while external scores are more concentrated in the range between 2 and 3 – making up 78% of all scores, versus 53% of all scores in the internal score distribution. This entails an overall distribution of risks which is more heavily concentrated in the band between 2 and 3.

There are thirteen coastal States not operating ports (8%). These have not been assigned scores and have been excluded from further analysis.

Table 7 overleaf presents the top three and bottom three performing countries by internal, external and overall risks, grouped into their respective world regions. The full table of country ranks is appended in **Appendix D** (in supplementary material).

Table 7 reveals that countries generally appear as top performers in either internal or external risk categories, but rarely in both. Exceptions are Sweden, Grenada and the Cook Islands, which appear as top performers in both categories for their respective regions, and consequentially also as top performers in the overall score. It is noted that countries have much more control over their internal risk score, primarily based on their performance in applying port State measures, while they have less control over their external risk score, providing a measure of exposure to IUU risk – which can only be partially mitigated through domestic policies.

***Table 7.* Top & bottom performers across the Port State IUU Risk Index (by region)**

	Region	**Internal risk score**	**External risk score**	**Overall risk score**
Top 3 (starting with the strongest)	**Africa**	Sao Tomé & Principe Senegal Mauritania	Gabon Kenya Tanzania	Gabon Senegal Sao Tomé & Principe
	Asia	Sri Lanka Korea Thailand	Timor Leste Brunei Korea (PRK)	Sri Lanka Pakistan Myanmar
	Europe	Slovenia Belgium Sweden	Romania Sweden Germany	Romania Sweden Belgium
	Latin America & the Caribbean	Grenada Uruguay St Vincent & the Grenadines	Antigua and Barbuda Saint Kitts and Nevis Grenada	Grenada St Vincent & the Grenadines Uruguay
	Near East	Oman Egypt Lebanon	Kuwait Lebanon Djibouti	Oman Lebanon Djibouti
	North America	USA	Canada	Canada

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	Region	Internal risk score	External risk score	Overall risk score
	Southwest Pacific	New Zealand Australia Cook Islands	Vanuatu Cook Islands Tonga	Cook Islands Vanuatu New Zealand
Bottom 3 (starting with the weakest)	**Africa**	Congo (DRC) Congo, Rep. of Benin	Sudan Algeria Ghana	Congo (DRC) Benin Congo, Rep. of
	Asia	Vietnam Korea (PRK) Timor Leste	China Korea Taiwan	China Vietnam Japan
	Europe	Russia Great Britain Italy	Russia Norway Ukraine	Russia Ukraine Italy
	Latin America & the Caribbean	Dominican Republic Mexico Argentina	Venezuela Guatemala Cuba	Jamaica Venezuela Dominican Republic
	Near East	Bahrain Kuwait Iraq	Saudi Arabia Libya Egypt	Bahrain Saudi Arabia Iraq
	North America	Canada	USA	USA
	Southwest Pacific	Papua New Guinea Solomon Islands Fed. States of Micronesia	Australia Western Samoa Kiribati	Papua New Guinea Solomon Islands Tuvalu / Kiribati (same rank)

Table 8 overleaf provides the average risk score by category (internal, external and overall) for every world region, allowing for the ranking of world regions according to their average score. The regional ranks in the table provide guidance as to which world regions lead or lag in the three components of the Port State IUU Risk Index.

For internal risks, the spread in scores is quite large, reflecting the spread shown in Figure 1 above. Europe is the region with the lowest average score, very closely followed by North America. This entails, *inter alia*, that port States in these two regions have adopted advanced policies in the domain of PSM and are participating and performing well in RFMOs. It has to be noted that internal indicators 7 and 8 on carding status have a latent tendency to bias the analysis in favor of the Europe region, as many of its countries are EU members, and since EU members cannot be carded by the EU Commission. The same holds true for the US carding system, and the USA. The Southwest Pacific and the Near East rank last, with the Near East figuring as the bottom performer by a very wide margin. The results suggest that the Near East is the world region where PSM is afforded the lowest priority in public policy making.

Table 8. **Ranking of world regions across the different risk categories**

Rank	Internal risk score	External risk score	Overall risk score
1	Europe (2.06)	Southwest Pacific (2.31)	North America (2.24)
2	North America (2.06)	North America (2.41)	Europe (2.27)
3	Africa (2.22)	Latin America & Caribbean (2.42)	Latin America & Caribbean (2.35)
4	Latin America & Caribbean (2.26)	Near East (2.47)	Africa (2.40)
5	Asia (2.48)	Europe (2.48)	Southwest Pacific (2.41)
6	Southwest Pacific (2.51)	Africa (2.54)	Asia (2.54)
7	Near East (2.68)	Asia (2.59)	Near East (2.65)

For external risks, the overall spread in scores is much more limited. This indicates that while exposure to IUU risks differs between countries and regions, the variance is comparatively smaller – and the risks comparatively higher – than the variance and risks relating to internal risks and the policy and governance frameworks. The Southwest Pacific and North America are the regions where external risks are lowest, while they are highest in Africa and in Asia.

In terms of overall risk, North America is the region with the lowest overall risk, followed by Europe. Though Europe and North America achieve an almost identical internal risk score, Europe's higher external risk score is not entirely surprising; it is a highly diverse continent made up of many sovereign port States performing differently, it represents the biggest consumer seafood market globally, and has a more important exposure to external risks as a consequence[12]. Asia and the Near East are the worst performing regions overall. Across all three categories it arises that both these bottom performing regions suffer in terms of important and combined internal and external risk exposure, with internal risks being relatively more important to the Near East, and external risks – typically embodied by weak flag State performance of vessels visiting ports – to the Asia region. The latter is

[12] The USA and the EU represent 42.7% of the global seafood import market in 2016. However, EU seafood imports outrank US imports by USD6.7 billion (or 32.6%). (FAO 2017)

not surprising, as Asia has globally important seafood markets (both for processing and consumption), while the Near East does so to a substantially lesser degree.

Having assessed regional scores across the spectrum of the port State risk index and having gained an impression of the interplay between internal and external risk factors, and how they define the overall outcome for each individual country, and regions as a whole, it is of use to consider issues of interdependence and correlation. Figure 2 renders the outcome of such analysis, when risk scores are plotted against each other, with the internal risk score along the x axis as the independent variable, and the external risk score along the y axis as the dependent variable. In this dataset, all countries not operating ports (13), and those operating ports but not receiving foreign vessels (3), have been eliminated.

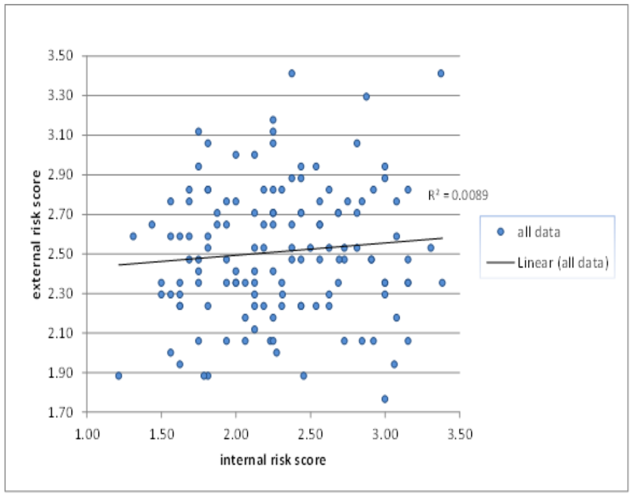

Figure 2: Distribution of internal versus external risk scores (n=140)

There is high scatter in the data, leading to a low goodness-of-fit for the regression line. However, as would be expected, the fitted line indicates a mild positive trend, indicative of the fact that when a country improves its internal processes relating to PSM and to the mitigating IUU risks, the exposure to external risks has a tendency to decline. In practical terms, this implies that fishing vessels in poor standing would tend to avoid ports in States with good PSM performance. The fact that the rate of change is limited is partially expected, as the scores for external risk are much more limited in their overall measured variance, than the variance of internal risk scores (see Figure 1 also). Regression analysis finds the correlation and resulting slope (trend) to be insignificant at the 0.05 level ($p=0.27$), yielding a >27% probability that the observed correlation is due to chance.

In light of the importance of the PSMA, and its entry into force in 2016, another key element to assess is the potential influence of PSMA adherence on the performance of parties in the domain of PSM. Adherence to the PSMA implies that countries seek guidance from the terms of the agreement to upgrade their domestic

PSM frameworks, resulting in improvements in their internal risk scores. Figure 3 shows the results of this analysis. The dataset used for this analysis is the same as for the dataset represented in Figure 2, with the difference that it is split into 2 groups, regrouping parties to the PSMA on one hand, and non-parties to the PSMA on the other. Indicator 3, establishing the status of the country with regards to PSMA adherence has been eliminated from the internal score of both groups in Figure 3, as it naturally works to separate both groups. This analysis thus compares all internal against all external risk factors – except the adherence to the PSMA itself, whose influence is neutralized.

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The cluster of parties to the PSMA yield an average internal and external risk score of 2.12 and 2.45 respectively. The countries not having adhered to the agreement yield both a higher internal and external average risk score, of 2.28 and 2.52 respectively. This means that PSMA parties do form a group within which both internal and external risks are lower. Again, the wider spread between internal risk scores (0.16) and the more limited spread between external scores (0.07) is observed. The difference in average internal risk between PSMA parties on one hand, and non-parties on the other, is statistically significant at the 0.05 level (p=0.017). The same is true for the difference in average external risk (p=0.045). The result establishes that adherence to the PSMA either leads to improvements in the application of PSM in general, or that it is an associated phenomenon of such improvements. The analysis verifies that PSMA adherence may be used as a general proxy for lower IUU risk exposure and better PSM performance. However, given the scatter in the data, such proxy cannot be applied to individual countries with any degree of confidence. The overall difference of both internal and external scores between both groups is small. In order to gauge the global impact of the PSMA, it would be of interest to understand how this difference evolves over time by running the same analysis on a recurrent basis, with a specific focus on internal risks.

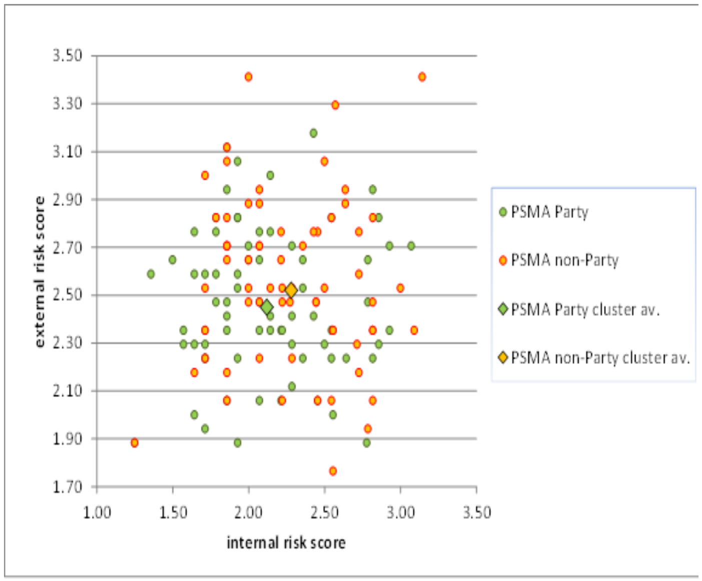

Figure 3: Distribution of internal versus external risk scores for two groups of countries (n=140)

The relationship between the incidence of IUU fishing and the perceived levels of government corruption – as a proxy for the quality of governance – has been established in the past (Agnew *et al.* 2009). It is of interest to assess how the overall port State risk index evolves as a function of corruption, using the CPI produced by Transparency International. In addition to the countries not operating ports and not having received any foreign vessel visits, sixteen more countries have no allocated

CPI scores, limiting the dataset used for this analysis to 124 port States. Given that CPI is an indicator and component of internal risk, it has been neutralized as an internal risk component for this particular analysis.

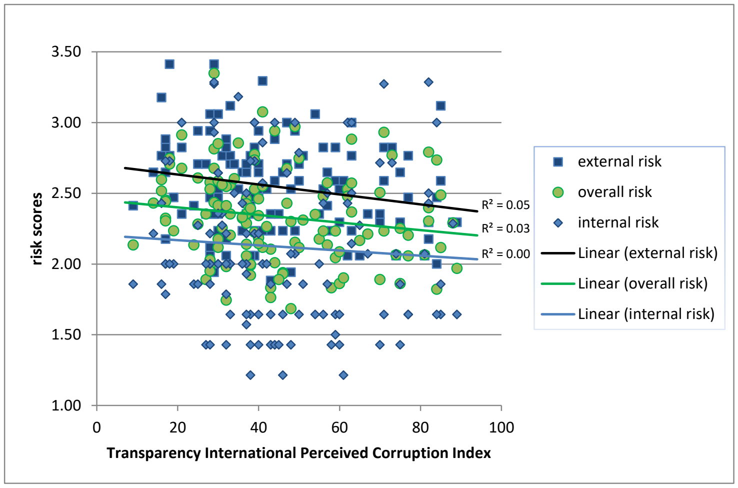

Figure 4: Port State IUU Risk Index versus TI Corruption Perceptions Index scores (n=124)

The results, rendered in Figure 4, confirm earlier findings on the relationship between IUU fishing and corruption, in that higher CPI scores (signifying better performance / lower corruption), induce a downward trend in internal, external and overall risk. The drop in external risk with improving port State CPI scores is more than twice as important as the drop in internal risk. External risk diminishes from 2.66 to 2.35 (a total of 0.31 points), when the CPI scores rises from 10 (very high perceived corruption) to 90 (very low perceived corruption), while internal risk falls from 2.19 to 2.05 (a total of 0.14 points) over the same range of CPI scores.

The significance of the correlation of external port State IUU risk to CPI scores is 2.7 times higher than the one relating to PSMA adherence, underscoring the importance of the corrosive effect of corruption on deterrence and law enforcement outcomes. Scatter, while still important, is also diminished, leading to higher R^2 values on the fitted regression line for external risk, indicative of a better fit, which in turn is indicative of the structuring effect of good governance. Regression analysis finds the linear correlation and resulting slopes to be significant for external risk ($p_{external}$=0.017), while correlation of internal and overall risk are both insignificant ($p_{internal}$=0.459; $p_{overall}$=0.069).

Given the strong relationship between port State CPI and external risk established above, it is opportune to examine the relationship between the CPI scores of port States and the average CPI score of the flag States of all foreign fishing vessels visiting their ports.

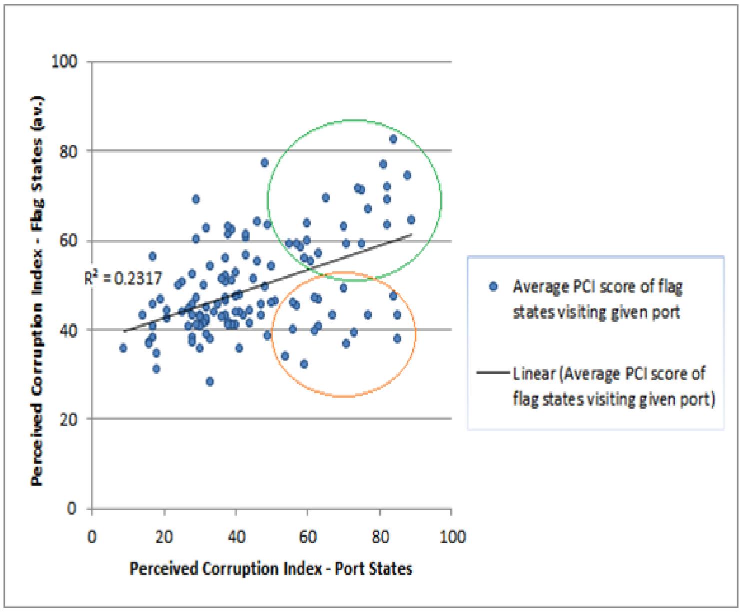

Figure 5: Average flag State CPI score versus CPI scores of visited port States (n=124)

The same selection of 124 port States used for the analysis in Figure 4 is used here. The results are represented in Figure 5. The spread in the average CPI score of fishing vessel flag States visiting ports (y axis) is less than the spread of the port State CPI scores (x axis). This owes to the fact that the scores along the x axis are individual port State scores, while the scores plotted against the y axis are average scores of all flag States having visited individual port States, naturally reducing the spread in values. The regression analysis results in a positive trend. Regression analysis finds the linear correlation and resulting slope to be highly significant (p=0.00000002). As the governance index of the port State goes up, the average governance index of the flag States conferring flags to vessels visiting ports goes up too. While the predicted average flag State governance score of fishing vessels visiting a port State with a CPI score of 10 is 40, the same score is predicted to be just over 60 when visiting a port State with a CPI score of 90 – embodying a >50% mean flag State CPI score increment across the full range of port State CPI scores.

The other remarkable outcome of this analysis is the fact that average flag State CPI scores clearly split into two distinct groups for visited port States with a CPI score above 50, one group falling above the regression line (green oval), and the other falling below the regression line (orange oval). The upper group in the green oval (22 countries)[13] trends strongly upwards against higher port State CPI scores, while the lower group (18 countries)[14] trends flat.

The upper group is dominated by countries from North America (100% of the North America region countries contained in this group), and Europe, providing 16 out of the total 22 countries. 50% of all existing Europe region port States are in this group, and Europe makes up 73% of all countries in this upper group. With the exception of Iceland, all of the European countries are EU Member States. The lower group in the orange oval contains countries more evenly spread across world regions, with Europe providing another 33% of all countries, and Asia 28%. With regards to the six Europe region countries, only two are EU Member States, while the five Asian countries represent 26% of all the countries in the Asia region[15], dominating this particular metric.

These results – partially reflecting findings conveyed in Table 8 – underscore the dominance of the North America and Europe regions as consistent performers in PSM matters; with Europe being more diverse in outcomes, owing to its larger number of countries, its wider spread of national income levels, its more diverse fisheries make-up, and its higher exposure to direct seafood imports via foreign

13 BEL, BHS, CAN, CPV, DEU, DNK, ESP, EST, FRA, GBR, IRL, ISL, LTU, LVA, NLD, NZL, POL, PRT, SVN, SWE, SYC, USA

14 ARE, AUS, BRN, CHL, CRI, CYP, FIN, GEO, ISR, JPN, KOR, MLT, NAM, NOR, QAT, SGP, TWN, URY

15 Only Cambodia has been eliminated from the Asia region in the dataset underlying this analysis.

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fishing vessel and reefer landings.[16] With regards to the split in trends noted above for a port State CPI score of 51 or higher, the results also imply that the use of any of the above indicators and metrics to predict the performance of individual port States (or ports therein) would be ill-advised.

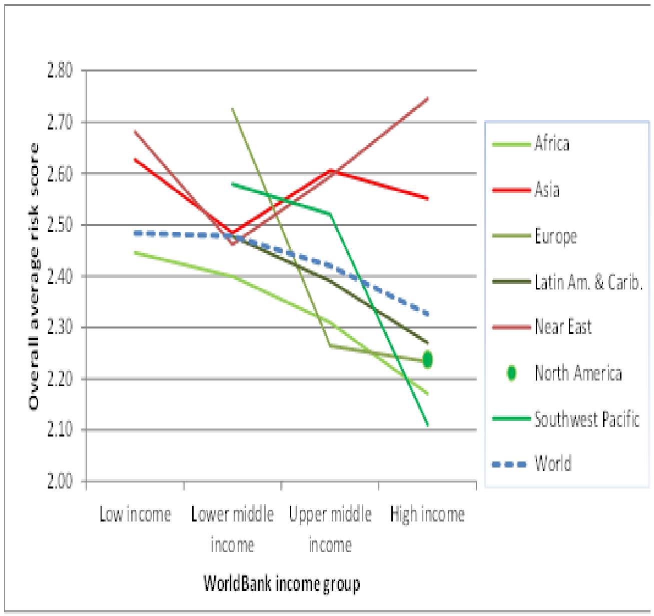

Figure 6: Overall average Port State IUU Risk

Finally, it is of interest to assess the effect of national income levels[17] on the distribution of port State IUU risk index scores, bearing in mind that Monitoring, Control and Surveillance (MCS) and the combatting of IUU fishing invariably implies important budgetary commitments. In running this analysis, the potential influence and dynamics relating to world regions and/or ocean basins was assessed. Figures 6 & 7 show the results. Figure 6 plots overall average risk scores by region versus income, while Figure 7 plots overall average risk scores by ocean basin versus income. One country (the Cook Islands) had to be removed from this dataset, as no income level has been assigned to it by the World Bank.

The average global trend (dashed line) is the same for both datasets, owing to the fact that it shows the global average score per income group, which is not affected by either region or ocean basin influences. The global trend of the average overall port State IUU risk score by income group is declining across the four tiers in income levels. The difference between low income and lower middle-income groups is very small. The average score of low-income countries is 2.484, followed by 2.478 (lower middle income), 2.42 (upper middle income), and 2.326 (high income). This implies that income level overall has a measurable and important

[16] Note that 819 foreign vessel movements in and out of US ports were detected, while the single EU member State of Denmark scored 2,121 foreign vessel port visits.

[17] National income levels are obtained from the 2018 World Bank list of economies.

impact on PSM performance, with the biggest rate of improved performance occurring between countries of the upper middle income and high-income groups.

Figure 6 also shows scores for seven world regions, by income group. In some regions, not all income groups are represented. Both Europe and the South West Pacific are lacking low income countries, while North America harbors two high income countries only.

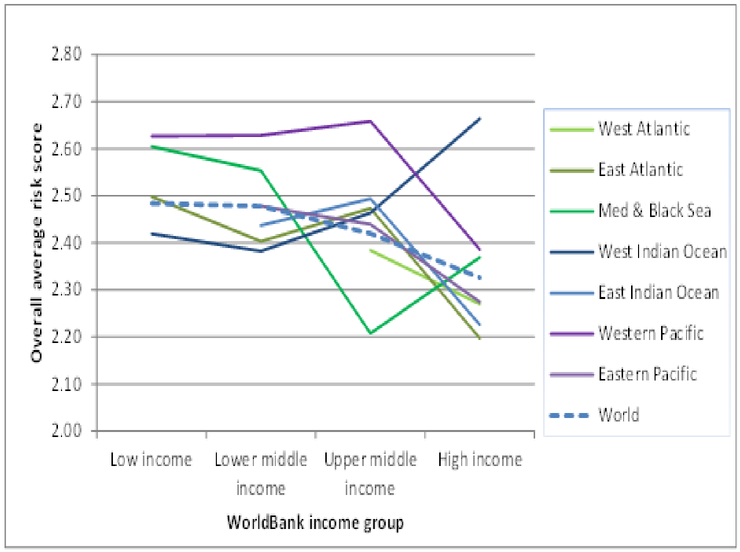

Figure 7: Overall average Port State IUU Risk score by ocean basin versus income (n=139)

With regards to regional trends, there are two fundamentally different types of world regions. In one set of regions, overall average scores improve consistently with higher income, while this is not the case in the other group. The regions where progression in income does not give rise to a marked trend in improved risk scores are Asia and the Near East, the lowest performing world regions overall (see Table 8). Not only are these lines flat or, in the case of the Near East, rising – the latter signifying a worsening performance with rising income, moving opposite to the global trend line – but the overall average scores for these two world regions are also higher than all others across the entire range – with the exception of two out of a total of 14 available points of comparison. Overall, a relative consistency in trends for any single world region across the four income groups is verified. With the exception of Asia and the Near East, scores consistently fall from lower to higher income groups, suggesting that income underpins and drives the performance of individual countries which are part of the same world region.

Figure 7 shows scores for seven ocean basins by income groups of the countries bordering them. The Arctic and Antarctic basins were not considered in the global analysis, owing to the very limited number of countries bordering those oceans. This graph differs markedly from Figure 6 with regards to trend consistency. In

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fact, no ocean basin displays trend consistency in the way it is observed for four out of six world regions – with the exception of the Eastern Pacific Ocean. All other scores are invariably switching trend direction at least once, mostly twice. When looking at the structuring influence and net effect of country groupings when organized along world regions or ocean basin lines, ocean basin groupings seem to have a much more limited directional influence on average overall port risk scores – if any.

3.1.4 Discussion

3.1.4.1 Global ranking of ports

The external indicators of global risk and the global ranking of fishing ports produced by this study are based primarily on a data source, AIS, that has limitations which must be considered when reviewing results. The limitations have been addressed partly through the methodology, but all of the findings must be viewed through an understanding of this data source, as this is the first time it has been used for a global port analysis of the type proposed here. The results provide great value in understanding the relative risks between ports and countries, even if data limitations may impact the absolute values of reported port visits and especially the estimated hold capacity of these visits. These data and algorithmic limitations have different impacts in different countries and ports due to the unique physical circumstances of these locations and how those must be translated to a computational approach. There are opportunities for different approaches to be used, but the results represent an important first step in understanding the global risks related to ports, and this crucial opportunity for interventions to stop illegally harvested fish products from entering global supply chains.

The method for grouping different stops into single events was also impacted by the combined effects of poor detection of AIS transmissions in some regions and substantial gaps in transmission (intentional or not) that in a minority of instances led to the inappropriate naming of a port visit event. However, while these instances resulted in an inappropriate association of an event with a specific port, in rare cases only did the grouping result in the mis-identification of the country of a port visit. This means that the global risk indicators produced from this analysis were unaffected by the issue, although it had some small impact on the absolute value of port visits, which in turn could affect the rankings.

Some stop events could not be grouped with a visit to a known port as it was not possible to implement an algorithm that accounted for every configuration of port in relation to land and vessel movements. This grouping methodology did capture and properly group the majority of port visit events from a typical slow down or delay on approach to a major port by a fishing vessel and all the subsequent internal movements the vessel makes. However, the unique circumstance of some ports likely lead to some overcounting of Port Visit Events by failing to group all Vessel Stop Events into a single Port Visit Event, although significant effort was made to account for the different circumstances of ports around the world.

Significant effort also went into properly assigning the names of the ports identified through this AIS analysis. This effort revealed significant gaps in current global databases for the name and location of ports. Significant research and effort was made to add and properly name possible ports that captured all of the major concentrations of port visit events identified from AIS, even when they were not located near a known port. However, there were many visit events that could not be assigned to a known port identity and were categorized as visits to unknown ports or unknown anchorages depending on the distance from land.

At a global level, over 36% of fishing vessels port visits produced by this analysis were characterized as to “unknown” ports and anchorages. Three quarters of these visits to unknown locations were in China with a small proportion in Norway and the remainder distributed across many port States. Interestingly, when accounting for only visits by known “foreign” vessels to port States, only 8.5% of foreign-flagged visits were to unknown ports. Approximately one-fifth of these foreign-flagged visits occurred in China with the remainder distributed across many port States. 21% of visits were reefer vessels, the majority of these at unknown anchorages.

The majority of reefer visits to unknown ports were in China, the Philippines, the Maldives and Spain. This indicates that the analysis was able to identify the location and associated name of the ports visited by a significant majority of foreign-flagged vessels using AIS, a key goal of this study.

The limitations of the analysis to identify port visits and likely errors range are amplified when these visits were linked to estimates for hold size, due to the poor globally available records of actual hold size. Several RFMOs publish this information but it is concentrated on certain size classes and types vessels, primarily larger ones engaged in international fisheries. These sources were useful for the purpose of this study as they support more accurate assessment of hold capacity of port visits by vessels travelling to foreign countries which are generally larger. But it is much weaker for the smaller vessels that primarily operate within their flag State's waters, which is less of a concern given the focus of this paper on foreign-flagged vessels falling under the PSMA. This issue about source data with smaller vessels also led to more questionable results when the hold size was estimated based on variables like vessel type, length, and flag. Flag States without significant numbers of hold records on international registries were the most likely to have weaker estimates, while those flag States with many fishing vessels and carriers in international service likely yield more accurate results.

When comparing the results of this study with those from an earlier study (Huntington, et al, 2015) that ranked the world's fishing ports by landings, several ports are identified in both studies but fundamental differences in the approach and the data lead to many major landing ports in the previous study failing to make an appearance here. This is because there is a difference between landing, which is the first point at which fish is discharged under the responsibility of a national authority, and an arrival by a vessel that has the potential to carry a certain amount of fish based on its hold capacity. Not every vessel arrival was linked to the actual discharge or transfer of a full hold of fish, but could have been associated with partial unloading, loading of fish, or unrelated activity such as refueling or resupplying (which is still relevant to the PSMA). This study did not attempt to ascertain what percentage of visits was linked with those activities at the global scale.

While earlier discussion has highlighted some potential data and methodological limitations of this analysis, the findings in general appear to be consistent with understandings of the global fishing industry in terms of the relative scale of vessel visits between ports, even if the absolute values are indicative only, owing to the fact that not all fishing vessels carry AIS as well as the various limitations of AIS outlined above.

3.1.4.2 Port State IUU risk analysis

The Port State IUU risk analysis in this study provides a ranking of world (FAO) regions by overall port State IUU risk index score (Table 8). Regions rank from high risk to low risk as follows:

> *Near East* > *Asia* > *Southwest Pacific* > *Africa* > *Latin America* > *Europe* > *North America*

The sequence of regions, ranked for overall port risk in the IUU Fishing Index (Macfadyen *et al*. 2019),[18] also a global level analysis, is as follows:

> *Asia* > *Middle East* > *South America* > *Africa* > *Caribbean & Central America* > *Oceania* > *Europe* > *North America*

While the regions used in both studies are not exactly the same (Latin America in the latter study is split into 2 sub-regions), the overall findings resonate between the two studies.[19] Near East and Asia, carrying highest overall port risks in this study, are matched in inverse order by Asia and the Middle East in the IUU Fishing Index. Similarly, Europe and North America are ranked in the same order as the two regions with the lowest risk. And in both studies, Africa is sitting in the middle of the range, leaving only Oceania (equivalent to the Southwest Pacific) with a lower risk in the IUU Fishing Index ranking, than in this study.

In the IUU Fishing Index, China, Russia and Cambodia are the countries with the highest IUU port-related risks. In this study – in which Cambodia has been eliminated for lack of AIS-fitted vessel port entries – Russia and China also rank amongst the three top-risk port States. This underlines that there is an important

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[18] www.iuufishingindex.net/ranking

[19] Note that 5 out of the 16 port State indicators establishing overall risk in this study and serving to rank countries, mirror indicators used in the IUU Fishing Index. Conversely, these 5 indicators embody 71% of the indicators used to compute overall port risk in the IUU Fishing Index study, implying that an important influence for the alignment of regional ranks between studies owes to indicator alignment.

degree of coherence in the findings between studies of the same nature, providing a good degree of confidence in the general validity of the approach and findings.

Analyses of scored port State risks against other port State-related factors, represented in Figures 2 to 7, confirms a number of expected relationships, the majority of which being statistically significant. When internal port State risk rises, external risk rises as well, indicating that better PSM performance leads to reduced risks carried ashore by visiting foreign vessels – broadly speaking (Figure 2). This relationship and resulting positive trend are weak (statistically insignificant at p=0.27), indicating that many other factors determining external risks are also at work. However, the related trend in figures 4 and 5 are highly significant, indicating that the effect of improved port State governance on lowering external risk is real.

Being a party to the PSMA (Figure 3) yields a lower and statistically significant average risk score across all dimensions measured – albeit modest – indicative of the fact that the adoption of this international regulatory framework has a positive and structuring influence on port State performance in the domain of PSM.

The relationship of external port State risks against the CPI of the same port State (Figure 4) is revealing, as the correlation is much stronger than the one of internal versus external risks, and it is clearly established through this study that the quality of governance – in its broad sense, and as measured through the CPI – is a major determining factor of port State performance in the domain of PSM, and its exposure to foreign vessel IUU risks. The related analysis (see Figure 5) using the CPI, produces the clearest trend, and strongest correlation. Fishing vessels from flag States with a low CPI have a tendency to visit ports with a low CPI and a generally higher port State IUU risk score, and vice-versa. This cements earlier findings of the same nature. The underlying data and the analysis confirm that the corrosive effect of corruption – or weak governance in general – directly favors the existence of high port-associated IUU risks.

Finally, it is established that country income is an important factor determining port State performance, with higher income countries generally performing better, and lower income countries performing worse. This is partially explained by the fact that IUU mitigation measures at the port level require important human and financial resources that are less available in lower income countries. Two factors susceptible in modulating this response were analyzed, namely the region and the ocean basin in which a port State is located (Figures 6 and 7). It was found that regions – as an assemblage of countries - produce consistent trends in their response to income changes, with most regions yielding improving risk scores with increasing income. However, two regions (Asia and the Near East) were conspicuously inert to this effect, producing risk that was trending flat or even rising with increasing income levels.

On the other hand, when countries are regrouped by ocean basin, no consistent trends were detected – leading to the understanding that regions have a structuring effect on their countries, while ocean basins do not. This is a finding that is of true importance for RFMOs, in order to understand and to incorporate these fundamentals in PSM work targeting their members across the fisheries and the ocean basins they regulate. The structuring effect that CMM 16/11[20] of the Indian Ocean Tuna Commission (IOTC) – the first of its kind, and one of the most advanced in terms of implementation modalities – has on the group of countries bordering the Indian ocean basin, is largely impalpable in the data (Figure 7), considering that the two trend lines for the West and East Indian Ocean basins are separated by a notable difference in average total scores (2.50 and 2.43 respectively), and trend in opposite directions.

[20] IOTC Resolution 16/11 On port State measures to prevent, deter and eliminate illegal, unreported and unregulated fishing

4 DISCUSSION

4.1 Conclusions

This study firmly cements the value and utility of AIS (and its resulting public-source data) in the domain of fisheries monitoring, control and surveillance. This has been the preserve of VMS for decades, a satellite-based communication system of which the resulting data are generally richer, better quality, and largely publicly unavailable. AIS technology has reached a degree of maturity and adoption which allows stakeholders to take it to the next level, although it is important to keep in mind the limitations of the technology; in this context by aiming it specifically at IUU-related risk analysis to inform monitoring, law enforcement and capacity development endeavors. This type of analysis could be made more robust by incorporating VMS data, as well as new forms of vessel tracking such as GSM-based reporting tools for small, inshore vessels – noting that the majority of the world's fishing vessels are mainly small-scale and do not carry transponders.

It is possible to determine the locations and identities of global ports important to the industrial fishing industry using AIS data if it is properly layered with other sources and a comprehensive methodology for identifying port visits is used. A careful methodology is critical to this type of analysis to account for some of the inconsistencies of satellite-derived AIS data and the particular and diverse geographies of different ports. However, there will always be some abnormal results in this type of global analysis unless all data are manually reviewed, as it is not possible to develop an algorithm that accounts for the unique circumstances of every port in the world. Without synthesis with other sources (especially identity and hold capacity), AIS data is unlikely to produce these results for fishing vessels and fish carrier vessels.

Most of the publicly available global port information, especially the location and names of ports, is incomplete, and currently insufficient as a starting point for this type of analysis. There were major gaps in the knowledge of known world port locations used by major fishing fleets that the study had to fill. By using AIS-derived port locations, it is possible to identify "visits" by fishing vessels and carrier vessels to specific ports. Given the focus of the study on informing implementation of the PSMA, it is notable that the analysis was able to identify and associate over 91% of port visits by foreign-flagged vessels with ports and anchorages that were defined through this study. When only foreign-flagged vessel visits are considered, the names and relative rankings of the identified ports are familiar to those knowledgeable with the global fishing industry.

There are differences in the mandatory use of AIS by fishing vessels as well as the ability of satellites and terrestrial antenna networks to record transmissions that affect any global analysis. The discrepancies within AIS positional and identity information, both intentional and unintentional, add another layer of difficulty and reduce the potential data available for analysis.

The risk analysis – rooted in both AIS and AIS-independent data – show that AIS data can be combined with data from other sources to build useful indicators. In this study, many indicators with an AIS component also had an AIS-independent component, turning them into powerful hybrid indicators; the average governance index of foreign vessels' flag States visiting ports is one such example. Other indicators were either fully AIS, or fully non-AIS based, but worked in unison to produce relevant IUU risk scores in their respective internal and external components.

The port State IUU risk analysis allowed for the identification of major regions and major fishing nations where high port State IUU risks prevail, and where – specifically with regard to regions – positive trends of improving risk mitigation with improving national incomes would seem to apply as the general rule, but with the notable exception of Asia and the Near East. The methodology used is capable of analyzing and identifying national, regional and global trends – through the use of weighted indicators and resulting risk scores – that allow a deeper understanding, not only of how IUU risk is distributed, but also how it would seem to evolve along gradients such as national income or the quality of governance.

In the same vein, the study established that the quality of governance – using Transparency International's Corruption Perceptions Index – of a port State is the strongest structuring factor that determines the magnitude of its external risks to IUU exposure – within the set of factors analyzed. For countries with high levels of endemic corruption/weak governance, this implies that focusing on the improvement of PSM, in the absence of concomitant improvements in governance in general, is unlikely to generate substantial results.

While the study finds important differences between regions in terms of IUU risk mitigation and risk exposure, it also shows that every region harbors weak and strong performers. The study finds that for a port State being part of a given income group, a given region, having a particular CPI score, or receiving visits from particular types of fleets, is never sufficient to confidently predict its performance in the domain of PSM – owing to the wide scatter in data.

The ‘deep-dive’ analysis of fourteen individual ports, published separately as a supplement to this paper, led to the conclusion that a lot of progress remains to be achieved in the domain of translating key PSMA provisions into national practice – starting with the designation of ports and the publicly available information accompanying these port State measures. In general terms, the study found that national PSMA- or PSM-related information has been very hard to locate in all cases and that publicizing of PSM information, by individual States and by FAO, as provided for in the PSM Agreement, is severely lacking. This lack of public information also limits the depth of analysis that may be achieved by studies such as this one when looking into the performance of individual ports.

That analysis also found that individual ports do not necessarily reflect the performance of their countries, nor their region – except by chance – implying that substantial variation in the performance between individual ports of the same country is to be expected as a rule, rather than an exception.

4.2 Recommendations

The following recommendations are derived from results and conclusions, and ordered by specific domain first, and by target audience next.

For AIS-related work in this domain

1. National authorities should consider requirements that make AIS as reliable as VMS for determining compliance. These may include requiring tamper-proofing to prevent the manipulation of position and identity. This may enable greater use of AIS and other tracking technologies for fisheries control that is more cost effective than traditional VMS.

2. Countries not having done so should publish national registries, update identity information associated with their vessels’ IMO numbers, and provide vessel data for inclusion in FAO’s Global Record of Fishing Vessels, Refrigerated Transport Vessels and Supply Vessels, in order to enable a greater understanding of the legal standing of vessels operating in given areas. This should include the MMSI for all authorized vessels required to have AIS.

3. Given potential current and/or future resolutions regulating effort, RFMOs and States should collect and publish vessel hold capacity data. While creating transparency and improving capacity knowledge at RFMO and State levels, this would also strengthen the type of analysis presented in this study.
4. The number of terrestrial AIS receiver networks should be expanded, to ensure greater port coverage of AIS data in high traffic areas. This will increase processing requirements.
5. Flag States should mandate the use of AIS on fishing vessels and carriers leaving their waters.

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For port and flag States

1. Flag and port States should sanction the intentional or unintentional transmission of false identity and/or positional AIS data. This is important for safety of life at sea as well as for compliance monitoring efforts and studies such as this one.
2. Port States should publish vessel movement data on port authority websites (based on physical vessel monitoring routines). Such data should be kept in a format that can be readily used (e.g. as a downloadable spreadsheet), with the port of Las Palmas presenting the best practice case identified in this study.
3. Port States not having done so to date should plan for the formal designation of their ports and ensure robust prior notification and authorization regimes are put in place.
4. Port States having ratified the PSMA should ensure that their PSM-related information is submitted to FAO for public hosting of the relevant information – including on designated ports.
5. Port States should develop an easy-to-locate national PSMA-themed web portal providing third party access to a comprehensive set of resources regarding port State rules, designated ports, rules of port entry, forms, and contacts.
6. Port States should consider the use of AIS, among other tools, to actively monitor sections of known ports frequented by fishing vessels and fish carrier vessels that may not be part of current compliance plans.
7. Port States should consider the use of AIS, among other tools, to identify stopping events outside of known ports that may indicate attempts to evade inspection.

For FAO

1. FAO should endeavor to greatly improve the collection of comprehensive data on PSMA implementation by its Members, for public hosting. Such data should go beyond the strict requirements of the PSMA, for States that wish to submit and/or publicize such information. Ideally, such data would include the following:

    a. Name and location of designated port.

    b. Links to port authority websites.

    c. Link(s) to rule set(s) governing prior notification and authorization for port entry, including risk assessment inspection requirements and potential penalties.

    d. Link(s) to legislation establishing designated ports.

    e. Contacts (central fisheries administration and port-specific authorities).

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