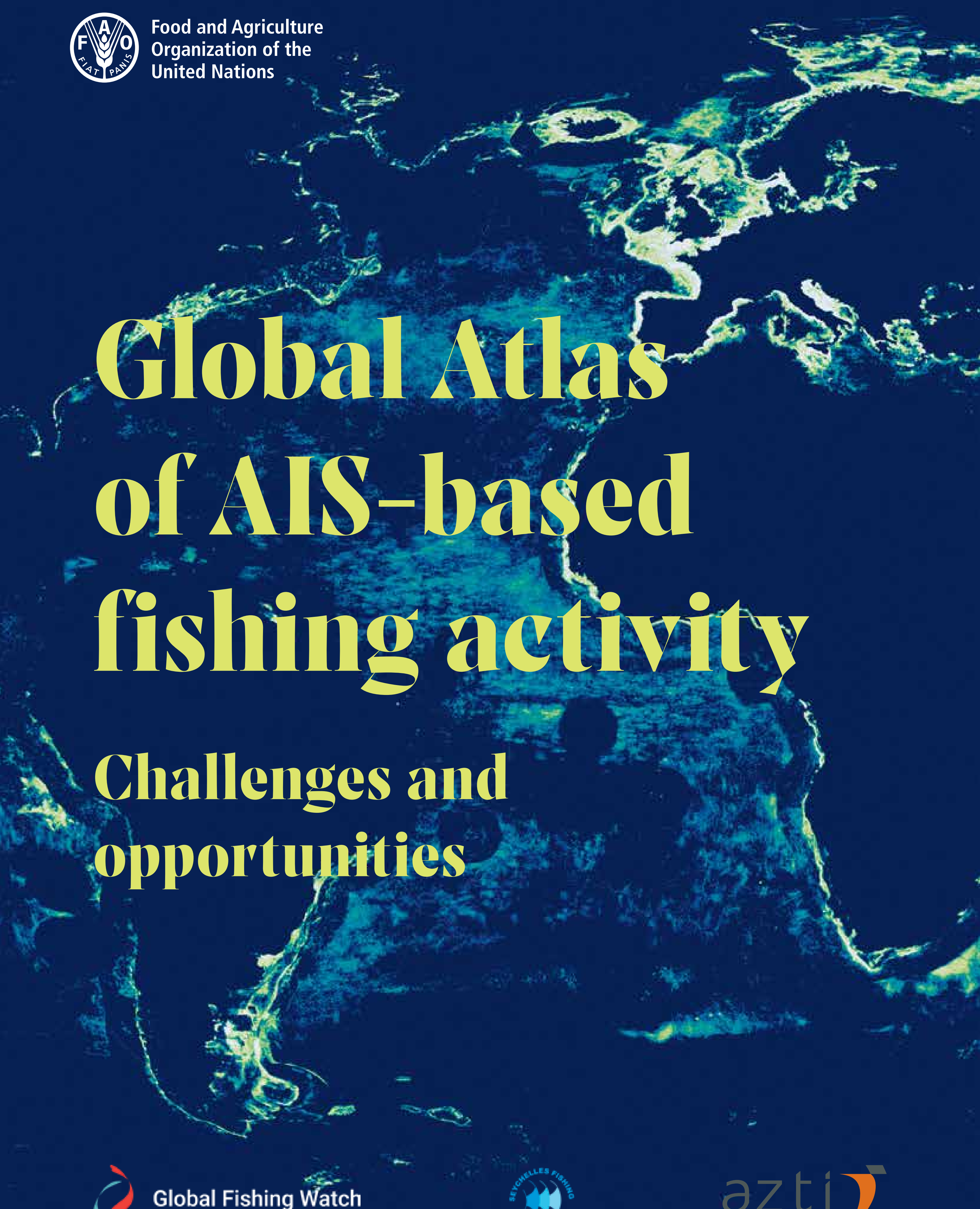


Food and Agriculture Organization of the United Nations

Global Atlas of AIS-based fishing activity

Challenges and opportunities

Global Fishing Watch

Seychelles Fishing Authority

azti tecnalia

Global Atlas of AIS-based fishing activity

Challenges and opportunities

M. Taconet, D. Kroodsma and J. A. Fernandes

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2019

Required citation:
Taconet, M., Kroodsma, D., & Fernandes, J.A. 2019. *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf).

ISBN 978-92-5-131964-2

Preparation of this document

With advances in information technology, it is becoming possible to create a global database of fishing effort by gear type with an unprecedented spatial and temporal resolution. Such a database has the potential to assist with fisheries management and research around the globe. When initiating this publication, FAO intended to present this potential by reviewing AIS-based data in the context of global and regional knowledge on fisheries, and to communicate the main findings as well as the strengths and limitations of these data and current processing methodology.

The aim of this document, hereafter referred to as the Atlas, is to enable stakeholders to understand the opportunity and challenges of mapping and analysing fishing activity using AIS data. For each FAO Area, based on AIS data, this Atlas presents the number and percentage of vessels broadcasting AIS, the spatial patterns of presence and intensity of fishing activity, and an analysis by gear type. For these data, the Atlas includes detailed methods, case studies, and comparisons with other data. These comparisons, explanatory text, and caveats are presented with the goal of helping FAO Members understand how this new dataset can be applied. To ensure the accuracy of the conclusions, 80 fishery experts from around the world either authored, reviewed or assessed the maps, charts, and supporting text produced by the authors and editorial team.

This Atlas has been prepared through a collaboration between Food and Agriculture Organization of the United Nations (FAO), Global Fishing Watch (GFW), and Fundación AZTI – AZTI Fundazioa. Seychelles Fishing Authority (SFA) has also contributed with a local study chapter.

FAO is a specialized agency of the United Nations (UN) that leads international efforts to defeat hunger. FAO's goal is to achieve food security for all and ensure people have regular access to enough high-quality food to lead active, healthy lives. FAO has contributed to the Atlas with 1) the initial idea; 2) project partner coordination; 3) revision of fleet data statistics for FAO area chapters led by GFW; 4) coordination of external review; 5) leading introductory chapters and the conclusions chapter; and 6) overall study material editing and reviewing.

GFW is an independent and non-profit organization originally set up through a collaboration between three partners: Oceana, an international ocean conservation organization; SkyTruth, experts in using satellite technology to protect the environment; and Google, which provides

the tools for processing big data. GFW's aim is to advance ocean sustainability and stewardship through increasing transparency. GFW has contributed to the Atlas with: 1) the initial idea, together with FAO; 2) providing the processed data, graphs and maps; 3) leading the writing of chapters on AIS data processing, methods and use; 4) leading revision of fleet statistics for FAO areas chapters together with FAO; 5) providing text and revision of FAO regions chapters; and 6) revision of the two detailed comparisons with VMS/logbook data (Bay of Biscay and Seychelles comparisons).

AZTI is an independent and non-profit research and technology organization that aims to develop sustainable products and services for the long-term healthy development of society. Its marine research division works closely with fisheries and related industries towards increasing environmental and economic sustainability. AZTI has contributed to the Atlas with: 1) as an independent reviewer and editor of all Atlas materials; 2) data analysis and writing of the AIS and VMS/logbook data comparison chapter for the Bay of Biscay; and 3) leading the writing and review of FAO area chapters and the conclusions chapter.

SFA is the competent fisheries and marine resources management authority for the Seychelles. The SFA monitors its national coastal and high seas fishing fleets and the foreign fleets licensed to operate within Seychelles waters. The SFA has contributed to the Atlas with:
1) the detailed case study comparing AIS data to VMS and logbook data in the Seychelles tuna fisheries and 2) the revision of the Bay of Biscay case study.

Contents

Acknowledgements

The editors would like to thank Manuel Barange, Director of FAO's Fisheries and Aquaculture Policy and Resources Division, for the original ideation given to this work, and his general support. Jennifer Gee and Kiran Viparthi contributed respectively to FAO fleet statistics and charts/maps design, and provided valuable inputs to initial ideation, document scoping and coordination within the editorial team. The editors warmly thank Alejandro Anganuzzi, Alexander Kotlarov, Andrés Domingo, Andrew Wright, Carolina Minte-Vera, Daniel Gilardoni, Dario Pinello, Dean Hurholtz, Enzo Acuña, Eva Garcia Isarch, Keith Reid, Fernando Jara, Graham Pilling, Hazel Oxenford, Hintzen Niel, Igor Granado, Jaeyoon Park, James Geehan, Jennifer Gee, John Virdin, Josefine Egekvist, Kiran Viparthi, Luis J. López Abellán, Manuel Feliz Pérez Moreno, Manuel Hidalgo, Marcello Vasconcello, Mark Dimech, Marta Soffker, Maurizio Gibin, Nancie Cummings, Nathan Miller, Philippe Michaud, Paulus Kainge, Peter Flewwelling, Roberto Sarralde, Richardo Alpoim, Ricardo Federizon, Rishi Sharma, Sebastian Rodriguez, Stephen Akester, Souad Kifani, Tony Long, Vincent Lucas, Vladimir Radchenko, and Yimin Ye for excellent comments and feedback during the elaboration of the chapters. Emmanuel Blondel is recognised for helping with worldwide GIS layers and Marianne Guyonnet for guidance to the publication styles. Graphical design was elaborated by Juan Carlos Alonso. Layouts were produced by Virginia Rodríguez. Jefferson Murua helped with the final revision of text before publication. The Seychelles case study authors thank Freddy Lesperance, Roddy Allisop, Loreen Esther, Julie Jean and Alisa Belmont for their great assistance with Vessel Monitoring System (VMS) and Stig Fjellberb and Duncan Copeland from TM-Tracking for initial discussions on the pros and cons of AIS. Dr Jose A. Fernandes research on fishing impacts reduction and sustainable growth is partly funded through the Gipuzkoa Talent Fellowships programme, by the Gipuzkoa Provincial Council, Spain; and, by DataBio project (No 732064) within European Union's Horizon 2020 research and innovation programme. Global Fishing Watch would like to thank Marisla Foundation, The Waterloo Foundation, Bloomberg Philanthropies, Leonardo DiCaprio Foundation, and Oceans 5 for their support. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Acronyms

- **AIS** – Automatic Identification System
- **AZTI** – Fundación AZTI – AZTI fundazioa
- **DWF** – Distant water fleet
- **EEZ** – Exclusive Economic Zone
- **FAO** – Food and Agriculture Organization of the United Nations
- **FFA** – Pacific Islands Forum Fisheries Agency
- **GFW** – Global Fishing Watch
- **IUU** – Illegal, unreported and unregulated
- **IMO** – International Maritime Organization
- **MMSI** – Maritime Mobile Service Identity
- **RFMO** – Regional Fisheries Management Organization
- **SFA** – Seychelles Fishing Authority
- **VMS** – Vessel Monitoring System

Executive summary

The Automatic Identification System (AIS) provides detailed tracks of tens of thousands of industrial fishing vessels, and these detailed tracking data have the potential to provide estimates of fishing activity and effort in near real time. Realizing this potential, though, is not straightforward and depends on the vessel size, gear type, and the species targeted. This Atlas, using a global database of AIS data from 2017, assesses this potential and shows that AIS can start to be considered a valid technology for estimating fishery indicators. This Atlas reveals both promising findings and key limitations of inferring fishing effort from AIS data.

AIS use is steadily increasing and its utility in tracking fishing vessel activity is growing. In 2017, AIS was broadcast by approximately 60 000 fishing vessels of which just over 22 000 could be matched to publicly available vessel registries. This number is steadily increasing, and between 2014 and 2017, the number of vessels broadcasting increased by 10 to 30 percent each year. Moreover, AIS can be used to track the majority of the world's large fishing vessels (above 24 m), especially those from upper and middle-income countries and territories, distant water fleets and vessels operating on the high seas. AIS tracking performs less well on smaller vessels: only a small fraction of vessels under 24 m, which account for the vast majority of fishing vessels globally, use AIS.

The current algorithms perform well at classifying the most common gear types among larger vessels: longlines, trawls and pelagic purse seines. The classification algorithms do less well at differentiating gear types that are more common in smaller coastal vessels, such as set gillnets, trollers and pots and traps. Also, the current AIS algorithms can assign only one gear type, limiting the ability to classify the type of fishing when vessels change gears on a voyage or between voyages.

Poor AIS reception limits the ability to monitor fleets in some regions. In particular, satellite AIS reception is weakest in Southeast Asia, followed by East Asia, the northern Indian Ocean, the Gulf of Mexico and Europe, although terrestrial receivers along coastlines can, in some of these regions, compensate for poor satellite reception. The reception quality also depends on the specific type of AIS device in use (Class A or B).

Comparing AIS-based fishing vessel activity with catch reconstructions and literature reveals varying use of AIS by region and gear and possible biases in the relative importance of different gears. Catch reconstructions mostly show that areas with high catch have high activity by vessels with AIS, although some areas with high catch have little AIS activity, such as in Southeast Asia (Area 71), as a result of few vessels having AIS. Catch reconstructions agree on

the most important gears worldwide (trawlers, followed by purse seiners), although AIS data show a higher importance of longliners because a higher fraction of these broadcast AIS. The recent increasing importance of squid jiggers in the high seas was not captured in the slightly lagged catch reconstruction work.

In optimal conditions where AIS use and reception are good, and where vessel registries with gear type exist AIS algorithm can perform well for gears such as longline or trawl and provide good estimates of fishing effort.

This work has contributed to improving the quality of FAO fleet statistics, revealed some errors in classifications of gear types in the European Union (EU) registry, and pinpointed limitations of catch reconstructions. With regard to the AIS data, in addition to showing limitations of AIS, this project has helped improve methods for analysing AIS data and align AIS-based metrics with fishery statistical standards, and this work can provide a basis for further improvement of these methods and algorithms.

Introduction of Global Atlas of AIS-based fishing activity

Marc Taconet, David Kroodsma, Jennifer Gee and Jose A. Fernandes

PREFACE

The spatial impact of fishing can be measured in several ways. It can be measured through the inputs required, such as the fuel used or time expended (Basurko *et al.*, 2013), or by analyzing outputs such as catch, where catch is measured in tonnes of fish or total primary production indirectly consumed through the food web (Swartz *et al.*, 2010). Another measure is the impact various fishing gears have on ecosystems, such as the catch of non-target species (bycatch), the disturbance of benthic habitats by trawlers (Sciberras *et al.* 2018; van Denderen *et al.* 2014; Puig *et al.* 2012; Venetoulis and Talberth, 2008) or the wider effects on fish community structure (Queirós *et al.*, 2018). Because different fishing methods have different impacts, fishing environmental footprints often need to be calculated and estimated differently depending on the gear type (Puig *et al.*, 2012; Sciberras *et al.*, 2018; van Denderen *et al.*, 2014; Victorero *et al.*, 2018). For instance, baitboats may have a relatively small impact on ecosystems due to their higher selectivity (Suuronen *et al.*, 2012), but this benefit might come at the cost of more fuel use and higher greenhouse gas emissions. Indeed, greenhouse gas emissions from the fishing industry are gaining increased attention (Basurko *et al.*, 2013; Tyedmers *et al.*, 2004; Tyedmers *et al.*, 2005) and, as such, the new FAO report on climate change has an entire chapter with recommendations on how to reduce fishing vessels' fuel consumption and derived emissions (Barange *et al.*, 2018). These various costs, or environmental footprints, must of course also be weighed against the benefits or socio-economic footprint that fishing brings to society, including food security and income for coastal communities and national economies (Fernández-Macho *et al.*, 2015; Fernandes *et al.*, 2017).

To understand many of the impacts of fishing, one needs to know the presence and measure the intensity of fishing activity, operations, and effort, ideally at a spatial and temporal resolution sufficient to assess the impacts and benefits outlined above. One way to estimate the presence and intensity of fishing is to use detailed tracking data from logbooks and Vessel Monitoring Systems (VMS). Logbook and VMS data are usually established by national governmental authorities or Regional Fisheries Management Organizations (RFMOs) for monitoring, control, and surveillance. VMS monitor vessel movements with GPS and then broadcast the positions, usually encrypted, to satellites. The information is then shared with the authorities that monitor a given fishery. Commonly, VMS is a mandatory system for vessels above a given size, but the regulations vary by jurisdiction. Detailed VMS data, however, are usually not shared publicly by

authorities or are only provided as aggregated values and with a time lag of several months to safeguard confidentiality. Further, confidentiality requirements often ressult in a lack of VMS data sharing between states and RFMOs, even among those with overlapping jurisdictions. This confidentiality further limits the full potential of using VMS. Similarly, logbooks are often treated as highly confidential, limiting their use for assessing fisheries in some regions and at a global scale.

Whether logbook and/or VMS data are available or not, some fishing activity can be assessed with the Automatic Identification System (AIS). AIS devices contain a GPS unit and broadcast, via VHF radio, a vessel's position, course, and other information every few seconds (ITU, 2014). AIS was initially intended to improve ship safety by broadcasting and receiving AIS signals to avoid collisions between vessels, and is used by large, oceanic vessels. While the purpose of these signals is to alert nearby marine traffic of a vessel's presence, the messages can be received by a wide array of satellites and terrestrial receivers that operate worldwide. In addition, every three minutes, AIS devices broadcast the vessel's identity, including callsign, name, IMO number, activity, and size, allowing one to identify and distinguish fishing vessels. During 2017, more than 300 000 unique AIS devices broadcasted the location of a vessel in the world's oceans and this large quantity of available AIS data is increasingly being viewed as a tool to monitor and provide historical analysis of vessel activity. Many recent applications of AIS data aim to understand the distribution of and changes in human activity. Some examples include estimating fishing activities (Natale *et al.*, 2015; McCauley *et al.*, 2016; Merten *et al.*, 2016; Russo *et al.*, 2016; Souza *et al.*, 2016; Vespe *et al.*, 2016; Wang and Wang, 2016; Le Guyader *et al.*, 2017), vessel behavior (Eguiluz *et al.*, 2016), and shipping emissions (Smith *et al.*, 2014; Coello *et al.*, 2015).

For monitoring fishing, AIS has some notable limitations. AIS is carried by only a small fraction of the world's roughly 2.8 million fishing vessels (FAO, 2018), and this fraction of vessels is not evenly distributed between regions, making it difficult to compare activity in different areas of the ocean. Compared with most VMS units, vessels can more easily turn off their AIS or broadcast incorrect identity information. In some parts of the ocean with high vessel traffic, AIS messages can interfere with one another, limiting the ability of satellites to receive these messages. Also, inferred fishing activity from AIS data is based on machine learning models that analyze how vessels move, and these models are inherently less accurate than most VMS or well-collected logbook data. Moreover, models are only as good as the data used to train them (Fernandes *et al.*, 2009), and errors and bias in training data sets can lead to misclassification of gear types.

The aim of this document, henceforth referred to as the Atlas, is to use AIS data to provide an initial footprint of fishing activity and highlight the strengths and weaknesses of using this new dataset. Specifically, the Atlas seeks to quantify, for each FAO Area, the number and

percentage of vessels broadcasting AIS and the presence of fishing activity, including by gear. The number of gear types that can be accurately identified is limited, but the general overview is an important first step in mapping global fishing activity. Although the Atlas also provides case studies that compare fishing effort measured with AIS to official measurements from VMS and logbooks, the key focus of the Atlas is to identify fishing vessel activity and its intensity in FAO areas based on AIS.

The Atlas includes 1) definitions of fishery indicators and their mapping to AIS metrics; 2) a lengthy discussion of the methods used to assemble the Atlas, which build on the methods used in Kroodsma *et al.* (2018); 3) an analysis of the use of AIS by the world fishing fleet over time and in various jurisdictional contexts; 4) detailed comparisons of AIS information with logbook and VMS data for two regions of the world — the Spanish fleet operating in the Bay of Biscay and the Seychelles tuna fleet operating in the Indian ocean; and 4) an analysis, by each FAO Area, of the completeness and accuracy of AIS data. The Atlas concludes with key findings on strengths and weaknesses of the AIS dataset and GFW algorithms to estimate fishing activity, provides summaries by gear type and FAO areas and suggests future possible work and likely developments.

APPROACH AND METHODOLOGY FOR THE REGIONAL COMPARISONS

Some specific methodological notes are here provided regarding the set of regional chapters, a major work of this Atlas, which aim to present a comprehensive evaluation of GFW-AIS's ability to estimate fishing vessel activity. This proceeds by reviewing for each FAO area the fleets and fishing gears for which the AIS-based metrics might be good or not. The challenge is double since it implies revising the fishing activity detected by AIS against other sources of data, but also identifying what important activity is not being seen by AIS data. This second challenge is particularly important, since it aims at correcting possible bias and misleading picture of the fishing activity of an area which can be inferred from using a convenient data source such as AIS. A typical case of such bias lies with longliners given that their activity is widespread and the use of AIS devices is very common in these fleets, which can result in the false impression that longliners dominate fishing activity in many regions; the regional chapters in this Atlas illustrate that this is often not true. For this purpose, we have used several approaches to compare 2017 AIS data (as available in mid-2018) with data from other sources as described in the following paragraphs.

For an estimation of AIS use among fleet segments, comparison was done between vessels that AIS can identify and vessels contained in FAO fleet statistics, and/or other sources of fleet

statistics (e.g. GFCM fleet statistics, European Union Registry). This comparison highlights the existence in many regions of a large activity by smaller vessels and artisanal fisheries that is not tracked by AIS. It also shows some potential of AIS to improve FAO statistics given that FAO statistics are not very detailed and are based on country reports that sometimes are not accurate or outdated. Some FAO statistics have been corrected using outside sources when the only available statistics were clearly inaccurate, outdated or based on estimates. In some other cases the FAO statistics contained accurate total figures but without a breakdown in size and/or vessel type distribution, and in these cases more accurate distribution data were taken from other sources and applied to the reported statistics.

For an estimation of the spatial distribution patterns of fishing vessel activity by fleet segment and fishing gear, comparison was done with the catches reconstruction of the Global Fisheries Landings database. GFLD allows one to identify the likely main fishing gears in each region, though GFLD has its own bias and catches cannot be used to accurately estimate fishing activity. However, GFLD does provide a systematic approach to consistently review all regional estimates based on AIS data. In some regions, however, where it was easy to obtain more accurate data sources, the comparison has been performed with these other sources of data (e.g. official regional databases such as ICES or CCAMLR, or the use of BlueBridge tuna atlas data reconstructed from RFMOs data). Also, RFMOs reports and scientific publications have also been used to contrast the maps and graphs based on AIS data. One challenge overall is that we were constrained to use the 2017 AIS datasets (i.e. the best available when work started at mid-2018) to assess GFW capacity to provide a close to real time AIS estimate of fishing vessel activity, while the most recent available public data has a several year time lag. GFLD reconstruction of catches by fishing gear provides information only until 2014, and RFMOs data often have at least a one- or two-year delay before becoming available to the public. These differences in years need to be kept in mind and might in certain cases of very dynamic fisheries induce some bias in the analysis.

Finally, we asked different regional fisheries experts with a long history of expertise in each area to review the text, and assess the maps produced against their knowledge of fisheries, and to give additional insights. A minimum of two reviews per area have been received with some areas receiving comments and suggestions from up to five reviewers. Altogether, over 40 external reviewers have provided their feedback. Some of these reviewers’ comments have identified some significant issues that have led to corrections in some maps and graphs.

Despite all these efforts, this Atlas provides only an overview of the potential of AIS to improve our knowledge about fishing activity. Maps and conclusions should therefore be used carefully and contrasted with local sources of data and knowledge.

FISHERIES INDICATORS IN THIS ATLAS

This Atlas work is a unique opportunity to evaluate AIS in a context of fisheries and aquaculture knowledge, and to promote alignment and standardization of new AIS-based metrics with existing fishery statistics and data standards. In this respect, several concepts related to fisheries management and monitoring are referenced throughout the Atlas and are explained in this section.

Fleet capacity: Fleet capacity is a measure of the number of fishing vessels of a country/territory. Beyond a count of the number of vessels, it might include an estimate of their size, power, or type but does not contain information on time spent on the water (e.g. days at sea or hours of fishing). Fleet capacity is best measured with fleet registries or censuses, and here it is measured as the count of vessels from the FAO fleet statistics.

Active fleet: Whereas fleet capacity measures the size of the fishing fleet, active fleet measures the size of the fleet that is active in a given water area over a given time period. In this Atlas, a fishing vessel is deemed an "active fishing vessel" if it undertook more than 24 hours of fishing operations in the calendar year in a given area. Note that because inactive vessels generally do not broadcast AIS, AIS can only be used to measure the active fleet and not fleet capacity. This Atlas compares fleet capacity as measured by the FAO against the active fleet as measured either at a global scale, or at a regional scale, by AIS. This comparison is limited by the fact that fleet capacity from FAO cannot distinguish components of a fleet fishing in different regions.

Fishing vessel activity: Fishing vessel activity includes all activity of a fishing vessel when it is away from port, including transiting, searching for fish, fishing operations, and transshipments. In this Atlas, fishing vessel activity is measured in the number of hours or days that fishing vessels are at sea ("hours at sea" or "days at sea").

Fishing operation: A fishing operation is a routine sequence of actions to catch fish and which lasts until fish is removed from the fishing gear; it may involve, among other things, searching for fish, deployment, hauling and retrieval of fishing gear, and removal of catch from the gear. The AIS algorithms used for this Atlas measure the number of hours that gear is being deployed or hauled, hereafter "fishing hours." This measure of fishing operations omits searching time, and sometimes omits removal of catch from the gear. Searching time can be important for some gears, such as purse seines.

Fishing presence: Fishing presence measures the presence or absence of fishing vessel activity or fishing operations in a giving area and given time frame (e.g. calendar year). The presence can be measured as a Boolean value—is fishing present (true) or not (false) in a given area or grid cell. The indicator is not utilized in maps or tables of this publication.

Fishing intensity: Fishing intensity measures the amount of fishing vessel activity or fishing operations in each grid cell within given time frame (here a calendar year). In this Atlas, the intensity of fishing vessel activity is mapped by "hours at sea" of fishing vessels, which corresponds to the amount of time a vessel spent in each cell without differentiating between when gear is deployed or not. The intensity of fishing operations is measured in "fishing hours", which is the number of hours fishing vessels spent operating gear in each grid cell (i.e. 0.1 x 0.1 degree in this Atlas).

Fishing effort: Fishing effort is a measure of anthropogenic work inputs used to catch fish. In fisheries science, it is defined in the context of stock assessment science where fishing effort intends to provide a measure proportional to the amount of fish captured for a given fish stock (i.e. fishing mortality). FAO and the Coordinating Working Party on Fishery Statistics (CWP) set standards for different measures of fishing effort. It can be the sum of the time spent searching for fish (search duration, including fishing operations), or it can be the amount of fishing gear of a specific type used on the fishing grounds over a given unit of time, e.g. hours trawled per day, number of hooks set per day, or number of hauls of a beach seine per day.

Although gear-specific metrics are usually better for estimating fish mortality, these cannot be summed across gears to give a single value. As a result, using total time searching for or catching fish (essentially all time at sea except transiting) is the best effort metric that can be summed across gears. Given this definition, the measure of fishing activity in this Atlas, which is in days at sea, is the closest to a traditional measure of effort that can be used as common denominator across gears.

Because there is no global dataset of fishing effort and because fishing effort should be proportional to fishing mortality, in this Atlas, total catch by gear type by region is compared to fishing effort in AIS days at sea in summary tables for each FAO Area. However, to compare catch spatially with AIS data, the intensity of fishing operations, measured in fishing hours, is used instead of total fishing effort (which would be better measured as total time at sea). The reason to measure fishing hours is that it can better localize where fish was likely caught, thus allowing better spatial comparisons between catch and effort distributions. Mapping total fishing effort would include the searching time which, while contributing to the effort, extends beyond where the fish catches were taken.

A synoptic view of the concepts and measures presented and used in this Atlas is presented in Table Int. I.

		MEASURES				
		Fishing presence			Fishing intensity	
		Aggregated worldwide	Aggregated by FAO Area	Over a grid cell	Aggregated by FAO Area	Over a grid cell
		(Low spatial resolution)		(High spatial resolution)	(Low spatial resolution)	(High spatial resolution)
FISHERY INDICATORS	Fleet capacity	**Number of vessels[0]**				
	Active Fleet (by country/ territory and by gear type)	**Number of vessels with AIS present[1]**	**Number of vessels with AIS present[2]**			
	Fishing vessel activity			*	**Number of days at sea in FAO Area[3]**	**Intensity of fishing activity[4]** Hours of fishing vessels presence (hours/km^2)
	Fishing operations (by gear type)			*		**Intensity of fishing operations[5]** Hours of fishing operations (hours/km^2)

Table Int. I. Synoptic view of the concepts and measures used in this Atlas. The metric in reference is utilized in the Atlas chapters as follows: [0]from FAO fleet statistics used in 'Use of AIS by world's fishing fleet' (Figure Use. 1) and in regional chapters in section "Region fleets and AIS use" (e.g. Figures 18.3 and 18.4); [1]in chapter 'Use of AIS by world's fishing fleet' (Figure Use. 1 to Figure Use. 4); [2]in regional chapters section 'Regions fleet and AIS use' (e.g. Fig.18. 4); [3]in tables of regional chapters (e.g. Table 18. I) and in the comparisons with catch data in conclusions chapter (Figure Conc. 7); [4]in regional chapters section 'AIS reception and fishing vessel activity' (e.g. Figure 18.5a,b) and in conclusion chapter (Figure Conc. 1); [5]in regional chapters section 'Fishing vessel activity and operations by gears' (e.g. Figure 18.7 and following maps) and in conclusion chapter (Figures Conc. 2-5).
*Not utilized in maps or tables of this publication. Note that for the AIS-based indicators used for the world and for FAO areas, only vessels that had fishing operations for more than 24 hours in the year are included.

LIMITATIONS AND CHALLENGES OF AIS DATA

The key factors that affect the completeness and accuracy of footprints derived from AIS are **AIS use**, **AIS reception**, and **AIS algorithm performance**. Throughout this Atlas, these terms are used to describe the reliability of the AIS fishing maps globally and regionally.

AIS use is a measure of the number of vessels that have an AIS device installed and that broadcast. For analyses in this Atlas, we included only likely fishing vessels with at least 24 hours of fishing operations, measured in "fishing hours," in 2017.

AIS reception is a measure of how likely it is for a vessel's AIS message to be received correctly by the existing network of satellites and terrestrial antennas along the world's coastlines. In regions of the world with high maritime traffic, AIS signals can interfere with each other, which reduces reliable satellite reception. Terrestrial receivers, for various reasons, do not have as many challenges with signal interference, but they are not present along all coastlines.

AIS algorithm performance is a measure of how well algorithms can identify the type of vessels (whether the vessel is a fishing vessel or not and what type of gear it uses) and identify fishing operations.

AIS use, reception, and algorithm performance have varying importance to measuring the different fisheries indicators (Table Int. II). To estimate fleet capacity, AIS is of limited usefulness because many vessels do not have AIS devices, and even if they have AIS devices, they might be inactive or they may not broadcast. AIS use, though, can help identify the active fleet; if AIS use is high, then it should be possible to identify the number of active vessels. To identify the active fleet, though, AIS Reception and algorithm performance are less important; even in areas of poor reception, it is generally possible to receive some AIS messages from vessels and estimate the number of fishing vessels broadcasting. To measure the spatial extent of vessel activity, though, it is important to have both good AIS use and good reception. Finally, to estimate the intensity of fishing vessel activity and fishing operations, and to provide estimates of fishing effort by gear type for use in stock assessment, one needs good AIS use, reception, and algorithm performance.

		Quality of AIS estimates		
		AIS use	AIS reception	AIS algorithm performance
Fisheries indicators	**Nominal data**			
	Fleet capacity			
	Active fleet			
	Fishing characterization			
	Fishing presence			
	Fishing vessel activity			
	Fishing operation			
	Fishing effort			

Table Int. II. Mapping between AIS and fishery indicators concepts. The color intensity in the cell represents the level of importance of the AIS data factors (use, reception, and algorithm performance) for providing a good estimate of the concerned fisheries indicator.

In addition to limitations due to AIS reception and use, there are several challenges to working with AIS data associated with data quality that must be addressed when identifying fishing activity. These are reviewed in the following chapter "AIS-Based Methods for Estimating Fishing Vessel Activity and Operations".

Required citation for this chapter:

Taconet, M., Kroodsma, D., Gee, J., Fernandes, J. A. 2019. Introduction of Global Atlas of AIS-based fishing activity. *In* Taconet, M., Kroodsma, Fernandes, J. A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities*. Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K.L., Funge-Smith, S. & Poulain, F. 2018. *Impacts of climate change on fisheries and aquaculture: synthesis of currrent knowledge, adaptation and mitigation options.* FAO Fisheries and Aquaculture Technical Paper (FAO) no. 627. (also available at http://agris.fao.org/agris-search/search.do?recordID=XF2018002008).

Basurko, O.C., Gabiña, G. & Uriondo, Z. 2013. Energy performance of fishing vessels and potential savings. *Journal of Cleaner Production*, 54: 30–40. https://doi.org/10.1016/j.jclepro.2013.05.024

Coello, J., Williams, I., Hudson, D.A. & Kemp, S. 2015. An AIS-based approach to calculate atmospheric emissions from the UK fishing fleet. *Atmospheric Environment*, 114: 1–7. https://doi.org/10.1016/j.atmosenv.2015.05.011

FAO. 2018. *The State of World Fisheries and Aquaculture 2018. Meeting the Sustainable Development Goals.* Rome.

Fernandes, J.A., Irigoien, X., Boyra, G., Lozano, J.A. & Inza, I. 2009. Optimizing the number of classes in automated zooplankton classification. *Journal of Plankton Research*, 31(1): 19–29. https://doi.org/10.1093/plankt/fbn098

Fernandes, J. A., Papathanasopoulou, E., Hattam, C., Queirós, A. M., Cheung, W. W., Yool, A.,... & Calosi, P. 2017. Estimating the ecological, economic and social impacts of ocean acidification and warming on UK fisheries. *Fish and Fisheries*, 18(3), 389-411. https://doi.org/10.1111/faf.12183

Fernández-Macho, J., Murillas, A., Ansuategi, A., Escapa, M., Gallastegui, C., González, P., Prellezo, R. & Virto, J. 2015. Measuring the maritime economy: Spain in the European Atlantic Arc. *Marine Policy*, 60: 49–61. https://doi.org/10.1016/j.marpol.2015.05.010

ITU. 2014. *Technical Characteristics for an Automatic Identification System Using Time Division Multiple Access in the VHF Maritime Mobile Frequency Band.* [online]. [Cited 11 September 2019]. https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.1371-5–201402-I!!PDF-E.pdf

Kroodsma, D.A., Mayorga, J., Hochberg, T., Miller, N.A., Boerder, K., Ferretti, F., Wilson, A., Bergman, B., White, T.D., Block, B.A., Woods, P., Sullivan, B., Costello, C. & Worm, B. 2018a. Tracking the global footprint of fisheries. *Science*, 359(6378): 904–908. https://doi.org/10.1126/science.aao5646

Kroodsma, D.A., Mayorga, J., Hochberg, T., Miller, N.A., Boerder, K., Ferretti, F., Wilson, A., Bergman, B., White, T.D., Block, B.A., Woods, P., Sullivan, B., Costello, C. & Worm, B. 2018b. Response to Comment on "Tracking the global footprint of fisheries". *Science*, 361(6404): eaat7789. https://doi.org/10.1126/science.aat7789

Le Guyader, D., Ray, C., Gourmelon, F. & Brosset, D. 2017. Defining high-resolution dredge fishing grounds with Automatic Identification System (AIS) data. *Aquatic Living Resources*, 30: 39. https://doi.org/10.1051/alr/2017038

McCauley, D.J., Woods, P., Sullivan, B., Bergman, B., Jablonicky, C., Roan, A., Hirshfield, M., Boerder, K. & Worm, B. 2016. Ending hide and seek at sea. *Science*, 351(6278): 1148–1150. https://doi.org/10.1126/science.aad5686

Merten, W., Reyer, A., Savitz, J., Amos, J., Woods, P. & Sullivan, B. 2016. Global Fishing Watch: Bringing Transparency to Global Commercial Fisheries. *arXiv*:1609.08756 [cs]. (also available at http://arxiv.org/abs/1609.08756).

Natale, F., Gibin, M., Alessandrini, A., Vespe, M. & Paulrud, A. 2015. Mapping Fishing Effort through AIS Data. *PLOS ONE*, 10(6): e0130746. https://doi.org/10.1371/journal.pone.0130746

Puig, P., Canals, M., Company, J.B., Martín, J., Amblas, D., Lastras, G., Palanques, A. & Calafat, A.M. 2012. Ploughing the deep sea floor. *Nature*, 489(7415): 286–289. https://doi.org/10.1038/nature11410

Queirós, A.M., Fernandes, J., Genevier, L. & Lynam, C.P. 2018. Climate change alters fish community size-structure, requiring adaptive policy targets. *Fish and Fisheries,* 19(4): 613–621. https://doi.org/10.1111/faf.12278

Russo, T., D'Andrea, L., Parisi, A., Martinelli, M., Belardinelli, A., Boccoli, F., Cignini, I., Tordoni, M. & Cataudella, S. 2016. Assessing the fishing footprint using data integrated from different tracking devices: Issues and opportunities. *Ecological Indicators,* 69: 818–827. https://doi.org/10.1016/j.ecolind.2016.04.043

Sala, E., Mayorga, J., Costello, C., Kroodsma, D., Palomares, M.L.D., Pauly, D., Sumaila, U.R. & Zeller, D. 2018. The economics of fishing the high seas. *Science Advances*, 4(6): eaat2504. https://doi.org/10.1126/sciadv.aat2504

Sciberras, M., Hiddink, J.G., Jennings, S., Szostek, C.L., Hughes, K.M., Kneafsey, B., Clarke, L.J., Ellis, N., Rijnsdorp, A.D., McConnaughey, R.A., Hilborn, R., Collie, J.S., Pitcher, C.R., Amoroso, R.O., Parma, A.M., Suuronen, P. & Kaiser, M.J. 2018. Response of benthic fauna to experimental bottom fishing: A global meta-analysis. *Fish and Fisheries*, 19(4): 698–715. https://doi.org/10.1111/faf.12283

Smith, T. W. P., Jalkanen, J. P., Anderson, B. A., Corbett, J. J., Faber, J., Hanayama, S. & Raucci, C. 2015. *Third IMO GHS study.*

Souza, E.N. de, Boerder, K., Matwin, S. & Worm, B. 2016. Improving Fishing Pattern Detection from Satellite AIS Using Data Mining and Machine Learning. *PLOS ONE*, 11(7): e0158248. https://doi.org/10.1371/journal.pone.0158248

Suuronen, P., Chopin, F., Glass, C., Løkkeborg, S., Matsushita, Y., Queirolo, D. & Rihan, D. 2012. Low impact and fuel efficient fishing—Looking beyond the horizon. *Fisheries Research*, 119–120: 135–146. https://doi.org/10.1016/j.fishres.2011.12.009

Swartz, W., Sala, E., Tracey, S., Watson, R. & Pauly, D. 2010. The Spatial Expansion and Ecological Footprint of Fisheries (1950 to Present). *PLOS ONE*, 5(12): e15143. https://doi.org/10.1371/journal.pone.0015143

Tyedmers, P. 2004. Fisheries and Energy Use. Encyclopedia of Energy, pp. 683–693. *Elsevier.* (also available at https://linkinghub.elsevier.com/retrieve/pii/B012176480X002047).

Tyedmers, P.H., Watson, R. & Pauly, D. 2005. Fueling Global Fishing Fleets. AM*BIO: A Journal of the Human Environment,* 34(8): 635–638. https://doi.org/10.1579/0044-7447-34.8.635

Van Denderen, P.D., Hintzen, N.T., Rijnsdorp, A.D., Ruardij, P. & van Kooten, T. 2014. Habitat-Specific Effects of Fishing Disturbance on Benthic Species Richness in Marine Soft Sediments. *Ecosystems*, 17(7): 1216–1226. https://doi.org/10.1007/s10021-014-9789-x

Venetoulis, J. & Talberth, J. 2008. *Refining the ecological footprint. Environment, Development and Sustainability,* 10(4): 441–469. https://doi.org/10.1007/s10668-006-9074-z

Vespe, M., Gibin, M., Alessandrini, A., Natale, F., Mazzarella, F. & Osio, G.C. 2016. Mapping EU fishing activities using ship tracking data. *Journal of Maps*, 12(sup1): 520–525. https://doi.org/10.1080/17445647.2016.1195299

Victorero, L., Watling, L., Deng Palomares, M.L. & Nouvian, C. 2018. Out of Sight, But Within Reach: A Global History of Bottom-Trawled Deep-Sea Fisheries From >400 m Depth. *Frontiers in Marine Science*, 5. https://doi.org/10.3389/fmars.2018.00098

Wang, Y.B. & Wang, Y. 2016. Estimating catches with automatic identification system (AIS) data: a case study of single otter trawl in Zhoushan fishing ground, China. *Iranian Journal of Fisheries Sciences*, 15(1): 75–90.

Watson, R.A. 2017. A database of global marine commercial, small-scale, illegal and unreported fisheries catch 1950–2014. *Scientific Data*, 4: 170039. https://doi.org/10.1038/sdata.2017.39

AIS-Based Methods for Estimating Fishing Vessel Activity and Operations

David Kroodsma, Nathan A. Miller, Tim Hochberg, Jaeyoon Park and Tyler Clavelle

This chapter outlines how Global Fishing Watch (GFW) processes billions of AIS messages to develop databases of fishing vessels and fishing operations. To produce these datasets, GFW has developed two separate models: 1) a model that identifies the type of vessel based on its GPS tracks, which differentiates fishing from non-fishing vessels and identifies the gear type and size of vessels; and 2) a model that determines, based on GPS tracks, when fishing vessels are likely setting or hauling their gear and engaging in fishing operations. As this chapter outlines, these new datasets have great promise and perform well for most vessels, especially larger ones. There are, though, some key limitations, largely due to incomplete AIS reception in parts of the world and limited algorithm training data for many lesser gear types. Much of this chapter builds on the methods described in Kroodsma et al. (2018).

AIS TECHNOLOGY

In 2002, an agreement under the International Maritime Organisation (IMO) International Convention for the Safety of Life at Sea (SOLAS) aimed to improve safety at sea: to avoid collisions between vessels, all vessels on international voyages that are above 300 gross tonnage are required to carry and operate an AIS device. Each vessel with AIS broadcasts by radio not only a unique nine-digit Maritime Mobile Service Identity (MMSI) number, but also the vessel's position, course, speed, and identity, as well as other information. This information is received by AIS devices on nearby vessels and displayed to alert captains of the presence of nearby marine traffic.

Most AIS devices fall into one of three "classes": Class A, Class B, and Class B+. Class A devices broadcasts at a stronger power (12.5 watts versus 2 and 5 watts for class B and class B+ respectively) and they broadcast a vessel's position more frequently (while moving, every 2 to 10 seconds versus 30 seconds for class B and every 5-30 seconds for class B+). AIS broadcasts on only two frequencies, and if two messages are broadcast on the same frequency simultaneously the messages will interfere with each other. To address this challenge, Class A and B+ AIS devices use a scheme called Self Organizing Time Domain Multiple Access (SOTDMA) to

coordinate with devices on nearby vessels so that they do not broadcast at the same time. The messages are short in duration and can be broadcast at a rate of 4 500 per minute without interference. Across most of the oceans, the density of vessels is relatively low, allowing sufficient time slots for every vessel equipped with Class A devices to broadcast their position without interference. Class B devices, in contrast, use Carrier Sense Time Domain Multiple Access (CSTDMA) to look for unused slots in which to broadcast. If no unused slots are available, Class B devices cannot broadcast. Class B+ is a relatively recent addition and is not as widely deployed as Class A or Class B. For the remainder of this document, Class B and Class B+ are grouped together and referred to simply as Class B (Digital Yacht, 2018).

SATELLITE AND TERRESTRIAL AIS RECEPTION

AIS was initially designed to communicate with vessels in line of sight. Nonetheless, in the past decade, governments and private companies have launched satellite constellations that can record AIS messages. Each satellite can receive messages from a wide swath of the earth, up to 4 500 km to 6 000 km away (McCauley et al., 2016), which means a single satellite can monitor approximately 5 percent of the earth's surface at a given time. These satellites, though, travel quickly, orbiting the earth roughly once every 90 to 110 minutes. Consequently, each satellite will receive messages only from a given location on earth for only a few minutes before passing out of range. For these reasons, a constellation of many satellites is used to obtain coverage of the world's ocean. It should be noted that Class B devices, with their weaker signal, generally are limited to a reception distance of less than 1000 km from a satellite, thus making the messages less detectable than those from Class A devices (Chen, 2014).

AIS satellite companies also aggregate data from a network of terrestrial AIS receivers along the coastlines of many nations, and these terrestrial data provide an important supplement to the satellite data. Because the terrestrial receivers receive messages only from vessels that are a few dozen nautical miles out to sea, they receive messages from fewer vessels than do satellites and are therefore less challenged by message interference. As a result, in some regions, such as coastal China, where AIS satellite reception is poor, terrestrial towers can provide reasonable AIS reception close to shore. Note that the dataset used for this Atlas does not incorporate data from terrestrial receivers along the coasts of southeast Asia and much of south Asia, limiting reception in these areas.

Many satellite and terrestrial providers also do not record every AIS message that they receive. Some terrestrial stations save only one message every 15 minutes, likely because higher frequencies are not needed for most applications. Nor do satellite companies save every AIS message they receive. As a result, graphics of "reception quality" in this Atlas necessarily reflect any AIS processing that has been done by the providers.

The distribution of Class A and B fishing vessels varies among the oceans, but Class B has consistently poorer reception quality (Figure Meth. 1). Vessels broadcast messages every two seconds to three minutes depending on their speed and class, but only a fraction of these messages are recorded in the global databases of satellite and terrestrial data obtained by GFW from the satellite companies Spire and Orbcomm. Not all messages are recorded because satellites may not be overhead, because of interference with other AIS messages, or because the satellite providers do not store every message received. To measure reception quality, GFW counts the fraction of five-minute intervals in a day that a message from a continuously broadcasting vessel is likely to be received (lower panel, Figure Meth.1).

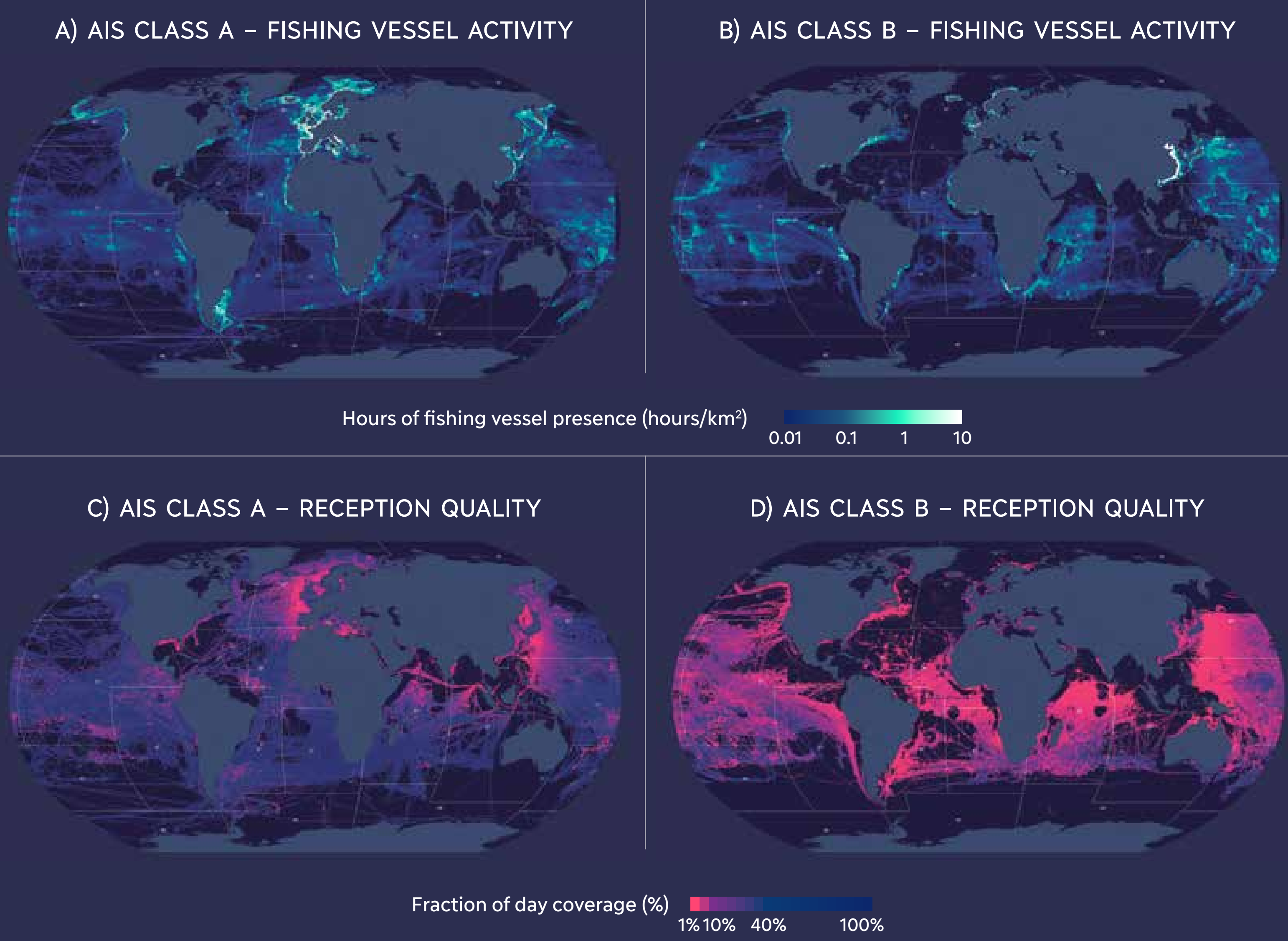


Figure Meth. 1. Fishing Vessel Activity, measured in hours at sea, and AIS reception quality for Class A and B devices during 2017. Note that fishing vessel activity does not differentiate between different activities (fishing, searching, transiting). A value of 100 percent on reception quality on the above chart would mean that, for an average vessel that broadcast all day, at least one signal was received in each five-minute interval of the day.

Because Class A devices have stronger and more frequent signals, they perform better across the globe, and areas with reception quality under 30 percent cover only a fraction of the globe's surface (bottom, Figure Meth.1), with the lowest quality reception in southeast Asia. Other notable areas of poor Class A reception include the Gulf of Mexico and regions around Europe that are out of range of the terrestrial receivers along the coast. Class B devices perform much more poorly, with a wider area of poor performance around southeast Asia, the northern Indian Ocean, and much of the Atlantic basin. On average, Class B reception is one third that of Class A, largely because Class B, on average, broadcasts about one third as frequently. This ratio, however, is even worse in areas of poor reception because of Class B's weaker signal, though Class B devices do perform relatively well when near terrestrial receivers. Also, note that there are some regions of the ocean where few fishing vessels with Class B operate.

DATA PROCESSING BY GLOBAL FISHING WATCH

Each day, GFW receives over 50 million AIS messages from satellite providers Orbcomm and Spire, which in turn have collected these messages from a constellation of dozens of satellites and a global network of terrestrial antenna along the world's coastlines. These messages, which are from both fishing and non-fishing vessels, track the movements of over 300 000 seafaring vessels in a given year (Kroodsma *et al.*, 2018). GFW uses two core algorithms, one to identify fishing vessels and a second model to identify fishing activity. These models, and how they are used to estimate the footprint of global fisheries, are briefly outlined in subsequent sections. Much of these sections draws on methods described in Kroodsma *et al.* (2018), but some notable changes have been made to improve the dataset based on review and feedback from AZTI, FAO, and FAO's partners.

IDENTIFICATION OF FISHING VESSELS AND GEAR TYPES

Identification of fishing vessels in AIS Data

According to regulations from the International Telecommunications Union, each vessel is required to have a unique MMSI number, and a vessel only very occasionally changes its MMSI numbers (such as when a vessel changes ownership or is reflagged). For this Atlas, unique MMSI number are counted as unique vessels. A few MMSI, however, are used by multiple vessels, and these MMSI have been removed from the analyses in this Atlas.

Another challenge in identifying fishing vessels with AIS is that some MMSI appear to be very inactive. Many likely fishing MMSI (described in the following section) broadcast for only a few hours or a few days in the year. In 2017, almost 19 000 Chinese MMSI and almost 6 000 non-Chinese MMSI were likely fishing vessels but fished for less than 24 hours. With so little activity, the vessel classification model has less information to assess, and it is difficult to be sure that these actually are unique fishing vessels, though some had been active in other years. The key questions are whether these vessels are 1) truly inactive, 2) broadcasting AIS for only a small portion of the year, 3) using one MMSI number for a short part of the year and then using a different one for the rest of the year, thus getting double counted, or 4) operating in a region without AIS reception. Poor reception may explain some of the apparently inactive vessels in the Chinese fleet, as east Asia has very poor satellite AIS reception (Figure Meth. 1). Within China, GFW also lacks registries to compare AIS data with, making it difficult to ascertain if vessels are switching MMSI numbers in the middle of the year, which may also account for the vessels without AIS. Outside of China and southeast Asia, though, reception quality is unlikely to account for this number of inactive vessels, and comparison with registries suggests that few of these inactive vessels are rotating MMSI numbers.

Other assessments of vessel activity suggest that a high number of vessels in the world are relatively inactive. An analysis of the European Union fleet found that in 2014, presumably a representative year, 25 percent of vessels under 12 m were inactive, as were 7 percent between 12 and 24 m and 10 percent above 24 m (Paulrud *et al.*, 2015). Given these data, the high number of MMSI with few fishing hours may be accurate. For most analyses in this report, vessels that fished less than 24 hours were excluded so as to keep a more conservative estimate of the number of fishing vessels broadcasting and trackable through AIS. Vessels that fished less than 24 hours in 2017 accounted for only 0.2 percent of the total fishing activity.

Country	Number of unique MMSI of fishing vessels	% of MMSI matched to vessel registries	% of MMSI matched to registries that contain information on vessel length	% of MMSI matched to registries that contain gear type information
China	37 217	23%	3%	2%
Norway	2 190	97%	76%	2%
United States of America	1 984	92%	58%	35%
Spain	1 694	85%	83%	84%
Korea, Republic of	1 541	14%	13%	13%
Italy	1 471	91%	90%	91%
Taiwan, Province of China	1 467	61%	53%	51%
Japan	1 203	74%	28%	31%
United Kingdom	1 121	88%	45%	61%
France	973	98%	83%	87%
Iceland	905	80%	56%	19%
Russia	601	95%	84%	78%
Turkey	537	93%	40%	32%
Canada	515	96%	33%	22%
Netherlands	434	85%	27%	27%
Denmark	424	79%	0%	7%
Portugal	395	97%	96%	96%
Greece	333	99%	79%	81%
Argentina	295	96%	0%	1%
Bahrain	236	0%	0%	0%

Table Meth. 1. Active fleet by Flag State as measured by AIS and the Fraction of Vessels Matched to Registries. Percentages are shown as a percent of MMSI. It includes all likely fishing MMSI that fished for at least 24 hours in 2017.

To both train GFW's vessel classification model, and to identify vessels, GFW matched vessel registries with AIS data. Vessel information was mainly drawn from the following sources:

- European Union 's Community Fishing Fleet Register (http://ec.europa.eu/fisheries/fleet/index.cfm)
- International Telecommunications Union (http://www.itu.int/).
- Consolidated List of Authorized Vessels (http://clav.iotc.org/browser/search/).
- Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR https://www.ccamlr.org/).
- Inter-American Tropical Tuna Commission (https://www.iattc.org/).
- The South Pacific Regional Fisheries Management Organization (SPRFMO) (https://www.sprfmo.org/).
- Western and Central Pacific Fisheries Commission (WCPFC) (https://www.wcpfc.int/).
- International Seafood Sustainability Foundation (ISSF) (http://iss-foundation.org/).
- Pacific Island Forum Fisheries Agency (FFA) (http://www.ffa.int/).
- North Pacific Fisheries Commission (NPFC) (https://www.npfc.int/).
- Merchant Vessels of the United States of America (https://www.dco.uscg.mil/).
- Federal Communication Commission of the United States of America (https://www.fcc.gov/).
- Norwegian Directorate of Fisheries Vessel Registry (http://www.fiskeridir.no).
- Directorate of Fisheries, Iceland (http://www.fiskistofa.is/).
- Korean Register (http://www.krs.co.kr/).
- Russian Maritime Register of Shipping (https://lk.rs-class.org/).
- Transport Canada (http://www.tc.gc.ca/).
- Innovation, Science and Economic Development Canada (http://sd.ic.gc.ca/).

Vessel classification model

To identify the almost 40 000 fishing vessels that were not matched to official registries, GFW developed a model to identify vessel characteristics, including vessel size and gear type, based on vessel movements. This model is trained using GFW's matched vessel database described above. The database (with known attributes of type, length, tonnage and/or engine power) was stratified by gear type and randomly divided in half to create a train and a test dataset. The model – a convolutional neural network – learned to distinguish vessel type, vessel size and engine power from the movements of known vessels in the matched database. For full description of the vessel characterization model, see the supplemental materials of Kroodsma *et al.* (2018).

For each vessel, the neural net classifier produces a score for each of the vessel classes in Table Meth. 2. The sum of these scores adds up to 1. For example, a vessel might receive scores of 0.8 for the class trawlers, 0.2 for drifting longlines, and 0 for the remaining classes. The highest value is the class that is accepted as the assigned class. For this Atlas, a specific class was assigned only if that class had a score above 0.5.

Gear classes used in this Atlas	Gear classes assigned by GFW vessel classification model
Trawlers	Trawlers
Purse seines	Tuna purse seines Other purse seines
Drifting longlines	Drifting longlines
Squid jiggers	Squid jiggers
Other and unknown fishing	Pole and line Pots and traps Set longlines Set gillnets Dredge fishing Other seines Driftnets Trollers

Table Meth. 2. Fishing vessel classes in this Atlas and from GFW. The left column shows the classifications used in this Atlas. The right column shows the classifications by the GFW vessel classification algorithm. For instance, the GFW classification algorithms identifies “tuna purse seines” and “other purse seines,” but for this Atlas these are combined to be simply “purse seines.”

Because there are many vessel classes, it is possible for the highest vessel class score to be less than 0.5. For instance, a vessel may have a score of ‘purse seines’ of 0.4, and scores of ‘passenger’ of 0.3 and ‘tanker 0.3’. In this case, the most likely class of the 13 classes is a purse seine, even though, according to these scores, it is more likely that it is not a purse seine (and not a fishing vessel) than it is a purse seine. In these cases, the values for all fishing and non-fishing classes were summed, and if the sum of the fishing classes was over 0.5, then it was labeled as a fishing vessel of unknown gear type. Other classes that have lower confidence in the model, including set longlines, set gillnets and pots and traps, are also grouped together into fishing vessels of unknown class. These are vessels that we believe to be fishing vessels, but whose gear we are not confident of. For this report, all of these vessels are grouped together into the category of “other and unknown fishing.” As a result, the five AIS gear types are trawlers, purse seines, drifting longlines, squid jiggers and other and unknown fishing (Table Meth. 2). It should also be noted that the squid jiggers class includes some vessels that are not fishing for squid, but they use

lights and similar nets, such as the fishing done by vessels in the northwest Pacific for Pacific Saury (Tseng *et al.*, 2011; Oozeki *et al.*, 2018).

The results were also adjusted based on registries. For a vessel to be assigned a specific gear type, both a registry and the neural network vessel classifier had to agree. If they differed – such as the case when a registry listed the vessel as a trawler but the neural net identified it as a drifting longline – then, if both sources agreed that it was a fishing vessel, the vessel would be classified as "unknown fishing." Vessels classified as non-fishing by either the registry or the neural net were excluded. These disagreements, though, were rare. Less than one percent of vessels identified as fishing by the neural net was on registries as non-fishing vessels, and one and half percent of vessels listed on registries as fishing were identified as non-fishing by the neural net.

Performance of GFW models

The GFW model is relatively accurate at predicting vessel power, tonnage, and length (Figure Meth. 2). Note that the model is able to test the model only on vessels that have been matched to registries. It is likely that these vessels are not fully representative of all vessels in the world because they tend to skew towards larger boats from higher-income countries, and thus the model may have lower accuracy on vessels from other regions of the world.

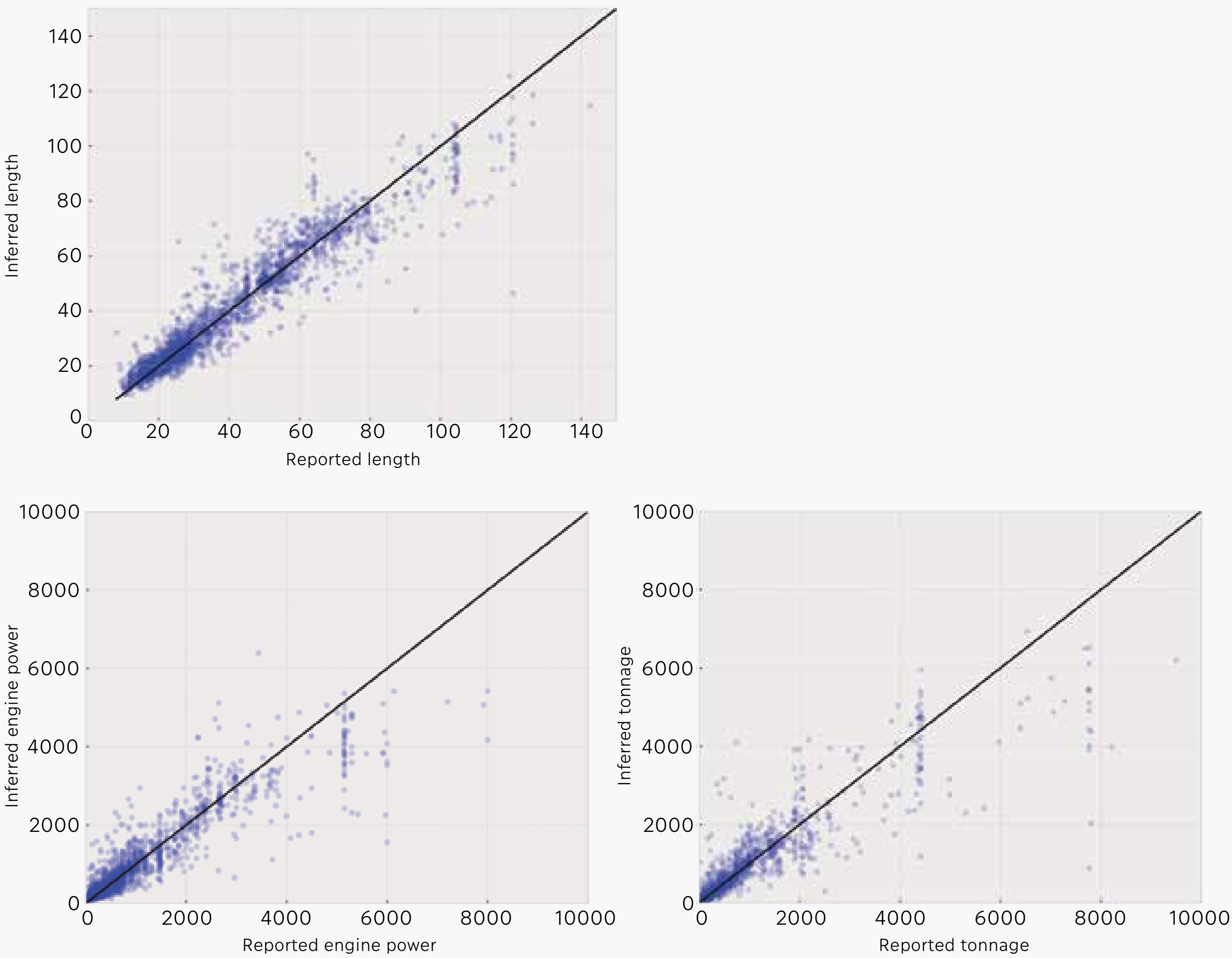
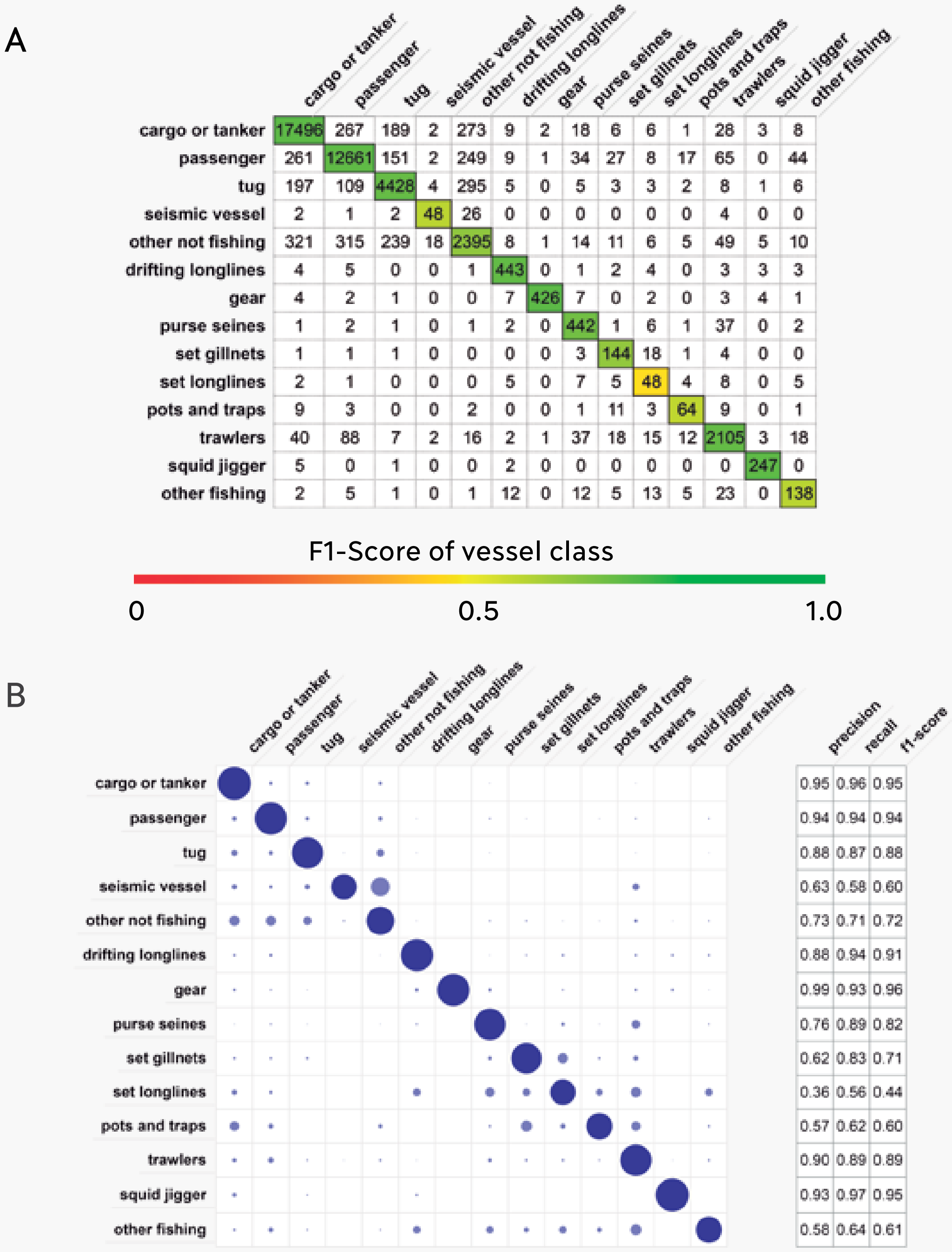


Figure Meth. 2. Performance of Neural Network at Predicting Vessel Size.

These three charts show the accuracy of the neural network at predicting a vessel's length (r = 0.96), engine power (r = 0.93), and gross tonnage (r = 0.89). These values consider only fishing vessels that were in the GFW test dataset.

Overall the neural network model does well at identifying fishing vessels, as illustrated by two views of how the confusion matrix for the neural network predicts vessel class (Figure Meth. 3). The model performs with a precision of 0.90, a recall of 0.95, and an F-1 score of 0.93 at differentiating fishing and non-fishing vessels.



A	cargo or tanker	passenger	tug	seismic vessel	other not fishing	drifting longlines	gear	purse seines	set gillnets	set longlines	pots and traps	trawlers	squid jigger	other fishing
cargo or tanker	17496	267	189	2	273	9	2	18	6	6	1	28	3	8
passenger	261	12661	151	2	249	9	1	34	27	8	17	65	0	44
tug	197	109	4428	4	295	5	0	5	3	3	2	8	1	6
seismic vessel	2	1	2	48	26	0	0	0	0	0	0	4	0	0
other not fishing	321	315	239	18	2395	8	1	14	11	6	5	49	5	10
drifting longlines	4	5	0	0	1	443	0	1	2	4	0	3	3	3
gear	4	2	1	0	0	7	426	7	0	2	0	3	4	1
purse seines	1	2	1	0	1	2	0	442	1	6	1	37	0	2
set gillnets	1	1	1	0	0	0	0	3	144	18	1	4	0	0
set longlines	2	1	0	0	0	5	0	7	5	48	4	8	0	5
pots and traps	9	3	0	0	2	0	0	1	11	3	64	9	0	1
trawlers	40	88	7	2	16	2	1	37	18	15	12	2105	3	18
squid jigger	5	0	1	0	0	2	0	0	0	0	0	0	247	0
other fishing	2	5	1	0	1	12	0	12	5	13	5	23	0	138

B	precision	recall	f1-score
cargo or tanker	0.95	0.96	0.95
passenger	0.94	0.94	0.94
tug	0.88	0.87	0.88
seismic vessel	0.63	0.58	0.60
other not fishing	0.73	0.71	0.72
drifting longlines	0.88	0.94	0.91
gear	0.99	0.93	0.96
purse seines	0.76	0.89	0.82
set gillnets	0.62	0.83	0.71
set longlines	0.36	0.56	0.44
pots and traps	0.57	0.62	0.60
trawlers	0.90	0.89	0.89
squid jigger	0.93	0.97	0.95
other fishing	0.58	0.64	0.61

Figure Meth. 3. Confusion Matrix Showing High Model Accuracy at Classifying Test Data.

Figure Meth. 3A shows the number of vessels in a given class (row) that were classified as one of the 14 vessel classes in GFW database; the color along the diagonal corresponds to the F-1 score for that vessel class. Figure Meth. 3B shows the same data as does Figure Meth. 3A, but with circles corresponding to the fraction of each vessel class proportioned to different classes.

Errors in vessel classification identified by this Atlas

The review of data for this Atlas revealed a number of errors in the classification of vessels by gear type in Kroodsma *et al.* (2018). Some of these errors appear to be at least partially attributable to bad training data, in which registries used by GFW contained incorrect or incomplete information. For example, some vessels identified by GFW as purse seiners or set gillnets in the Bay of Biscay were actually engaged in trolling. A review of the training data showed that GFW had identified the vessels correctly based on the European Union 's Community Fishing Fleet Register, but that the European Union list had either listed the gear type incorrectly or had not listed that the vessels had a secondary gear of trolling. In another case, many of the set longlines in CCAMLR (fishing near Antarctica) were incorrectly identified as drifting longlines. Fortunately, improved training data has since corrected many of these errors and better training data should continue to reduce these errors in future versions of this dataset. Collectively, these errors have resulted in adopting a simpler, more conservative classification of gears that does not include all of the classes listed above.

A key limitation for vessel classification is that the GFW vessel classification algorithm currently cannot identify multi-gear vessels or differentiate between their fishing activities. The result is that some of the gear types that are more frequently changed are more likely to have errors. The vessel classes that the GFW algorithm had the most trouble with, including set longlines, set gillnetters, and pots and traps, are sometimes used by vessels that switch gears in different seasons. Additionally, distinguishing between set longlines and drifting longlines was a challenge that has been addressed by this Atlas. To be a drifting longline in the Atlas, in addition to either being identified as a drifting longline by the vessel classification algorithm or a registry, a vessel has to fish in waters that are, on average, at least 200 m deep. This rule is in line with the FAO description of drifting longlines as only operating in pelagic waters (FAO 2001).

FISHING ALGORITHMS

Fishing operations model

A key aspect of this Atlas is being able to differentiate fishing operations from transiting and other non-fishing activity. To accomplish this goal, GFW used a second convolutional neural network that classified each AIS position as being part of a fishing operation or not. To train this fishing model, GFW staff and research partners hand labeled the tracks of 624 fishing vessels, labeling 247 000 hours of AIS tracks. Over 569 000 positions were labeled as fishing or not fishing. Judgement was based on experiences of former fisheries observers and a literature review. This training data also included the training data from de Souza *et al.* (2016). For this classification, only times with likely gear in water or hauling gear out of water were considered fishing operations. Searching was classified as "not fishing" even though searching by some fishing gears is sometimes included in measures of fishing hours (e.g. purse seines, trolling). This issue should be further developed in the future by using training datasets based on purse seine and/or trolling VMS fishing activities.

The labeled data included drifting longlines, pole and line vessels, purse seines, set gillnets, set longlines, trawlers and trollers. The model discriminates between fishing and non-fishing points in the test set with over 90 percent accuracy. Note that the test set contains only vessels with known vessel classes (dominated by drifting longlines), typically from registries, and so is likely biased toward larger, more predictable vessels. In addition, the test set is biased towards areas with better AIS reception. As a result, the overall accuracy is likely lower than the quoted 90 percent figure. Also, the model does not know the fishing class of a vessel. So, a purse seine that moves like a drifting longline will have its fishing activity classified like a drifting longline. Finally, for gears that are less common in the AIS data, such as trollers, pole and lines and set longlines, there are fewer training examples, and the model could likely benefit from more training data. For a full description of the fishing operations neural net classifier, see the supplemental materials of Kroodsma *et al.* (2018).

The fishing operations model is used for all vessels except those identified as squid jiggers. As no training data were collected for squid jiggers, GFW instead applied a simple heuristic based on conversations with experts and a review of the activity of the squid fleet operating outside the Peruvian EEZ (Paulino *et al.*, 2017). These vessels fish only at night and only while relatively stationary. The heuristic labels positions as fishing if the vessel is more than 10 nautical miles from shore and moving slower than 1.5 knots at night for more than four hours.

Effect of AIS reception on estimating fishing operations by gears

To determine the effect of reception on these AIS fishing algorithms, GFW took data from parts of the world with good AIS reception, randomly removed AIS positions, reran the models, and measured fishing hours (Figure Meth. 4). The effect of AIS reception varies considerably by gear type. When reception is above 20 percent (about 55 positions out of a maximum possible 288 5-minute periods per day), the fishing hours vary by less than 5 percent; below 20 percent, the effect depends on the gear. Drifting longlines provide relatively stable estimates of fishing hours until reception drops below 5 percent (about 15 positions in a day); in contrast, fixed gear (a combination of set longlines, pots and traps, and set gillnets) and purse seines detect about 80 percent of the actual number of fishing hours when reception is at 10 percent, and only about 65 percent of the fishing hours at 5 percent reception. Interestingly, drifting longlines record slightly higher fishing hours at 20 to 30 percent than they do at more than 40 percent reception.

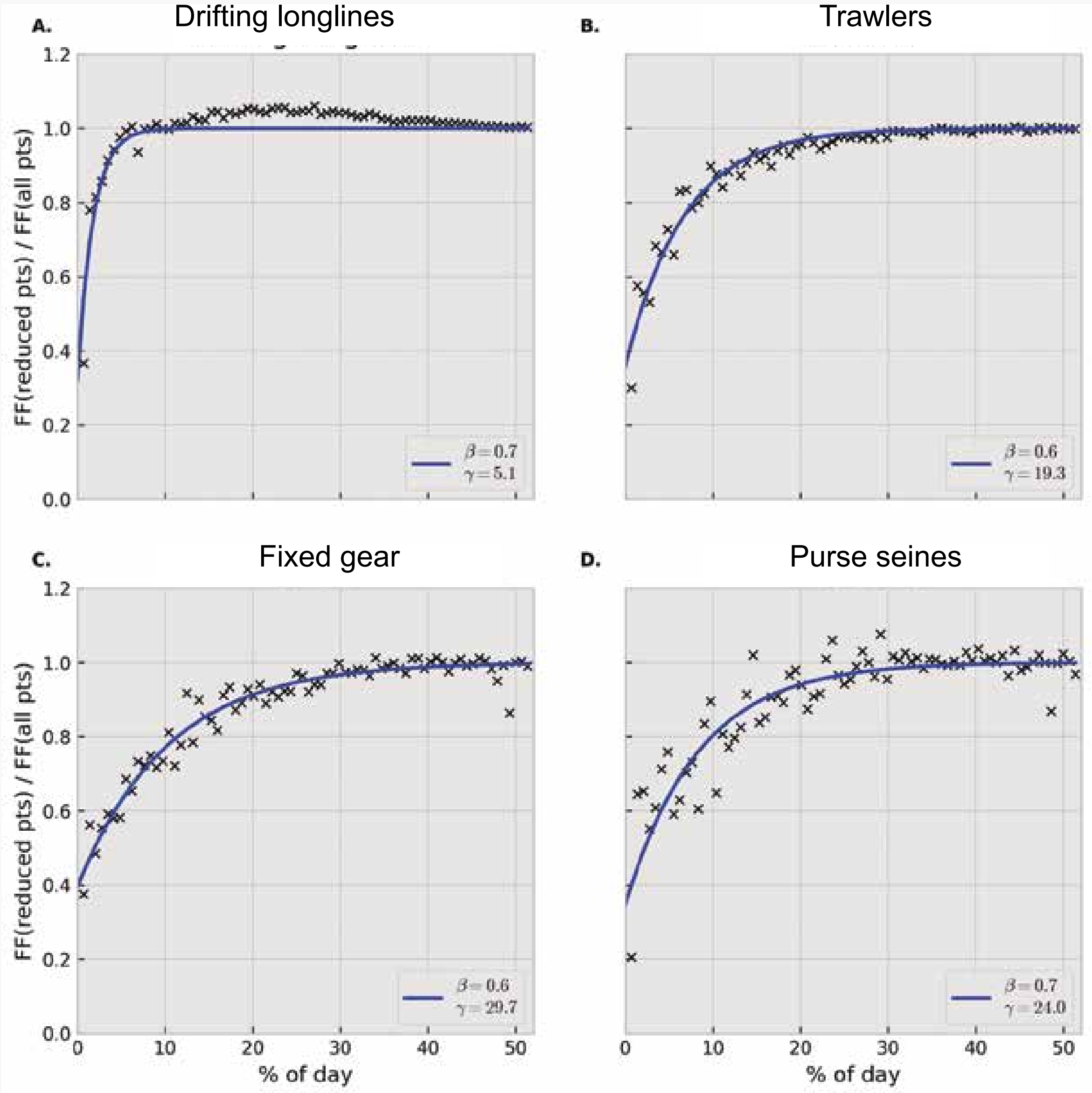


Figure Meth.4 Effect of AIS Reception on Fishing Hours.

To calculate the effect of reception on fishing activity, GFW randomly removed AIS positions and reran the fishing model to estimate time in fishing operations (FF). Figure Meth.4 shows, for grid cells that had good AIS reception before the data was thinned (>33% reception quality), how the modeled time in fishing operations deteriorates with fewer positions, thus simulating the effect of poorer AIS reception. The effect varied by gear type, and an equation of form F_missing=1-β*e^((-x/γ)) (blue line) was fit to each gear type, where x is the observed number of five-minute intervals per vessel in the grid cell. Values for β and γ for each gear type are shown on each plot.

Measuring fishing hours and days at sea

To translate the placing or hauling of fishing gear, as measured by the neural net, into hours of fishing operations, each position is assigned half the time to the previous and next AIS position. Time between positions is calculated up to 24 hours between positions; after that, no time is assigned. If the position is classified as fishing, then all the time associated with that position is considered "fishing."

Measuring fishing hours requires running the fishing classifier on AIS tracks, and this classifier does not perform as well when AIS reception is very poor, which in turn has a noticeable effect on estimated total fishing hours in some parts of the world, especially for Class B devices. Specifically, the ability to measure fishing hours with AIS starts to degrade when reception drops below 30 percent, and performs very poorly below 10 percent reception. GFW estimated that in 2016 reception reduced fishing hours in the GFW dataset by 8 percent, with the effect being highest for purse seines (20 percent reduction) and lowest for drifting longlines (2 percent; see Technical Appendices in Kroodsma *et al.*, 2018). The same analysis has not been repeated for 2017, but because AIS reception has improved due to more satellites being launched, the estimation of fishing operations is likely improved for 2017.

By using fishing hours, fishing operations can be mapped in high detail. Comparing fishing hours across gear types can be problematic, however, because vessels will spend a different portion of the day with their gear in the water. A purse seine, for instance, will either be setting or hauling for a small fraction of their time at sea, while a drifting longline will be setting or hauling for the majority of a given day while fishing. In the GFW dataset, purse seines are "fishing" for about 15 percent of the time they are at sea, while drifting longlines are "fishing" for 60 percent. As a result, one drifting longline will appear to fish as many hours as four purse seines in a given day, and thus record four times the effort. The problem is that only time of set is considered for purse seine activity, not searching time. Another challenge is the fishing hours measure treats both small and large vessels exactly the same. A 100-m tuna purse seine vessel fishing for one day will catch many times the fish that are caught by a 25-m tuna

purse seine. GFW research partners are currently developing better ways to aggregate fishing operations to estimate effort. One possibility is to calculate the energy expended by a vessel over its journey and assign that energy spatially using fishing hours. In that way vessel size is considered in the estimation of effort.

To compare fishing with catch in this Atlas, the number of days that a vessel is at sea is used because that is likely a better metric of fishing effort. Using the number of calendar days at sea provides a more uniform way to compare effort between gear types in a given region than does fishing hours. The number of days at sea is also much less sensitive to lower AIS reception than fishing hours, and thus provides a more stable comparison between high reception and low reception parts of the globe. Although days at sea is a basic unit that can be compared between regions, it does not consider the different size of vessels or other metrics of catching power.

Other challenges with AIS data

In addition to limitations due to AIS reception and use, there are several challenges to working with AIS data associated with data quality that must be addressed when identifying fishing activity.

Noise: Poor error checking in AIS transmission protocols and the loss of individual units of data (bits) during transmission may lead to a significant number of AIS messages containing errors and incorrectly broadcast positions. Plots of every position reported from an AIS device show vessel positions in impossible places such as the middle of continents. To deal with this "noise" issue, the distance and time between each consecutive position for a given vessel is calculated. If the implied speed between the positions -- the distance divided by the time -- is realistic for a vessel, those points are added together into a realistic vessel track "segment." The unrealistic, incorrect positions end up in short segments and most of the noise is eliminated from the dataset by removing segments with fewer than 10 positions.

Segmenting and Spoofing: In theory, each MMSI number, the unique vessel identifier in AIS, is supposed to be used by only one vessel. In practice, however, some vessels use an invalid number or use the number of another fishing vessel. Plots of the tracks of an MMSI used by multiple vessels show the vessel's position jumping back and forth across the globe. These tracks can be separated by an algorithm that groups tracks into realistic segments. Each point is added to a segment only if a realistic speed between the positions is possible. In 2017, about 700 fishing MMSI, or about one percent of fishing MMSI, were used by two or more vessels at the same time for at least 24 hours. These MMSI numbers, the majority (~90 percent) of which were Chinese and operated predominantly in the Chinese EEZ, were removed from this database.

Offsetting: A few vessels appear to broadcast locations that are hundreds of miles away from their actual location. These offsets can be identified because GFW has the orbital location at the time of reception of the satellite that received the AIS transmission. As a result, GFW can identify those vessels whose purported locations are outside the footprint of the satellite that received their AIS transmission. Vessels that are being recorded by terrestrial receivers, but which report that they are far out to sea, can also be identified. The reason for these offsets is unclear, and it is possible that they are unintentional. Only about 200 vessels were identified as offsetting their positions, and they have been removed from the analysis.

ACKNOWLEDGEMENTS

The authors and editors would like to thank Jennifer Gee, Kiran Viparthi, Marc Taconet, Jose A. Fernandes for excellent comments and feedback during the elaboration of the chapter. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Required citation for this chapter:

Kroodsma, D., Miller, N. A., Hochberg, T., Park, J., Clavelle, T. 2019. AIS-based methods for estimating fishing vessel activity and operations. *In* Taconet, M., Kroodsma, Fernandes, J. A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

Chen, Y. undated. *Detection Probability Analysis of Space-Based AIS Signal by Using Geometrical Model. : 11.*

FAO. 2001. Fishing Gear types. Drifting Longlines. Technology Fact Sheets. *In* FAO Fisheries and Aquaculture Department [online]. [Cited 11 September 2019].

International Convention for the Safety of Life at Sea (SOLAS). 2002. *SOLAS Chapter V - Annex 17 - Automatic Identification System (AIS).* [Cited 11 November 2018]. http://solasv.mcga.gov.uk/Annexes/Annex17.htm

Kroodsma, D.A., Mayorga, J., Hochberg, T., Miller, N.A., Boerder, K., Ferretti, F., Wilson, A., Bergman, B., White, T.D., Block, B.A., Woods, P., Sullivan, B., Costello, C. & Worm, B. 2018a. Tracking the global footprint of fisheries. *Science*, 359(6378): 904–908. https://doi.org/10.1126/science.aao5646

McCauley, D.J., Woods, P., Sullivan, B., Bergman, B., Jablonicky, C., Roan, A., Hirshfield, M., Boerder, K. & Worm, B. 2016. Ending hide and seek at sea. *Science*, 351(6278): 1148–1150. https://doi.org/10.1126/science.aad5686

Oozeki, Y., Inagake, D., Saito, T., Okazaki, M., Fusejima, I., Hotai, M., Watanabe, T., Sugisaki, H. & Miyahara, M. 2018. Reliable estimation of IUU fishing catch amounts in the northwestern Pacific adjacent to the Japanese EEZ: Potential for usage of satellite remote sensing images. *Marine Policy*, 88: 64–74. https://doi.org/10.1016/j.marpol.2017.11.009

Paulino, C., Aroni, E., Xu, H., Alburqueque, E. & Demarcq, H. 2017. Use of nighttime visible images in the study of the spatial and temporal variability of fishing areas of jumbo flying squid (Dosidicus gigas) outside Peruvian EEZ 2004–2015. *Fisheries Research*, 191: 144–153. https://doi.org/10.1016/j.fishres.2017.03.009

Paulrud, A., Carvalho, N., Alessandra Borrello & Motova, A. 2015. *The 2015 Annual Economic Report on the EU Fishing Fleet (STECF 15-07).* JRC Scientific and Policy Reports No. STECF 15-07. European Commission. (also available at https://www.researchgate.net/profile/Sebastien_Metz/publication/295909430_Scientific_Technical_and_Economic_Committee_for_Fisheries_The_2015_Annual_Economic_Report_on_the_EU_Fishing_Fleet_STECF_15-07/links/56d0462408ae059e375d0dff.pdf).

Souza, E.N. de, Boerder, K., Matwin, S. & Worm, B. 2016. Improving Fishing Pattern Detection from Satellite AIS Using Data Mining and Machine Learning. *PLOS ONE*, 11(7): e0158248. https://doi.org/10.1371/journal.pone.0158248

Tseng, C.-T., Sun, C.-L., Yeh, S.-Z., Chen, S.-C., Su, W.-C. & Liu, D.-C. 2011. Influence of climate-driven sea surface temperature increase on potential habitats of the Pacific saury (*Cololabis saira*). *ICES Journal of Marine Science*, 68(6): 1105–1113. https://doi.org/10.1093/icesjms/fsr070

U.S. Coast Guard Navigation Center. 2019a. *AIS Frequently Asked Questions.* [Cited 11 November 2018]. https://www.navcen.uscg.gov/?pageName=AISFAQ#9

U.S. Coast Guard Navigation Center. 2019b. *AIS Requirements.* [Cited 11 November 2018]. https://www.navcen.uscg.gov/?pageName=AISRequirementsRev

Use of AIS by the world's fishing fleet

David Kroodsma, Nathan A. Miller, Jennifer Gee, Tim Hochberg, Jaeyoon Park and Tyler Clavelle

SUMMARY AND CONCLUSIONS OF AIS-DATA BASED METHODS

In 2017, AIS was broadcast by approximately 60 000 fishing vessels. These vessels were identified in AIS data that appear to have demonstrated fishing activity for a total of at least 24 hours in the year. Of these, just over 22 000 were identified by matching AIS to vessel registries, while the rest were identified by Global Fishing Watch (GFW) algorithms, which identify fishing vessels based on their behavior. The number of vessels broadcasting AIS is also increasing each year as more vessels install devices: between 2014 and 2017, the number of vessels broadcasting increased by 10 percent to 30 percent each year.

The active fleet derived from AIS data is biased toward 1) large vessels; 2) upper-income and middle-income countries/territories; and 3) distant water fleets. Although the majority of fishing vessels larger than 24 m use AIS (between 52 percent and 85 percent), relatively few fishing vessels between 12 and 24 m in length broadcast AIS (14 percent to 19 percent), and only a tiny fraction of vessels under 12 m do so (<0.4 percent). Also, the vessels broadcasting are predominantly from upper-income and upper middle-income countries because 1) the majority of vessels over 24 m are from these countries/territories and 2) these countries/territories generally have higher use of AIS, largely due to stronger regulations. Last, AIS use is relatively high in distant water fleets (fleets of vessels fishing in the Exclusive Economic Zones (EEZ) of foreign nations or in the high seas).

FAO STATISTICS ON FISHING VESSELS BY FLEET

FAO fleet statistics, which are reported to the FAO by FAO member states, were used to compare the vessels broadcasting AIS to all fishing vessels in the world. The reporting, which varies in time and in coverage, is requested on an annual basis and includes fleet dimensions of vessel type, overall length, power, and gross tonnage. Aside from the European Union reporting, which is registry-based, the FAO dataset does not contain vessel-by-vessel data.

This Atlas uses fleet statistics for the most recent year reported to the FAO (2017), with a few exceptions. These exceptions include the following:

- For China, the numbers are obtained from the Chinese Statistical Yearbook for 2017, which provides the number of vessels by size class.
- For vessels larger than 24 m, the United States of America, Indonesia, and Japan provided more accurate data than were available in the FAO statistics; the Atlas uses those data for this size class and then uses FAO statistics for vessels under 24 m. For Indonesia, data from Indonesian VMS, obtained by GFW, were used to estimate the number of vessels over 24 m. For the United States of America, the Merchant Vessels of the United States of America, provided by the U.S. Coast Guard, was used. For Japan, the Japan 2013 Census of fisheries available at Portal Site of Official Statistics of Japan was used.
- Pakistan's number of vessels larger than 24 m was reported incorrectly, so vessels of this size are not reported in this Atlas.
- Thailand, Australia, and Malaysia reported all vessels sizes as "unknown" in 2017, likely in error, as they appear to have no similar errors or missing data in previous years. The Atlas uses the previous year's data to obtain the ratio of size classes for each country, and then applies that ratio to the total number of vessels reported in 2017.

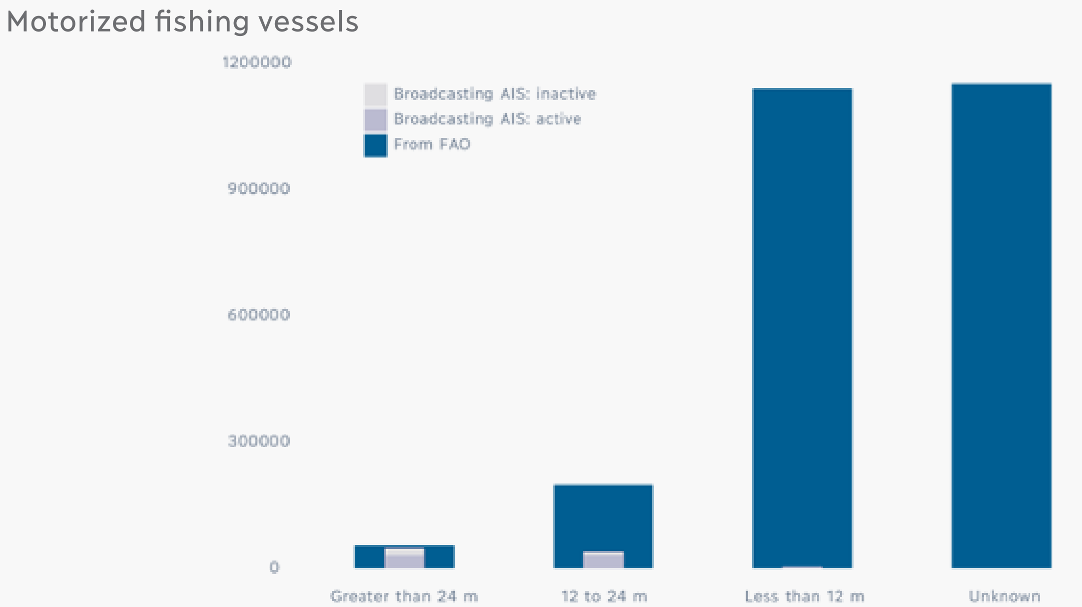


Figure Use. 1. Number of fishing vessels (unique MMSI) by size identified by GFW in 2017 compared with FAO fleet statistics for motorized fishing vessels. Active vessels are those that fished for more than 24 hours in 2017.

Use of AIS varies considerably among the world's fishing fleets. Approximately two thirds of the world's fishing vessels larger than 24 m are Chinese, and the majority of these were seen to broadcast at some point during 2017 (Figure Use. 2a). For the next top 20 fleets, as measured by the number of vessels larger than 24 m (Figure Use. 2b), Indonesia has the second largest fleet but has only a tiny fraction of vessels with AIS, while most European Union countries have high adoption. Notably, most of the countries with large fleets, according to the World Bank classification, are upper middle income or higher income states. The only countries to be grouped in the World Bank's "lower middle income" group or poorer in the top 20 fleets are Indonesia, Myanmar, Tunisia, and Papua New Guinea, all of which have a very low adoption of AIS when compared to the rest of the top 20 countries/territories. Additionally, the use of Class A and B AIS devices varies significantly by fleet. For instance, the majority of the Chinese fleet uses Class B, while most of the European fleets use Class A.

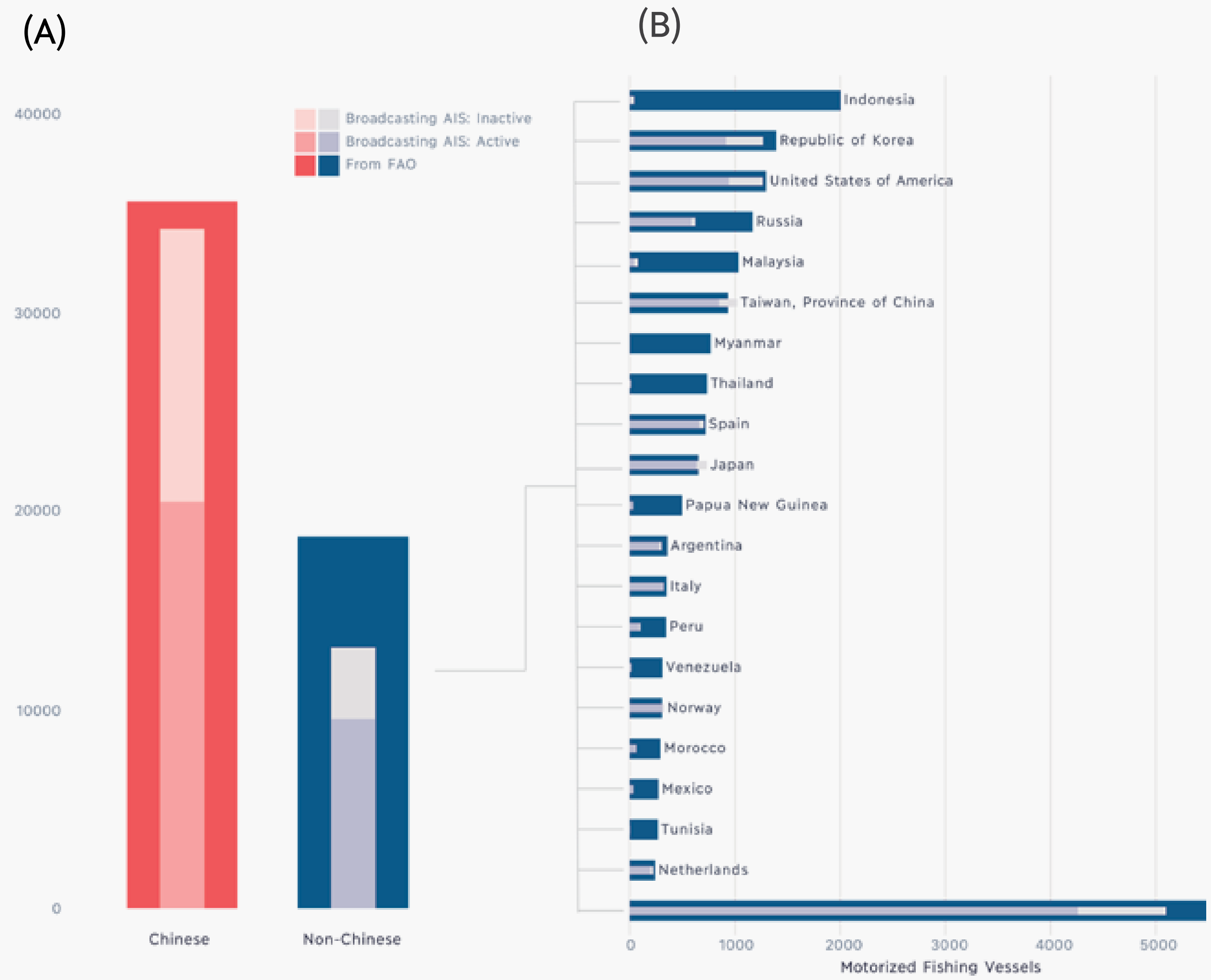


Figure Use. 2: Number of vessels larger than 24m that used AIS in China (A) and the world's 20 largest fleets (B), compared with fleet capacity measured by FAO fleet statistics. Because China's fleet has almost two thirds of the world's fishing vessels larger than 24m, it is shown separately (red bar). Active vessels are represented by dark shading, inactive by light shading, as defined by vessels having more than or less than 24 hours of fishing in the 2017 GFW AIS dataset. A vessel is a unique MMSI that was identified as fishing by GFW (see Identification of Fishing Vessels and Gear Types) and was not used by multiple vessels.

In general, AIS can be used to estimate the active fleet for larger vessels for many different flag states because a high fraction of these large vessels broadcast AIS (Figure Use. 2). The high number of vessels over 24 m that broadcast AIS is not due to international regulations; the Convention for the Safety of Life at Sea (SOLAS) requires AIS use only on vessels over 300 gross tonnage on international voyages. Most fishing vessels are smaller than this size. Fishing vessels larger than 300 gross tonnage are, on average, 37 m in length and larger, and only about 4 000 of the world's 2.8 million fishing vessels are of this size (Kroodsma *et al.*, 2018). More importantly, fishing vessels are explicitly exempted from having to follow the SOLAS regulations.

The high level of AIS use is mainly because many flag states adopt regulations stricter than SOLAS. A review of the rules governing 64 flag states, including almost all the top fishing nations, showed that over 50 flag states have regulations stricter than SOLAS (McCauley *et al.*, 2016). Some of the strictest AIS regulations are in Europe, where all fishing vessels over 15 m are required to broadcast AIS (EC Council Regulation 1224/2009 Article 10). AIS regulations in the United States of America require AIS on all vessels larger than 19 m (65 feet). The Pacific Islands Fishing Forum Agency (FFA), which governs the waters of 17 states in the Pacific, requires all foreign vessels to have AIS (Pacific Islands Forum Fisheries Agency, 2018). The review, however, did not find any AIS regulations for the top fleets in east Asia, including China, Japan, Korea, and Taiwan, Province of China, although use of AIS by these countries suggests implementation stricter than SOLAS (Figure Use. 2), as most of their vessels larger than 24 m appear to broadcast AIS.

FRACTION OF VESSELS WITH AIS BY RFMO AND IN THE HIGH SEAS

Because larger vessels fish farther from shore than do smaller vessels, and because a higher fraction of larger vessels uses AIS than do smaller ones, the fraction of fishing effort captured by AIS is higher farther away from shore than close to shore, even if the total fishing effort is higher close to shore. Over half of the fishing operations more than 100 nautical miles from shore was estimated to be by vessels that have AIS devices (Kroodsma *et al.* 2018). Another analysis suggests that about 80 percent of vessels fishing more than 200 nautical miles from shore (i.e., the high seas) have AIS devices (Sala *et al.* 2018).

Sala *et al.* (2018) also performed a detailed review of high seas fleets and the fraction of vessels with AIS by fleet and RFMO. One challenge is that different documents provide conflicting information on the fleet activity, making it challenging to calculate the fraction of fishing activity that is captured by AIS. For instance, according to Sala *et al.* (2018), the Chinese Ministry of Agriculture reports that 840 vessels are active in the high seas, and Sala *et al.* identified 838 Chinese fishing vessels active in the high seas in 2016, suggesting that AIS is capturing the entire Chinese longline fleet. In contrast, the Indian Ocean Tuna Commission (IOTC) reports that 67 Chinese longlines were active in commission waters during 2016, but only 18 Chinese longlines using AIS are identified in this region, suggesting that not all Chinese vessels are broadcasting AIS. Nonetheless, this review helps estimate which regions have relatively better use of AIS.

AIS use appears lowest in the high seas of the Indian Ocean and highest in the Pacific, with intermediate AIS use in the Atlantic Ocean (Sala *et al.* 2018). For instance, the Republic of Korea was observed to have 100 percent AIS usage in every basin except the Indian Ocean, where only 75 percent of the vessels used AIS in 2016. Another example is the USA, which had a higher proportion of vessels with AIS in the Pacific (~100 percent in IATTC and 75 percent in the WCPFC) than in the Atlantic (55 percent). For a full table, see the supplemental materials of Sala *et al.* (2018), in which 3 619 active vessels are identified with AIS on the high seas in 2016.

AIS USE OVER TIME

With changing regulations, the number of vessels carrying AIS has increased with time. The GFW AIS database starts in 2012, although only a few fishing vessels had AIS in that year. In 2013, AIS was adopted by the European Union and Chinese fleets, which resulted in a significant increase in use, and AIS use has gradually increased in each subsequent year (Figure Use. 3).

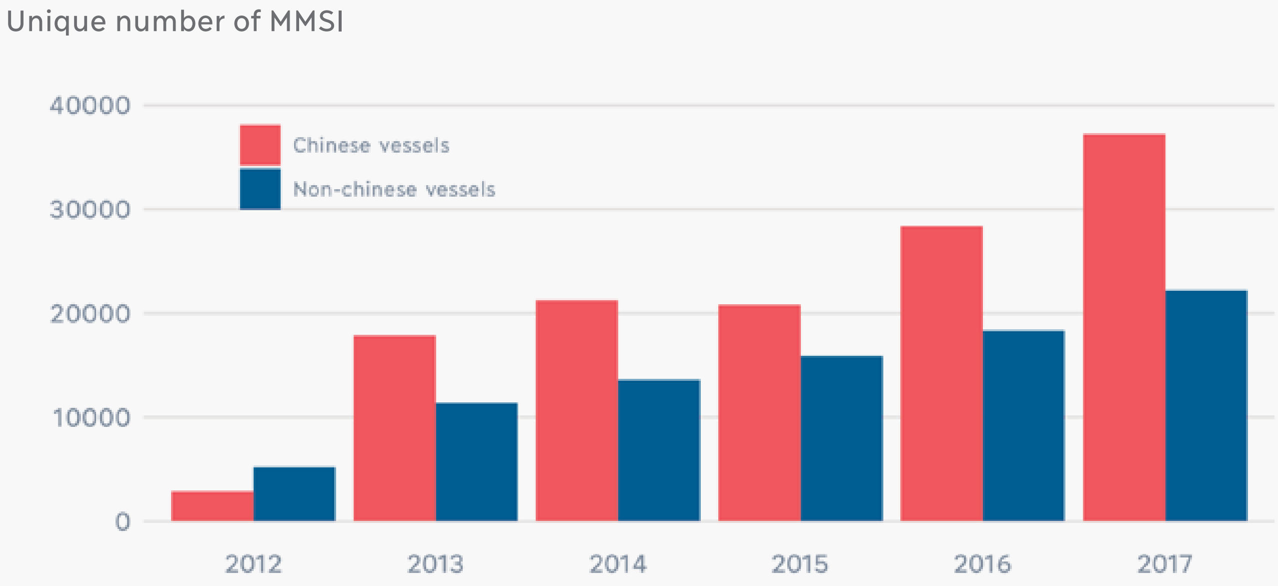
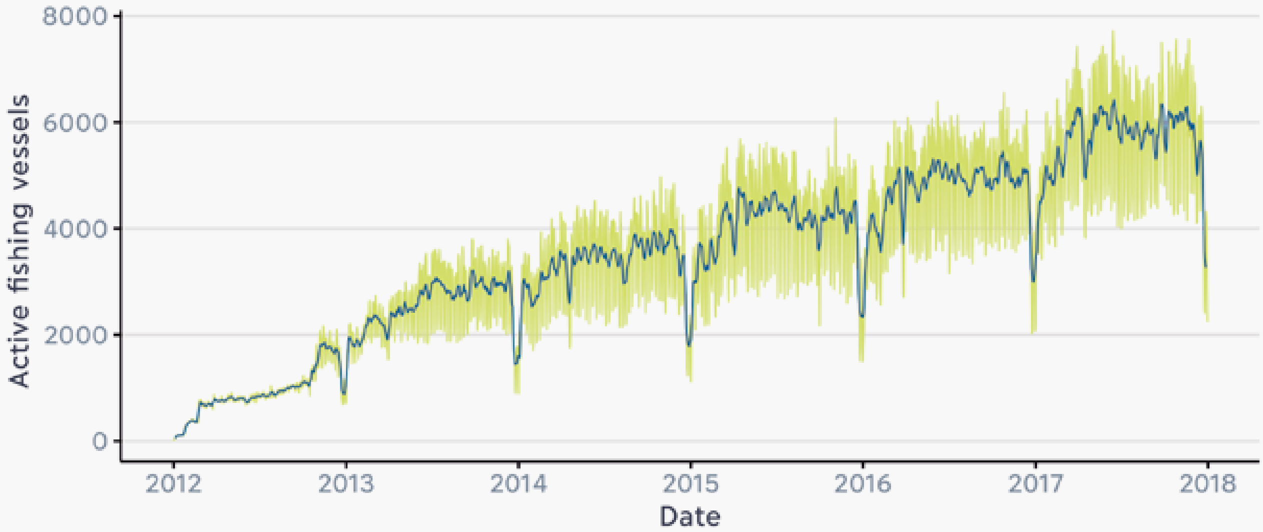
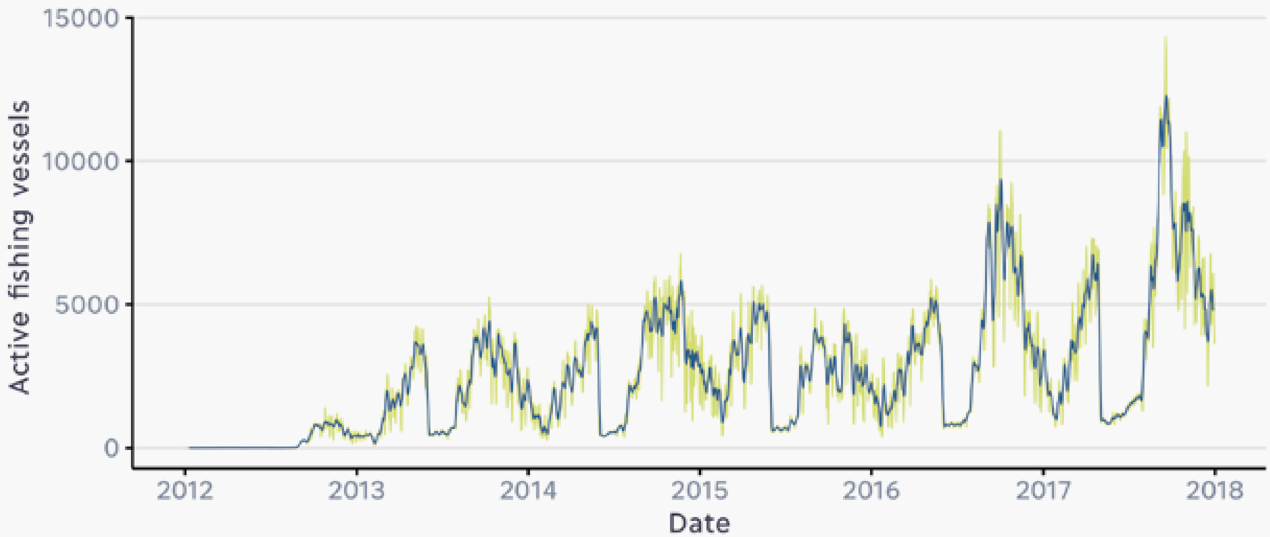


Figure Use. 3. Number of Active MMSI Fishing Vessels Active per Year in GFW Database. Shown is the number of fishing vessels that fished for at least 24 hours in each year of the GFW database.

AIS use per year and day by active vessels (those that fished for at least 24 total hours in a given year) shows a steady increase over time, with seasonal fluctuations (Figure Use. 4). The Chinese fleet has a minimum fishing activity during the summer months because of moratorium on most fishing within the country's EEZ for most gear types, as well as in February during the Chinese New Year. This moratorium was extended from three to four months in 2017, which can be seen in Figure Use. 4b. Non-Chinese vessels, which are largely dominated by European countries, show a strong weekly pattern and a dip during the Christmas holiday (note that the timing aligns more strongly with Christmas than New Years) (Kroodsma *et al.*, 2018).



Number of unique (MMSI) non-Chinese fishing vessels active per day



Number of unique (MMSI) Chinese fishing vessels active per day

Figure Use. 4. Number of Unique MMSI Fishing Vessels Active per Day. For this analysis, only "active vessels" (those that fished for at least 24 hours in a given calendar year) that were moving and were more than 3 kilometers from port were included. The yellow line shows the daily number active, while the blue line shows a seven-day average.

AIS USE IN DISTANT WATER FLEETS

AIS use is relatively high in the world's distant water fleets, that fish in the Exclusive Economic Zones (EEZs) of foreign nations. An analysis by Global Fishing Watch and the Stimson Center (Sally and Shaver 2019) shows that, excluding European Union nations fishing in the waters of other European Union nations, the top distant water fleets fishing in the EEZs of foreign nations are the same as the top fleets fishing in the high seas: China and Taiwan Province of China, Japan, Republic of Korea, and Spain (Figure Use. 5).

All of these fleets have a high use of AIS as they are predominantly large vessels (> 24 m) and predominantly fish within the EEZs of developing Pacific Island States or off Africa (19 of the top 20 EEZs fished by DWF). In both of these regions, adoption of AIS by domestic fleets is low. As a result, AIS fishing vessel activity in these regions is dominated by foreign fleets. For instance, in the EEZs of West Africa, European and Asian fleets appear to have several times more fishing vessel activity than African flagged vessels. While it is possible that these fleets are taking a disproportionate amount of the catch, the relative AIS use by foreign and domestic fleets exaggerates this difference, and the AIS data alone cannot show that foreign fleets dominate the region.

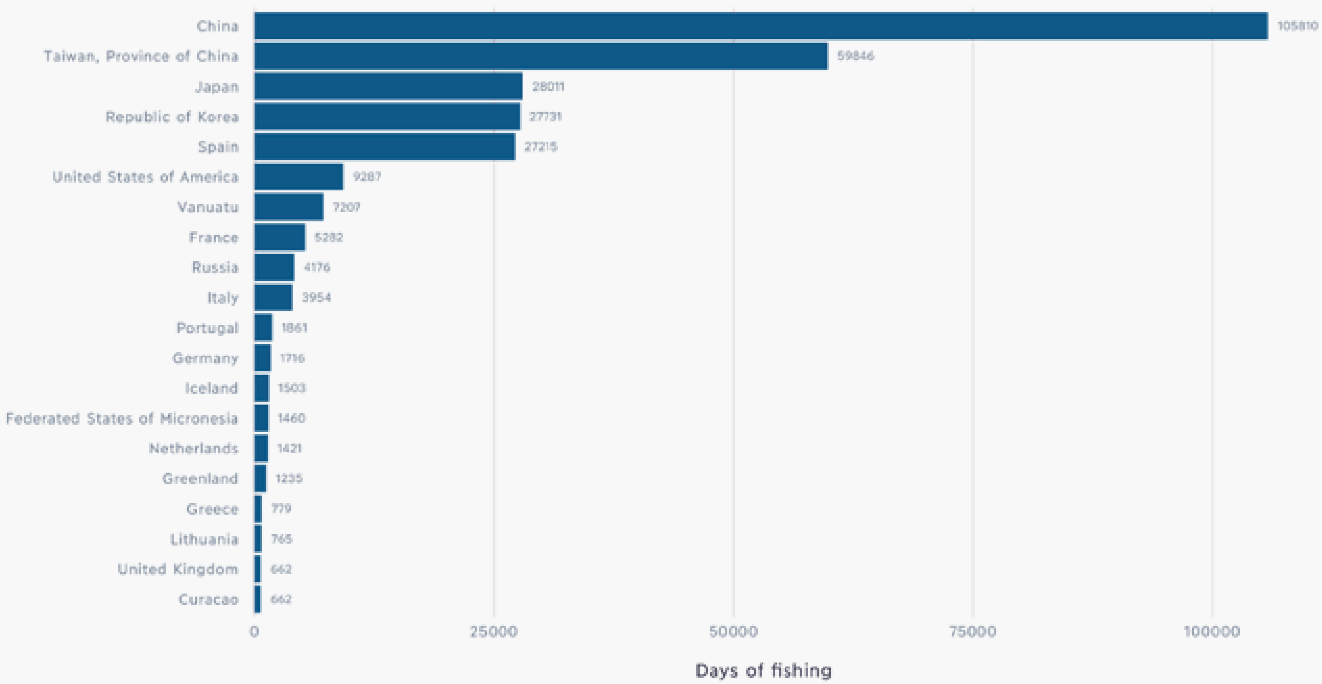


Figure Use.5 Top Distant Water Fleets, 2016-2017. Shows the number of fishing days, by distant water fleet, in foreign exclusive economic zones (EEZs) in 2016 and 2017, as calculated by the Stimson Center and Global Fishing Watch. EEZs that are adjacent to the flag state are excluded (so Chinese vessels fishing in Vietnamese waters are not included, nor Spanish vessels fishing off Morocco), as are any European Union vessels fishing in other European waters.

ACKNOWLEDGEMENTS

The authors and editors would like to thank Kiran Viparthi, Marc Taconet and Jose A. Fernandes for excellent comments and feedback during the elaboration of the chapter. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Required citation for this chapter:

Kroodsma, D., Miller, N. A., Gee, J., Hochberg, T., Park, J., Clavelle, T. 2019. Use of AIS by the world's fishing fleet. *In* Taconet, M., Kroodsma, Fernandes, J. A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

Kroodsma, D.A., Mayorga, J., Hochberg, T., Miller, N.A., Boerder, K., Ferretti, F., Wilson, A., Bergman, B., White, T.D., Block, B.A., Woods, P., Sullivan, B., Costello, C. & Worm, B. 2018a. Tracking the global footprint of fisheries. *Science*, 359(6378): 904–908. https://doi.org/10.1126/science.aao5646

McCauley, D.J., Woods, P., Sullivan, B., Bergman, B., Jablonicky, C., Roan, A., Hirshfield, M., Boerder, K. & Worm, B. 2016. Ending hide and seek at sea. *Science*, 351(6278): 1148–1150. https://doi.org/10.1126/science.aad5686

Sala, E., Mayorga, J., Costello, C., Kroodsma, D., Palomares, M.L.D., Pauly, D., Sumaila, U.R. & Zeller, D. 2018. The economics of fishing the high seas. *Science Advances*, 4(6): eaat2504. https://doi.org/10.1126/sciadv.aat2504

Sally Yozell & Shaver, A. 2019. Shining a Light: The Need for Transparency across Distant Water Fishing. Resources & Climate. *Stimson.* (also available at https://www.stimson.org/sites/default/files/file-attachments/Stimson%20Distant%20Water%20Fishing%20Report.pdf)

Bay of Biscay VMS/ logbook comparison (FAO Subarea 27.8)

Jose A. Fernandes, Igor Granado, Hilario Murua, Haritz Arrizabalaga, Lucia Zarauz, Estanis Mugerza, Luis Arregi, Ibon Galparsoro, Jefferson Murua, Ane Iriondo, Gorka Merino, Oihane C. Basurko, Iñaki Quincoces, Josu Santiago and Xabier Irigoien

SUMMARY AND CONCLUSIONS OF BAY OF BISCAY (FAO SUBAREA 27.8)

This comparison highlights that Automatic Identification System (AIS)-based methods to estimate fishing effort such as the Global Fishing Watch (GFW) methodology can provide the general pattern of relative distribution of fishing effort intensity. These results were obtained in an area where coverage is quite good in general and with good vessels registers (except for the trollers). However, important limitations exist in terms of underestimating the real absolute intensity since AIS overpredicted fishing activity in relation to estimates based on VMS outside of the continental shelves. There was a dramatic overestimation of fishing intensity in Subarea 27.8e (47.5 percent), which is the high seas area where AIS coverage is lower.

AIS estimates better the fishing effort for the two most common fishing gears, namely trawlers and set longliners. Open sea effort for set longliners seemed to be erroneous too. Especially noteworthy was the inability to properly identify two important activities in the region such as trolling and pole and line. In addition, the GFW methodology is not yet able to correctly deal with multi-gear fleets. Some of these limitations (e.g. failure to distinguish seasonal changes of fishing gear) could be properly addressed in the next generation of algorithms.

Despite current limitations, the AIS data can allow to study and optimize fishing vessel behaviour to reduce impacts (e.g. fuel emissions and habitat destruction impacts). This behavioural analysis is influenced by fishers' tactics, such as the switching off of AIS devices to keep secret their fishing spots and avoid potential conflicts between fleets competing for the same resources. Understanding these conflicts might help minimize socio-economic impacts in regulations or spatial planning changes.

INTRODUCTION TO BAY OF BISCAY (FAO SUBAREA 27.8)

The Bay of Biscay corresponds to FAO Subarea 27.8 (ICES subarea 8), which is situated between 48° 00' and 43° 00' N latitudes and 18° 00' W longitude and the Spanish and French coastlines (approx. 1° 00' west longitude). This subarea is further divided into 5 divisions (Figure 3. d.i.0), where the continental shelf (high productivity area) covers areas 27.8a-c:

- Division 27.8.a: Bay of Biscay-North is within the French Exclusive Economic Zone (EEZ).
- Division 27.8.b: Bay of Biscay-Central is mainly within the French EEZ and a small area within the Spanish EEZ.
- Division 27.8.c: Bay of Biscay-South is mainly within the Spanish EEZ and a small area within the French EEZ.
- Division 27.8.d: Bay of Biscay-Offshore is mainly within the Spanish and French EEZs and a small proportion in the United Kingdom EEZ and another small proportion in international waters (27.8.d.1).
- Division 27.8.e: West of Bay of Biscay is mainly within the Spanish EEZ (Sub-division 27.8.e.2) and international waters (Sub-division 27.8.e.1).

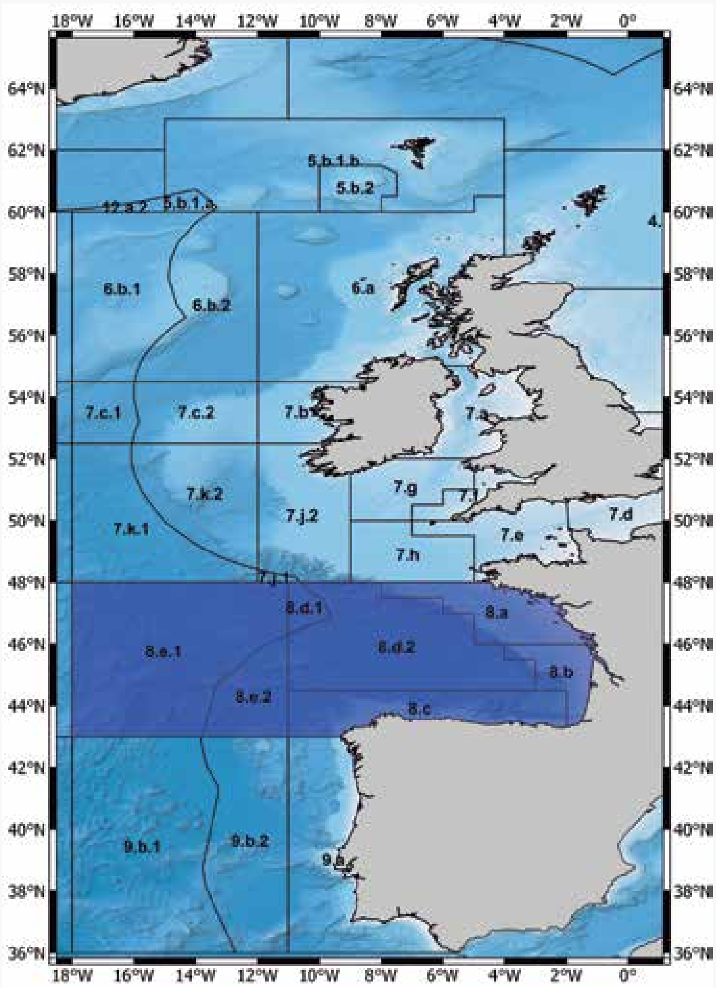


Figure BoB. 1. Map of ICES statistical divisions in the Bay of Biscay.

The Bay of Biscay is characterized by a wide shelf extending west of France and a narrow shelf off the north of Spain. Upwelling events occur during summer along the whole Spanish and French coastlines, leading to a rich fish diversity (ICES, 2016). The pelagic habitat is mainly dominated by sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*) fished mainly from March to June, mackerel (*Scomber scombrus*) fished mainly during February and March, horse mackerel (*Trachurus trachurus*), and blue-whiting (*Micromesistius poutassou*). Albacore (*Thunnus alalunga*) and bluefin tuna (*Thunnus thynnus*) are migratory species which appear in the summer season during their feeding migration. Tuna fishing activity in the Bay of Biscay and adjacent areas starts annually in late spring just after the end of the anchovy purse seiner season. Basque fishermen target albacore using trollers (trolling lines) and baitboats (pole and line) and bluefin tuna with baitboats. Bigeye and skipjack may also appear occasionally in the catches. The bluefin tuna fishery has traditionally taken place in the south-eastern area of the Bay of Biscay from June to October. Most of the catches are composed of juveniles (1-4 years) and are usually concentrated in a very limited area where the fleet operates and occasionally combines this activity with albacore fishing. When targeting albacore, the fleet spreads over wider areas, especially the trollers that can distribute from southern Ireland to northeast Azores (Dufour *et al.*, 2010). Pelagic fisheries are therefore highly seasonal, and the vessels target different species throughout the year. Hake (*Merluccius merluccius*) is one of the most abundant demersal species with a high economic value. Anglerfish (*Lophius piscatorius*), megrim (*Lepidorhombus sp.*), and sole (*Solea solea*) are more abundant in the northern part of the Bay of Biscay. Demersal fisheries are mainly mixed fisheries targeting hake, anglerfish, megrim and other species operated by bottom otter trawlers, gillnets and longlines. Cold-water species such as whiting (*Merlangius merlangus*) and pollock (*Pollachius pollachius*) occur off the north of Portugal. Skates, sharks, and deep-sea fisheries occur over the continental slope and in the deeper parts of the region. Trawl and longline are the main gears used in deep-sea ecosystems (Punzón *et al.*, 2011). A general decrease of fishing effort in the region (in many cases through reduction of the number of vessels) has contributed to an overall decline in the fishing mortality (F) of commercial fish stocks since 1988 (ICES, 2016). The recreational fishery is becoming an important activity and is, therefore, taken into consideration for the evaluation of some stocks such as seabass (*Dicentrarchus labrax*) in the Bay of Biscay (ICES, 2016).

This chapter provides a case study comparing effort based on 2017 AIS data (Kroodsma *et al.*, 2018) with local detailed fisheries data in the Bay of Biscay (Figure BoB. 1). The local fisheries data used for this work were the Spanish electronic fishing logbooks (DEA) and VMS data. One of the main limitations of AIS and VMS data for fisheries footprint estimation is that they are not mandatory for all vessels. Having an AIS Class A device became compulsory in

the European Union in May 2014 for all fishing vessels over 12 m length (EC No 1224/2009). However, there are some exceptions for vessels with an overall length of between 12 and 15 m if they fish only in national waters or the fishing trips are shorter than 24 hours (EC No 1224/2009). In other areas of the world, the AIS Class A mandate is for vessels over 300 gross tonnage (on average larger than 37 m). In the Bay of Biscay, some fishing vessels with an overall length under 15 m are voluntarily using AIS transducers through the local government EBArtesa project. With regards to VMS data, in the European Union, vessels over 12 m length must use VMS and electronic logbooks (European Union No 404/2011; Corrigendum European Union No 404/2011). National Coast Guards issue fines and eventually suspend fishing activity if a vessel is found to switch off their VMS. They usually do not monitor AIS regularly, as this equipment was designed to avoid collisions and not for activity monitoring which would be a redundant effort to VMS monitoring. However, EC No 1224/2009S making AIS equipment mandatory allows the replacement of traditional control means by satellite-based control ones when there is clear evidence of a cost-benefit trade-off. To get an idea of the global fleet composition, large fishing vessels which require ballast water systems (and likely to use AIS) represent approximately 15 percent of the worldwide large vessel fleet (Fernandes *et al.*, 2016). Another example from the UK shows that vessels under 15 m represent 88 percent of the total number of fishing vessels (Fernandes *et al.*, 2017). Artisanal fleets are often represented by small vessels with low tonnage (Battaglia *et al.*, 2009). More than 83 percent of the total European Union fishing fleet is considered artisanal (Macfadyen *et al.*, 2011), mainly vessels under 12 m using passive gear. However, the definition of artisanal vessels varies across regions without a common definition at European level but often referred to as small-scale fisheries (EC No 1198/2006). In our study area, the Basque country fishing fleets are considered artisanal when composed of local traditional crafts that conduct short fishing trips (usually one day) in coastal fishing grounds (Murillas *et al.*, 2012). In the Basque country, this fleet consists of 129 vessels (Pascual *et al.*, 2013), and includes small (5–6 m length) and large vessels (up to 28.5 m length). Small vessels represent 66 percent of the fleet in number of vessels. The fleet of vessels over 15 m length is composed mainly of vessels using trolling to target tuna species and a few vessels using longline targeting demersal species (Murillas *et al.*, 2012).

LIST OF MAIN FISHING GEARS IN THE BAY OF BISCAY

The list of common fishing gears in Europe can be consulted in Appendix IV of the 2010/93/EC or online (https://datacollection.jrc.ec.europa.eu/wordef/gear-type). The 12 main Spanish fishing gears in the Bay of Biscay for vessels over 15 m length are shown in Table BoB. I. The GFW classification model has attempted to identify 11 gear types for the study area: set longlines, drifting longlines, trawls, pole and line, purse seines, squid jigger, set gillnets, driftnets (none in Bay of Biscay), pots and traps, other fishing, and trolls. The correspondence between GFW identified fishing gears within the Bay of Biscay and the European Union listed fishing gears is shown in Table BoB. I. Although GFW differentiates between pots (FPO) and troll lines (LTL) in their global classification, the dataset fails to show any activity for those fishing gears in the Bay of Biscay. As FPO is a minor artisanal fishery in the Bay of Biscay we combined these vessels into an "other gears" group for better comparison in the maps below. However, LTL is an important fishing gear in the Bay of Biscay and has been kept as a separate gear.

GEAR TYPE	Fishing events (%)*	Total catches (%)*	GFW fishing gear identified
Pots (FPO)	< 1	< 1	Pots and traps
Handlines and pole-lines (mechanized; LHM)	~ 10	~ 10	Pole and line
Handlines and pole-lines (hand-operated; LHP)			
Drifting longlines (LLD)	< 2	< 2	Drifting longlines
Set longlines (LLS)	~ 14	~ 5	Set longlines
Troll lines (LTL)	~ 9	~ 2	Trollers
Trammel nets (GTR)	~ 1	~ 1	Other gears
Miscellaneous Gear (MIS)	~ 6	~ 1	
Set gillnets (GNS)	~ 9	~ 2	Set gillnets
Bottom otter trawl (OTB)	~ 15	~ 15	Trawls
Bottom pair trawl (PTB)	~ 10	~ 15	
Purse seines (PS)	~ 25	~ 50	Purse seines

Table BoB. I. Main fishing gears in the Bay of Biscay and correspondence with fishing gears identified by GFW. (* Based on Spanish logbooks information from 2017).

Pots and traps refer to small or large cages or baskets made with various materials and designs (e.g. one or more openings). Most pots are set on the bottom, while a few models are designed to be in mid-water. In the Bay of Biscay they target high value species such as lobster (*Homarus gammarus*), velvet crab (*Necora puber*), brown crab (*Cancer pagurus*) and common octopus (*Octopus vulgaris*). Pots are often deployed at the limit between rock beds and sand patches in sets of up to 60 traps per line when targeting lobsters (Galparsoro *et al.*, 2009; Garmendia *et al.*, 2015).

Handlines and pole-lines can be used manually (LHP) or mechanized (LHM). A pole and line consists of a hooked line attached to a pole. This method is common in sport fisheries (i.e. angling) but it is also used in commercial fisheries. For handline, crew members handle a line which has up to 30 hooks. Each hook has a fragment of wool, normally red colored, acting as bait (Punzón *et al.*, 2004). LHM mainly targets mackerel which is a seasonal fishery where catches are predominantly in March and April (Punzón *et al.*, 2004). LHM may also target albacore and bluefin tuna using live bait, but this activity occurs mainly between July and October (Dufour *et al.* 2010; Nikolic *et al.*, 2016). Some of the vessels targeting tuna during the summer also operate as purse seiners (mixed gear vessels), fishing anchovy and mackerel in spring.

Drifting longlines consist of a mainline kept near the surface or at a certain depth by means of regularly spaced floats and with relatively long snoods with baited hooks evenly spaced on the mainline.

Set longlines consist of a mainline and snoods with baited, or occasionally unbaited, hooks at regular intervals, generally set on or near the bottom. Set longlines are considered an artisanal fishery in the Bay of Biscay, generally with lines of less than 1 000 hooks (maximum 2 000) (Pascual *et al.*, 2013). Longlines are often used as selective fishing gears aiming high value species in specific seasons and regions (Punzón *et al.*, 2011).

Troll lines consist of a line with natural or artificial baited hooks trailed by a vessel near the surface. In the Bay of Biscay troll lines target albacore tuna (Goñi and Arrizabalaga 2005; Goñi *et al.*, 2015; Sagarminaga and Arrizabalaga, 2014).

Trammel nets consist of three layers of netting with a slack small mesh inner netting between two layers of large mesh netting to entangle fish. Trammel nets are used to capture benthic fish, such as common sole, monkfish, turbot (*Scophthalmus maximus*) and brill (*Scophthalmus rhombus*) (Sancho *et al.*, 2003; Morandeau *et al.*, 2014).

Set gillnets consist of a single netting wall kept more or less vertical by a float-line and a weighted ground-line. Set gillnets target hake, seabass and seabream species (*Diplodus spp., Sparus aurata, Litognathus mormyrus*; Morandeau *et al.*, 2014).

Both, trammel nets and set gillnet fishing usually involve short, coastal trips to deploy and collect the nets the same day or the day after depending on the targeted species.

Bottom otter trawls use a cone-shaped net consisting of a body, normally made from two, four and sometimes more panels, closed by one or two codends and with lateral wings extending forward from the opening. The net is hauled at a towing speed of 4 knots at depths ranging from 30 m to 200 m. Trawl vessel trips last generally 5 to 7 days (Alzorriz *et al.*, 2016). A boat can be rigged to tow a single or two parallel trawls from the stern or from two outriggers. Bottom otter trawls (OTB) are used to target a mix of demersal species such as hake, megrims, and anglerfish (Prellezo *et al.*, 2016). During the winter season, OTB may target cephalopods such as squid (Loligo spp.) and cuttlefish (*Sepia officinalis*) as well as fish species such as red mullets (*Mullus surmuletus*), seabass, mackerel and horse mackerel (Prellezo *et al.*, 2016).

Bottom pair trawling involves two vessels pulling a single fishing net across the seabed by two boats. Within the Bay of Biscay the fleet uses trawl nets with a very high vertical opening to primarily target hake (Prellezo *et al.*, 2016).

Purse seines are made of a long wall of netting framed with a float-line and a lead-line, having purse rings hanging from the lower edge of the gear, through which runs a purse line made from steel wire or rope to allow pursing or closing the net. Purse seines primarily target shoaling species including small pelagics such as sardine and anchovy, but they can also target tuna especies (Uriarte *at al.*, 1996; Uriarte *et al.*, 2008; Fernandes *et al.*, 2009).

Miscellaneous Gear includes many minor fishing gears.

COMPARISON OF REGION FLEET REGISTERS AND AIS DETECTIONS AND CLASSIFICATION BY GFW

In the GFW database the Bay of Biscay represents a region with a very high percentage of the vessels matching official registries. In the Bay of Biscay, GFW matched roughly 90 percent of the Spanish-flagged vessels it classified as likely fishing vessels to the European Union community fishing fleet register. This also implies that most of the GFW gear types were obtained from this registry. About 20 percent of vessels in the European Union registry were listed as multi-gear vessels, and for these the neural net was used to identify the most commonly used gear. In 2017, GFW identified 530 vessels as present within FAO Subarea 27.8 using AIS, but 19 of those vessels were too inactive (less than 500-point records in a year) for the neural net to classify their gear type. Vessel inactivity could represent true inactivity or alternatively suggest that these vessels had their AIS off most of the time (see analysis at the end of the chapter). For the current comparison these 19 vessels were excluded, focusing on a list of 510 Spanish active fishing vessels detected by GFW and for which activity was recorded both in the Spanish VMS and logbooks registers.

		GFW-AIS (Neural net prediction)		AIS-GFW (Corrected gear type)		VMS/logbook	
Fishing gear	Unknown	<15m	>15m	<15m	>15m	<15m	>15m
Set_longlines		6	76	4	77	5	66
Drifting longlines		1	20	0	20	0	14
Trawls		1	96	1	96	0	86
Pole_and_line		0	4	0	3	3	54
Purse_seines		0	193	0	191	0	142
Set_gillnets		28	84	31	86	0	32
Other_fishing		1	0	1	0	3	21
Trollers		0	0	0	0	16	53
Non-classified	19	0	0	0	0	0	0
Sub-Total	19	37	473	37	473	27	468
Total	19		510		510		495

Table BoB. II. Vessel classification according to the main fishing gear. GFW classification is based on a computer algorithm (neural net classifier) and information from vessel registries.

From the list of 510 GFW vessels, 467 were larger than 15 m according to the official Spanish fishing vessels census. When possible to match a vessel to vessel registry the predicted gear type was updated using registry data. When registry data were not available or contained more than one gear registered, a vessel was assigned the predicted gear type by GFW classification algorithm. We have considered as 'ground truth' the manual verification of vessels with VMS records against the Spanish official census in order to obtain the length of the vessels.

From the official Spanish VMS registers, we identified 565 unique vessels with activity in area 27.8 during 2017, of which 512 were over 15 m length according to the Spanish fishing vessels census. Using a combination of VMS and logbook data we identified several vessels that fished outside the 27.8 area, despite departing from or returning to ports located in the north of Spain. Omitting these vessels, we were left with 495 Spanish vessels that fished within the Bay of Biscay during 2017, 468 being larger than 15 m. Using logbook data from 2017 each vessel was assigned a primary fishing gear based on the gear type with the greatest number of recorded fishing events.

The GFW model's vessel classification was compared manually with the Spanish vessels census (Table BoB. II). The GFW neural net model classified 473 vessels as larger than 15 m, 5 more than VMS-Spanish census data. However, closer analysis comparing with the Spanish census showed 12 vessels classified as larger than 15 m by the AIS-GFW model being in reality smaller than 15 m and 6 vessels classified as smaller than 15 m being larger than 15 m. Moreover, GFW was only able to differentiate 6 fishing gears (Table BoB. II), which led to an overestimation of these gears, except for pole and line (underestimated by about 95.5 percent). In addition, GFW failed to identify other gear types such as trolling lines and other fishing methods. This could be due to the use of different gears by the same vessels depending on the season. Another explanation could be that purse seiners and trawlers are more frequent than other vessels and they might have been overrepresented in the training-set used by GFW to classify vessels worldwide (Kroodsma *et al.*, 2018).

In an initial classification of vessels by GFW, there were 3 vessels in GFW that were not present in the Spanish register of fishing vessels. Those vessels corresponded to a rescue ship, a passenger ship and a cargo vessel. These misclassifications of non-fishing vessels as fishing vessels represented less than 0.1 percent of the total VMS effort and 0.005 percent of the fishing effort based on GFW estimates. In a re-classification (processed in this case study), only the rescue vessel was present in the GFW and not in the Spanish fishing vessel register.

There were 31 vessels larger than 15 m in AIS-GFW data (6.6 percent vessels) that were not present in the Spanish VMS register. This mismatch could be due to vessels that operate outside

of the 27.8 area. This accounted for about 1.5 percent of the total hours and 0.08 percent of the fishing hours based on GFW estimates. Moreover, GFW missed detection of 27 fishing vessels larger than 15 m when compared to vessels in the VMS data set (5.8 percent vessels), which represented less than 3.3 percent of the fishing hours recorded by VMS data. However, if using the Spanish census to select vessels larger than 15 m in the GFW data, 20 vessels were not present in the official activity register. This accounted for 0.8 percent of the total hours and 0.03 percent of the fishing activity based on GFW estimates. Furthermore, GFW was unable to detect 22 vessels that were present in VMS data. This accounted for 2.9 percent of the total effort and 2.9 percent of the fishing effort based on GFW estimates. Therefore, it was concluded that the final mismatch caused by vessel misclassification accounted for a total error below 4 percent with a low rate of over-estimation due to false positives (0.8 percent), and a higher rate of underestimation due to false negatives (2.9 percent). Overall, although GFW's model made notable errors in fishing gear assignations, it did provide a good estimate for the total number of fishing vessels. A review of these vessels by GFW revealed that most errors were due to 1) failure of GFW to properly account for multi-gear vessels, and 2) missing information from the European Union community registry, which was the training data source for GFW for the European Union vessels. For instance, a review of trolls in the European Union fishing fleet register showed that almost all were registered for their primary gear as set gillnets and had no secondary gear assigned. Most likely, the GFW algorithm learned that these vessels operated as set gillnets part of the year, and did not consider they operated as trolls the rest of the year. Therefore, the algorithm might have incorrectly learned troll fishing patterns as set gillnet patterns and misclassified vessels that operated solely as trolls as set gillnets. The European Union fleet register is an important source of GFW training data for identification of some of these fishing gears with fewer vessels, and our study suggests that for these less common gears results should be interpreted with caution.

AIS reception quality in the North East Atlantic (FAO Area 27) tended to vary spatially. Some nearshore and high seas regions exhibited relatively high reception quality while intermediate regions, with comparatively high vessel densities having a reception quality below 30 percent (Figure BoB. 2).

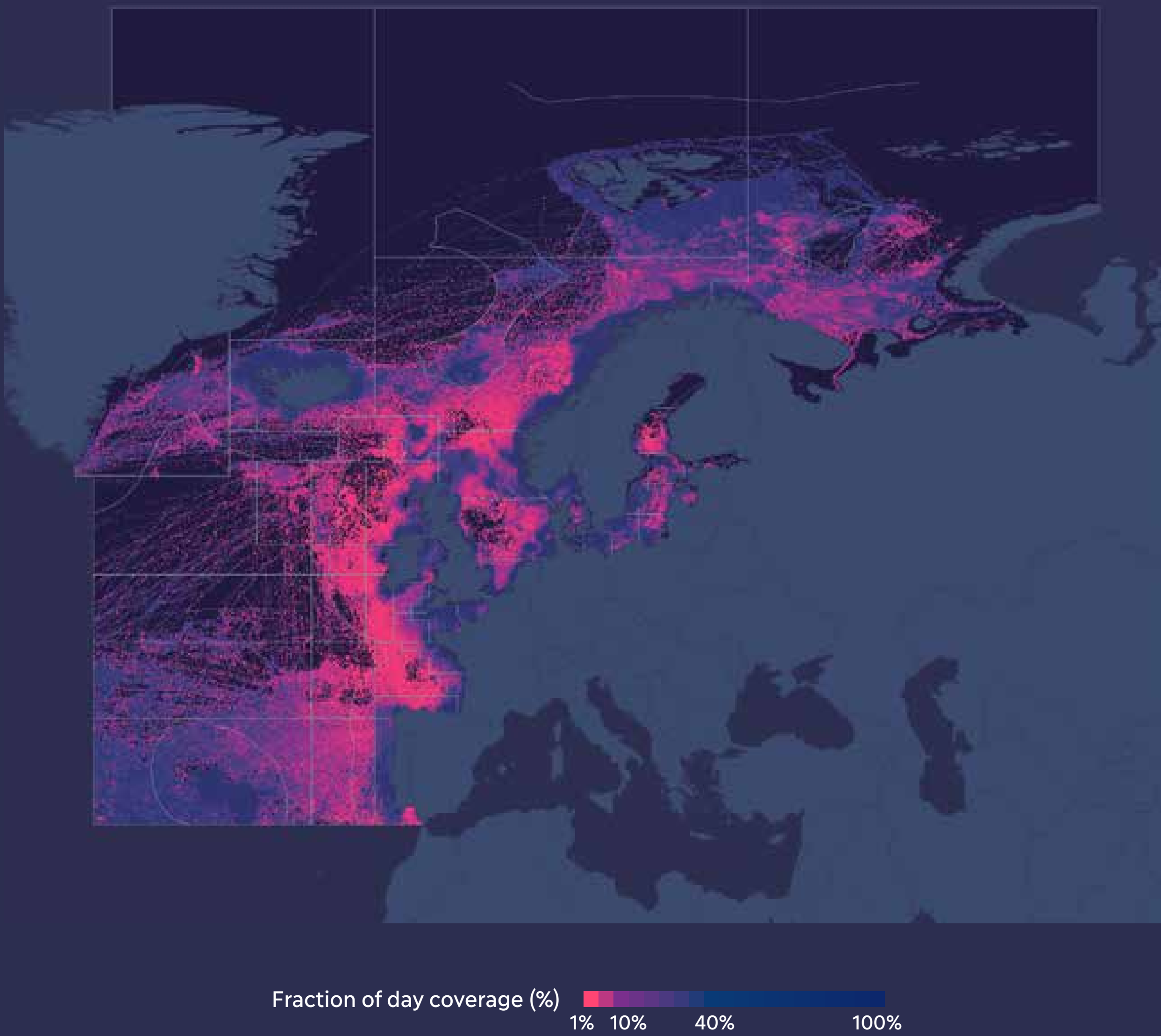
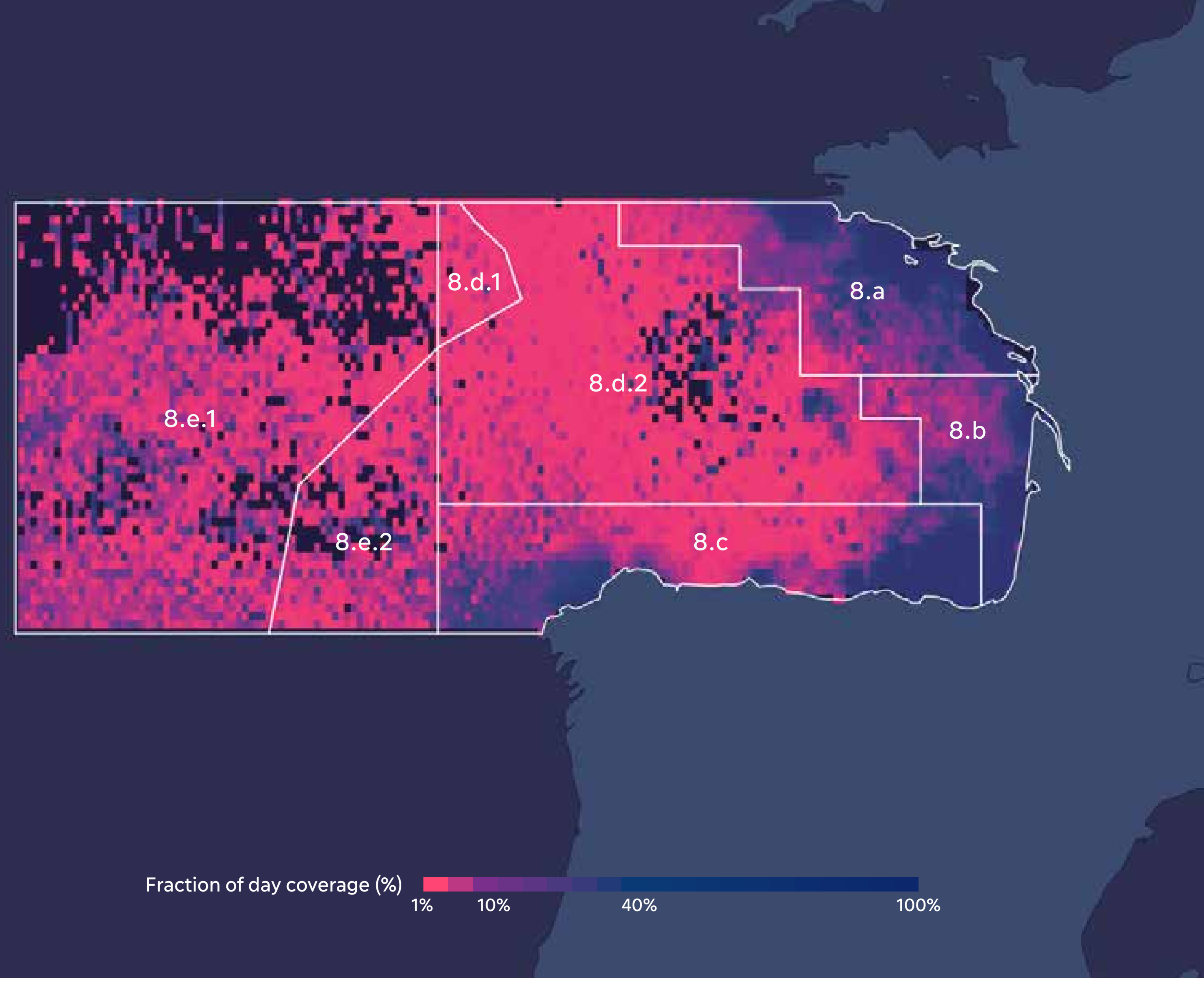


Figure BoB. 2. Class A AIS coverage in North Atlantic (FAO Area 27) during 2017.

AIS reception quality within the Bay of Biscay followed a similar pattern with most nearshore regions having high AIS reception, and a declining reception offshore (Figure BoB. 3). AIS reception was very good along the French and northeastern Spanish coastlines, where a network of terrestrial receivers provides coverage tens of nautical miles out to sea. In the middle of the Bay of Biscay and northwestern Spanish coastline AIS reception was reduced, largely due to higher densities of AIS broadcasting vessels. However, these regions are also areas of lower fishing activity.

Figure BoB. 3. AIS coverage in the Bay of Biscay (FAO Subarea 27.8).



COMPARISON OF TOTAL RECORDED FISHING ACTIVITY INTENSITY DISTRIBUTION

This comparison focused on assessing the capacity of AIS-GFW algorithms to estimate a meaningful fishing effort taking into account that previous sections identified a good AIS use for the Bay of Biscay fleet segments, but also some areas of limited AIS reception. To use the AIS hours for fishing effort estimation, these should be qualified as 'cruising' (or 'transiting') and 'fishing'. Fishing effort should include 'searching' and 'gear operation' hours. Fishing effort estimation from a fisheries management viewpoint should be able to distinguish 'searching' from 'cruising' hours given the objective of estimating and managing fishing mortality. However, from a climate change and emissions reduction perspective it could be argued that the differentiation is not important when the aim is to reduce fishing vessel emissions in all activities (He *et al.*, 2018).

In this chapter, VMS was adopted as the fishing activity intensity distribution baseline against which the two algorithms used by GFW (convolutional neural network and logistic regression) would compare. Duplicated records and impossible time stamps and locations from VMS data were removed (2.3 percent and 8.4 percent of the logbook and VMS records, respectively). Then the VMStools package developed by Hintzen *et al.* (2012) was used with the freeware environment R (R Core Team 2018) to link VMS and logbook databases. Once logbook and VMS databases were linked, fishing hours for each fishing gear could be calculated and the the hours of vessels that cruised the area 27.8 but did not fish in it were removed. The distinction between fishing and cruising hours was based on vessel speed. We used 6-7 knots for LTL, 2-4 knots for TB and 0-3 knots for the rest of fishing gears to discriminate fishing hours. Many vessels use a single fishing gear during all the year. This is the case of bottom trawlers (PTB and OTB). However, there are some vessels that might use different fishing gears during different seasons of the year in different areas and targeting different species (e.g. set gillnets and trolling lines). Similarly, some purse seiner (PS) vessels fishing for mackerel and anchovy in spring also do pole and line (LHM and LHP) to target tunas in summer. Multi-gear vessels might be misclassified by GFW. As a result, hours based on GFW current methodology would not be correctly assigned across multiple gears and would only be assigned to a single gear vessel type. In contrast, the use of logbooks allows to assign VMS hours to the right fishing gear. Based on logbooks data we have estimated that over 40 percent of vessels in the Bay of Biscay are involved in multi-gear fishing, amounting to at least 45 percent of the total hours.

VMS and AIS-GFW data showed similar spatial patterns once the data were cleaned by removing signals at ports or vessels cruising towards fishing grounds through the 27.8 area, but not fishing there (Figure BoB. 4). The hours spent in each cell (1 x 0.5-degree resolution),

were considered as a value for comparison use, by calculating the root-mean-square error (RMSE) and root-mean-square deviation (RMSD) of both models in relation to VMS data. The RMSE of the neural network was lower (3 154 hours) than the RMSE of the logistic model (3 781 hours) and had a lower deviation (±592 hours vs. ±719 hours). Lower error and variance are both desirable properties for selecting one model over another (Fernandes *et al.*, 2010; 2013; 2015). Because the difference was not statistically significant (paired t-test; Nadeau and Bengio, 2000), maps based only on the neural network are shown hereafter for readability.

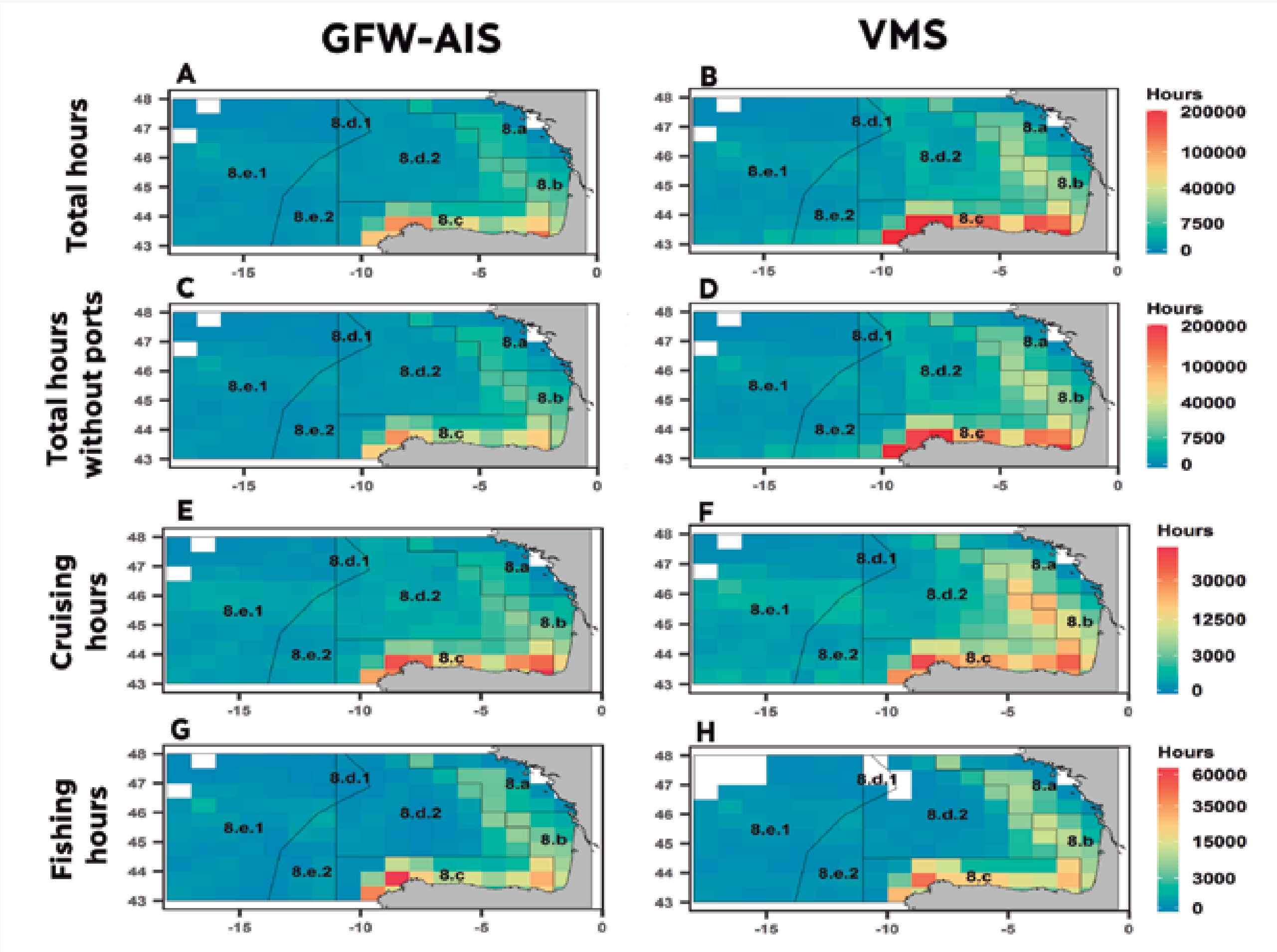


Figure BoB. 4. Activity by Spanish fishing vessels larger than 15 in the Bay of Biscay (FAO Subarea 27.8) comparing analysis of VMS and AIS data processed by GFW methodology using a neural network. The first row, panels A and B, shows the total hours that Spanish fishing vessels stayed in each cell. Second row, panels C and D, shows the total hours after removing hours at port (1 km away in the case of AIS). The last two rows show the cleaned hours distinguishing cruising (panels E and F) and fishing hours (panels G and H).

Total hours estimated by GFW based on AIS data were ~ 820 000 hours for the whole Bay of Biscay area during 2017, which is 80 percent of the hours estimated by VMS data (~1 025 000 hours). For the hours observed, GFW had a higher fraction of them labelled as fishing than VMS, and as a result, GFW detected only ~70 percent of the non-fishing hours (e.g. "cruising" hours in VMS), but ~90 percent of the fishing hours. This extra time identified as fishing was somewhat surprising, as target species searching by purse seiners, trollers, and pole and liners was not considered as fishing effort in the AIS-GFW estimations. This should have clearly led to an underestimation of the fishing footprint by those gears as searching for fish schools is an integral part of their fishing hours and activity calculation. This could be a significant source of discrepancies between hours calculated with GFW- and VMS-based approaches for purse seiners, trollers and pole and liners. Regarding the GFW purse seine algorithm, it only considered "fishing" as the time during the set and the hauling/processing while drifting after the set.

	FAO/ICES sub-areas	Cruising hours	Fishing hours	Total hours
AIS-GFW (hours)	27.8	420 923	397 556	818 479
	27.8a	7 661	24 583	32 244
	27.8b	40 706	51 444	92 150
	27.8c	336 896	292, 916	629 812
	27.8d	26 301	23 267	49 568
	27.8e	9 359	5 346	14 705
VMS (hours)	27.8	588 792	435 363	1 024 155
	27.8a	45 143	42 979	88 122
	27.8b	86 213	64 266	150 479
	27.8c	342 356	289 301	631 657
	27.8d	94 814	35 194	130 008
	27.8e	23 266	3 623	23 889
AIS underestimation by areas (%)	27.8	28.5	8.7	20.1
	27.8a	83.0	42.8	63.4
	27.8b	52.8	19.9	38.8
	27.8c	1.6	**-1.2**	0.3
	27.8d	72.3	33.9	61.9
	27.8e	59.8	**-47.5**	38.4
RMSPE by cells (%)	27.8	64±86	75±181	54±86
	27.8a	81±10	71±72	54±23
	27.8b	54±29	28±31	37±27
	27.8c	38±26	42±25	34±21
	27.8d	104±155	110±344	100±155
	27.8e	46±18	74±64	36±17

Table BoB. III. Comparison of fishing hours estimated by GFW using a neural network with hours estimated using VMS and logbooks for vessels larger than 15 m. Fishing, cruising hours and total hours are compared using GFW, VMS, percentage of GFW intensity that was underestimated based on VMS estimation by FAO divisions, and the root mean square percentage error (RMSPE) and the standard deviation of each FAO division (FAO divisions by rectangles of 1x0.5 degrees). Fishing intensity overestimation highlighted in bold.

The best match by areas (~100 percent) was in division 27.8c, which is the narrowest coastal area in the northern Spain. Other coastal areas showed less matching, with ~80 percent of the fishing activity detected by AIS in division 27.8b and only 58 percent in division 27.8a. Open sea areas far away from the coast identified only ~75 percent of the total activity with AIS based methods. Cruising and searching activity showed in general higher levels of underestimation than fishing activity in all the areas, except for 27.8c area where the global match was good. The most marked difference was in coastal division 27.8a where only ~17 percent of cruising and searching activities were detected. There was a slight overestimation of fishing effort (1.2 percent) in division 27.8c and a very marked overestimation of fishing effort in division 27.8e (47.5 percent).

COMPARISON OF FISHING OPERATIONS DISTRIBUTION BY FISHING GEARS

In this section, the capacity of the GFW approach to determine fishing operations by fishing gear was evaluated. The estimation of total fishing activity aggregated is very similar in AIS-GFW and VMS (Figure BoB. 4, panel G and H). However, fishing opearations by fishing gear (Figure BoB. 5) using GFW showed variation in level of accuracy depending on the fishing gear.

Trawl was the fishing gear where a better match between AIS and VMS based methods occurred in terms of space and intensity (Figure BoB. 5a-b). Trawlers together with set longliners and purse seiners are the most common fishing gears in the Bay of Biscay with 60-75 percent of the fishing hours according to VMS data. Purse seiners (Figure BoB. 5e-f) and set gillneters (Figure BoB. 5g-h) showed also a good match between AIS and VMS based estimations.

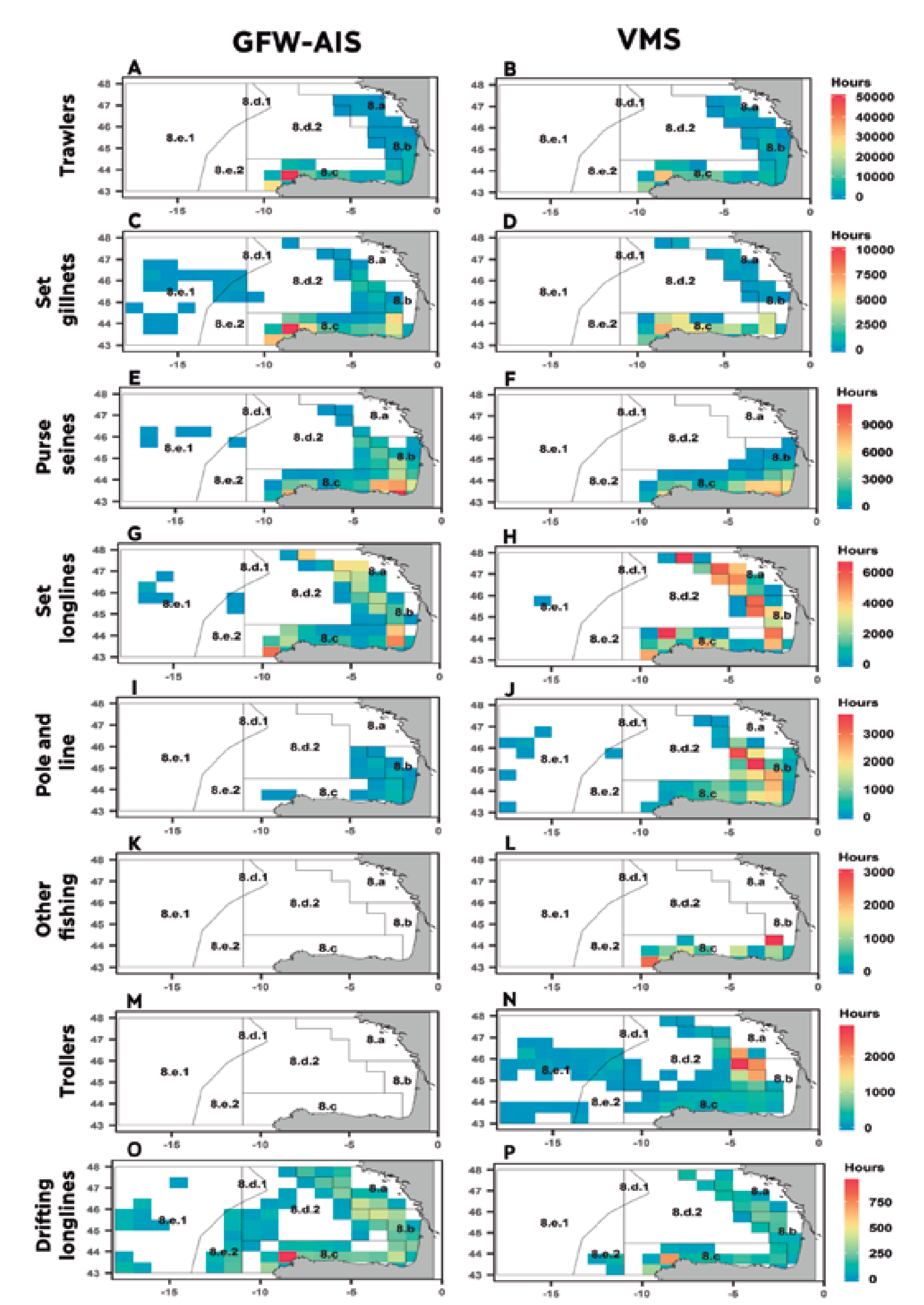


Figure BoB. 5. Fishing intensity by gears of Spanish vessels larger than 15 m in the Bay of Biscay (FAO subarea 27.8) comparing analysis of VMS and AIS data processed by GFW (cells with less than 25 hours of effort have been considered empty). Fishing gears are ordered by decreasing effort intensity. Notice that the legend ranges for hours change with fishing gear.

However, AIS methods often showed erroneous intensities in the open sea division 27.8e, where no intensity for set gillneters, set longliners and purse seiners is expected. This is particularly observable for set gillneters (Figure BoB. 5g-h) where AIS detected intensity in almost one-third of the cells in division 27.8e. Although, the detected fishing activity for this area was low, the error could be due to the misclassification of trollers as set gillneters. Furthermore, panel C shows a slightly higher fishing intensity than panel D for cells located in the union of divisions 27.8a, b and c, which could be due to the above-mentioned vessel misclassification. Longliner set intensity distribution by cell (Figure BoB. 5g-h) showed a poor match, with cells of higher intensity not matching between AIS and VMS methods. In addition, there were cases of fishing activity errors in division 27.8e for set longliners (Figure BoB. 5c-d). Pole and line fishing gear was poorly detected, with the GFW algorithm only being able to classify as pole and line 3 out of 54 vessels (Table BoB. I). Drifting longliners (Figure BoB. 5o-p) showed a similar pattern to trawlers and purse seiners, with the AIS method detecting accurately the fishing intensity distribution patterns in coastal areas, but showing erroneous intensity in the open sea divisions 27.8e and 27.8d. The remaining fishing gears (miscellaneous gears and trolling lines) were not detected by the GFW algorithm. This point is key given the fact that trolling lines together with pole and lines account for most of the tuna catches in the area.

POTENTIAL AIS SWITCH-OFF

In this section we compare the amount of time registered by AIS tracks to VMS data to detect potential AIS devices being switched off by fishing vessels in relation with AIS coverage. We used a 0.25° x 0.25° grid on the basis that this is the area under good conditions that a vessel can "see" well around itself (human vision and electronic devices such as sonars). The use of a different sized grid could lead to changes in the number of false positives and negatives. It must be considered that the discrepancy with higher time reported by VMS does not necessarily mean the AIS has been switched off. It is probably due to differences between both technologies and individual devices that require calibration and data harmonization for a better comparison. For example, a randomly selected vessel showed a 14.4 percent lower activity reported by AIS (Figure BoB. 6), although it appeared there had not been a signal loss or a potential AIS switch off by the vessel operators.

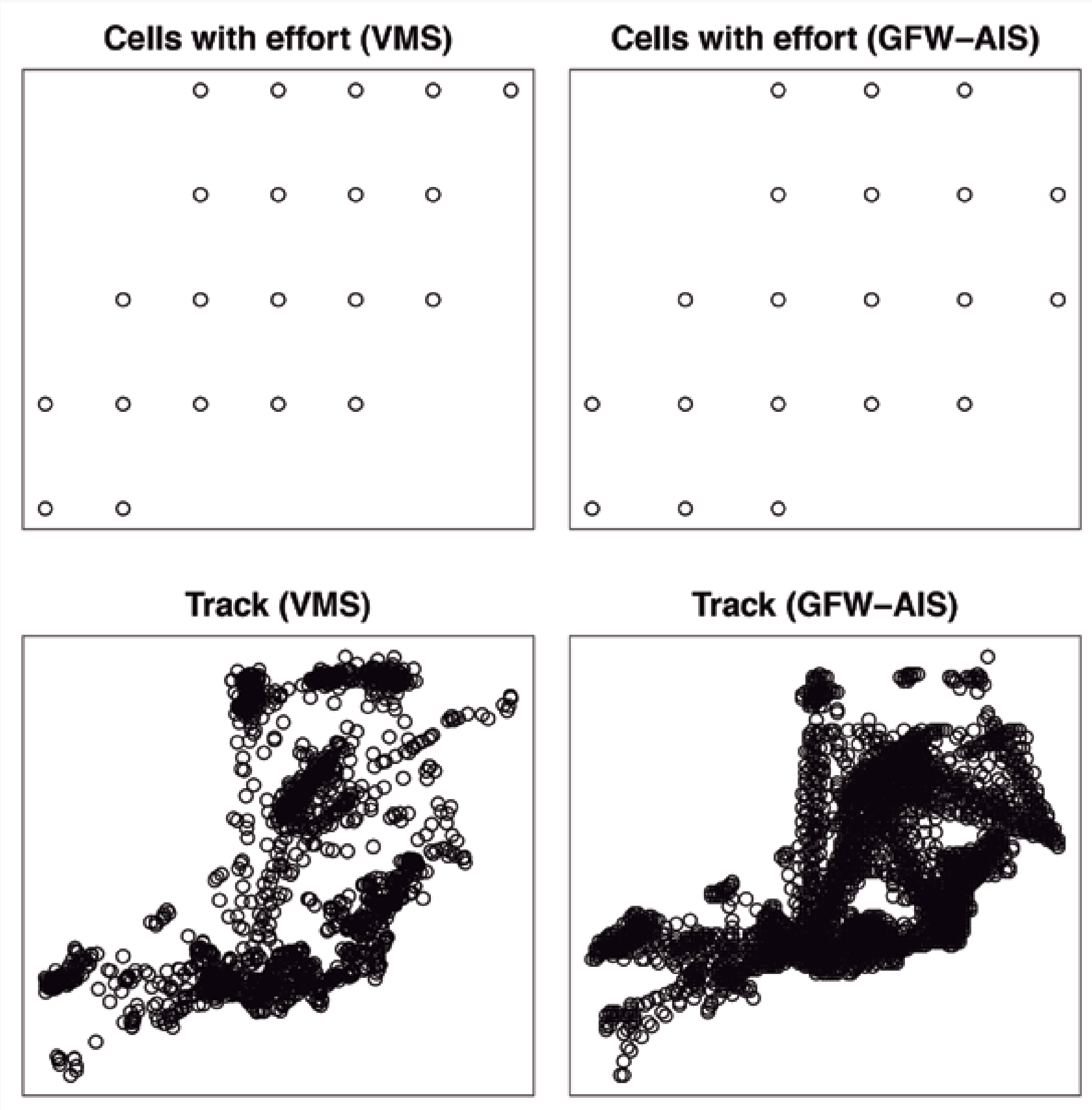


Figure BoB. 6. Example of a vessel activity recorded by VMS and AIS during 2017 where there is no evidence of AIS device switch off despite a lower activity reported by GFW (right side panels).

The number of vessels where the AIS signals were at least 40 percent lower than the time recorded by VMS was ~77 (~17.7 percent), and ~38 (~8.7 percent) if we considered over 60 percent of the time with signal lost (Figure BoB. 7). Therefore those 8.7 percent vessels could be potentially the ones that switched off their AIS signal since slightly lower differences (< 40 percent difference between AIS and VMS) could be explained by low satellite coverage. Authorities have a very tight control over VMS, which is continuously monitored and associated with heavy fines or the obligation of returning to port if the signal is lost. In addition, AIS was not designed to monitor fishing activities and it is not exclusive to fishing vessels, therefore fisheries authorities do not monitor AIS like they do with VMS.

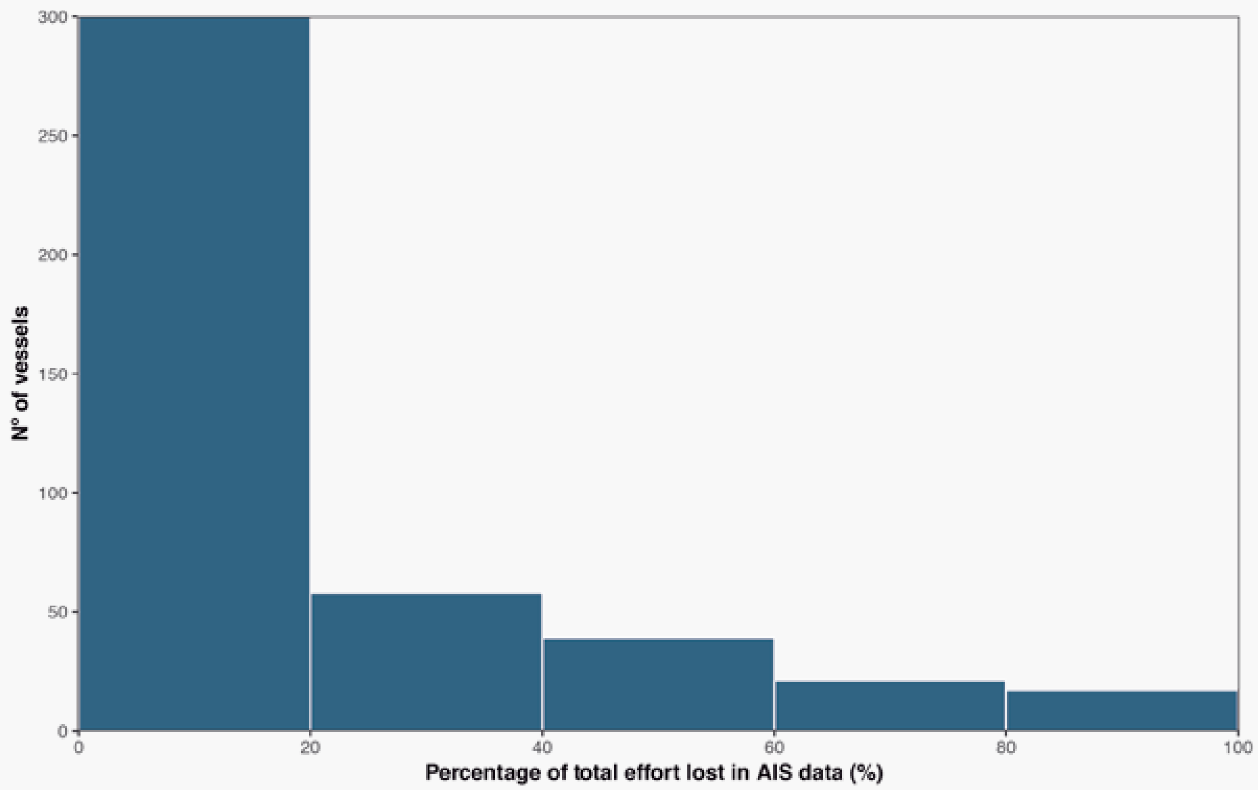


Figure BoB. 7. Histogram with number of vessels classified by the percentage of time where signal from AIS is lower than the time recorded by VMS.

Yearly tracks were also visually revised for all vessels during 2017 in FAO subarea 27.8 to identify clear signal losses that could potentially be associated with AIS switch off events. Around 108 vessels were found with an evident signal loss which could be due to a potential temporal AIS shut down or also due to a coverage issue.

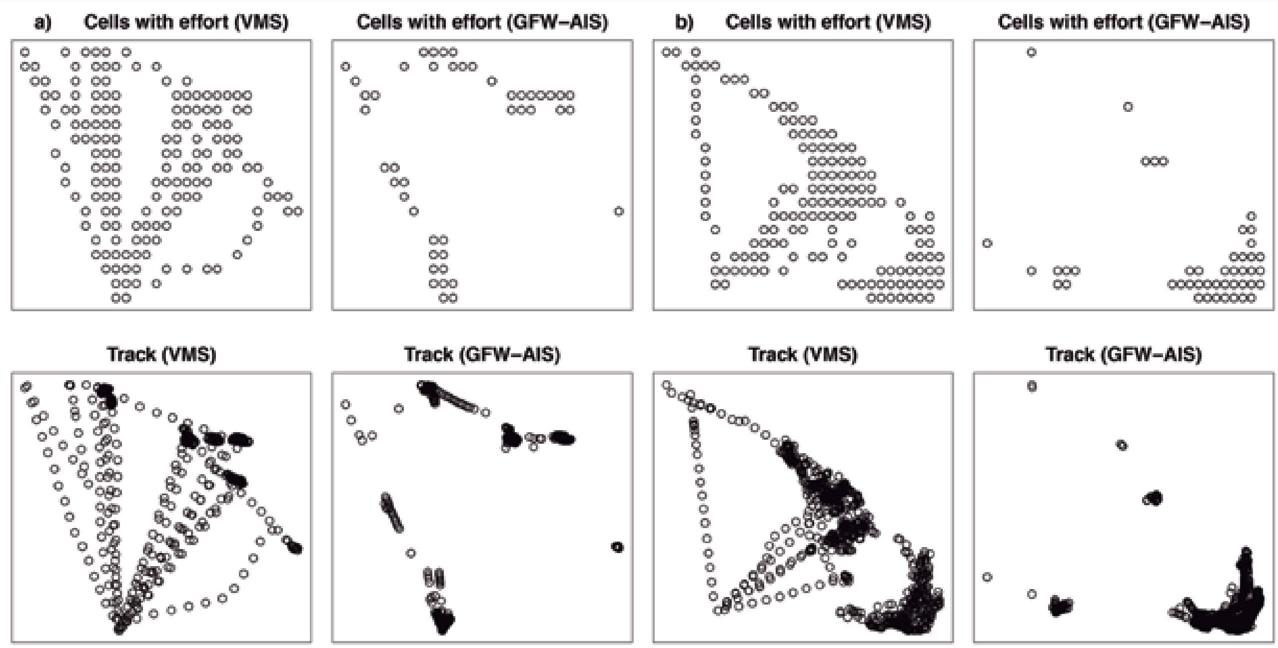


Figure BoB. 8. Example of the activity of two vessels a) and b) with different fishing gears recorded by VMS and AIS during 2017 where there is a signal loss that could be due to an AIS device switch off.

In a few cases patterns were observed that were more likely due to AIS disconnection than a coverage issue (Figure BoB. 8). It seemed that more signals were lost farther from the ports. This could be due to vessel operators not considering necessary having AIS on or because of lower coverage (Figure BoB. 9). Looking at AIS signal loss by fishing gear, there was no clear pattern suggesting that vessels of one type could have been switching off AIS more than others. Neither could we detect that any 27.8 FAO divisions concentrated more signal losses than others. Therefore, it seemed quite random and driven by individual vessels and signal coverage.

Looking at the spatial distribution of AIS signal loss at a 0.25 degree grid scale (Figure BoB. 9), no specific hotspot with a high number of hours lost was identified since those are widely distributed across the different areas of high activity. In addition, the number of vessels that lost their signal in each cell followed some patterns (Figure BoB. 9): First, signal loss in coastal areas could be a technology limitation caused by a high number of AIS messages which receivers are not able to cope with. Second, losses in areas that are the boundaries

between subareas and country EEZs might be due to high competition between fishing fleets trying to avoid revealing their fishing areas to competitors. Fishermen reported they did not wish other vessels or fleets to know the positions where they operate. This is to avoid competition and being disturbed during fishing operations. However, these signal losses were also in an area where the AIS coverage is under 10 percent (Figure BoB. 3). Similarly, we could see frequent AIS signal losses in the open waters of area 27.8e, where AIS coverage is poor (Figure BoB. 3).

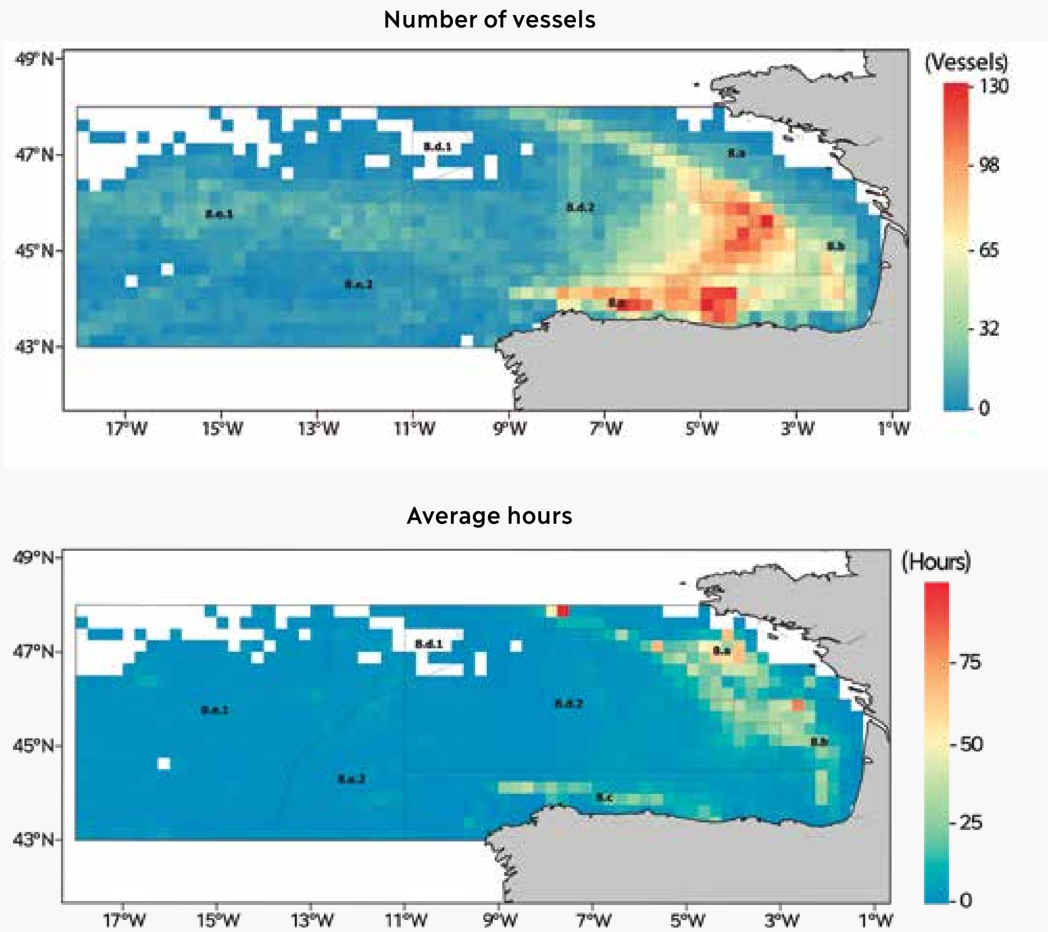


Figure BoB. 9. AIS signal loss by cells in terms of number of vessels and time it represents.

OPPORTUNITIES FOR BASQUE FLEETS AND FISHERIES MANAGERS

Marine Spatial Planning (MSP) provides decision makers with a general framework for managing activities over space and time (Coccoli *et al.*, 2018). MSP is generally defined as a public process for analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that are usually specified through a political process (Ehler and Douvere, 2009). In addition, the most widely accepted management example of MSP is ecosystem-based management, which strives to support healthy and productive marine ecosystems (Katsanevakis *et al.*, 2011). Due to the present and future demand for marine resources, human activities in the marine environment are expected to grow and competition for space is inherently bound to increase.

For example, the rising demand for marine aquaculture installations and oilrigs can generate conflicts with existing fishing and commercial routes. Since fishers move between various areas depending on fishing season and targeted species, fishing route visualization overtime is an important factor to be considered in the process of MSP (Jentoft and Knol, 2014). Newly developed tools and algorithms can be used to identify and analyse potential effort reallocation scenarios for fishing activities whose traditional grounds may be closed for aquaculture development (Coccoli *et al.*, 2018). Development of offshore renewable energy generating installations could produce the same impact on fishing activities and maritime traffic, as they also produce closures of certain areas to other activities. Moreover, the claim of marine spaces for the designation of Marine Protected Areas (MPA) and networks of MPAs to achieve the international and national conservation objectives and agreements should also be integrated in MSP processes.

Marine activity information is of high interest to understand the past and present pressures under which certain areas of interest have been exploited, as well as for the adoption of the best management plans that guarantee the recovery or maintenance of conservation features. At present, new decision support tools and algorithms have been developed to improve capacity to integrate marine activity and environment information, but potential optimal results rely on spatial and temporal information (Pınarbaşı *et al.*, 2017; Stelzenmüller *et al.*, 2010). In this context, managers facing the development of MSP that help reduce conflicts and optimize the use of available resources, must consider the spatiotemporal patterns of all relevant maritime activities, and their interactions (Tuda *et al.*, 2014). Moreover, assessing the spatiotemporal distribution of marine activities can inform managers of interactions of such activities with the environment (Hiddink *et al.*, 2007). This information is needed to achieve Good Environmental Status (GES) under the European Union Marine Strategy Framework Directive (James *et al.*, 2018).

AIS data represent a fundamental source of information, since its analysis can highlight the presence of congested areas (Tidd *et al.*, 2014; Le Guyader *et al.*, 2017) and provide inputs for planning methodologies related to fishing activities that consider socio-economic implications and space historical use (Coccoli *et al.*, 2018). Thus, it is crucial to have a clear and easy-to-use representation, generated from the MSP process, of the maritime traffic scenario (Fiorini *et al.*, 2016). Sparsity of data to characterize artisanal fleets makes it difficult to assess the socio-economic implications of new regulations in the Bay of Biscay (Murillas *et al.*, 2012) and in other areas (Breen *et al.*, 2015; Gloaguen *et al.*, 2016). Within the project EBArtesa (funded by Basque Government, Ministry of Fisheries and Aquaculture) 40 vessels had AIS installed, which is close to half of the coastal artisanal fleet in this area of the Basque country. This is expected to allow artisanal vessels that do not require VMS to be able to benefit from a monitoring scheme that allows them to certify their compliance with objectives of European Union legislation such as the Marine Strategy Framework Directive (MSFD, 2008), Integrated Marine Policy (IMP, 2007), Common Fisheries Policy (CFP, 2011) and the common European Union framework for Maritime Spatial Planning and Integrated Coastal Management (COM, 2013).

Estimation of abundance indexes and fishing effort is crucial for effective fisheries management. For example, the International Commission for the Conservation of Atlantic Tunas (ICCAT) assesses and manages albacore tuna in the Atlantic. A range of stock assessment models are used by the Standing Committee on Research and Statistics (SCRS), from biomass dynamic models using catch biomass and effort data with only a few parameters to statistical catch-at-size models with over 1 000 parameters (Merino *et al.*, 2014; Kell *et al.*, 2017). Despite these differences in model data, they are all being used for the same purpose of estimating population parameters from fisheries dependent data. The stock assessment process improves when the input data can be evaluated with consistency. Therefore, increasing the amount and quality of input data is expected to improve stock assessment conclusions, which would in turn result in greater ecological and economic sustainability. Management objectives aim to maximize long-term fishery yield by maintaining a spawning stock biomass capable of producing the maximum sustainable yield with at least a 60 percent probability and minimize inter-annual fluctuations total allowable catch (TAC) levels (Kell *et al.*, 2017). Reducing the stock assessment uncertainty when evaluating minimum spawning stock biomass is necessary for achieving the objectives of maximum sustainable catches with minimum TAC fluctuations.

In tuna stock assessments, indices of standardized catch per unit effort (CPUE) time series are used as proxies for relative abundance. However, these series, based on fishery data, present analytical challenges, such as lack of scientific design, correlated observations,

non-random sampling or variable catchability (Maunder *et al.*, 2006). In the case of bluefin tuna, the drastic reduction in fishing opportunities as part of the recovery plan has affected CPUE indices, and the SCRS of ICCAT recommended the urgent development of catch independent indices of abundance (ICCAT, 2016). Currently, the standardized CPUE of the Bay of Biscay baitboat fleet is used as the only abundance index for the juvenile fraction of the entire eastern stock (Rodriguez-Marín *et al.*, 2003; Santiago et la., 2016). The estimation of tuna abundance in the Bay of Biscay using fishery independent methods remains challenging, but new scientific data based on novel technologies and approaches can provide new opportunities to address these challenges (Uranga *et al.*, 2017). For example, recent acoustic survey developments show a proof-of-concept about the feasibility of automatically distinguishing between tuna signals and random noise in sonar information from fishing vessels (Uranga *et al.*, 2017). The methodology can be calibrated and validated by using already scheduled bluefin tuna (BFT) Index acoustic oceanographic surveys (Goñi *et al.*, 2016). Similarly, fishing vessels already have the capacity to use GPS tracking and many are incorporating AIS tracking which can provide valuable information about fishing effort (McCauley *et al.*, 2016).

Sustainable fishing certifications, also referred to as eco-labels, are growing in importance at retail level, with multiple initiatives throughout the supply chain developing to satisfy this market demand. Consumer demand for canned tuna varies depending on the species, whether the product is sold in an organic or conventional supermarket and whether the product is considered conventional or eco-friendly and thus associated with a higher willingness by the consumer to pay a premium for the latter (Guillotreau *et al.*, 2017). There are a number of certification and advisory programs, such as the Marine Stewardship Council (MSC), FAO's standard, Monterey Bay Aquarium's Seafood Watch in the U.S.A., International Seafood Sustainability Foundation (ISSF) standards and their Proactive Vessel Register (PVR) (https://iss-foundation.org/knowledge-tools/databases/proactive-vessel-register/) which are ways for vessel owners to identify themselves as active participants in meaningful tuna sustainability efforts and the fishing of tuna responsibly.

International safety and sustainability certifications for fisheries can be a successful driver of change in industries to improve infrastructure, people training, commodity values, diversify markets and support the ecological sustainability of the activities of associated industries in some countries (Fernandes, 2018). Despite controversy about their absolute impact, scientists seem to agree that credited certification programs significantly help achieve sustainable fishing (Hoggarth *et al.*, 2010; Agnew *et al.*, 2013a,b; Christian *et al.*, 2013; Froese *et al.*, 2012, 2013). Certifications are helping to open international markets, which account for 75 percent of the global fish trade

(European Union, Japan, and the USA) for South Asian countries in the Indian Ocean (Fernandes, 2018).

In the Bay of Biscay, 57 Basque and Cantabrian purse seine vessels have the MSC certification for fishing European anchovy (MSC, 2017) and sardine (MSC, 2018), and another 40 vessels are expected to obtain this certificate by the end of 2019. In addition, MSC certification has been achieved by 87 trolling vessels and 42 pole and line vessels fishing albacore in North Atlantic oceanic areas (MSC, 2017); and 2 bottom trawlers targeting cod (*Gadus morhua*) in Norwegian and Arctic Seas. To attain MSC certification these fisheries have to achieve compliance with the three MSC Principles (Principle 1 on sustainable target fish stocks, Principle 2 on environmental impact of fishing and Principle 3 on effective management).

AIS effort data can help certify the compliance of these principles if it proves to be a reliable cost-effective way of assessing fishing mortality for Principles 1 and 3. AIS can also aid to assess compliance with Principle 2, for example by verifying that MPA regulations for key benthic habitats are respected. The Spanish tropical tuna purse seiner fishing sector is committed to ISSF standards, with all vessels included in the PVR list, and is immersed in fisheries improvement projects for MSC Certification. This fleet has also promoted and obtained the AENOR responsible tuna fishing (Atún de Pesca Responsible – APR) standard (UNE195006). This sector has also worked to include social issues, such as crew working conditions, in this standard, together with control and monitoring aspects, environmental ones (e.g. bycatch mitigation measures), and marine and health control requirements. Social and job safety conditions are in line with the International Labour Organization Convention 188 and the Spanish tuna fleet aims to differentiate itself from the cheap labour low-cost attributed to other large fishing fleets (Sala *et al.*, 2018). This is a first step to include the social dimension in certification programs, in addition to sustainability and control aspects in the fight against illegal, unreported and unregulated (IUU) fishing and which could be adopted in the future by other standards such as the MSC and ISSF. AIS might be useful to monitor changes in effort which could indicate changes in fish mortality, but the link between AIS and effort/mortality is difficult to establish since AIS does not provide catch information. It becomes even harder to establish that relationship for distant water fleets that use fish aggregating devices (FADs) or if they switch off AIS due to piracy, competition or other reasons (please see next chapter about fisheries in the Indian Ocean).

ACKNOWLEDGEMENTS

This chapter authors and editors would like to thank Dr. Emmanuel Chassot, Nathan A. Miller, Jennifer Gee and Kiran Viparthi for excellent comments and feedback during the elaboration of the chapter. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Required citation for this chapter:

Fernandes, J. A., Granado, I., Murua, H., Arrizabalaga, H., Zarauz, L., Mugerza, E., Arregi, L., Galparsoro, I., Murua, J., Iriondo, A., Merino, G., Basurko, O. C., Quincoces, I., Santiago, J., Irigoien, X. 2019. Bay of Biscay VMS/logbook comparison (FAO Subarea 27.8). *In* Taconet, M., Kroodsma, D., Fernandes, J.A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

Agnew, D. J., Gutiérrez, N. L., Stern-Pirlot, A., & Hoggarth, D. D. 2013. The MSC experience: developing an operational certification standard and a market incentive to improve fishery sustainability. *ICES Journal of Marine Science*, 71(2), 216-225. https://doi.org/10.1093/icesjms/fst091

Agnew, D. J., Gutiérrez, N. L., Stern-Pirlot, A., Smith, A. D. M., Zimmermann, C., & Sainsbury, K. 2013b. Rebuttal to Froese and Proelss "Evaluation and legal assessment of certified seafood". *Marine Policy*, 38, 551-553. https://doi.org/10.1016/j.marpol.2012.07.002

Basurko, O. C., Gabiña, G., & Uriondo, Z. 2013. Energy performance of fishing vessels and potential savings. *Journal of Cleaner Production*, 54, 30-40. https://doi.org/10.1016/j.jclepro.2013.05.024

Battaglia, P., Romeo, T., Consoli, P., Scotti, G., & Andaloro, F. 2010. Characterization of the artisanal fishery and its socio-economic aspects in the central Mediterranean Sea (Aeolian Islands, Italy). *Fisheries Research*, 102(1), 87-97. https://doi.org/10.1016/j.fishres.2009.10.013

Blanchard, F., LeLoc'h, F., Hily, C., & Boucher, J. 2004. Fishing effects on diversity, size and community structure of the benthic invertebrate and fish megafauna on the Bay of Biscay coast of France. *Marine Ecology Progress Series*, 280, 249-260. https://doi.org/10.3354/meps280249

Breen, P., Vanstaen, K., & Clark, R. W. 2014. Mapping inshore fishing activity using aerial, land, and vessel-based sighting information. *ICES Journal of Marine Science*, 72(2), 467-479. https://doi.org/10.1093/icesjms/fsu115

Castro, J., Punzón, A., Pierce, G. J., Marín, M., & Abad, E. 2010. Identification of métiers of the Northern Spanish coastal bottom pair trawl fleet by using the partitioning method CLARA. *Fisheries Research*, 102(1-2), 184-190. https://doi.org/10.1016/j.fishres.2009.11.011

CEC. 2007. *Commission of the European Communities. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. An integrated maritime policy for the European Union.* http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2007:0575:FIN:EN:PDF

CEU. 2009. *Council of the European Union. Council Regulation (EC) No 1224/2009 of 20 November 2009 establishing a Community control system for ensuring compliance with the rules of the common fisheries policy, amending Regulations (EC) No 847/96, (EC) No 2371/2002, (EC) No 811/2004, (EC) No 768/2005, (EC) No 2115/2005, (EC) No 2166/2005, (EC) No 388/2006, (EC) No 509/2007, (EC) No 676/2007, (EC) No 1098/2007, (EC) No 1300/2008, (EC) No 1342/2008 and repealing Regulations (EEC) No 2847/93, (EC) No 1627/94 and (EC) No 1966/2006.* https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:343:0001:0050:EN:PDF

CEU. 2011. *Council of the European Union. Corrigendum to Commission Implementing Regulation (EU) No 404/2011 Search for available translations of the preceding link of 8 April 2011 laying down detailed rules for the implementation of Council Regulation (EC) No 1224/2009 establishing a Community control system for ensuring compliance with the rules of the Common Fisheries Policy.* https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:328:0058:0058:EN:PDF

Christian, C., Ainley, D., Bailey, M., Dayton, P., Hocevar, J., LeVine, M.,... & Jacquet, J. 2013. A review of formal objections to Marine Stewardship Council fisheries certifications. *Biological Conservation*, 161, 10-17. https://doi.org/10.1016/j.biocon.2013.01.002

Coccoli, C., Galparsoro, I., Murillas, A., Pınarbaşı, K., & Fernandes, J. A. 2018. Conflict analysis and reallocation opportunities in the framework of marine spatial planning: A novel, spatially explicit Bayesian belief network approach for artisanal fishing and aquaculture. *Marine Policy*, 94, 119-131. https://doi.org/10.1016/j.marpol.2018.04.015

Compeán-Jimenez, G., & Bard, F. X. (1983). *Growth increments on dorsal spines of eastern Atlantic bluefin tuna, Thunnus thynnus, and their possible relation to migration patterns.* NOAA Tech. Rep. NMFS, 8, 77-86. https://repository.library.noaa.gov/view/noaa/5591/noaa_5591_DS1.pdf

Daurès, F., Rochet, M. J., Van Iseghem, S., & Trenkel, V. M. 2009. Fishing fleet typology, economic dependence, and species landing profiles of the French fleets in the Bay of Biscay, 2000-2006. *Aquatic Living Resources*, 22(4), 535-547. https://doi.org/10.1051/alr/2009031

Derrick, B., Noranarttragoon, P., Zeller, D., Teh, L. C., & Pauly, D. 2017. Thailand's missing marine fisheries catch (1950–2014). *Frontiers in Marine Science*, 4, 402. https://doi.org/10.3389/fmars.2017.00402

Dufour, F., Arrizabalaga, H., Irigoien, X., & Santiago, J. 2010. Climate impacts on albacore and bluefin tunas migrations phenology and spatial distribution. *Progress in Oceanography*, 86(1-2), 283-290. https://doi.org/10.1016/j.pocean.2010.04.007

EC. 2011. *European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Reform of the Common Fisheries Policy.* http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0417:FIN:EN:PDF

EC. 2013. *European Commission. Directive of the European Parliament and of the Council establishing a framework for maritime spatial planning and integrated coastal management* http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2013:0133:FIN:EN:PDF

EFF. 2006. European Fisheries Fund. Council Regulation (EC) No. 1198/2006 of 27 July 2006 on the European Fisheries Fund. *Official Journal of the European Union*, L, 232. https://publications.europa.eu/en/publication-detail/-/publication/3aa4fce8-0547-47d0-add3-4ee7b1e60608/language-en

Ehler, C., & Douvere, F. 2009. *Marine Spatial Planning: a step-by-step approach toward ecosystem-based management. Intergovernmental Oceanographic Commission and Man and the Biosphere Programme.* IOC Manual and Guides No. 53, ICAM Dossier No. 6. Paris: UNESCO.: 99pp. https://development.oceanbestpractices.net/bitstream/handle/11329/459/186559e.pdf?sequence=1&isAllowed=y

EPCEU. 2008. *The European Parliament and the Council of the European Union. DIRECTIVE 2008/56/EC of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive).* http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:164:0019:0040:EN:PDF

Fernandes, J., Irigoien, X., Uriarte, A., Ibaibarriaga, L., Lozano, J., & Inza, I. 2009. *Anchovy Recruitment Mixed Long Series prediction using supervised classification.* Tech. rep., Working document to the ICES benchmark workshop on short lived species (WKSHORT), Bergen, Norway. http://ices.dk/sites/pub/CM%20Doccuments/CM-2009/ACOM/ACOM3409.pdf

Fernandes, J. A., Irigoien, X., Goikoetxea, N., Lozano, J. A., Inza, I., Pérez, A., & Bode, A. 2010. Fish recruitment prediction, using robust supervised classification methods. *Ecological Modelling*, 221(2), 338-352. https://doi.org/10.1016/j.ecolmodel.2009.09.020

Fernandes, J. A., Lozano, J. A., Inza, I., Irigoien, X., Pérez, A., & Rodríguez, J. D. 2013. Supervised pre-processing approaches in multiple class variables classification for fish recruitment forecasting. *Environmental modelling & software*, 40, 245-254. https://doi.org/10.1016/j.envsoft.2012.10.001

Fernandes, J. A., Irigoien, X., Lozano, J. A., Inza, I., Goikoetxea, N., & Pérez, A. 2015. Evaluating machine-learning techniques for recruitment forecasting of seven North East Atlantic fish species. *Ecological informatics*, 25, 35-42. https://doi.org/10.1016/j.ecoinf.2014.11.004

Fernandes, J. A., Santos, L., Vance, T., Fileman, T., Smith, D., Bishop, J. D.,... & Austen, M. C. 2016. Costs and benefits to European shipping of ballast-water and hull-fouling treatment: Impacts of native and non-indigenous species. *Marine Policy*, 64, 148-155. https://doi.org/10.1016/j.marpol.2015.11.015

Fernandes, J. A., Papathanasopoulou, E., Hattam, C., Queirós, A. M., Cheung, W. W., Yool, A.,... & Calosi, P. 2017. Estimating the ecological, economic and social impacts of ocean acidification and warming on UK fisheries. *Fish and Fisheries*, 18(3), 389-411. https://doi.org/10.1111/faf.12183

Fernandes, J.A. 2018. Chapter 13: Southern Asian fisheries in the Arabian Sea, Bay of Bengal and East Indian Ocean. *In* Barange, M., Bahri, T., Beveridge, M., Cochrane, K., Funge-Smith, S., Poulain, F. (Eds.) 2018. *Impacts of Climate Change on fisheries and aquaculture: Synthesis of current knowledge, adaptation and mitigation options.* FAO Fisheries Technical Paper 627 (in press). http://www.fao.org/3/i9705en/i9705en.pdf

Fernández-Macho, J., Murillas, A., Ansuategi, A., Escapa, M., Gallastegui, C., González, P.,... & Virto, J. 2015. Measuring the maritime economy: Spain in the European Atlantic Arc. *Marine Policy*, 60, 49-61. https://doi.org/10.1016/j.marpol.2015.05.010

Fiorini, M., Capata, A., & Bloisi, D. D. 2016. AIS data visualization for Maritime Spatial Planning (MSP). *International Journal of e-Navigation and Maritime Economy*, 5, 45-60. https://doi.org/10.1016/j.enavi.2016.12.004

Foley, N. S., Corless, R., Escapa, M., Fahy, F., Fernandez-Macho, J., Gabriel, S.,... & Moylan, K. 2014. Developing a comparative marine socio-economic framework for the European Atlantic area. *Journal of ocean and coastal economics*, 2014(1), 3. https://doi.org/10.15351/2373-8456.1007

Froese, R., & Proelss, A. 2012. Evaluation and legal assessment of certified seafood. *Marine Policy*, 36(6), 1284-1289. https://doi.org/10.1016/j.marpol.2012.03.017

Froese, R., & Proelss, A. 2013. Is a stock overfished if it is depleted by overfishing? A response to the rebuttal of Agnew et al. to Froese and Proelss "Evaluation and legal assessment of certified seafood". *Marine Policy*, 38, 548-550. https://doi.org/10.1016/j.marpol.2012.07.001

FRSS (Fisheries Resources Survey System). 2017. *Yearbook of fisheries statistics of Bangladesh.* Fisheries Resources Survey System (FRSS), Department of Fisheries, Bangladesh. Volume 33. http://document.bdfish.org/2017/07/yearbook-of-fisheries-statistics-of-bangladesh-2015-2016-volume-33-april-2017/

Galparsoro, I., Borja, Á., Bald, J., Liria, P., & Chust, G. 2009. Predicting suitable habitat for the European lobster (Homarus gammarus), on the Basque continental shelf (Bay of Biscay), using Ecological-Niche Factor Analysis. *Ecological modelling*, 220(4), 556-567. https://doi.org/10.1016/j.ecolmodel.2008.11.003

Garmendia, J. M., Galparsoro, I., & Rodríguez, J. G. 2015. La pesquería con nasas de Cancer pagurus en el País Vasco: capturas, caracterización biológica, capturas por unidad de esfuerzo y modelización de la distribución de su hábitat. *Revista de Investigación Marina*, *AZTI-Tecnalia*, 22(3), 33-63. https://www.azti.es/rim/wp-content/uploads/2015/12/RIM_22_3_Def.pdf

García-Flórez, L., Morales, J., Gaspar, M. B., Castilla, D., Mugerza, E., Berthou, P.,... & Arregi, L. 2014. A novel and simple approach to define artisanal fisheries in Europe. *Marine Policy*, 44, 152-159. https://doi.org/10.1016/j.marpol.2013.08.021

Gloaguen, P., Woillez, M., Mahévas, S., Vermard, Y., & Rivot, E. 2016. Is speed through water a better proxy for fishing activities than speed over ground?. *Aquatic Living Resources*, 29(2), 210. https://doi.org/10.1051/alr/2016023

Golub, S. & Varma, A. 2014. *Fishery exports and economic development of least developed countries: Bangladesh, Cambodia, Comoros, Sierra Leone and Uganda.* Paper Prepared for the United Nations Conference on Trade and Development (UNCTAD). http://unctad.org/en/PublicationsLibrary/aldc2017d2_en.pdf

Goñi, N., & Arrizabalaga, H. 2005. Analysis of juvenile North Atlantic albacore (Thunnus alalunga) catch per unit effort by surface gears in relation to environmental variables. *ICES Journal of Marine Science*, 62(7), 1475-1482. https://doi.org/10.1016/j.icesjms.2005.05.014

Goni, R., & Latrouite, D. 2005. Review of the biology, ecology and fisheries of Palinurus spp. species of European waters: Palinurus elephas (Fabricius, 1787) and Palinurus mauritanicus (Gruvel, 1911). *CBM-Cahiers de Biologie Marine*, 46(2), 127-142. https://archimer.ifremer.fr/doc/2005/publication-3625.pdf

Goñi, N., Didouan, C., Arrizabalaga, H., Chifflet, M., Arregui, I., Goikoetxea, N., & Santiago, J. 2015. Effect of oceanographic parameters on daily albacore catches in the Northeast Atlantic. Deep Sea Research Part II: *Topical Studies in Oceanography*, 113, 73-80. https://doi.org/10.1016/j.dsr2.2015.01.012

Guillotreau, P., Squires, D., Sun, J., & Compeán, G. A. 2017. Local, regional and global markets: what drives the tuna fisheries?. *Reviews in fish biology and fisheries*, 27(4), 909-929. https://doi.org/10.1007/s11160-016-9456-8

He, P. 2018. Chapter 27: Countering climate change: measures and tools to reduce energy use and greenhouse gas emission in fisheries and aquaculture. *In* Barange, M., Bahri, T., Beveridge, M., Cochrane, K., Funge-Smith, S., Poulain, F. (Eds.). *Impacts of Climate Change on fisheries and aquaculture: Synthesis of current knowledge, adaptation and mitigation options.* FAO Fisheries Technical Paper 627. Rome, FAO. http://www.fao.org/3/i9705en/i9705en.pdf

Hiddink, J. G., Jennings, S., & Kaiser, M. J. 2007. Assessing and predicting the relative ecological impacts of disturbance on habitats with different sensitivities. *Journal of Applied Ecology*, 44(2), 405-413. https://doi.org/10.1111/j.1365-2664.2007.01274.x

Hintzen, N. T., Bastardie, F., Beare, D., Piet, G. J., Ulrich, C., Deporte, N.,... & Degel, H. 2012. VMStools: Open-source software for the processing, analysis and visualisation of fisheries logbook and VMS data. *Fisheries Research*, 115, 31-43. https://doi.org/10.1016/j.fishres.2011.11.007

ICES. 2016. *International Council for the Exploration of the Sea. Bay of Biscay and the Iberian Coast Ecoregion – Ecosystem overview. Bay of Biscay and the Iberian Coast Ecoregion.* ICES Advice 2016, Book 7. Copenhagen. https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2016/2016/Bay_of_Biscay_and_the%20Iberian%20Coast%20Ecoregion%20-Ecosystem%20overview.pdf

ILO. 2015. *International Labour Organization. Value chain analysis and competitiveness strategy: marine capture fisheries: Myeik and Yangon - Myanmar.* Myanmar, ILO Liaison Officer for Yangon. http://www.ilo.org/empent/areas/value-chain-development-vcd/WCMS_446510/lang--en/index.htm

Iriondo, A., García, D., Santurtún, M., Castro, J., Quincoces, I., Lehuta, S.,... & Ulrich, C. 2012. Managing mixed fisheries in the European western waters: Application of Fcube methodology. *Fisheries Research*, 134, 6-16. https://doi.org/10.1016/j.fishres.2012.07.019

James, M., Mendo, T., Jones, E. L., Orr, K., McKnight, A., & Thompson, J. 2018. AIS data to inform small scale fisheries management and marine spatial planning. *Marine Policy*, 91, 113-121. https://doi.org/10.1016/j.marpol.2018.02.012

Jentoft, S., & Knol, M. 2014. Marine spatial planning: risk or opportunity for fisheries in the North Sea?. *Maritime Studies*, 12(1), 13. https://doi.org/10.1186/2212-9790-12-13

Katsanevakis, S., Stelzenmüller, V., South, A., Sørensen, T. K., Jones, P. J., Kerr, S.,... & D'Anna, G. 2011. Ecosystem-based marine spatial management: review of concepts, policies, tools, and critical issues. *Ocean & Coastal Management*, 54(11), 807-820. https://doi.org/10.1016/j.ocecoaman.2011.09.002

Kell, L. T., Arrizabalaga, H., Merino, G., & de Bruyn, P. 2017. *The Implicit North Atlantic Albacore Management Procedure.* Collect. Vol. Sci. Pap. ICCAT, 73(4), 1339-1349. https://www.iccat.int/Documents/CVSP/CV073_2017/n_4/CV073041339.pdf

Kiszka, J., Macleod, K., Van Canneyt, O., Walker, D., & Ridoux, V. 2007. Distribution, encounter rates, and habitat characteristics of toothed cetaceans in the Bay of Biscay and adjacent waters from platform-of-opportunity data. *ICES Journal of Marine Science*, 64(5), 1033-1043. https://doi.org/10.1093/icesjms/fsm067

Korta, M., García, D., Santurtún, M., Goikoetxea, N., Andonegi, E., Murua, H.,... & Murillas, A. 2015. European hake (*merluccius merluccius*) in the Northeast Atlantic Ocean. *Hakes: Biology and Exploitation*, 1-37. https://doi.org/10.1002/9781118568262.ch1|

Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F.,... & Woods, P. 2018. Tracking the global footprint of fisheries. *Science*, 359(6378), 904-908. https://doi.org/10.1126/science.aao5646

Le Guyader, D., Ray, C., Gourmelon, F., & Brosset, D. 2017. Defining high-resolution dredge fishing grounds with Automatic Identification System (AIS) data. *Aquatic Living Resources*, 30, 39. https://doi.org/10.1051/alr/2017038

Macfadyen, G., Salz, P., & Cappell, R. 2011. Characteristics of small-scale coastal fisheries in Europe. Policy Department: Structural and Cohesion Policies, European Parliament. *Fisheries*, 162. http://www.europarl.europa.eu/RegData/etudes/etudes/join/2011/460059/IPOL-PECH_ET(2011)460059_EN.pdf

Marchal, P. 2008. A comparative analysis of métiers and catch profiles for some French demersal and pelagic fleets. *ICES Journal of Marine Science*, 65(4), 674-686. https://doi.org/10.1093/icesjms/fsn044

Maunder, M. N., Sibert, J. R., Fonteneau, A., Hampton, J., Kleiber, P., & Harley, S. J. 2006. Interpreting catch per unit effort data to assess the status of individual stocks and communities. *Ices Journal of marine science*, 63(8), 1373-1385. https://doi.org/10.1016/j.icesjms.2006.05.008

McCauley, D. J., Woods, P., Sullivan, B., Bergman, B., Jablonicky, C., Roan, A.,... & Worm, B. 2016. Ending hide and seek at sea. *Science*, 351(6278), 1148-1150. https://doi.org/10.1126/science.aad5686

Merino, G., Quetglas, A., Maynou, F., Garau, A., Arrizabalaga, H., Murua, H.,... & Lleonart, J. 2015. Improving the performance of a Mediterranean demersal fishery toward economic objectives beyond MSY. *Fisheries research*, 161, 131-144. https://www.sciencedirect.com/science/article/pii/S0165783614001982

Morandeau, G., Macher, C., Sanchez, F., Bru, N., Fauconnet, L., & Caill-Milly, N. 2014. Why do fishermen discard? Distribution and quantification of the causes of discards in the Southern Bay of Biscay passive gear fisheries. *Marine Policy*, 48, 30-38. https://doi.org/10.1016/j.marpol.2014.02.022

Murillas, A., Mugerza, E., Arregi, L., Alzorriz, N., & Artetxe, I. 2012. *PRESPO-Desarrollo sostenible de las pesquerías artesanales del País Vasco.* Colección Itsaso. Servicio Central de Publicaciones del Gobierno Vasco, Vitoria, Spain. http://www.euskadi.eus/contenidos/informacion/coleccion_itsaso/eu_dapa/adjuntos/prespo.pdf

Murillas-Maza, A., & Andrés, M. 2016. Providing incentives for fishermen through rights-based co-management systems. An impact-assessment on Basque fisheries. *Marine Policy*, 70, 128-136. https://doi.org/10.1016/j.marpol.2016.04.027

MSC. 2017a. *Marine Stewardship Council. Second Surveillance Report. Cantabrian purse seine anchovy fishery.* https://fisheries.msc.org/en/fisheries/cantabrian-sea-purse-seine-anchovy-fishery

MSC. 2017b. *Marine Stewardship Council. First Surveillance Report. North Atlantic albacore artisanal fishery.* https://fisheries.msc.org/en/fisheries/north-atlantic-albacore-artisanal-fishery/

MSC. 2018. *Marine Stewardship Council. First Surveillance Report. Bay of Biscay purse seine sardine fishery.* https://fisheries.msc.org/en/fisheries/bay-of-biscay-purse-seine-sardine-fishery/

Nadeau, C., & Bengio, Y. 2000. Inference for the generalization error. *In Advances in neural information processing systems* (pp. 307-313). http://papers.nips.cc/paper/1661-inference-for-the-generalization-error.pdf

Nikolic, N., Morandeau, G., Hoarau, L., West, W., Arrizabalaga, H., Hoyle, S.,... & Williams, A. J. 2017. Review of albacore tuna, Thunnus alalunga, biology, fisheries and management. *Reviews in fish biology and fisheries*, 27(4), 775-810. https://doi.org/10.1007/s11160-016-9453-y

Pascual, M., Borja, A., Galparsoro, I., Ruiz, J., Mugerza, E., Quincoces, I.,... & Arregi, L. 2013. Total fishing pressure produced by artisanal fisheries, from a Marine Spatial Planning perspective: A case study from the Basque Country (Bay of Biscay). *Fisheries research*, 147, 240-252. https://doi.org/10.1016/j.fishres.2013.06.010

Pawson, M. G., Pickett, G. D., Leballeur, J., Brown, M., & Fritsch, M. 2007. Migrations, fishery interactions, and management units of sea bass (Dicentrarchus labrax) in Northwest Europe. *ICES Journal of Marine Science*, 64(2), 332-345. https://doi.org/10.1093/icesjms/fsl035

Parker, R. W., Vázquez-Rowe, I., & Tyedmers, P. H. 2015. Fuel performance and carbon footprint of the global purse seine tuna fleet. *Journal of Cleaner Production*, 103, 517-524. https://doi.org/10.1016/j.jclepro.2014.05.017

Pınarbaşı, K., Galparsoro, I., Borja, Á., Stelzenmüller, V., Ehler, C. N., & Gimpel, A. 2017. Decision support tools in marine spatial planning: present applications, gaps and future perspectives. *Marine Policy*, 83, 83-91. https://doi.org/10.1016/j.marpol.2017.05.031

Prellezo, R., Carmona, I., & García, D. 2016. The bad, the good and the very good of the landing obligation implementation in the Bay of Biscay: A case study of Basque trawlers. *Fisheries Research*, 181, 172-185. https://doi.org/10.1016/j.fishres.2016.04.016

Puig, P., Canals, M., Company, J. B., Martín, J., Amblas, D., Lastras, G.,... & Calafat, A. M. 2012. Ploughing the deep sea floor. *Nature*, 489(7415), 286. https://doi.org/10.1038/nature11410

Punzón, A., Villamor, B., & Preciado, I. 2004. Analysis of the handline fishery targeting mackerel (Scomber scombrus, L.) in the North of Spain (ICES Division VIIIbc). *Fisheries Research*, 69(2), 189-204. https://doi.org/10.1016/j.fishres.2004.05.002

Punzón, A., Serrano, A., Castro, J., Abad, E., Gil, J., & Pereda, P. 2011. Deep-water fishing tactics of the Spanish fleet in the Northeast Atlantic. Seasonal and spatial distribution. *Scientia Marina*, 75(3), 465-476. https://doi.org/10.3989/scimar.2011.75n3465

Queirós, A. M., Fernandes, J., Genevier, L., & Lynam, C. P. 2018. Climate change alters fish community size-structure, requiring adaptive policy targets. *Fish and Fisheries*, 19(4), 613-621. https://doi.org/10.1111/faf.12278

Rodríguez-Marín, E., Arrizabalaga, H., Ortiz, M., Rodríguez-Cabello, C., Moreno, G., & Kell, L. T. 2003. Standardization of bluefin tuna, Thunnus thynnus, catch per unit effort in the baitboat fishery of the Bay of Biscay (Eastern Atlantic). *ICES Journal of Marine Science*, 60(6), 1216-1231. https://doi.org/10.1016/S1054-3139(03)00139-5

Rochet, M. J., Daurès, F., & Trenkel, V. M. 2012. Capacity management, not stock status or economics, drives fleet dynamics in the Bay of Biscay ecosystem on a decadal time scale. *Canadian journal of fisheries and aquatic sciences*, 69(4), 695-710. https://doi.org/10.1139/f2012-002

Rooker, J. R., Arrizabalaga, H., Fraile, I., Secor, D. H., Dettman, D. L., Abid, N.,... & Sakai, O. 2014. Crossing the line: migratory and homing behaviors of Atlantic bluefin tuna. *Marine Ecology Progress Series*, 504, 265-276. https://doi.org/10.3354/meps10781

Rueda, F. M., & Martínez, F. M. 2001. A review on the biology and potential aquaculture of Dentex dentex. *Reviews in Fish Biology and Fisheries*, 11(1), 57-70. https://doi.org/10.1023/A:1014276700138

Sala, E., Mayorga, J., Costello, C., Kroodsma, D., Palomares, M. L., Pauly, D., Sumaila, R., & Zeller, D. 2018. The economics of fishing the high seas. *Science advances*, 4(6), eaat2504. http://doi.org/10.1126/sciadv.aat2504

Sancho, G., Puente, E., Bilbao, A., Gomez, E., & Arregi, L. 2003. Catch rates of monkfish (Lophius spp.) by lost tangle nets in the Cantabrian Sea (northern Spain). *Fisheries Research*, 64(2-3), 129-139. https://doi.org/10.1016/S0165-7836(03)00212-1

Santiago, J., Arrizabalaga, H., Ortiz, M., & Goñi, N. 2016. *Updated standardized bluefin tuna CPUE index of the Bay of Biscay baitboat fishery (1952–2014).* Collect Vol Sci Pap ICCAT, 72(7), 1694-1714. https://www.iccat.int/Documents/CVSP/CV072_2016/n_7/CV07201694.pdf

Sciberras, M., Hiddink, J. G., Jennings, S., Szostek, C. L., Hughes, K. M., Kneafsey, B.,... & Hilborn, R. 2018. Response of benthic fauna to experimental bottom fishing: A global meta-analysis. *Fish and Fisheries*, 19(4), 698-715. https://doi.org/10.1111/faf.12283

Shelton, P. M. J., Shelton, R. G. J., & Richards, P. R. (**1981**). Eye development in relation to moult stage in the European lobster Homarus gammarus (L.). *ICES Journal of Marine Science*, 39(3), 239-243. https://doi.org/10.1093/icesjms/39.3.239

Stelzenmüller, V., Lee, J., Garnacho, E., & Rogers, S. I. 2010. *Assessment of a Bayesian Belief Network–GIS framework as a practical tool to support marine planning. Marine pollution bulletin, 60(10), 1743-1754.* https://doi.org/10.1016/j.marpolbul.2010.06.024

Suuronen, P., Chopin, F., Glass, C., Løkkeberg, S., Matsushita, Y., Queirolo, D., & Rihan, D. 2012. Low impact and fuel efficient fishing—Looking beyond the horizon. *Fisheries research*, 119, 135-146. https://doi.org/10.1016/j.fishres.2011.12.009

Tidd, A. N., Vermard, Y., Marchal, P., Pinnegar, J., Blanchard, J. L., & Milner-Gulland, E. J. 2015. Fishing for space: fine-scale multi-sector maritime activities influence fisher location choice. *PloS one*, 10(1), e0116335. https://doi.org/10.1371/journal.pone.0116335

Tuda, A. O., Stevens, T. F., & Rodwell, L. D. 2014. Resolving coastal conflicts using marine spatial planning. *Journal of environmental management*, 133, 59-68. https://doi.org/10.1016/j.jenvman.2013.10.029

Tyedmers, P. 2004. Fisheries and energy use. *Encyclopedia of energy*, 2, 683-693. http://www.armeris.fr/downloads/fuel/tyedmers_2004.pdf

Tyedmers, P. H., Watson, R., & Pauly, D. 2005. Fueling global fishing fleets. *AMBIO: a Journal of the Human Environment*, 34(8), 635-639. https://doi.org/10.1579/0044-7447-34.8.635

Uranga, J., Arrizabalaga, H., Boyra, G., Hernandez, M. C., Goñi, N., Arregui, I.,... & Santiago, J. 2017. Detecting the presence-absence of bluefin tuna by automated analysis of medium-range sonars on fishing vessels. *PloS one*, 12(2), e0171382. https://doi.org/10.1371/journal.pone.0171382

Uriarte, A. N. D. R. É. S., Prouzet, P., & Villamor, B. (**1996**). Bay of Biscay and Ibero Atlantic anchovy populations and their fisheries. *Scientia Marina*, 60(SUPL 2), 237-255. http://scimar.icm.csic.es/scimar/pdf/60/sm60s2237.pdf

Uriarte, A., Prellezo, R., Punzón, A., Aranda, M., & Villamor, B. 2008. *The Spanish fishery on anchovy in the Bay of Biscay: Analysis of the relationship between fishing Capacity, Effort and mortality*. ICES CM, 1, 18. http://ices.dk/sites/pub/CM%20Doccuments/CM-2008/I/I1808.pdf

Van Denderen, P. D., Hintzen, N. T., Rijnsdorp, A. D., Ruardij, P., & van Kooten, T. 2014. Habitat-specific effects of fishing disturbance on benthic species richness in marine soft sediments. *Ecosystems*, 17(7), 1216-1226. https://doi.org/10.1007/s10021-014-9789-x

Victorero, L., Watling, L., Deng Palomares, M. L., & Nouvian, C. 2018. Out of sight, but within reach: A global history of bottom-trawled deep-sea fisheries from> 400 m depth. *Frontiers in Marine Science*, 5, 98. https://doi.org/10.3389/fmars.2018.00098

Seychelles VMS/logbook comparison for tuna fisheries (FAO Area 51)

Anne-Elise Nieblas, Julien Barde, Johnny Louys, Juliette Lucas, Cindy Assan, Taha Imzilen, Chloé Dalleau, Calvin Gerry, Emmanuel Chassot

SUMMARY AND CONCLUSIONS OF SEYCHELLES CASE STUDY

Seychelles high seas tuna fleets have a high AIS use with a transmission frequency considerably higher than that of VMS. However, AIS has far fewer transmissions than VMS and many more gaps in transmission longer than a few hours. The spatial coverage of the AIS data is good for Seychelles longline vessels, with acceptable coverage over the core fishing grounds. By contrast, AIS data are deficient for purse seiners and supply vessels with most data only present around ports due to the switch-off behavior linked to the piracy threat.

Consistent with data coverage, AIS seems to be very useful in describing the spatiotemporal patterns of the longline fishery and for identifying fishing hotspots. The GFW neural net algorithm predicts well the fishing operations for longliners but predictions for purse seiners are not informative. Metrics for effort at the scale of 5° x 5° squares, such as those typically used by tuna regional fisheries management organizations (RFMOs) for longline fisheries, are well correlated between logbooks and GFW algorithms. Thus, GFW is able to accurately distinguish fishing from non-fishing activities for longliners. However, the frequent breaks in transmission, perhaps due to issues with AIS reception, lead to consistent underprediction by AIS and GFW algorithms of the "true" patterns shown using VMS and logbook data. The increased satellite coverage observed between 2016 and 2017 resulted in improved GFW algorithm performance in deriving estimations of longline fishing effort.

The relationships between GFW predictions of longline fishing and effort could be useful in data-poor fisheries where poor collection and management systems may prevent the reporting of spatial effort to the RFMO. In such cases, the availability of AIS or VMS data combined with information on the number of hooks deployed per operation may enable predictions of gridded effort, which would improve compliance with the Conservation and Management Measures.

A major issue with the use of AIS data for fisheries monitoring of the Indian Ocean purse seine fleet is the low spatial coverage and switch-off behavior linked to the piracy threat. Compared to longliners, purse seiners can conduct several fishing sets per day. Thus, to achieve good predictions of purse seine fishing sets, high data coverage would be required to identify successive same-day operations from AIS data. Meanwhile, the accurate estimation of purse seine nominal effort would mainly depend on the ability of algorithms to identify non-fishing operations dedicated to the search of tuna schools. However, estimations of purse seine effort based on fishing and searching time have been complicated by the extensive use of GPS-tracked Fish Aggregating Devices. Vessel movements, which are now a combination of search and cruise, are extremely difficult to separate with the current resolution of VMS data. The high resolution of AIS data may provide a way forward.

INTRODUCTION TO THE SEYCHELLES CASE STUDY

Significant advances in monitoring fishing activity have been greatly aided by technological advances in vessel monitoring. Historically, fishing activities have been mainly monitored through fishers' logbooks and observer programs, which record daily instances of positions and quantities of catch and effort, as well as port sampling programs. Since 2006, the vessel monitoring system (VMS) was broadly adopted to complement calculations of fishing activity, increasing the temporal resolution of fisheries data from days to hours, and enabling global spatial coverage via surface-to-satellite communication (Witt and Godley 2007). Increased spatiotemporal resolution allowed calculations of effort using vessel speed profiles and bearing to identify the different vessel activities at sea (e.g., Lee *et al.* 2010; Bez *et al.* 2011). With the advent of the automatic identification system (AIS), initially implemented for ship-to-ship collision avoidance (see introductory sections), the temporal resolution of monitoring has been further refined from hours to minutes or seconds (Robards *et al.* 2016). These data are publicly accessible via satellite companies (Kroodsma *et al.* 2018), whereas access to VMS data are highly restricted and only available at the national level. This high-frequency data source has allowed the development of high precision algorithms of vessel behavior, such as those developed by Global Fishing Watch (GFW; Kroodsma *et al.* 2018) and previous work (Eguíluz *et al.*, 2016). These algorithms have the potential to identify global trends in fishing activity, and the potential to infer fisheries effort (Miller *et al.* 2018; Sala *et al.* 2018).

Seychelles high seas tuna fishery operating within and outside Seychelles EEZ is composed of two distinct components that target different markets. First, the foreign-owned industrial longline fleet is composed of 50 large ultra-low temperature freezer vessels that mainly target adult bigeye tuna (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*) in the western and central Indian Ocean for the Japanese sashimi market and annually catch about 8 000 t of tuna. Second, a fleet of 13 foreign-owned large-scale purse seiners targets adult yellowfin in free-swimming schools and schools of skipjack (*Katsuwonus pelamis*) mixed with juveniles of yellowfin and bigeye associated with floating objects for the canning market. The total annual catch of Seychelles purse seine fleet was greater than 110 000 t during 2016-2017. It is noteworthy that Seychelles purse seine fleet also includes some non-fishing supply vessels that substantially contribute to the effort by searching for tuna schools and maintaining the network of fish aggregating devices (FADs) with satellite-tracked buoys used for increasing purse seiners' catchability (Assan *et al.* 2015). FADs are typically human-made rafts equipped with floats to ensure buoyancy and a sea sea anchor built from old fishing net that are deployed to attract schooling fish species underneath, thus increasing their catchability (Fonteneau *et al.* 2013).

Seychelles authorities are interested in investigating the potential of AIS for monitoring vessels, detecting fishing activities, and calculating fishing activity. Seychelles is a regional leader in the sustainable exploitation of marine ecosystems in the Western Indian Ocean. Seychelles government is currently developing a Marine Spatial Plan (MSP) that will protect 30 percent of its exclusive economic zone (EEZ) from fishing and extraction activities by 2021 (Figure Sey. 1). In addition, Seychelles is involved in the joint management with Mauritius of adjacent regions. In order to implement effective management plans, monitoring and compliance measures need also to be effective. Since the early 2000s, VMS in Seychelles has been well maintained and closely monitored for vessels >12 m length, but there are numerous smaller vessels that are not monitored. The high resolution of AIS data could be of interest for monitoring small-scale displacements of fishing vessels within MSP areas. In addition, AIS data may be useful when VMS data are not available due to confidentiality; for example, the VMS data of non-Seychellois vessels operating in the joint management area.

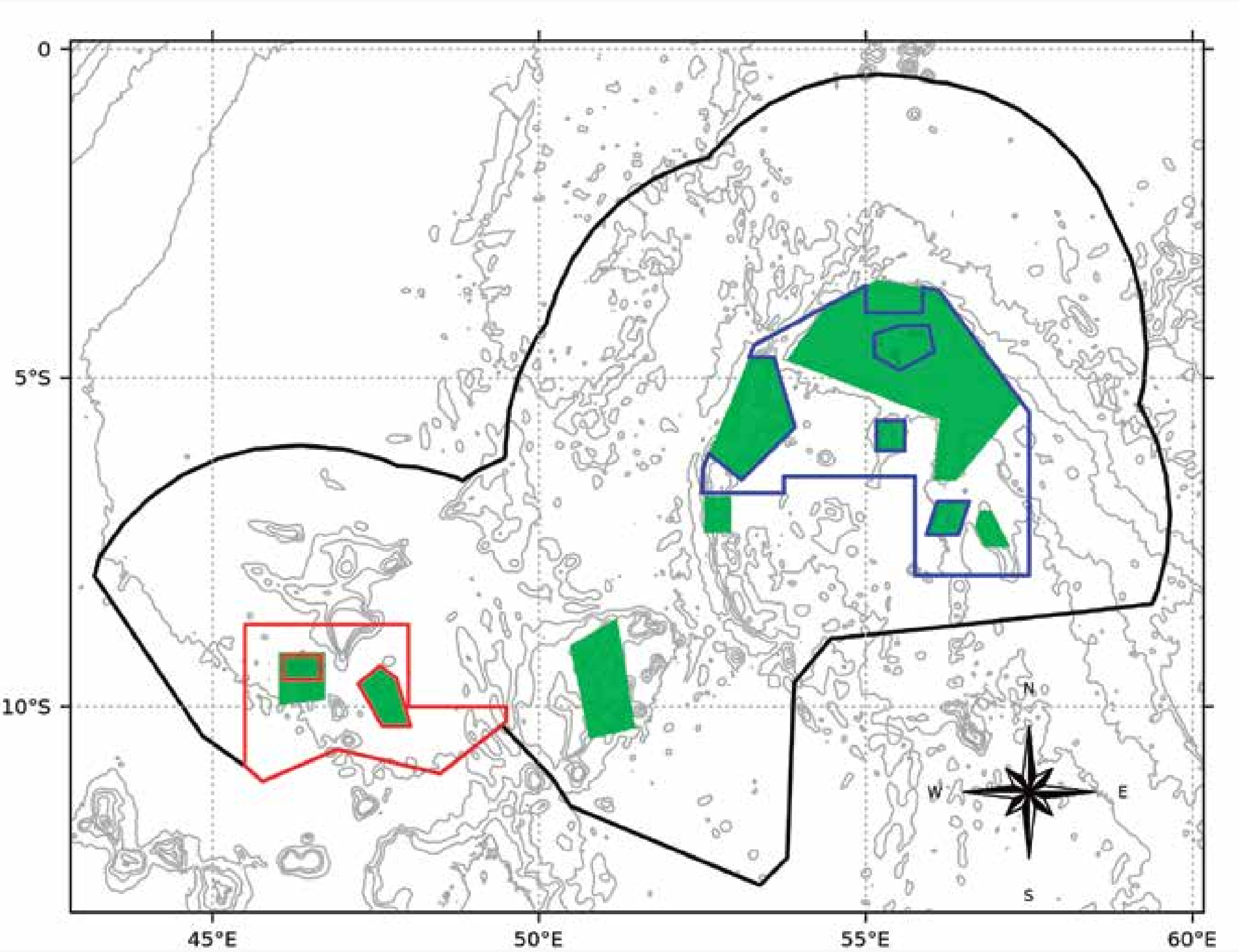


Figure Sey. 1. The exclusive economic zone (EEZ) of Seychelles (black line), located in the Western Indian Ocean, with the marine protected areas identified as part of the Fisheries Act (green polygons) and ongoing Seychelles Marine Spatial Plan as gazetted in February 2018. Red solid line = High Biodiversity Protection area; Blue solid line = Medium Biodiversity Protection and Sustainability Uses area.

Here, we investigate the difference between estimating fishing vessel activity with AIS data using GFW's algorithms and estimating fishing activity with VMS and logbook data for Seychelles high seas tuna fishery. VMS in Seychelles is continuously and rigorously monitored by Seychelles Fishing Authority (SFA), making it a highly reliable source of information on industrial fishing vessel activity. On the contrary, there are no specific mandates or requirements for AIS use in Seychelles fishing fleets. The majority of vessels that use AIS have been equipped for safety according to IMO legislation. In a first step, we compare the spatiotemporal patterns of AIS data to VMS data (i.e., the reference dataset) to investigate how well AIS data cover Seychelles industrial tuna fishing fleets and how well these data represent the spatiotemporal patterns of vessel activity. In a second step, for cases where we are able to establish that AIS data represent the spatiotemporal patterns of the fishery well, we derive indices of gear-specific fishing effort using AIS data. Finally, GFW predictions of fishing events are assessed against fishing effort and operations collected from fishers' logbooks, to assess the potential of AIS-based measures of fishing effort. We are particularly interested in assessing whether AIS could be useful for monitoring and management by the Indian Ocean Tuna Commission (IOTC) by deriving spatially aggregated effort for data-limited fisheries whose flag-countries have submitted little or no data about catch or effort.

DATA FOR THE SEYCHELLES CASE STUDY

Fishing fleets

Seychelles purse seine fleet is made up of 13 foreign-owned vessels (~90 m long) and 7 supply vessels (~40 m) that operate in Seychelles waters under annual licensing agreements. The majority of fishing by these vessels takes place on the high seas of the western tropical Indian Ocean, with ~15 percent of fishing occurring in Seychelles EEZ (Figure Sey. 1). Purse seines generally deploy their sets in waters >200 m (i.e. off the continental shelf) and can target schools between 50 m to 150 m depth.

Seychelles high seas longline fleet is made up of about 50 vessels (~50 m long), owned by locally operated Taiwanese companies that access Seychelles waters via fishing agreements. This fleet targets yellowfin and bigeye tuna in the western equatorial region with about 35 percent of fishing occurring in Seychelles EEZ. To a lesser extent, this fleet also targets albacore tuna (*Thunnus alalunga*), swordfish (*Xiphias gladius*), and oilfish (*Ruvettus pretiosus*) in the southwestern Indian Ocean near South Africa.

Data sources

Vessel activity based on AIS data for 2016 and 2017 were provided by GFW via Orbcomm (2016 and 2017) and Spire and Orbcomm (2017 only). Data were extracted specifically for drifting longliners, purse seiners, and supply vessels of Seychelles industrial tuna fishery, identified via their maritime mobile service identities (MMSI). AIS data were available for 43 longline vessels; 10 purse seine vessels; and six supply vessels (Table Sey. I). AIS data provided by GFW include information on the position of each vessel, the timestamp of this position with precision in seconds, and an indication of fishing activity based on the neural net algorithm (Kroodsma *et al.* 2018). This neural network model classifies each position as fishing or non-fishing and gives neural net scores as either 0 (no fishing) or 1 (fishing), and indicates when active fishing is occurring (i.e., a fishing operation). It does not consider effort spent searching.

VMS data for 2016 and 2017 for the longline and purse seine fleets were provided by the SFA. Data include position information of each vessel and timestamps with precision in seconds. Transmissions are required by law and frequency of emission is defined as part of the agreement protocols. Individual MMSI were associated with 47 out of the 52 distinct VMS-monitored longline vessels in Seychelles fleet, 12 out of 13 purse seiners, and seven out of seven supply vessels (Table Sey. I). The seven MMSIs missing for the VMS-monitored vessels of Seychelles fleet are due to identification errors, and the age of the vessels (i.e., very old vessels were never assigned an MMSI). Vessels with VMS and an MMSI can then be matched to vessels with AIS via the MMSI.

Logbook data were provided by the SFA and include information on the location, date, and catch for longline and purse seine vessels in 2016 and 2017. For both gears, we checked the VMS data against the date and location of each fishing set reported in the logbooks. Logbooks also provide information on the effort of each set, measured as 1) the number of hooks deployed for each fishing set for longliners, and 2) the hours at sea for purse seiners during daylight as these vessels do not operate at night. These logbook data constitute the basis of the aggregated catch-effort data reported by SFA to IOTC and were assumed to be comprehensive and accurate.

Preprocessing of the data

For the subsequent analyses, only the VMS and logbook data with a matching MMSI to AIS data were used (Table Sey. I, Figure Sey. 2). Data were further processed to remove impossible positions (i.e., on land or not on the globe); speeds > 13.5 knots for drifting longliners, > 18 knots for purse seiners and > 15 knots for supply vessels; distances < 5 m between each transmission; and points transmitted from within 10 km around ports. Finally, as VMS and AIS transmissions can be received by more than one satellite, data were filtered for positions that had duplicate timestamps. These duplicated timestamps gave positions that were generally < 500 m from each other, and we retained the mean of the two (or more) positions. Altogether, the filtering process for VMS data removed about 37 percent of longline data, 45 percent of purse seine data, and 37 percent of supply vessel data. For AIS data, about 39 percent of longline data, 88 percent of purse seine data, and 82 percent of supply vessel data were removed. The majority of the AIS data filtered from purse seine and supply vessel data were within 10 km around ports. Logbook data that did not have corresponding AIS data represented 34 percent of longline records and 27 percent of purse seine records. These missing data may be due to vessels not using AIS, issues with AIS reception, or potential misclassifications by GFW of fishing activity.

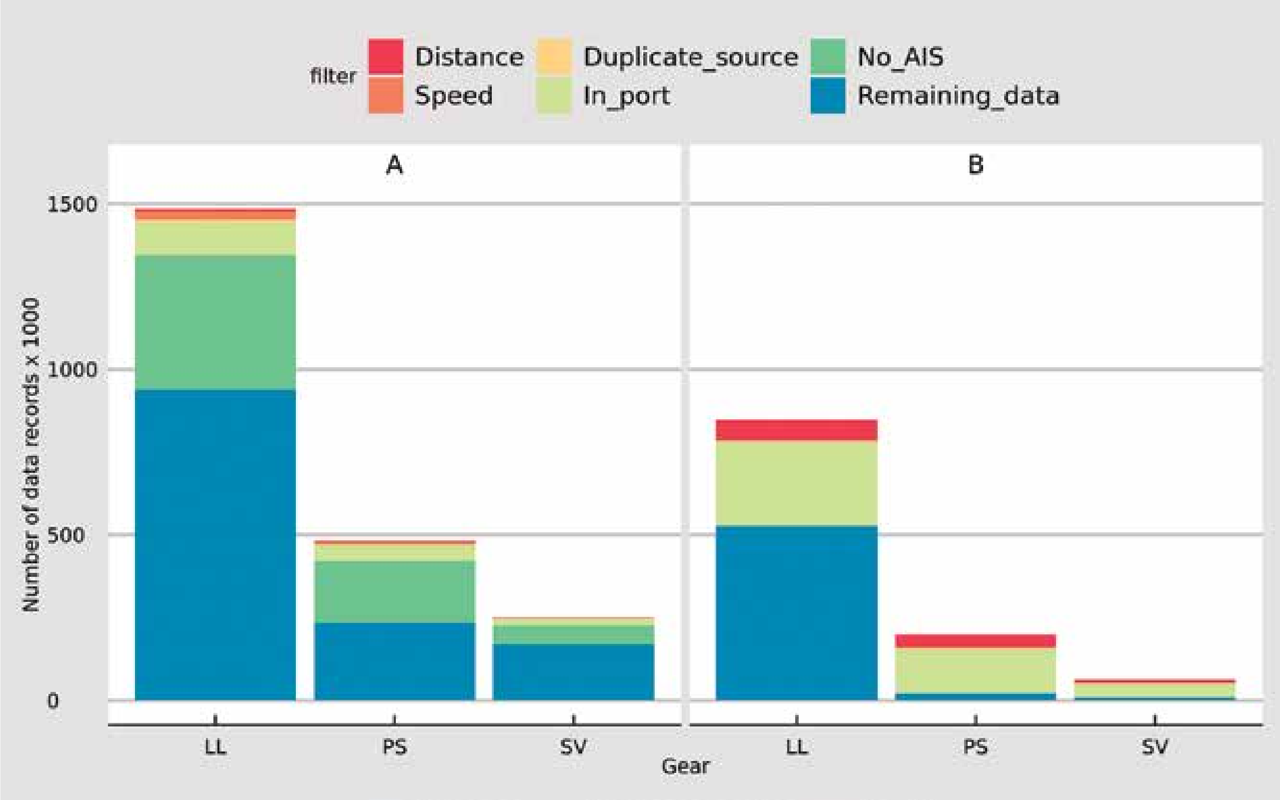


Figure Sey. 2. A) VMS and B) AIS data were filtered for distances < 5 m between transmissions, speed (> 13.5 knots for longliners (LL), > 18 knots for purse seiners (PS), and > 15 knots for supply vessels (SV)), duplicated timestamps due to transmissions received by different satellites or sources, and points within 10 km of a port. Only VMS data that matched AIS MMSIs were retained for further analyses.

METHODS FOR SEYCHELLES COMPARISON

Here, we outline the strategies used to first evaluate if AIS data are representative of the fishing fleet activity by comparing AIS data to VMS data in terms of transmissions and spatiotemporal patterns of vessel trajectories. The spatiotemporal metrics were converted into gear-specific indicators of fishing effort. We finally compared the predictions of fishing activity by the GFW algorithm with known fishing operations from logbook data.

Comparing AIS use and reception to VMS data

Transmissions

Of Seychelles vessels using AIS, about 34 percent were using Class A AIS and about 66 percent were using Class B. Class A systems transmit on average every 2 to 10 seconds while moving and Class B systems generally transmit every 30 seconds and also transmit at lower power, making their messages less likely to be received by satellite (Rec. ITU-R M.1371-5 02/2014) (see introductory sections). Class B systems have lower transmission frequencies when there is a high density of vessels. In terms of data coverage, we compared the quantity of VMS and AIS transmissions over the time period of the study by summing the number of transmissions in a given 1° x 1° grid cell over 2016 and 2017 and for both gears for each data source, consistent with the resolution of the data reported by SFA to IOTC.

Spatiotemporal patterns

Spatial resolution has been shown to be of major importance when estimating the extent of fishing activity from vessel positions (Amoroso *et al.* 2018). The spatial resolution of 0.5° (~50 km) was selected to be consistent with the extent and dynamics of the pelagic fisheries of interest (e.g., vessel speed, longline length, detection range) and finer than that required by IOTC for assessing catch and effort (typically 1°/month for purse seiners and 5°/month for longliners). Further work should however consider finer scales to fully assess the influence of the spatiotemporal resolution on the results.

Thus, vessel positions were overlaid on a 0.5° x 0.5° grid (e.g., Figure Sey. 3). Vessel positions of the filtered VMS and AIS data for longliners, purse seiners and supply vessels were interpolated into trajectories using a maximum time difference of 24 hours between subsequent points. The length of the trajectory within a grid cell was calculated and represents the distance covered by a vessel in that grid cell. Gridded data were aggregated by month for each cell following current IOTC requirements for the temporal resolution of statistical fisheries data and normalized for each data source (i.e., VMS and AIS). The aggregated vessel trajectories then represent the accumulated distance of vessels within each grid cell, which is then a spatial representation of the fleet activity within each grid cell. This can be used to compare the spatiotemporal patterns

of AIS and VMS data, and can describe the spatial and temporal patterns of fleet occurrence. Vessel trajectories are later converted to more specific indicators of effort for the purse seine fishery (below, this chapter: Calculating indicators of fishing effort using AIS data).

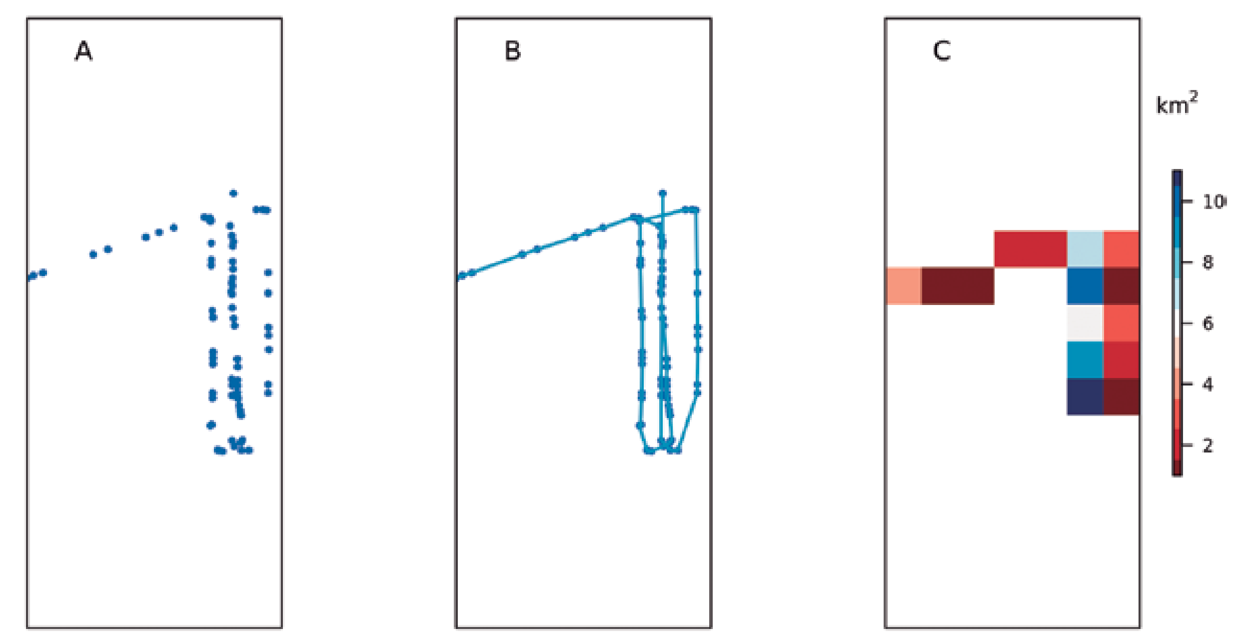


Figure Sey. 3. An example of the trajectory aggregation method using one month of position data. A) Vessel positions given as latitudinal and longitudinal points are B) interpolated into trajectories and then C) overlaid on a grid. Data are then aggregated by averaging the distance of the vessel trajectory within each grid cell over a month. Trajectories like this were then aggregated with trajectories from other vessels within the same time period.

Calculating indicators of fishing effort using AIS data

In fisheries sciences, most assessment methods require time series of abundance indices to inform the trajectories of stock biomass. In tuna fisheries, fishery-independent surveys are almost never available and abundance indices are essentially derived from the analysis of time series of commercial catch per unit effort (CPUE) (Campbell *et al.* 2004). A major prerequisite for the estimation of CPUE is the choice of a unit of fishing effort which aims to reflect the best measure of resources devoted to fishing for a given gear (Cunningham and Whitmarsh 1980).

Nominal fishing effort by purse seiners

For purse seiners, calculations of fishing effort are complex and under continuous evolution; however, nominal fishing effort is generally represented as time at sea and by the number of fishing sets made by a vessel (FAO 2019). As effort is primarily expended by searching for schools, the distance navigated and the surface area that is explored by each vessel can also constitute useful metrics to represent purse seine fishing effort. They could be particularly relevant to account for increased vessel speed and observation range of onboard equipment (e.g., bird radars) over time (Torres-Irineo *et al.* 2014).

Therefore, we use surface area searched by purse seines as a measure of fishing effort. The maximum radar range of detection of bird flocks generally associated with tuna is about 20-25 nm or 37-46 km (Assali *et al.* 2017). This was added as a buffer around the vessel trajectories to incorporate the search zone of the vessel into the total surface area explored by the purse seine vessels. Therefore, the nominal (i.e., not standardised) fishing effort proposed in this study for purse seiners and supply vessels was the surface area searched by the purse seine fleet in each 0.5° x 0.5° grid cell.

Nominal fishing effort by longliners

For longliners, nominal fishing effort is almost always represented as the number of hooks deployed (FAO 2019). Thus, as a measure of nominal fishing effort for longliners, we multiplied the number of fishing days identified by the GFW neural net algorithm (below, this chapter: Comparisons of GFW fishing predictions and logbook entries) by the average number of hooks deployed for each fishing set during 2016-2017 derived from SFA logbooks. To account for spatial differences in fishing practices, we considered a stratification between the area south of 20°S, where Seychelles longliners used on average 3 670 (± 540) hooks to target albacore, swordfish, and oilfish, and the tropical fishing grounds where they used on average 3 000 (± 280) hooks to target bigeye and yellowfin during 2016-2017. GFW-based effort estimates were then compared to logbook-based effort estimates using 1° x 1° and 5° x 5° grid cells, in line with IOTC reporting guidelines.

Comparisons of GFW fishing predictions and logbook entries

The outputs from the GFW neural net algorithm to predict fishing operations were compared to the fishing operations recorded in the official logbooks for Seychelles fleet. Logbook data give the date that a catch was made; neural net data are given at every AIS transmission. Therefore, to compare between the two datasets, we considered a day of fishing to be when there was at least one neural net prediction that indicated fishing (neural net = 1) during the day and we calculated the average position for that day. We then calculated the number of true positives (neural net = 1 at least once during a day that the logbook has an entry), false positives (neural net = 1 at least once during a day that the logbook does not have an entry), true negatives (neural net = 0 for all points during a day and the logbook has no entries), and false negatives (neural net = 0 for all points during a day but the logbook has an entry). Logbook data and neural net predictions were then rasterized to a 0.5° x 0.5° grid. The fishing days in each cell were summed for each year (2016 and 2017) and each gear (longlines, purse seines) and compared using linear regression models. We note that a daily scale is appropriate for longliners as they set once a day; however, purse seiners can set more often. This issue was not investigated further as preliminary results indicated that AIS data are not representative of the purse seine fleet; and thus, the GFW fishing predictions for this fishery are not valid.

RESULTS AND DISCUSSION OF SEYCHELLES CASE STUDY

In general, we find that AIS fleet use and fleet coverage is good for all types of vessels. Overall, we find that AIS data in the longline fleet has good data reception, represents well the spatiotemporal dynamics of the fleet, and have a good ability to predict the actual fishing activity made by longliners. Conversely, we find that AIS data for purse seiners and supply vessels are spatially very poor, with AIS transmissions received only around ports and not in the fishing grounds, making it of little use for further exploration. Thus, having established the utility of the AIS dataset for the different gears, we continue the investigation of longline data only, and compare the calculations of longline effort as derived from GFW data to that of the longline logbooks (both represented as the number of hooks) and find that AIS data can be a useful tool for reporting fishing effort for data-poor fisheries.

AIS fleet use and fleet covered

Fifty-two longliners, 13 purse seiners and 7 supply vessels are listed as active (i.e., have VMS data) in Seychelles official registry for 2016 and 2017 (Table Sey. I). Fourty-three MMSI were provided by GFW for Seychelles longline vessels. Of these, 35 were matched to the official registry of longline vessels that were active in 2016, and 36 were matched to longliners that were active in 2017. Therefore, the fleet use of AIS for 2016 is 74 percent of the 47 vessels active in the longline fishery, and 71 percent of the 51 active in 2017. Ten MMSI were found by GFW for the 13 Seychelles purse seiners, 8 of these MMSI could be matched to vessels active in 2016 (62 percent fleet use of AIS), and 10 could be matched to vessels active in 2017 (77 percent fleet use of AIS). Six MMSI were found by GFW for the 7 Seychelles supply vessels that had VMS data, of which 5 were matched for both years, indicating 71 percent fleet coverage. Reasons for mismatches may be due to the fact that not all vessels have AIS or may have broadcasted incorrect identification information.

Vessel type	Total VMS	Total MMSI	Total GFW AIS	2016				2017			
				VMS	VMS with MMSI	VMS match GFW	% Fleet with AIS	VMS	VMS with MMSI	VMS match GFW	% Fleet with AIS
Longline	52	47	43	47	42	35	74%	52	44	36	69%
Purse seine	13	12	10	13	12	8	62%	13	10	10	77%
Supply vessel	7	7	6	7	7	5	71%	7	7	5	71%

Table Sey. I. Fleet use of AIS data for the vessels with VMS activity in Seychelles fishing fleet for 2016 and 2017. The GFW column indicates the total number of vessels that Global Fishing Watch identified for each fleet for each year. The total active number of vessels with VMS data, the total number of vessels with VMS data that had a MMSI assigned to them, and the number of vessels with VMS data that could be matched to GFW data via the MMSI. The fleet use is calculated as the percent of the total active vessels with VMS data relative to the VMS-to-GFW matched vessels.

Transmission frequency

We found that the transmission frequency of VMS data indicates that both the Seychellois high seas longline and purse seine tuna fishing fleets largely comply with the standard of one transmission per hour, with the predominant peak in transmission frequency at 60 minutes (Figure Sey. 4 - left panel). There are numerous data with transmissions more frequent than this, with another peak in transmission frequency at 10 minutes and the overall median of the data at 22 minutes.

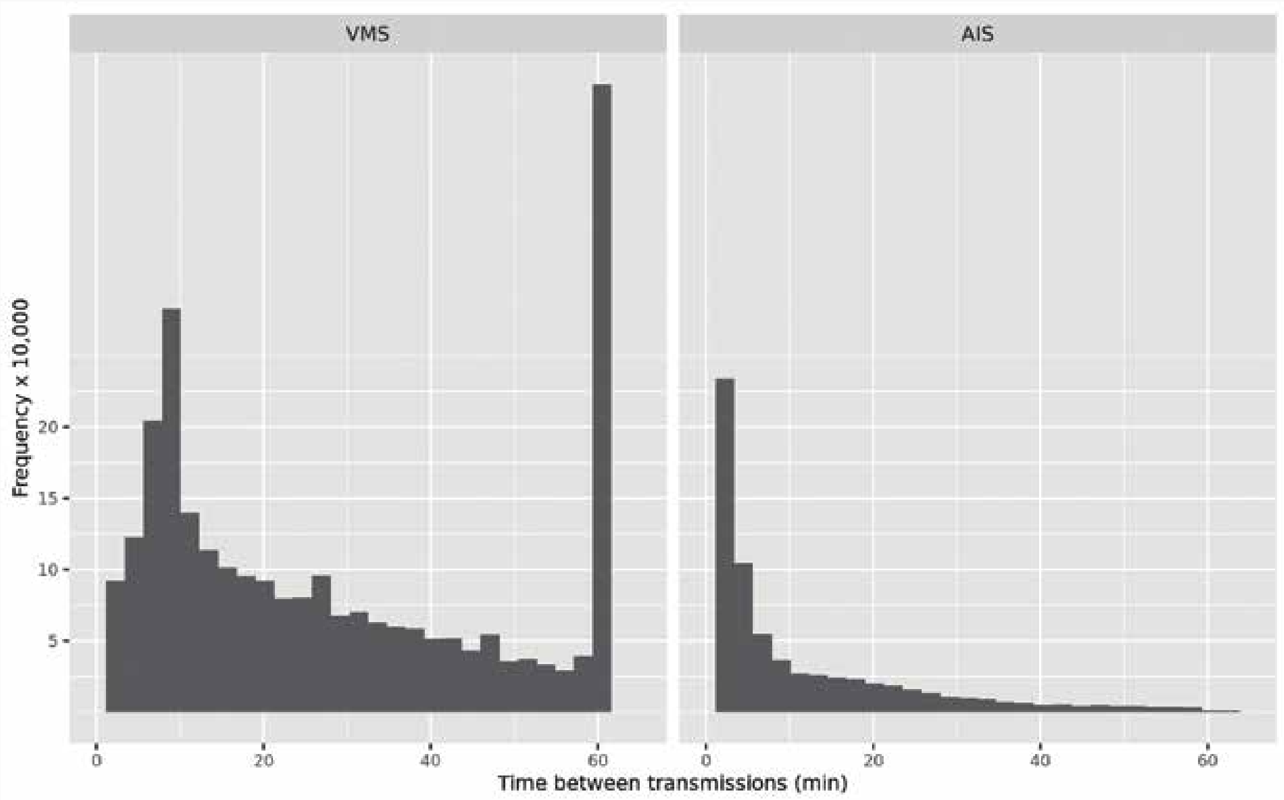


Figure Sey. 4. The frequency of transmissions for (left panel) VMS and (right panel) AIS data for all years and gears combined. Each plot represents the 90th percentile of each dataset.

Spatiotemporal coverage of transmissions by gear

Vessels with AIS were found to transmit their position approximately every 3 minutes (median = 3.1 minutes; Figure Sey. 4 - right panel). Although AIS transmissions were more frequent, we surprisingly found considerably more VMS than AIS transmissions across space and time (Figure Sey. 2; Figure Sey. 5). This may be because many vessels do not broadcast AIS or do not broadcast AIS all the time. The overall spatial trend between VMS and AIS transmissions is similar, but AIS have far fewer transmissions, especially in the Western Indian Ocean (Figure Sey. 5). However, we find more transmissions from AIS than VMS offshore of southern Africa and around the Seychelles, perhaps due to better coastal receiver coverage in these areas. Terrestrial coastal receivers receive messages between 10 to 50 nautical miles offshore (see regional chapter of FAO Area 51).

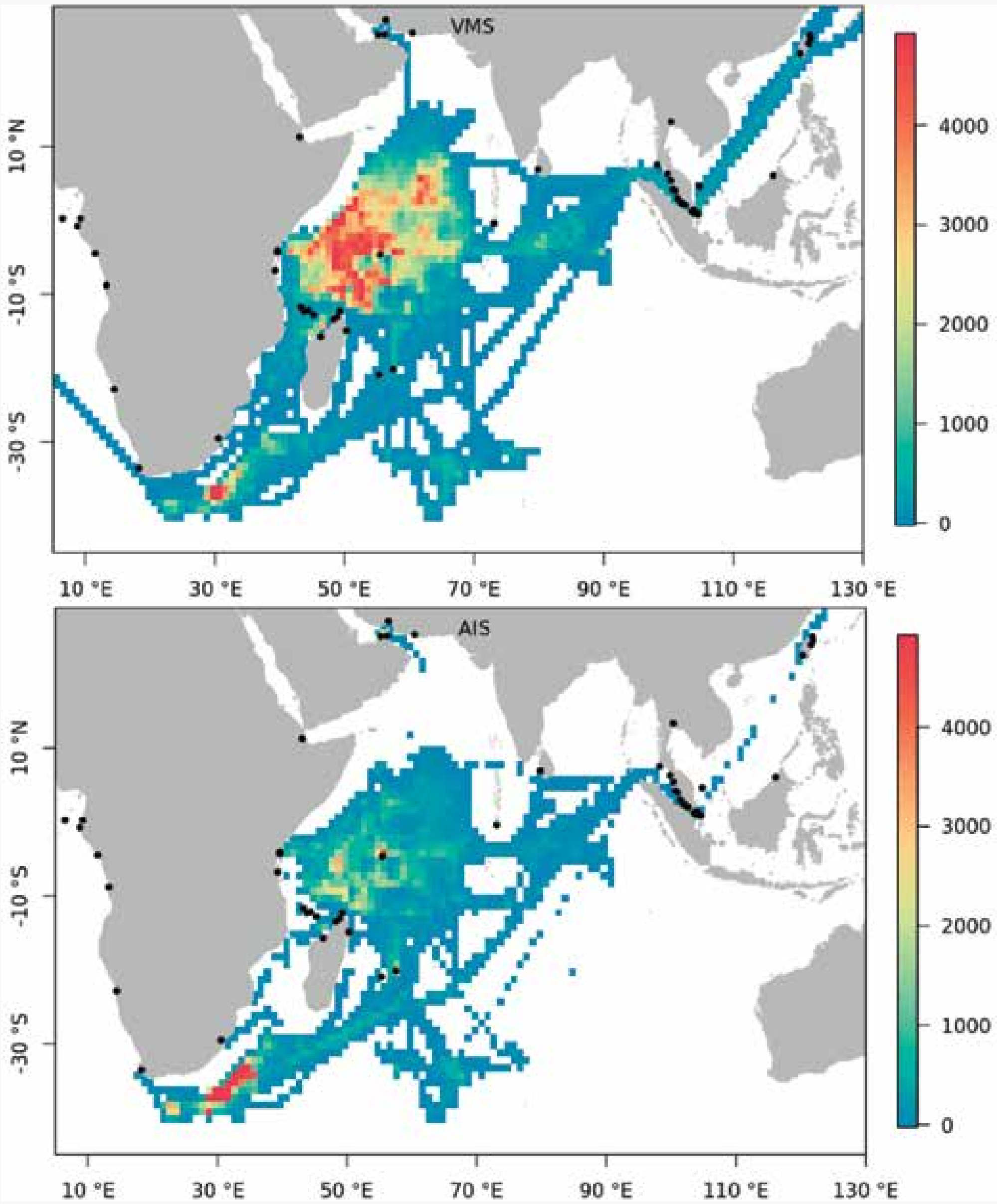


Figure Sey. 5. The number of transmissions per 1° x 1° grid cell for (top panel) VMS and (bottom panel) AIS data for both years and gears combined. Black points represent the ports identified in the study.

Spatiotemporal coverage of transmissions by gear

We found that AIS data match well with the spatial coverage of VMS data for longline vessels, and do not match well for that of purse seiners or supply vessels. AIS for longliners indicate that there is good coverage in the tuna fishing grounds in the Western Indian Ocean (Figure Sey. 6 - top panel). In general, AIS is lacking on the long trajectories made by a few vessels, potentially because AIS may not be in use during long transit periods.

For purse seiners and supply vessels, we found that the majority of AIS positions were transmitted while vessels were in port, and very few positions are transmitted outside of the port zones (Figure Sey. 6 - middle and bottom panel), though there are more AIS reports in the south east in 2017 (Figure Sey. 6 - middle, right panel").

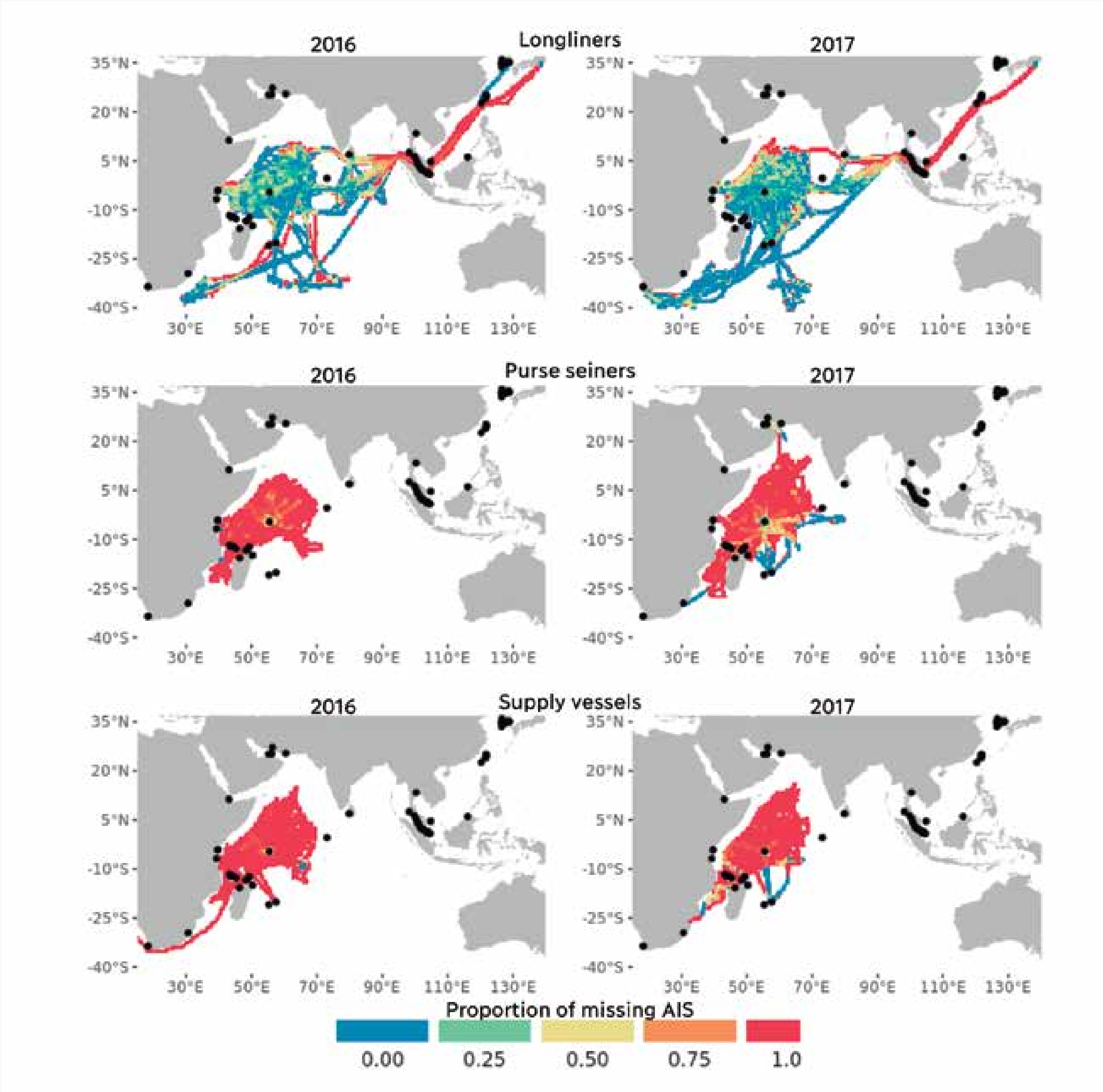


Figure Sey. 6. Spatial coverage of AIS data for (top panel) longliners in 2016 and 2017, (middle panel) purse seiners in 2016 and 2017, and (bottom panel) supply vessels in 2016 and 2017. The color spectrum indicates the proportion of the time when AIS data were available in the cell. Cells towards the red end of the spectrum indicate that no AIS data were available (i.e., AIS always reported NA) and cells towards the blue end of the spectrum indicate that AIS data were always reported. Black points indicate ports.

For longliners, purse seiners and supply vessels, we found that spatial coverage increased gradually over the two years of data (Figure Sey. 7). This may be due to an increase in the number of satellites that received the data (i.e., 15 satellites in 2016, > 50 in 2017; see introductory sections). This increase in satellite coverage is much more likely to affect Class B than Class A AIS transmissions. For the vessels broadcasting Class A, gaps in activity are most likely explained by vessels turning off their AIS. For Class B, poor reception may explain some of the data lacking in the northern fishing grounds (see map in chapter on FAO Area 51); and increased satellite coverage may explain some of the cells with a higher proportion of AIS use in 2017. Further analysis is needed to determine if the spatial variability of reception is due to reception or the systems being turned off.

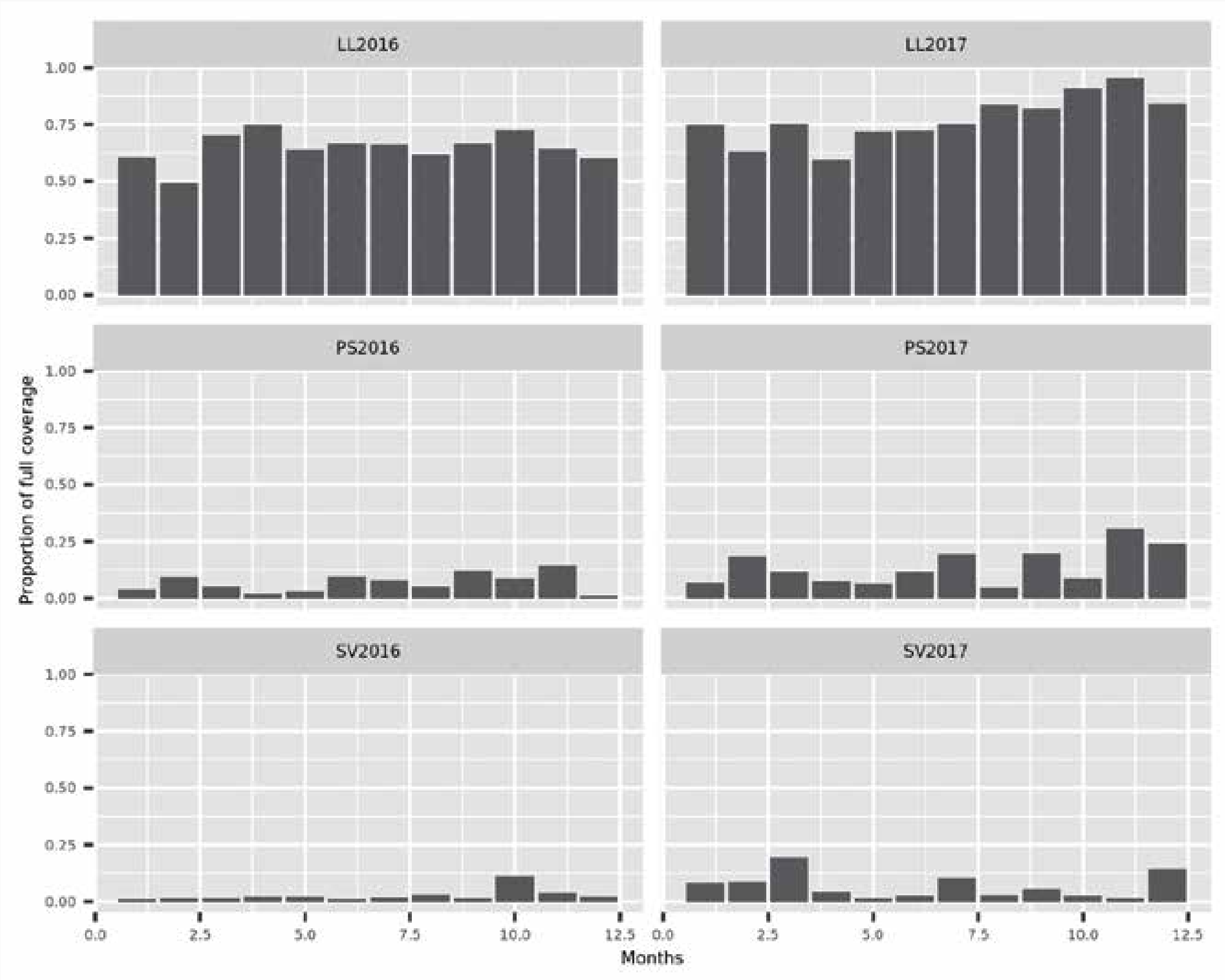


Figure Sey. 7. The monthly proportion of AIS spatial coverage relative to the full spatial coverage of AIS and VMS data combined for (top panel) longliners (LL) in 2016 and 2017, (middle panel) purse seiners (PS) in 2016 and 2017, and (bottom panel) supply vessels (SV) in 2016 and 2017.

AIS switch-off in the purse seine fleet

Our findings indicate that there is a high likelihood of considerable AIS switch off, particularly for the purse seine fleet and their supply vessels. This is supported by the fact that AIS data are transmitted at a maximum of around 25 percent of VMS data (Figure Sey. 7) and that these transmissions are essentially only in the port region (Figure Sey. 6). Furthermore, AIS transmissions are consistently and substantially lower in quantity than VMS data (Figures Sey. 2,4,5,6,7), even though the frequency of transmissions is much higher (Figure Sey. 4). This is evident for both longline and purse seine fleets (and supply vessels), but it is particularly pronounced for purse seiners. Concerns over safety due to piracy in the Western Indian Ocean starting in 2007-2008 (Chassot *et al.* 2010) led to purposeful AIS switch off once outside the port region following security recommendations of the counter-piracy military operations occurring in the region (e.g. Atalanta). Though piracy was less of a concern during the study period than previously, this switch-off behavior appears to continue for the purse seine fleet as part of the standard measures put in place by onboard private security companies.

The difference in the nature of the fishing activity between longliners and purse seiners may also play a role in this switch-off behavior. Longliners use a passive fishing gear, which consists of deploying a baited line and hauling it in several hours later. In contrast, purse seiners actively search for schools and their activity comes with a high risk of failure to catch, e.g. about a 50 percent failure rate for free-swimming schools. This failure comes at a cost, as it takes about 1.5 hours to retrieve a purse seine once it has been set, and if there is another purse seiner in the vicinity, it will approach the first vessel in an attempt to catch the school that the first vessel may have failed to catch. In addition, tuna schools can concentrate in very large abundances in some areas over several days (e.g., Fonteneau *et al.* 2008). Therefore, detecting a purse seiner in operation is not only an indication of tuna presence but it can also be rewarding if there is a high concentration of tuna whereby the vessels will be able to make several operations in a row, sometimes over several days. Finally, with the recent emergence of FADs equipped with echo-sounders, the presence of a purse seiner or of a supply vessel in an area now strongly indicates the detection of tuna around the FAD. In short, the presence of a longliner suggests there might be some tuna in an area while the presence of a purse seiner in operation indicates there are tuna in an area. Thus, purse seiners are likely more motivated to keep their position private by switching off their AIS than longliners.

Spatiotemporal comparisons of AIS and VMS fleet activity

Surface area explored by purse seiners and supply vessels

The surface area explored by purse seiners and supply vessels, as calculated using a buffer around the aggregated trajectories for VMS data, indicates that there are high rates of exploration in the areas to the northeast and southwest of Seychelles, in line with the known fishing grounds of the purse seine fleet (e.g., Figure Sey. 8 - top left panel). As there are very few AIS data for purse seiners and supply vessels outside of port, the surface area explored by these vessels using AIS data offers little useful information (e.g., Figure Sey. 8 - top right panel).

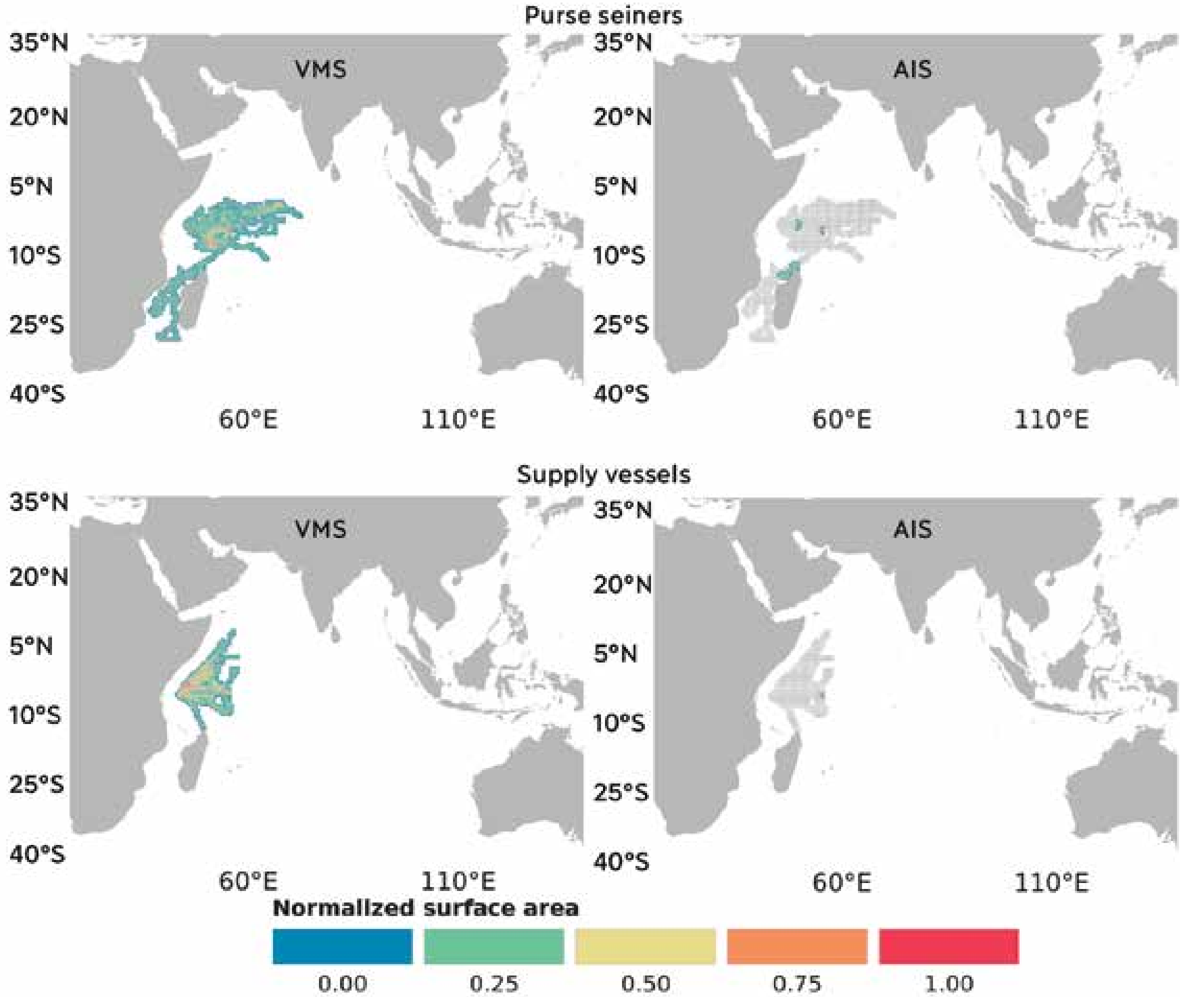


Figure Sey. 8. The normalised surface area explore by Seychelles purse seiners and supply vessels in May 2017 as calculated by determining the surface area from the length of the vessel trajectories with a buffer of 38 km around the trajectory. Surface area is aggregated over the month for each cell for VMS and AIS data of (top panel) purse seiners and (bottom panel) supply vessels. Light grey indicate missing data.

Distance covered by longline vessels

We find that AIS data for the distance covered by longline vessels as calculated from the aggregated trajectories matches well with that calculated using VMS data (e.g., Figure Sey. 9). The spatial pattern is very similar, indicating that vessels spend the majority of their time in the tropical Western Indian Ocean. AIS generally show lower magnitude values than VMS data for the distance covered by vessels. This is due to VMS data having fewer and longer trajectories because they continuously record data with few pauses between transmissions of > 24 hours, whereas AIS data have many but short trajectories due to frequent breaks in transmission > 24 hours (e.g., Figure Sey. 10).

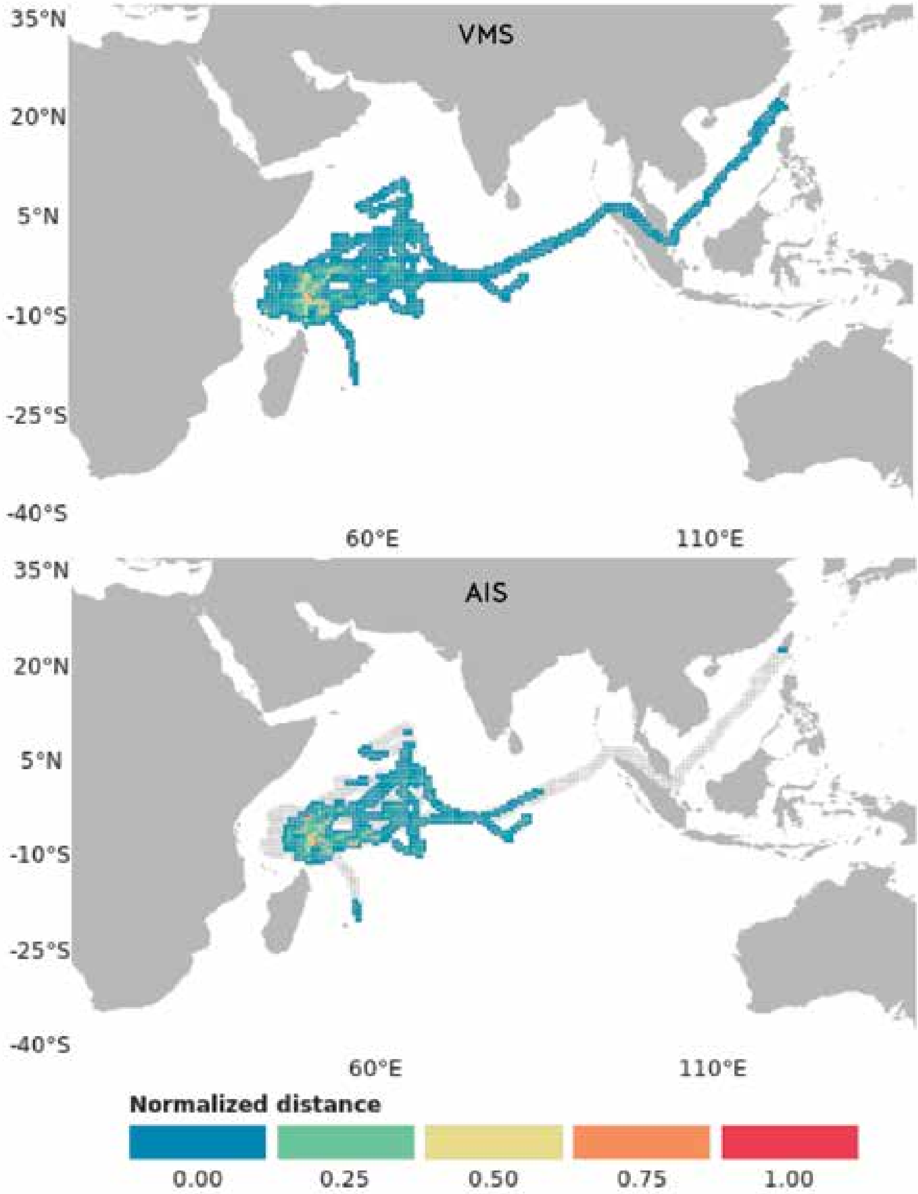


Figure Sey. 9. The normalized distance covered by Seychelles longliners in January 2016 as calculated by the length of the vessel trajectories within each 0.5° x 0.5° cell aggregated over the month for (top panel) VMS and (bottom panel) AIS data. Higher values indicate that more distance was covered in a cell. Light grey indicate missing data.

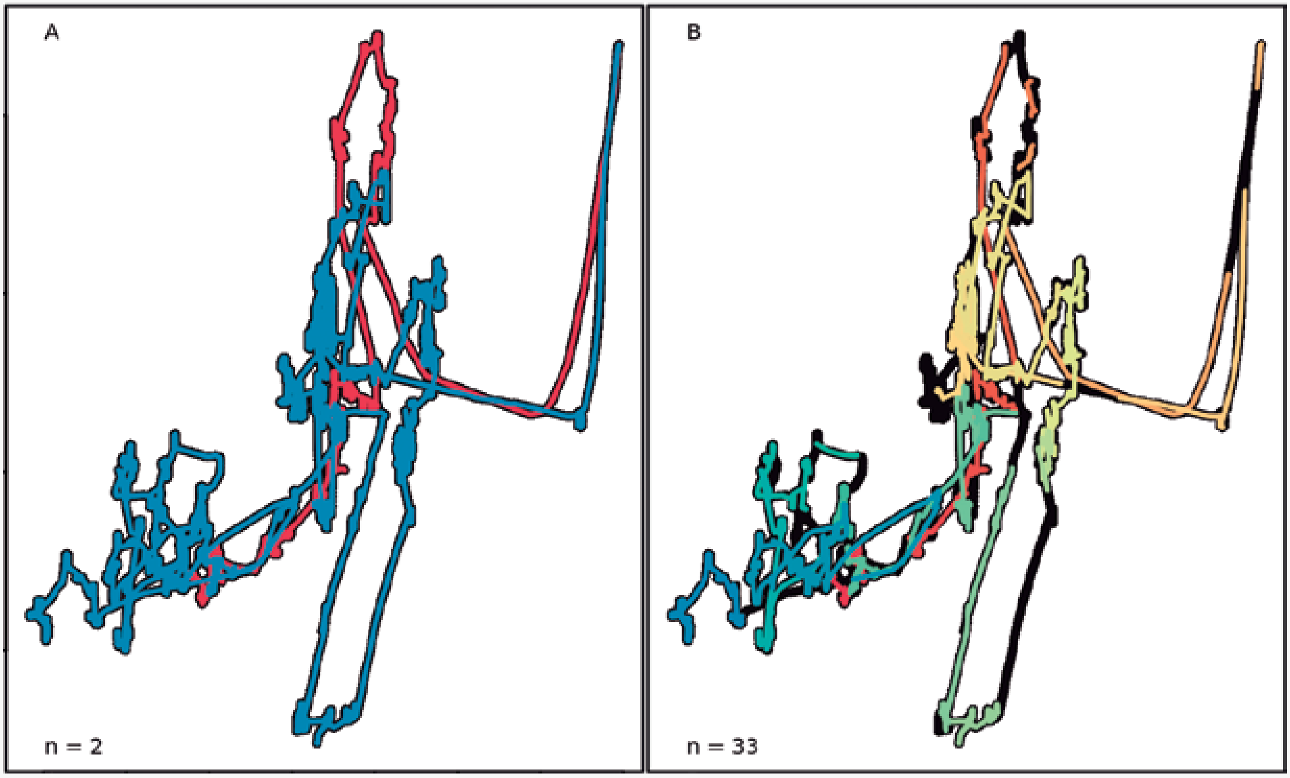


Figure Sey. 10. An example of trajectories calculated from one longline vessel to compare the difference in length and number VMS versus AIS trajectories. Black points on both plots are VMS transmissions. The different colored lines overlaid on the points represent different trajectories from A) VMS data (N trajectories = 2) and B) AIS data (N trajectories = 33). A trajectory is defined as a continuous transmission with breaks between transmissions < 24 hours. AIS points were overlaid on the VMS data in B) to show where the AIS data were and were not, considering VMS as the reference dataset.

Accuracy of GFW algorithm performance for predictions of fishing activity compared to reported fishing activity from logbook data

We find that the GFW neural net algorithm is able to predict days of fishing relative to logbook data (i.e., correctly predicted fishing days) for longline vessels between 45.3 percent of the time in 2016 to 70.5 percent of the time in 2017, and has very low prediction rates for the purse seine vessels (Table Sey. II).

Longliners

For longliners, days where GFW correctly predicts that no fishing occurred happened 91.4 percent (2016) and 96.5 percent (2017) of the time. Days where GFW incorrectly predicted that fishing occurred when the logbook indicated no fishing were found 19.4 percent of the time in 2016 and 36 percent of the time in 2017. Days where GFW did not predict fishing, but logbooks indicate catch, were found 8.6 percent (2016) and 3.5 percent (2017) of the time. In general, we find that fishing predictions are higher in 2017 than in 2016, including correct predictions of both fishing and non-fishing days, coinciding with better satellite coverage.

Longline 2016 **N=6988, M=4130**		AIS GFW algorithm		**Purse seine 2016** **N=2374, M=16**		AIS GFW algorithm	
		Fishing	No fishing			Fishing	No fishing
Logbook	Fishing	45.3%	8.6%	Logbook	Fishing	0.7%	2.9%
	No fishing	19.4%	91.4%		No fishing	0.4%	97.1%
Longline 2017 **N=6265, M=4488**		Fishing	No fishing	**Purse seine 2017** **N=2623, M=40**		Fishing	No fishing
Logbook	Fishing	70.5%	3.5%	Logbook	Fishing	1.5%	3.0%
	No fishing	36.0%	96.5%		No fishing	1.0%	97.0%

Table Sey. II. The accuracy of the predictions of days of fishing by the neural net algorithm provided by GFW for the longline and purse seine fleets in 2016 and 2017. GFW accuracy is calculated as the percentage of either fishing (neural net = 1) divided by the total number of fishing days from logbook data (N) or no fishing (neural net = 0) divided by the total number of days where no fishing was recorded in the logbooks. Green cells indicate true predictions and red cells indicate false predictions made by the GFW neural net algorithm. M indicates the total number of fishing days predicted by the GFW algorithm (i.e., where the neural net = 1).

The spatial patterns of the positions where the neural net algorithm indicated fishing and the positions recorded in the logbook are similar overall for longliners, though results show a high variability between grid cells (Figure Sey. 11 - top panel). Looking at the percent difference between logbook sets and GFW predictions of daily fishing activity (i.e., $(Sets_{logbook}-Sets_{gfw})/Sets_{logbook}$, Figure Sey. 11 - middle panel), we find that GFW neural net predictions show many good predictions (differences near 0), with about 50 percent of the points underpredicted by GFW (differences greater than 0). The linear regression of logbook fishing sets versus neural net predictions of days of fishing indicates a good relationship for both 2016 ($r^2 = 0.55$) and 2017 ($r^2 = 0.89$). However, it is worth noting that the coefficient of determination is biased due to the spatial autocorrelation of the data. We find that the neural net algorithm of daily fishing activity consistently underestimates the logbook sets by about 60 percent in 2016 (slope of the linear model = 0.39), and about 15 percent in 2017 (slope of the linear model = 0.85). Consistent with Table Sey. II, we find better predictions in 2017 than 2016 (Figure Sey. 11 - middle and bottom panel).

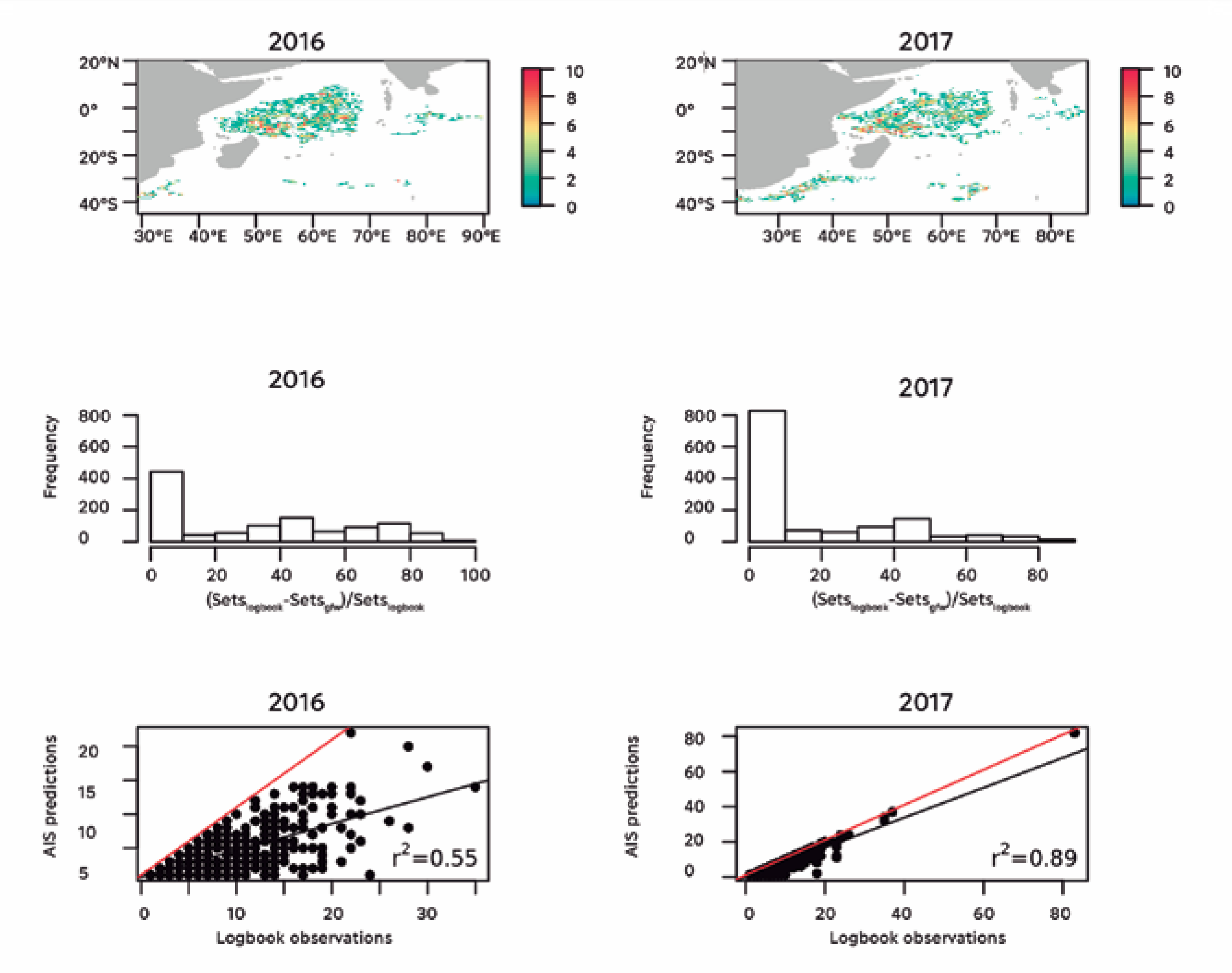


Figure Sey.11. Positions where the GFW neural net algorithm predicts a day of fishing to occur for longline vessels in 2016 and 2017 (top panel) on a 0.5° x 0.5° grid with fishing days summed over the period within each cell; the percent anomaly between coincident logbook data and the GFW predictions $(Sets_{logbook}-Sets_{gfw})/Sets_{logbook}$ for 2016 and 2017 (middle panel), and linear regressions of the relationship between logbooks and GFW predictions for 2016 and 2017 (bottom panel).

When comparing the true positive positions where the neural net algorithm predicts fishing on the same day as the logbook has a record (i.e., the daily mean position when a true positive fishing was detected), we find that the distances between the AIS true positive positions and the positions of longliner logbook sets are relatively close, i.e., 75 percent of the AIS points are within 50 km of the logbook points (Figure Sey. 12 - top panel). As individual longlines can be up to 100 km in length, these values indicate that the spatial distribution of the true positive points are representative of the logbook data.

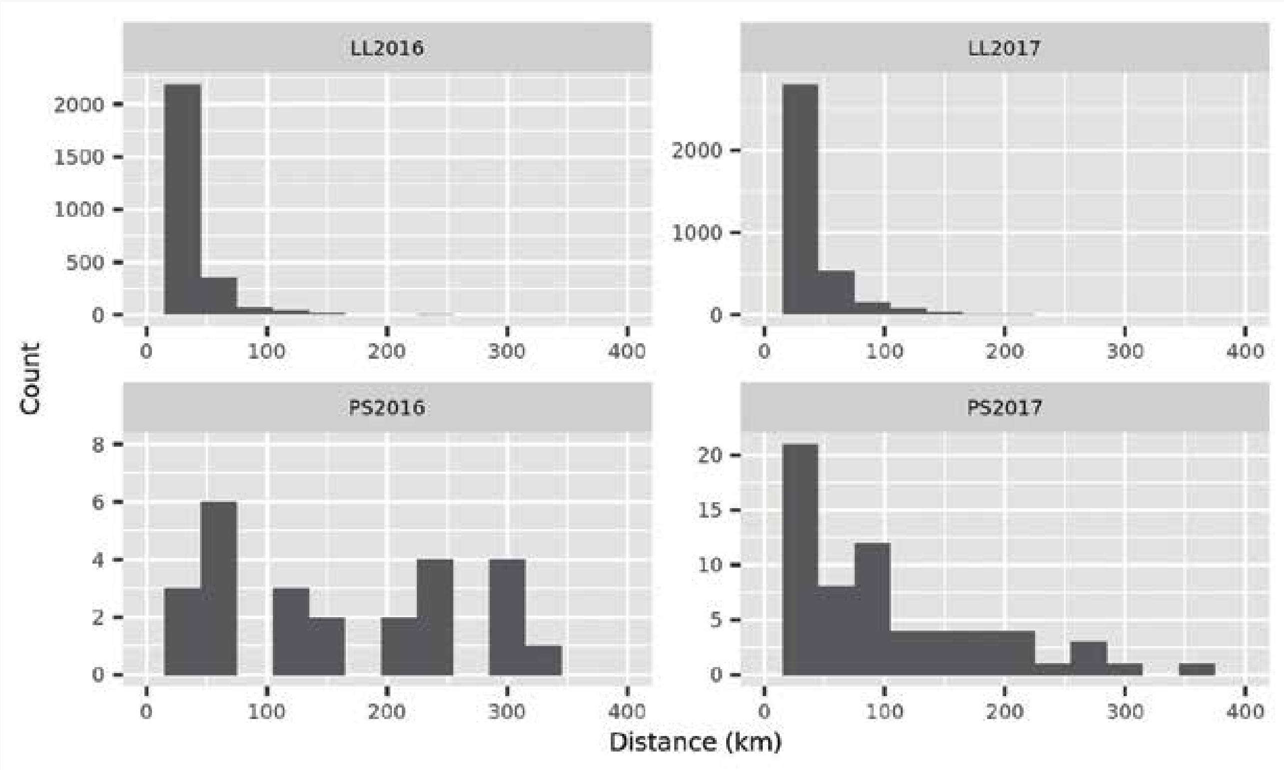


Figure Sey. 12. Distance (km) between logbook positions and AIS true positive fishing positions as predicted by the GFW neural net algorithm for (top panel) longliners and (bottom panel) purse seiners in 2016 and 2017.

We investigated the hour of the day in which the GFW neural net algorithm predicted fishing operations (all predictions, not limited to true positives), and found that for longline fishing, the predictions were reasonable (Figure Sey. 13 - top panel). The algorithm indicates that the majority of fishing occurs during two periods, in the morning (from 05:00 to 10:00) and in the evening (16:00 to 20:00). This corresponds to fishing practices of Seychelles longliners as longlines targeting tuna in the western-central Indian Ocean are generally set during the day and hauled in the evening and longlines targeting albacore, swordfish and oilfish south of 20°S off the coasts of South Africa are generally set at night and are hauled in the morning.

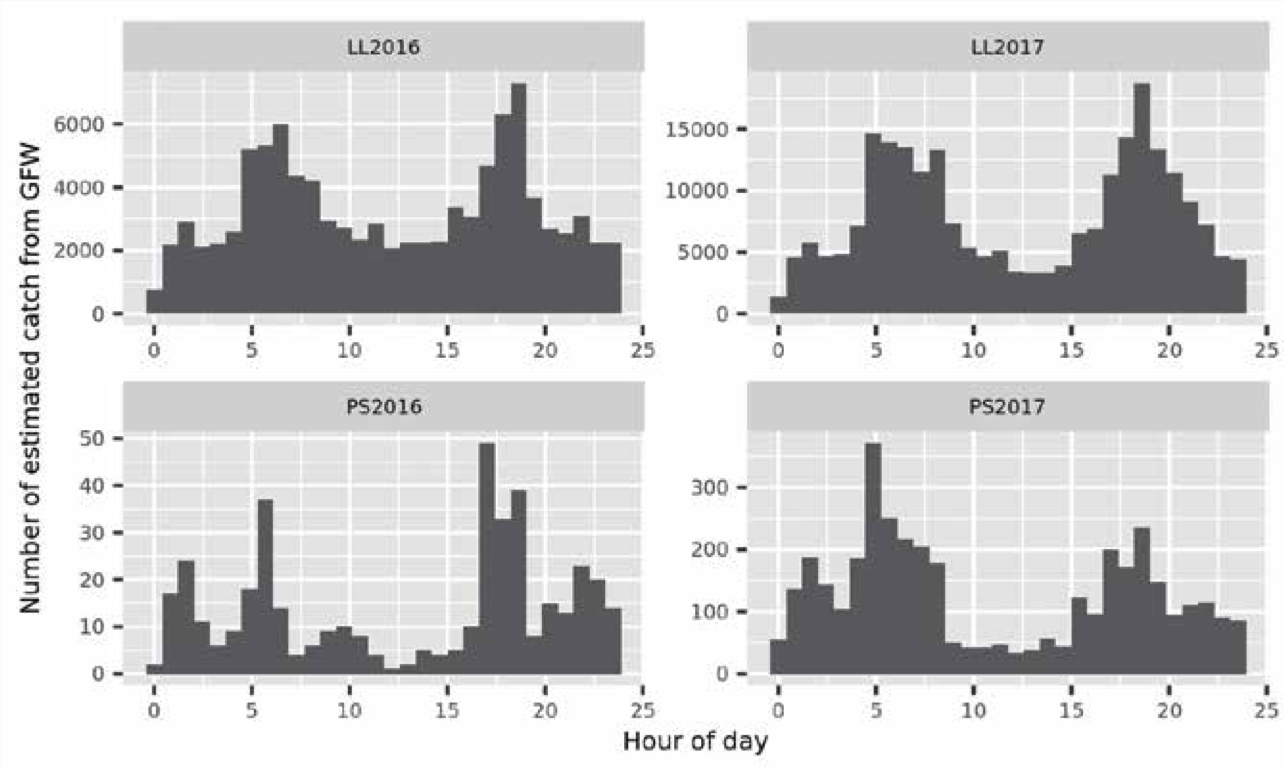


Figure Sey. 13. Hour of the day in which the GFW neural net algorithm identifies fishing for (top panel) longliners and (bottom panel) purse seiners in 2016 and 2017.

Purse seiners

There are few AIS data for purse seiners outside of the 10 km diameter around ports. Of those data that are available, very few are in regions where purse seine fishing is possible (> 200 m depth). The neural net algorithm does well in that it correctly predicts ‘No fishing’ for most of these data points, but only correctly predicts when fishing does occur less than 2 percent of the time in both 2016 and 2017 (Table Sey. II).

Very few AIS positions for purse seiners are reported in the fishing grounds. For those positions that are available, when comparing AIS positions where GFW predicted true positive fishing activity with the positions of purse seine logbook sets (i.e., daily mean positions), we find that 75 percent of the AIS points are at a distance of 200 km of the logbook points (Figure Sey. 12 - bottom panel). As purse seiners set their nets at a radius of ~500 m from the vessel, we find that the distance between the majority of AIS true positive predictions and logbook positions is far greater than that of a purse seiner set. This indicates that the true positive predictions of the GFW algorithm may not actually represent the logbook set for that day, i.e., the true positive predictions for purse seiners made by GFW may be a result of chance.

When considering the hours during which fishing is predicted for purse seiners, the results seem unlikely. Purse seine nets are only set during the day and the vessels do not fish at night; however, we find that the neural net algorithm makes predictions of fishing operations during hours of darkness, i.e., 20:00 to 04:00. This might instead correspond to the vessel being stopped and drifting at night (Figure Sey. 13 - bottom panel).

Indicators of longline fishing effort using AIS data

Based on the results above, it was deemed that for purse seiners and supply vessels AIS data do not show spatiotemporal coherence with VMS data in terms of either reception or fleet activity. Therefore, these data were not considered further in this study. However, for longliners, the spatiotemporal patterns of reception and fleet activity derived from AIS data showed good correspondence to that derived from VMS data; and GFW predictions of fishing activity are also reasonably coherent to allow further investigation.

Longline fishing effort as the number of hooks

Therefore, we correlated the estimations of longline effort derived from GFW predictions of fishing sets against the spatially aggregated effort reported by SFA to the IOTC, both of which are represented as the number of hooks deployed by longline vessels (see above, this chapter: Calculating indicators of fishing effort using AIS data). In each year, there is a strong linear relationship (the coefficient of determination, r^2, varies between 0.61 and 0.95) between the predicted GFW effort and the effort reported in logbooks aggregated for each grid cell (Figures Sey.14-15). As with GFW predictions of daily fishing activity, effort calculated using GFW predictions consistently underestimates the actual effort reported by logbooks by about 63 percent (slope of the linear model = 0.37) in 2016 to about 18 percent (slope of the linear model = 0.82) in 2017 for a 1° x 1° grid. These underestimations may be due to issues with AIS reception. Also, the predictions appear inconsistent for many grid cells, especially when considering a 1° x 1° spatial resolution (Figure Sey. 14). The fit to the data was improved between 2016

and 2017, i.e. r^2 increases from 0.61 to 0.92 for the 1° x 1° grid and from 0.81 to 0.95 for the 5° x 5° grid between 2016 and 2017, respectively. The larger spatial resolution of the 5° x 5° grid substantially improves the correlation and decreases the variability from that observed with the 1° x 1° grid (Figure Sey. 15).

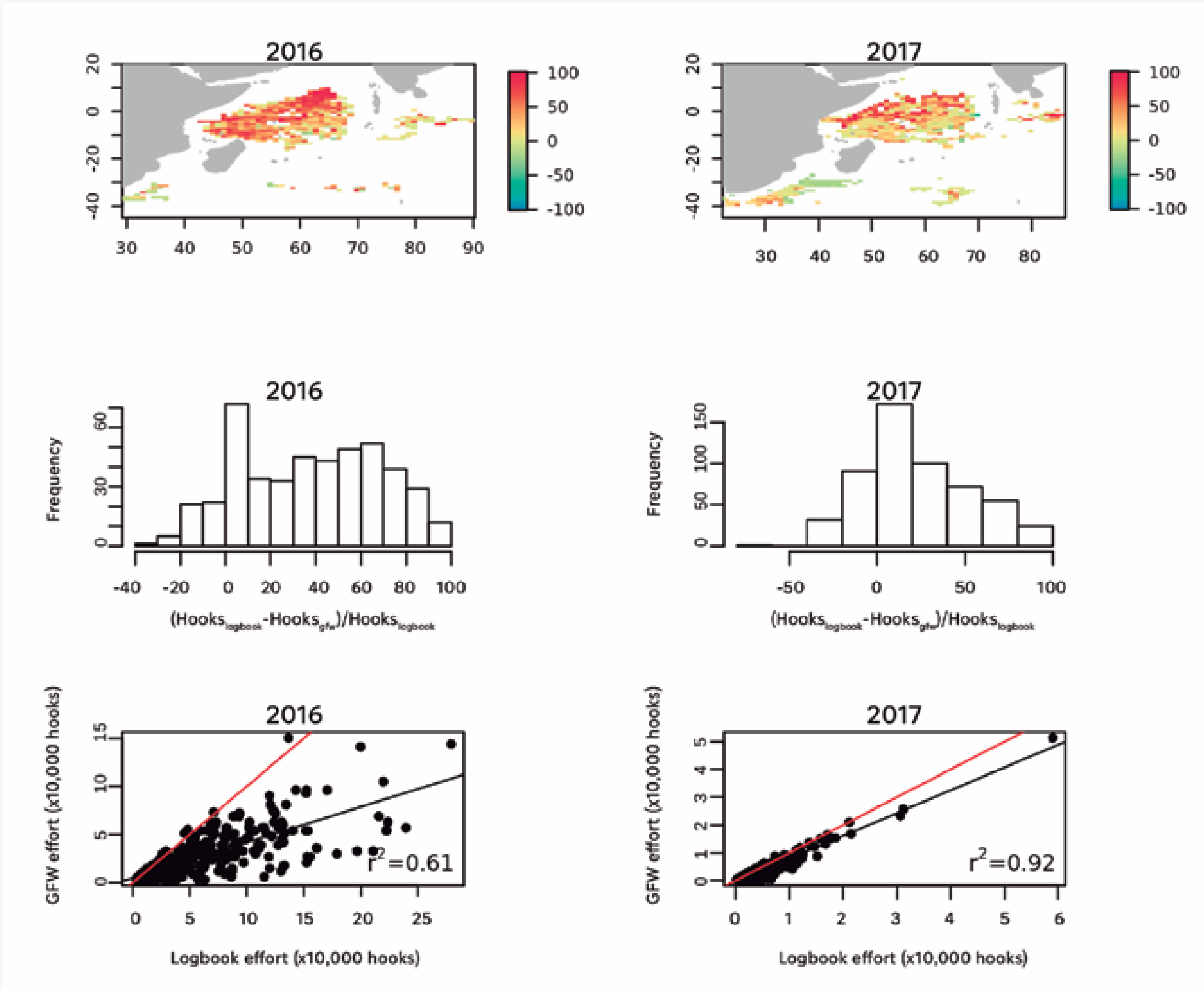


Figure Sey. 14. Normalised anomaly maps of longline fishing effort (hooks) calculated as the number of logbook hooks minus the number of GFW hooks on a 1° x 1° grid, normalised by the number of logbook hooks for 2016 and 2017 (top panel); the distribution of the normalised anomaly of fishing effort between logbooks and GFW for 2016 and 2017 (middle panel), and the linear relationship between logbook effort and GFW effort for (bottom panel).

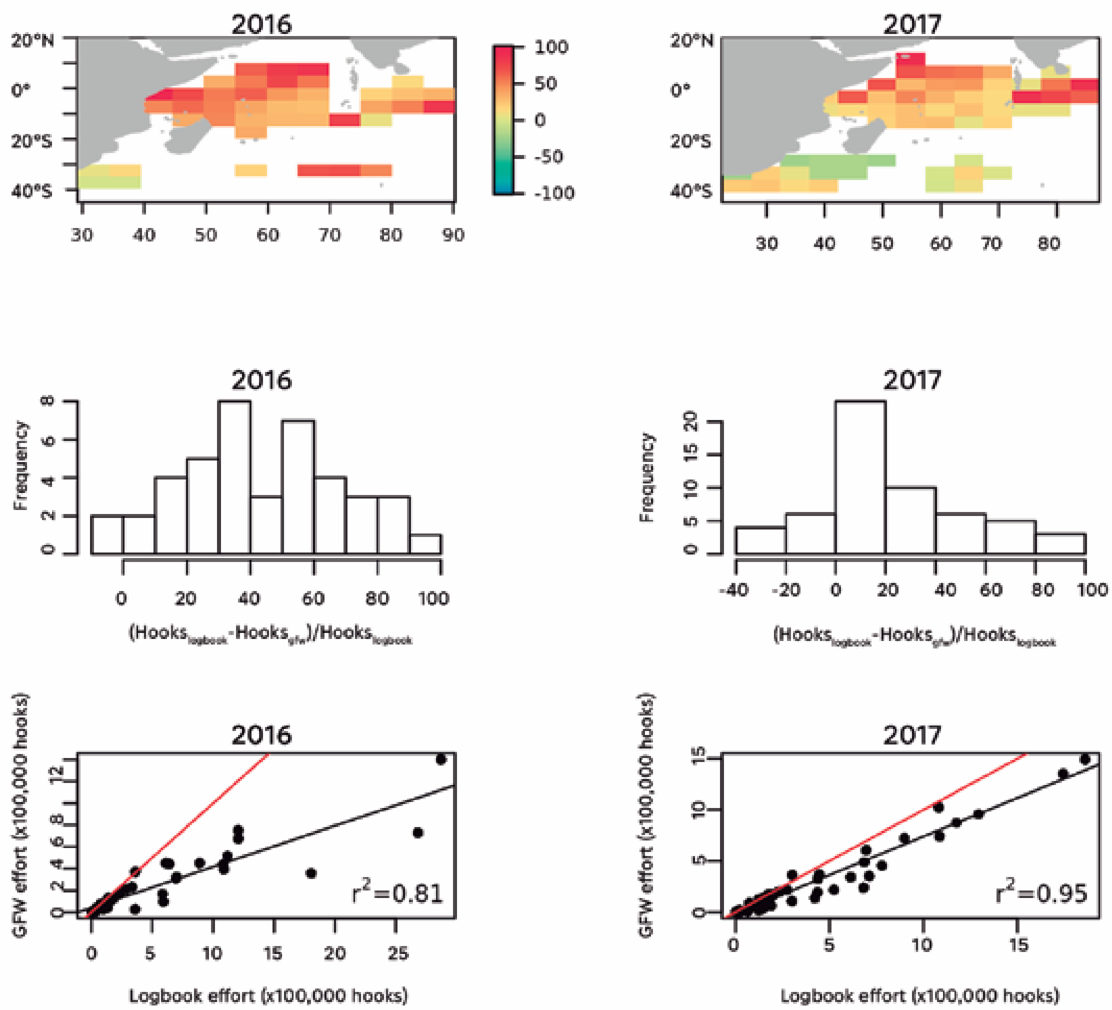


Figure Sey.15. Normalised anomaly maps of longline fishing effort (hooks) calculated as the number of logbook hooks minus the number of GFW hooks on a 5° x 5° grid, normalised by the number of logbook hooks for 2016 and 2017 (top panel); the distribution of the normalised anomaly of fishing effort between logbooks and GFW for 2016 and 2017 (middle panel); and the linear relationship between logbook effort and GFW effort for 2016 and 2017 (bottom panel).

ACKNOWLEDGEMENTS

We are grateful to all fishermen and scientific staff involved in the collection and management of the data used in the chapter. The authors warmly thank Jennifer Gee for excellent comments and feedback during the elaboration of the chapter. Many thanks to David Kroodsma, Marc Taconet, Nathan Miller, Jaeyoon Park and Tony Long from Global Fishing Watch for providing AIS data and Freddy Lesperance, Roddy Allisop, Loreen Esther, Julie Jean and Alisa Belmont for great assistance with VMS data. Many thanks to Igor Granado, Dr. Jose Fernandes and Dr. Maurizio Gibin for fruitful discussions on data analysis. Vincent Lucas and Philippe Michaud provided feedbacks on the report. We thank Stig Fjellberb and Duncan Copeland from TM-Tracking for initial discussions on the pros and cons of AIS. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Required citation for this chapter:

Nieblas, A-E., Barde, J., Louys, J., Lucas, J., Assan, C., Imzilen, T., Dalleau, C., Gerry, C., Chassot, E. 2019. Seychelles VMS/ logbook comparison for tuna fisheries (FAO Area 51). *In* Taconet, M., Kroodsma, Fernandes, J. A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

Amoroso, R. O., Parma, A. M., Pitcher, C. R., McConnaughey, R. A., & Jennings, S. 2018. *Comment on "Tracking the global footprint of fisheries". Science, 361(6404), eaat6713.* https://doi.org/10.1126/science.aat6713

IOTC. 2012. *The Indian Ocean Tuna Commisssion. Report of the 2012 ISSF stock assessment workshop: Understanding purse seine CPUE. Document IOTC-2012-WPM04-INF09. Rome, Italy, 16-19 July.* https://www.iotc.org/sites/default/files/documents/proceedings/2012/wpm/IOTC-2012-WPM04-INF09.pdf

Assan C, Lucas J, Augustin E, de Molina D, Maufroy A, Chassot E. 2015. *Seychelles auxiliary vessels in support of purse seine fishing in the Indian Ocean during 2005–2014: Summary of a decade of monitoring. Document IOTC–2015–WPTT17–41 Rev_1.* https://iotc.org/sites/default/files/documents/2015/10/IOTC-2015-WPTT17-12_-_EU_PS_statistics.pdf

Assali, C., Bez, N., & Tremblay, Y. 2017. *Seabird distribution patterns observed with fishing vessel's radar reveal previously undescribed sub-meso-scale clusters. Scientific reports, 7(1), 7364.* https://doi.org/10.1038/s41598-017-07480-6

Bez, N., Walker, E., Gaertner, D., Rivoirard, J., & Gaspar, P. 2011. *Fishing activity of tuna purse seiners estimated from vessel monitoring system (VMS) data. Canadian Journal of Fisheries and Aquatic Sciences, 68(11), 1998-2010.* https://doi.org/10.1139/f2011-114

Campbell, R. A. 2004. *CPUE standardisation and the construction of indices of stock abundance in a spatially varying fishery using general linear models. Fisheries Research, 70(2-3), 209-227.* https://doi.org/10.1016/j.fishres.2004.08.026

Chassot E, Dewals P, Floch L, Lucas V, Morales-Vargas M, Kaplan D. 2010. *Analysis of the effects of Somali piracy on the European tuna purse seine fisheries of the Indian Ocean. Document IOTC-2010-SC-09.* https://iotc.org/sites/default/files/documents/proceedings/2010/sc/IOTC-2010-SC-09.pdf

Cunningham, S., & Whitmarsh, D. (**1980**). *Fishing effort and fisheries policy. Marine Policy, 4(4), 309-316.* https://doi.org/10.1016/0308-597X(80)90004-4

Eguíluz, V. M., Fernández-Gracia, J., Irigoien, X., & Duarte, C. M. 2016. *A quantitative assessment of Arctic shipping in 2010–2014. Scientific reports, 6, 30682.* https://doi.org/10.1038/srep30682

FAO, Food and Agriculture Organization of the United Nations. 2019. Fishing effort. *In* Coordinating Working Party on Fishery Statistics (CWP). http://www.fao.org/cwp-on-fishery-statistics/handbook/capture-fisheries-statistics/fishing-effort/en/

Fonteneau, A., Chassot, E., & Bodin, N. 2013. *Global spatio-temporal patterns in tropical tuna purse seine fisheries on drifting fish aggregating devices (DFADs): Taking a historical perspective to inform current challenges. Aquatic Living Resources, 26(1), 37-48.* https://doi.org/10.1051/alr/2013046

Fonteneau, A., Lucas, V., Tewkai, E., Delgado, A., & Demarcq, H. 2008. *Mesoscale exploitation of a major tuna concentration in the Indian Ocean. Aquatic Living Resources, 21(2), 109-121.* https://doi.org/10.1051/alr:2008028

Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F.,... & Woods, P. 2018. *Tracking the global footprint of fisheries. Science, 359(6378), 904-908.* https://doi.org/10.1126/science.aao5646

Lee, J., South, A. B., & Jennings, S. 2010. *Developing reliable, repeatable, and accessible methods to provide high-resolution estimates of fishing-effort distributions from vessel monitoring system (VMS) data. ICES Journal of Marine Science, 67(6), 1260-1271.* https://doi.org/10.1093/icesjms/fsq010

Miller, N.A., Roan, A., Hochberg, T., Amos J. & Kroodsma D.A. 2018. *Identifying global patterns of transshipment behavior. Frontiers in Marine Science.* https://doi.org/10.3389/fmars.2018.00240

Recommendation ITU-R M.1371-5 (02/2014). *International Telecommunication Union. Technical characteristics for an automatic identification system using time division multiple access in the VHF maritime mobile frequency band. M Series Mobile, radiodetermination, amateur and related satellite services.* http://www.itu.int/pub/R-REC/en

Robards, M. D., Silber, G. K., Adams, J. D., Arroyo, J., Lorenzini, D., Schwehr, K., & Amos, J. 2016. *Conservation science and policy applications of the marine vessel Automatic Identification System (AIS)—a review. Bulletin of Marine Science, 92(1), 75-103.* https://doi.org/10.5343/bms.2015.1034

Sala, E., Mayorga, J., Costello, C., Kroodsma, D., Palomares, M. L., Pauly, D.,... & Zeller, D. 2018. *The economics of fishing the high seas. Science Advances, 4(6), eaat2504.* https://doi.org/10.1126/sciadv.aat2504

Torres-Irineo, E., Gaertner, D., Chassot, E., & Dreyfus-León, M. 2014. *Changes in fishing power and fishing strategies driven by new technologies: The case of tropical tuna purse seiners in the eastern Atlantic Ocean. Fisheries Research, 155, 10-19.* https://doi.org/10.1016/j.fishres.2014.02.017

Witt, M. J., & Godley, B. J. 2007. *A step towards seascape scale conservation: using vessel monitoring systems (VMS) to map fishing activity. PloS one, 2(10), e1111.* https://doi.org/10.1371/journal.pone.0001111

FAO AREA 18

AIS-based fishing activity in the Arctic

Figure 18. 1. Location of FAO Area 18.

Ane Iriondo, Hilario Murua, Igor Granado, David Kroodsma, Nathan A. Miller and Jose A. Fernandes

PREAMBLE

This chapter assesses, through a comparison with fleet statistics and public fisheries data, the capacity of Automatic Identification System (AIS) data and Global Fishing Watch (GFW) algorithms (Kroodsma *et al.*, 2018) to identify and quantify fishing vessel activity in the Arctic Sea. This assessment reviews fleet activity, main gear types, and spatial distribution of fishing vessel activity and fishing operations.

SUMMARY AND CONCLUSIONS FOR THE ARCTIC SEA

The Arctic, due to its extensive ice cover and remoteness, sees comparatively low amounts of industrial fishing. The only areas with many months of ice-free water are off far western Russia and in the waters near the Hudson Bay; partially as a result, all AIS fishing is concentrated in these regions. According to the Global Fisheries Landing Database (GFLD; Watson, 2017), there is no fishing activity by large scale industrial vessels in this area, and all the catch is made by small scale vessels. AIS data only sees 20 vessels operating in the FAO Area 18. Most of these vessels are trawlers operating in Russian waters in the far western corner of the area or trawlers operating in Canadian waters just to the east of Hudson Bay. While spatial patterns of trawling activity based on AIS data do not represent the full extent of fishing activity in the area, they do characterize its seasonality. AIS data provide little information regarding the fishing activity of small-scale purse seiners or set gillnetters, two significant gears in the FAO Area 18, due to their smaller size and lack of AIS use.

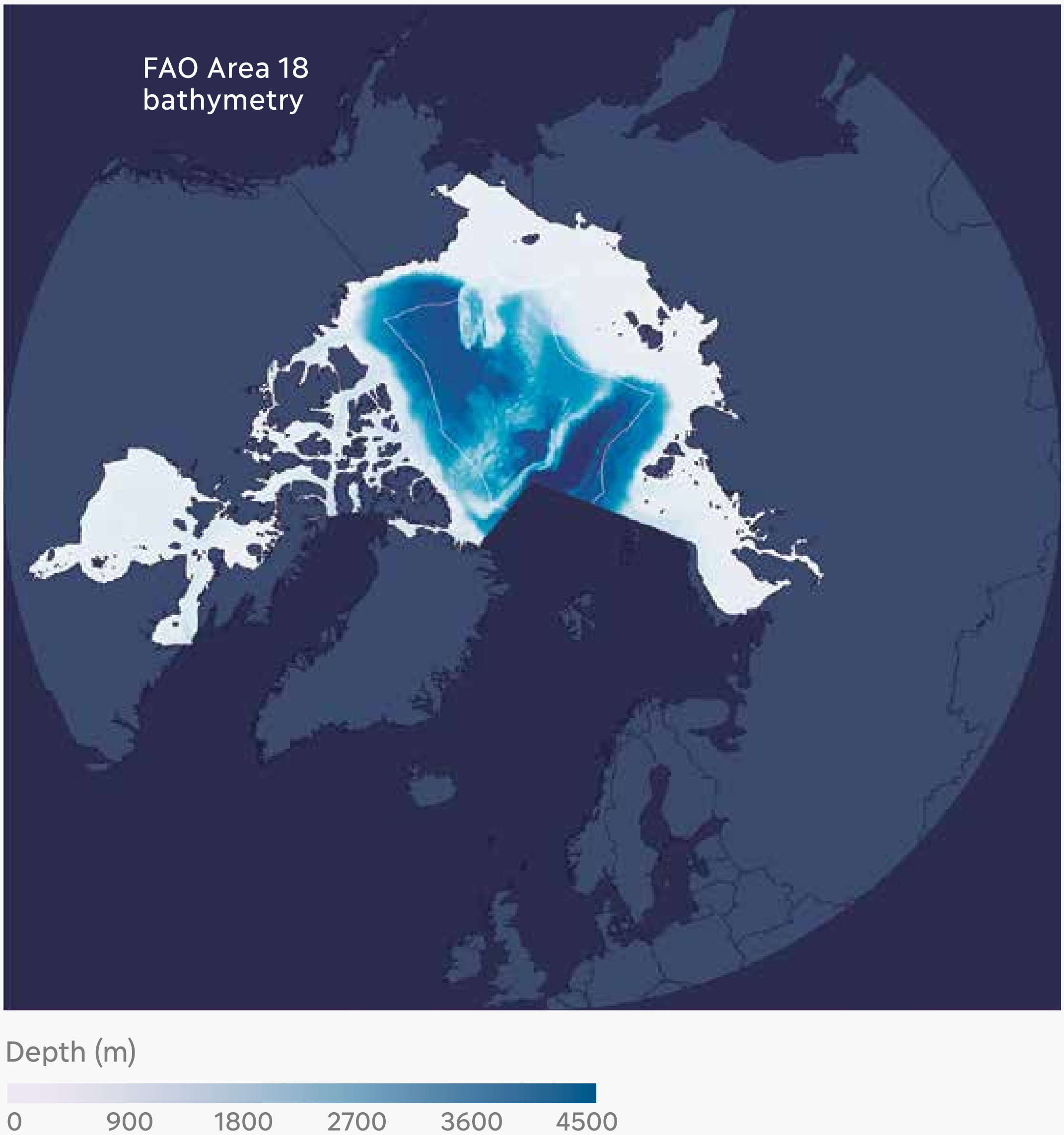


Figure 18. 2i. FAO Area 18 bathymetry (depth) and 200 miles coastal arc.

INTRODUCTION OF FAO AREA 18 FOR THE ARCTIC SEA

The Arctic Sea (FAO Area 18; FAO, 2019) encompasses all marine waters between the 68°30' E and 40° W longitudes over seven coastal Large Marine Ecosystems (Figure 18. 1). Canada, Greenland, Russia and United States of America are coastal countries/territories within FAO Area 18 (Figure 18. 2i), which has roughly 27 percent of marine waters in the high seas and the remainder under national jurisdiction. The high seas represent considerably less of FAO Area 18 than most other FAO areas (on average the high seas account for 54 percent of all FAO areas), though this proportion varies widely between areas (from 20 percent and 80 percent). Sea ice covers most of FAO Area 18 throughout the year, limiting fishing and shipping operations. Figure 18. 2ii shows the sea ice extent in March and September of 2017, the months of maximum and minimum sea ice range.

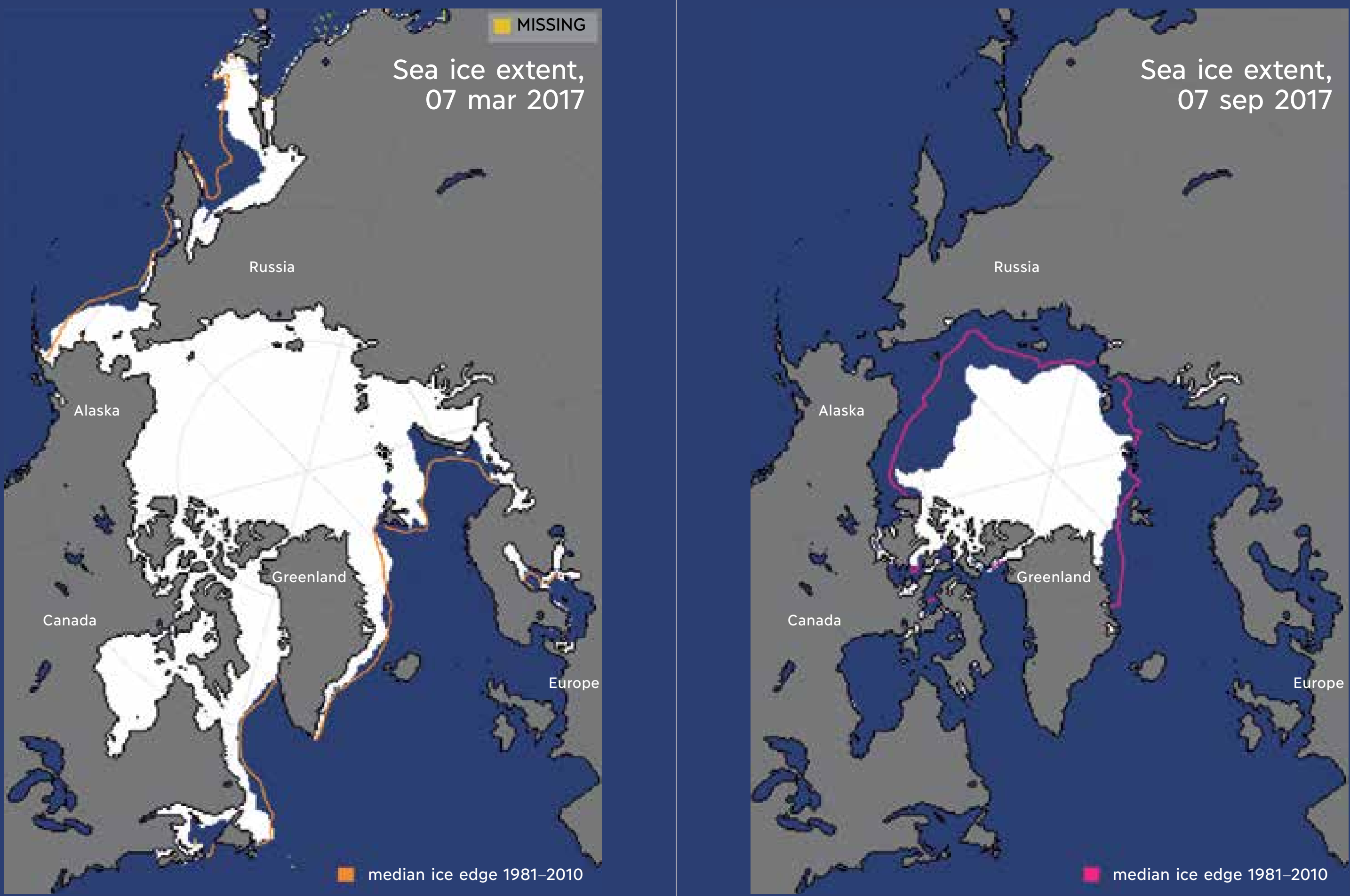


Figure 18. 2ii. Sea ice extent in March (left panel) and September (right panel) 2017. Source: National Snow and Ice Data Center.

The Arctic Ocean's shelf, comprises several continental shelves, including the Canadian Arctic shelf, underlying the Canadian Arctic Archipelago, and the continental shelf of Russia which includes the Barents Shelf, Chukchi Sea Shelf and Siberian Shelf (Figure 18. 2i). Of these three, the Siberian Shelf is the largest shelf of its kind in the world. Historically, the harsh climate has limited marine fisheries to small-scale operations conducted mainly in estuaries and river deltas. In August 2009, the United States of America Secretary of Commerce approved the Fishery Management Plan for the Fish Resources of the Arctic Management Area (https://www.arctic.noaa.gov). The plan initially prohibited commercial fishing in the Arctic waters of the United States of America, primarily the Chukchi and Beaufort Seas and established a framework for the sustainable management of Arctic marine resources. The prohibition on commercial fishing was deemed necessary until more information is available to support sustainable fisheries management, as warming ocean temperatures, migrating fish stocks and shifting sea ice conditions due to climate change may favour the development of commercial fisheries in the future.

Most of the catches in this region are thought to be unreported to FAO, and as a result reported catches are 75 times lower than total catches estimated by a catch reconstruction (1950 to 2006) (Zeller *et al.*, 2011). The largest estimated catches were those of whitefishes with five species (*Coregonus sardinella, C. muksun, C. autumnalis, C. nasus, and C. lavaretus*) accounting for over 65 percent of reconstructed total catches over the 50 years period (Zeller *et al.*, 2011). FAO landings statistics (FishStatJ, 2018) show that in the period from 2010 to 2014, catches were dominated by demersal fish species, mainly Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*).

REGION FLEETS AND AIS USE IN THE ARCTIC SEA

Region fleets of coastal states and territories in FAO Area 18 show that non-motorized fishing vessels are either not used or not reported to FAO. Motorized vessels are classified in three overall length classes, with 40.6 percent of the vessels being smaller than 12 m (and unlikely to have AIS installed), 34 percent of the vessels between 12 and 24 m, and only 2.8 percent of the vessels operating in this region over 24 m in length (Figure 18. 3).

Fleets of coastal countries/territories in FAO Area 18

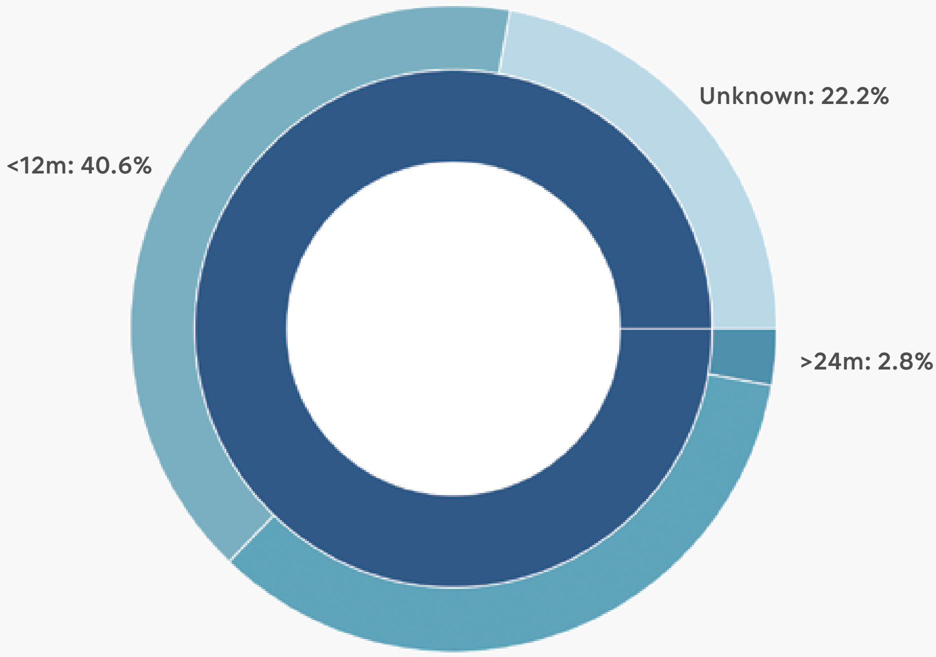


Figure 18. 3. Structural composition of coastal countries'/territories' fleets in FAO Area 18. All vessels in this region are motorized (complete dark blue circle). Notice that several coastal states are adjacent to several FAO areas, yet their entire fleet size is included here. Source: FAO statistics for year 2017.

Fishing fleets in Russia, the United States of America and Canada all have relatively high AIS use. In the United States of America and the Russian Federation,, nearly 100 percent of fishing vessels over 24 m have AIS installed, while in Canada this value is closer to 75 percent. However, only a minimal fraction of any size vessels from these countries are active in the far north. The United States of America's current management plan bans commercial fishing in the Arctic and, thus, no United States of America vessels were identified broadcasting AIS in FAO Area 18. In fact, in the area, only 17 active fishing vessels broadcast AIS, all using Class A AIS devices. These vessels were all matched to vessel registries, and for 13 vessels the registry also identified

the fishing gear. Figure 18. 4.b shows the number of vessels by flag state and the distribution of vessels by gear type. Only Russian and Canadian vessels were found within FAO Area 18 and all except two were identified as trawlers.

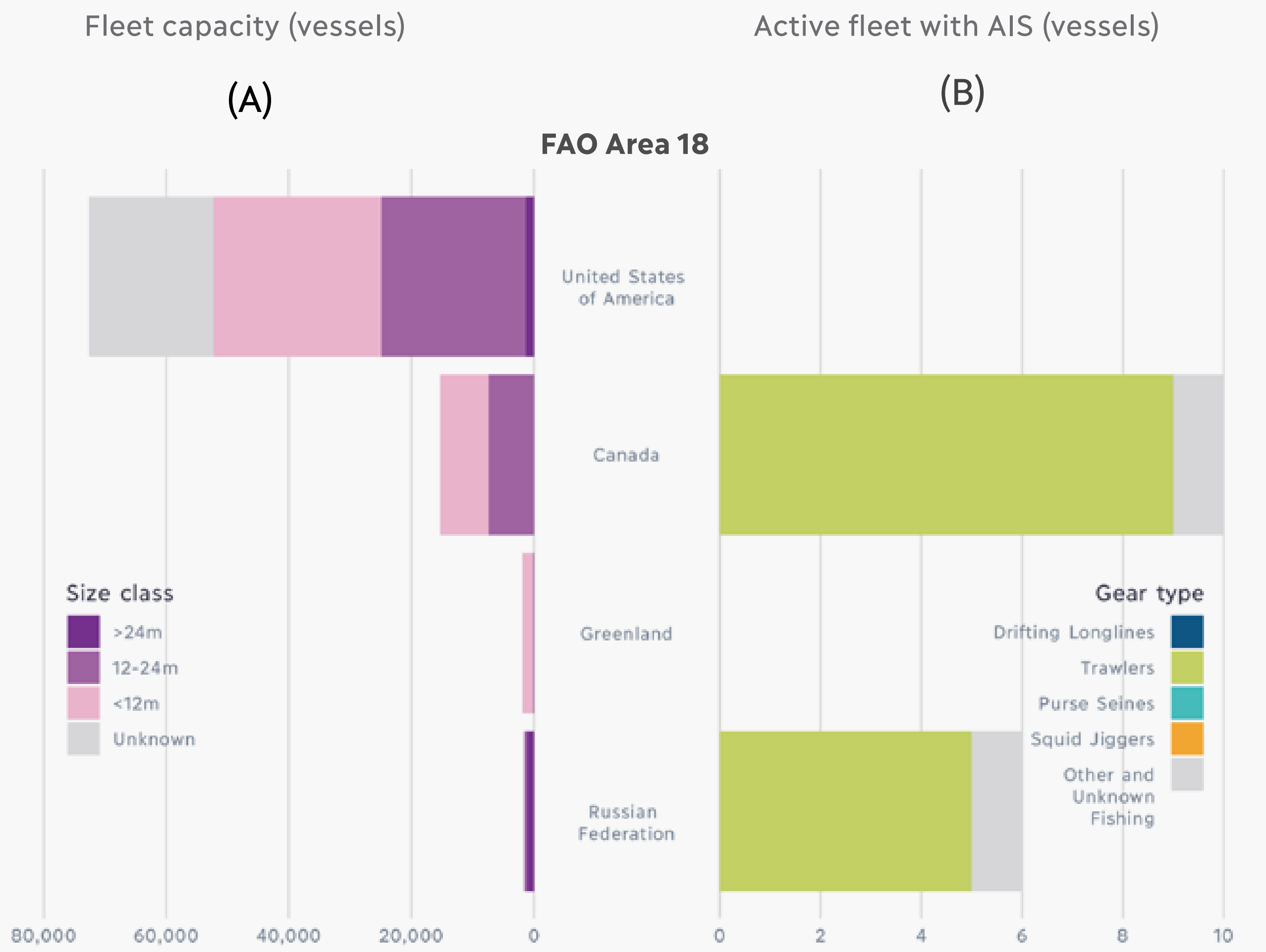


Figure 18. 4. Coastal fleets summary in FAO Area 18 during year 2017 based on FAO statistics and AIS data classification by GFW. A) The entire fleets of countries/territories are shown, even though these fleets are mostly active in other FAO areas (left panel). Source: FAO statistics. B) AIS-identified number of fishing vessels broadcasting AIS during their operations in FAO Area 18 by gear type and flag state. Only vessels that fished for at least 24 hours in the area are included (right panel). Source: GFW.

AIS RECEPTION AND FISHING VESSEL ACTIVITY IN THE ARCTIC SEA

Figure 18. 5a shows all fishing vessel activity (fishing, searching, in transit) identified by AIS in FAO Area 18. The few vessels operating in this area broadcast Class A AIS with good signal reception (Figure 18. 5b).

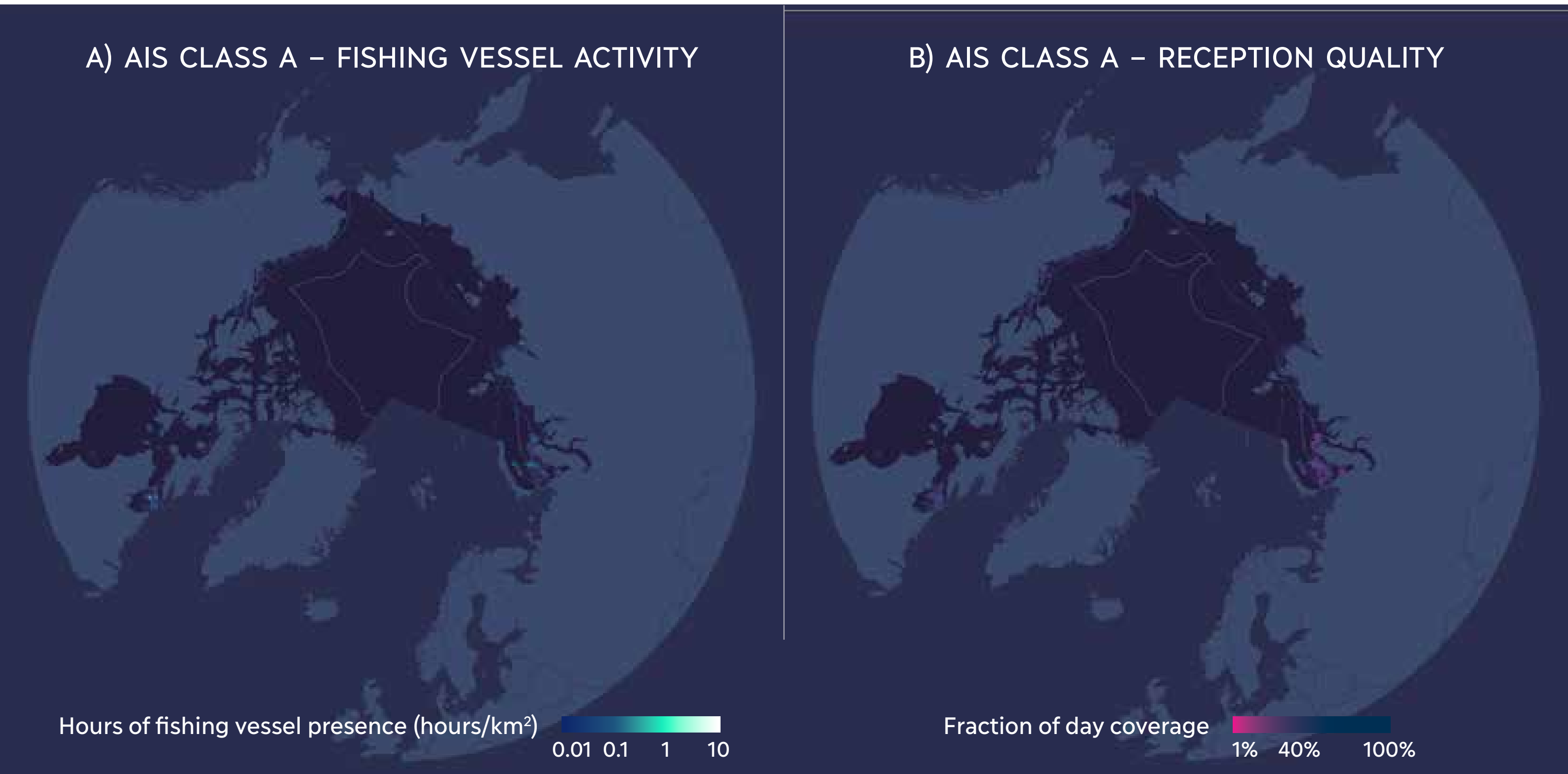


Figure 18. 5. Class A fishing vessel activity and AIS reception quality. The left panel shows the activity of fishing vessels using Class A AIS devices for the 2017 year, and the right panel shows their reception quality. Blank spaces on the map (i.e. dark blue ocean background) mean that no signals from fishing vessels in this area were received, which is due to either no vessel activity or poor reception.

The AIS data (Figure 18. 6) shows fishing operations only occur in specific areas (e.g. Kara Sea).

Figure 18. 6. The intensity of fishing operations based on AIS data for FAO Area 18 during 2017.

FISHING VESSEL ACTIVITY AND OPERATIONS BY GEARS IN THE ARCTIC SEA

This section reviews the spatial distribution patterns of the main fishing gears in FAO Area 18 as estimated by Global Fishing Watch (GFW) based on 2017 AIS data. The most recent datasets available as of mid-2018 have been used to assess GFW capacity to provide an AIS based characterization of fishing activity by fishing gear in terms of presence/absence, intensity, and hot spots. The Introduction chapter describes the rationale and challenges for use of contrasting data sources (e.g. Global Fisheries Landings database (GFLD; Watson, 2017)) for benchmarking AIS data classification.

The GFLD shows no catch for industrial vessels in FAO Area 18 and therefore Table 18. I compares the catch of small-scale vessels with the AIS data. For small scale fishing, the GFLD estimates that about 50 000 tonnes of fish are caught in this area, which is less than 0.01 percent of the global catch. Roughly two thirds of the small-scale catch is divided equally between trawlers and purse seiners, with the remainder divided among set gillnets and other gears. In the AIS data, we see 666 active days by trawlers and 91 active days by other fishing vessels, amounting to 757 total active days in the area. While GFLD considers purse seines and set gillnetters to also be relatively common gear types in FAO Area 18, no AIS information for these individual gears was available. Given the focus of Arctic fisheries in coastal and estuarine waters, it may be that these vessels are small and thus AIS use is not compulsory. For example, Alaskan coastal purse seiners target salmon and herring; whereas gillnets are subsistence small vessel fisheries occurring mainly in October and November.

GEAR TYPES	Catches (GFLD) by small scale vessels 2010–2014 average		Total fishing vessel activity (GFW-AIS) 2017	
	Tonnes of catch in 1000s	% of catch	Active days	% of active days
Trawls	18	36%	666	88%
Purse seines	16	32%	91	12%
Set gillnets	8.8	18%		
Other	5.4	19%		
Pole and line	1.7	4%		
Total	49	100%	757	100%

Table 18. I. Summary table comparing average catch from GFLD during 2010–2014 with fishing vessel activity from GFW in FAO Area 18. For GFW data, only vessels that fished for at least 24 hours in FAO Area 18 are included.

The fishing identified by AIS estimates that most of the fishing activity is by trawlers in FAO Area 18. Most of this activity by trawlers takes place in the far northwestern corner of the Russian Federation, which is the part of FAO Area 18 less covered by sea ice, or in the eastern edge of the Hudson straight in Canadian waters (Figure 18. 7). In general, the information on fishing activity for these Arctic fisheries is scarce. The lack of AIS data for some fishing gears could be due to fishing activity concentrated in smaller vessels close to land.

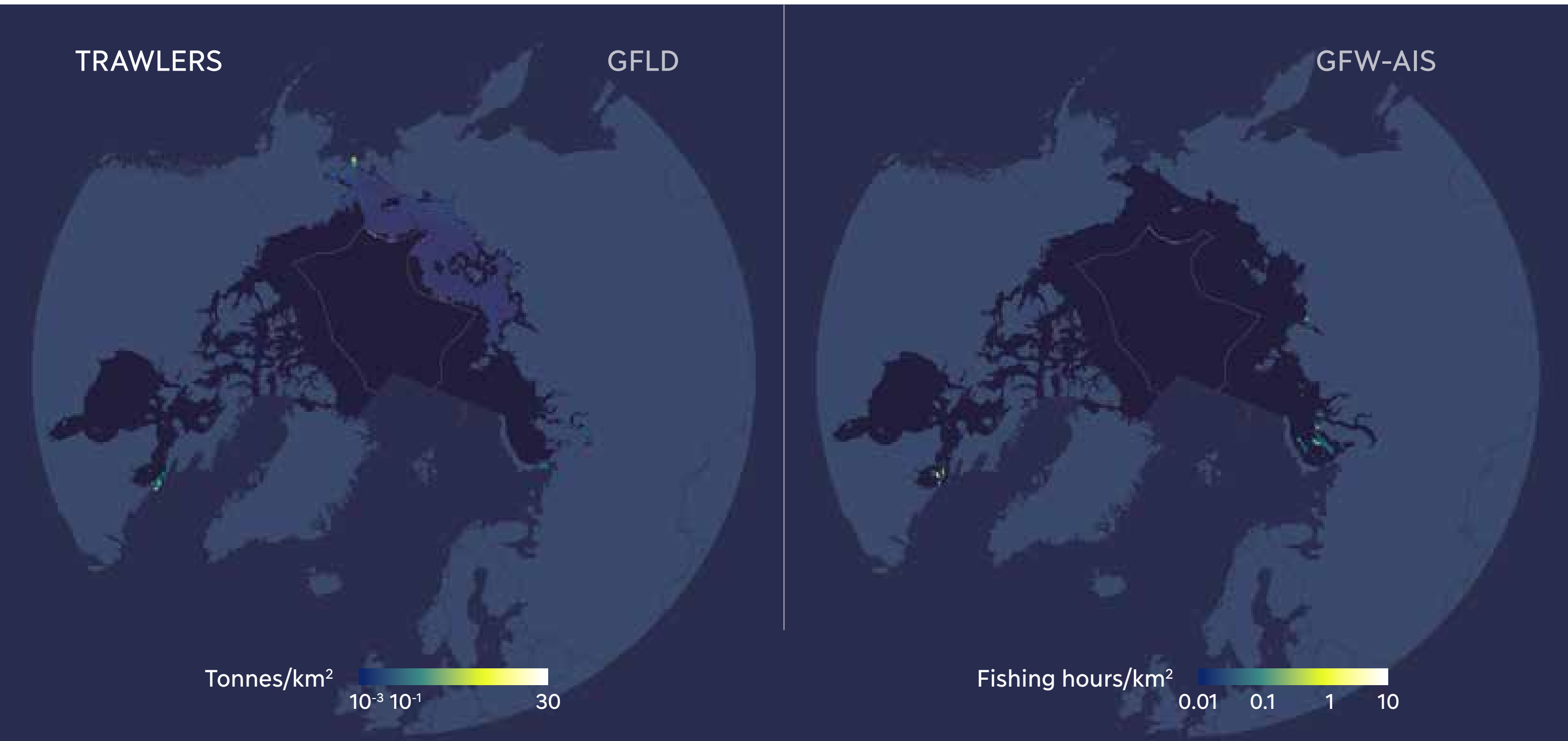


Figure 18. 7. Catch and activity of trawlers in FAO Area 18. Maps comparing average catch during 2010–2014 from GFLD (left panel) with trawlers fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

Fishing in the Arctic shows strong seasonality, corresponding to changing sea ice distribution. Few vessels are active during the winter and spring months, when sea ice covers most of the area. The number of vessels peaks in September when sea ice usually reaches its minimum range (Figure 18. 8).

Fishing vessels in FAO Area 18

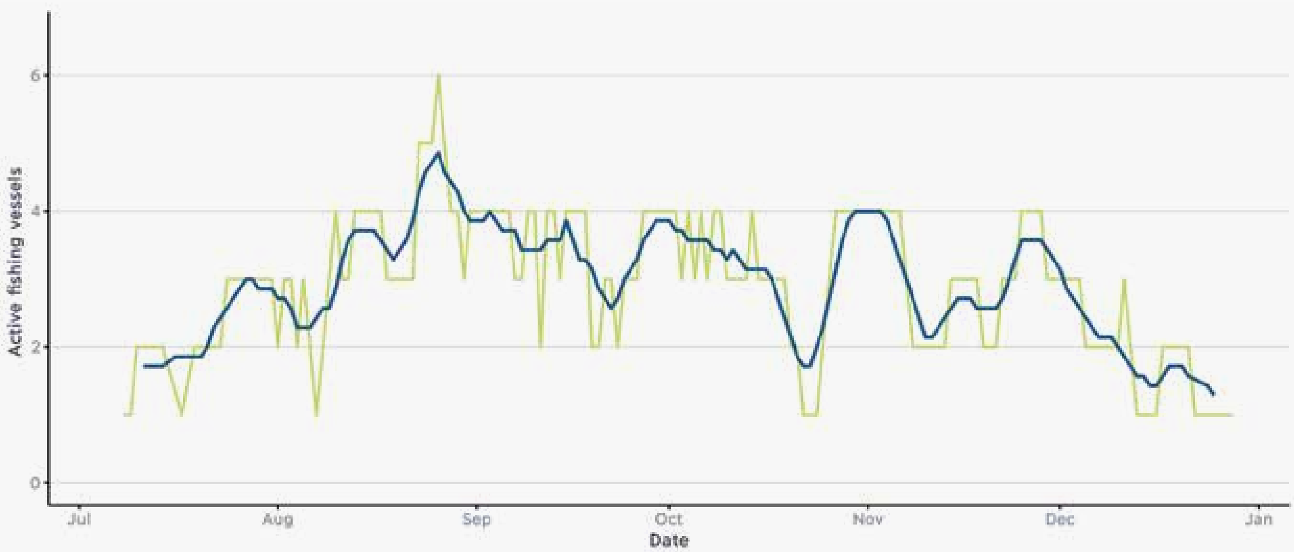


Figure 18. 8. Number of AIS-identified active fishing vessels in FAO Area 18 during 2017. Only vessels that fished at least 24 hours in the area over the course of the year are included. Dark blue line shows a 7-day rolling average.

ACKNOWLEDGEMENTS

The editors would like to thank Alexander Kotlarov for excellent comments and feedback during the elaboration of the chapter. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Required citation for this chapter:

Iriondo, A., Murua, H., Granado, I., Kroodsma, D., Miller, N. A., Fernandes, J. A. 2019. FAO Area 18 - AIS-based fishing activity in the Arctic. *In* Taconet, M., Kroodsma, Fernandes, J. A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

FAO. 2019. *Food and Agriculture Organization of the United Nations. FAO Major Fishing Areas. Arctic Sea (Major Fishing Area 18).* http://www.fao.org/fishery/area/Area18/en

FishStatJ. 2018. Fisheries and aquaculture software. FishStatJ - software for fishery statistical time series. *In* FAO Fisheries and Aquaculture Department [online]. Rome. Updated 21 July 2018. [Cited 19 November 2018]. http://www.fao.org/fishery/statistics/software/fishstatj/en

Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F.,... & Woods, P. 2018. Tracking the global footprint of fisheries. *Science*, 359(6378), 904-908. https://doi.org/10.1126/science.aao5646

Watson, R. A. 2017. A database of global marine commercial, small-scale, illegal and unreported fisheries catch 1950–2014. *Scientific data*, 4, 170039. https://doi.org/10.1038/sdata.2017.39

Zeller, D., Booth, S., Pakhomov, E., Swartz, W., & Pauly, D. 2011. Arctic fisheries catches in Russia, USA, and Canada: baselines for neglected ecosystems. *Polar Biology, 34(7), 955-973.* https://doi.org/10.1007/s00300-010-0952-3

FAO AREA 21

AIS-based fishing activity in the Northwest Atlantic

Figure 21. 1. Location of FAO Area 21.

Ane Iriondo, Josu Santiago, Igor Granado, David Kroodsma, Marc Taconet and Jose A. Fernandes

PREAMBLE

This chapter assesses, through a comparison with fleet statistics and public fisheries data, the capacity of Automatic Identification System (AIS) data and Global Fishing Watch (GFW) algorithms (Kroodsma *et al.*, 2018) to identify and quantify fishing vessel activity in the Northwest Atlantic. This assessment reviews fleet activity, main gear types, and spatial distribution of fishing vessel activity and fishing operations.

SUMMARY AND CONCLUSIONS FOR THE NORTHWEST ATLANTIC

The United States of America and Canada, which are responsible for most of the fishing activity in the FAO Area 21, have good use of AIS for vessels larger than 24 m. In addition, AIS reception is very good all over the area for larger vessels broadcasting with high-quality Class A AIS devices. However, reception is quite poor for lower quality Class B devices, and about three quarters of vessels in this area use Class B AIS devices. The AIS data also poorly represents two of the three most important gears in the FAO Area 21: dredgers and purse seiners. This underepresentation most likely occurred because only a small fraction of these vessels are broadcasting AIS. Overall, AIS showed realistic spatial patterns of fishing activity and intensity for the trawlers and longliners.

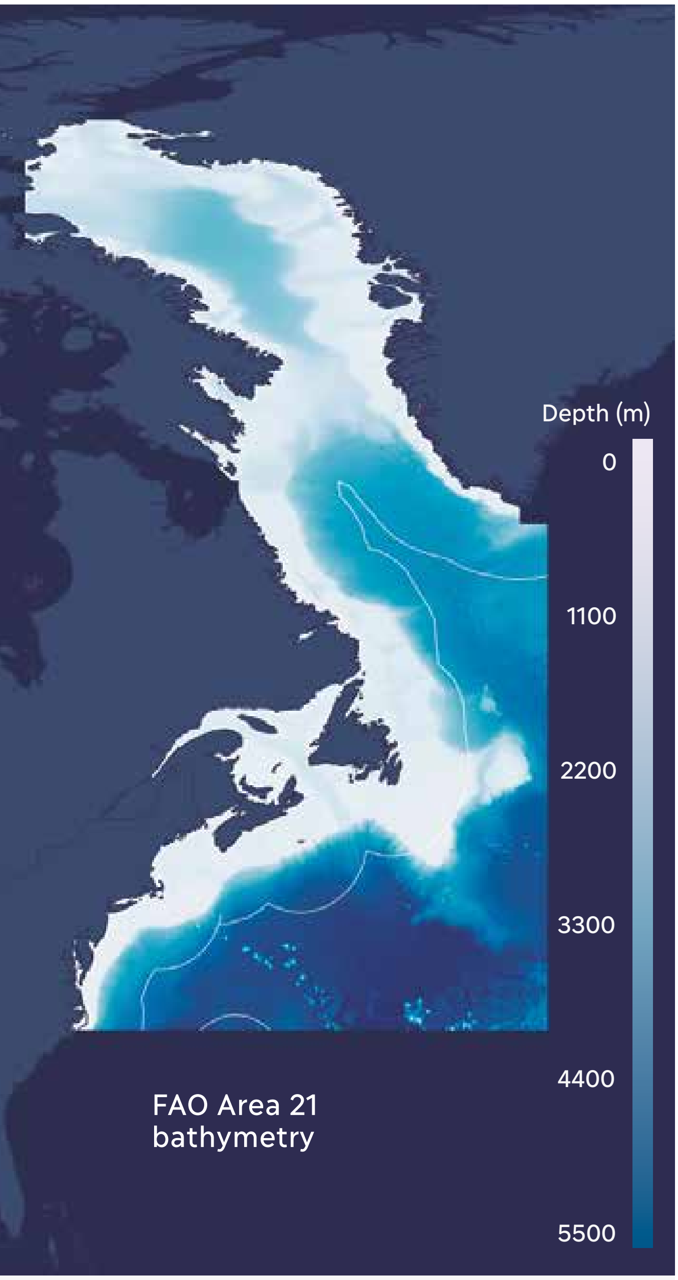


Figure 21. 2. FAO Area 21 bathymetry (depth) and 200 miles arc.

INTRODUCTION FOR THE NORTHWEST ATLANTIC

The Northwest Atlantic area (FAO Area 21; FAO, 2019) comprises the waters of the Northwest Atlantic bounded on the west by the coast of Canada and the United States of America, on the north by the coast of Greenland, and by Bermuda to the south (Figure 21. 1). The following coastal countries/territories are within FAO Area 21: Greenland, Saint Pierre and Miquelon, the United States of America and Canada (Figure 21. 2). All together, they constitute an area under national jurisdiction of 42 percent of the total marine waters in FAO Area 21, with the remaining 58 percent being high seas, mostly in southeastern part. This proportion of high seas in FAO areas is slightly higher than the world's average. The average area in the high seas for FAO Areas is 54 percent, with lower and upper ranges between 20 percent and 80 percent. In this region, fisheries are managed by a) North Atlantic Fisheries Organization (NAFO), a Regional Fishery Management Organization (RFMO) which regulates demersal fisheries in the high seas, including deep seas ecosystems (e.g. corals and sponges); and b) the International Commission for the Conservation of Atlantic Tunas (ICCAT) another RFMO managing migratory tuna species and their pelagic ecosystem.

The continental shelves throughout the Northwest Atlantic are broad, especially around Nova Scotia and the Gulf of Maine where it extends more than 200 nautical miles offshore (Townsend *et al.*, 2006). The marine environment of the Northwest Atlantic encompasses the extremes of the Arctic all the way to subtropical conditions. It includes three large oceanographic areas: the Eastern Arctic (EA), the Subpolar Northwest Atlantic (SP-NWA), and the Mid-Latitude where the subsurface temperatures change from subzero to over 20 °C within a few kilometers (FAO, 2011). Deep-sea corals, sponges, and vulnerable fish species are known to be present in the NAFO Regulatory Area (Waller *et al.*, 2007).

FAO landings statistics (FishStatJ, 2018) show that in the period from 2010 to 2014, catches were dominated by invertebrate and pelagic fish species. The largest catches were northern prawn, American sea scallop, Atlantic herring, Atlantic menhaden, American lobster, harp seal, ocean quahog, Atlantic surf clam, queen crab, Greenland halibut, ringed seal, blue crab, Atlantic cod, Atlantic redfish and capelin. These 15 species made up 80 percent of the reported catch in that period.

REGION FLEETS AND AIS USE IN THE NORTHWEST ATLANTIC

The main coastal nations with fleets in the Northwest Atlantic are the United States of America, Canada, and Greenland. These countries/territories also border other FAO areas, making it difficult to assess how many of these countries' vessels are active in the Northwest Atlantic. Vessels over 24 m, which are the ones most likely to use AIS, account for 1.6 percent of fishing vessels (Figure 21. 3). These countries do not report non-motorized fishing vessels, with 36.2 percent of vessels over 12 m and 41.3 percent of vessels under 12 m (not likely to use AIS).

Fleets of coastal countries/territories in FAO Area 21

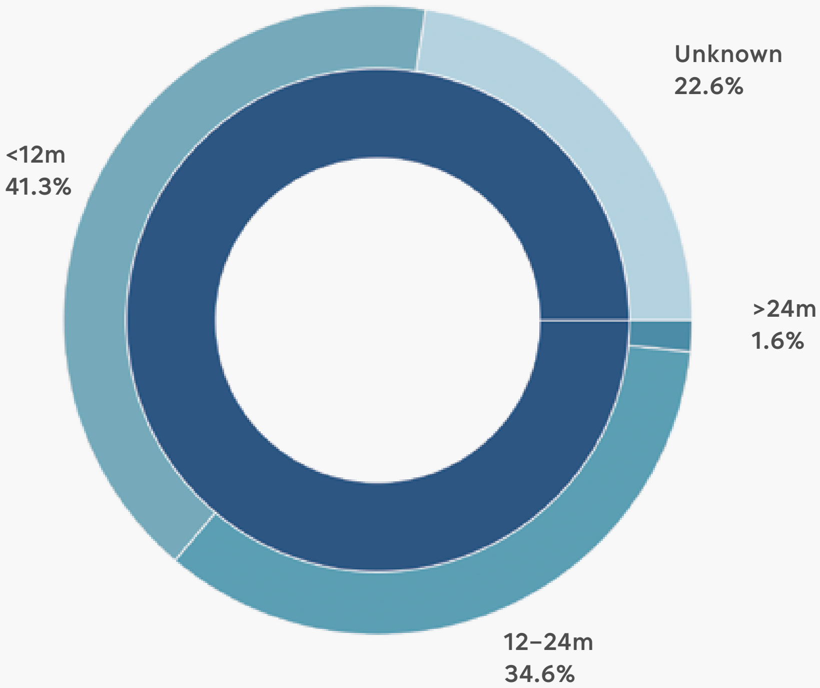


Figure 21. 3: Structural composition of fleets of coastal countries/territories in FAO Area 21. In dark blue motorized fishing vessels. There are no reports of non-motorized vessels to FAO. Distant water fleets active in FAO Area 21 are not included (see next figure). Notice that the United States of America is a coastal state bordering four FAO areas (21, 31, 67 and 77), Canada borders two FAO areas (21 and 67) and Greenland is within two FAO areas (21 and 27), yet their entire fleet size is included here. Source: FAO statistics for year 2017. Statistics were not available for the following countries/territories within FAO Area 21: Saint Pierre and Miquelon.

The United States of America and Canada have good use of AIS by large vessels, showing the highest number of vessels in the Northwest Atlantic in the AIS data. Despite Canadian regulations specifically exempting fishing vessels from having to broadcast AIS, most of their large vessels do so. Canada reported 52 fishing vessels over 24 m to the FAO. However, this

number is likely underreported or outdated since Global Fishing Watch (GFW) AIS identifies over 100 vessels of this size in the global Canadian fleet. The United States of America has stronger regulations in terms of AIS use, requiring that all fishing vessels over 19 m use AIS. As a result, almost all the United States of America vessels over 24 m and many smaller vessels have AIS. In the Northwest Atlantic, GFW identified 1 161 presumed fishing vessels operating. Of these, 982 were matched to vessel registries, confirming their status as fishing vessels. However, only 176 of the vessels found in the registries were associated to gear types, so most of the gear type information for vessels in the Northwest Atlantic derives from the GFW automatic classification.

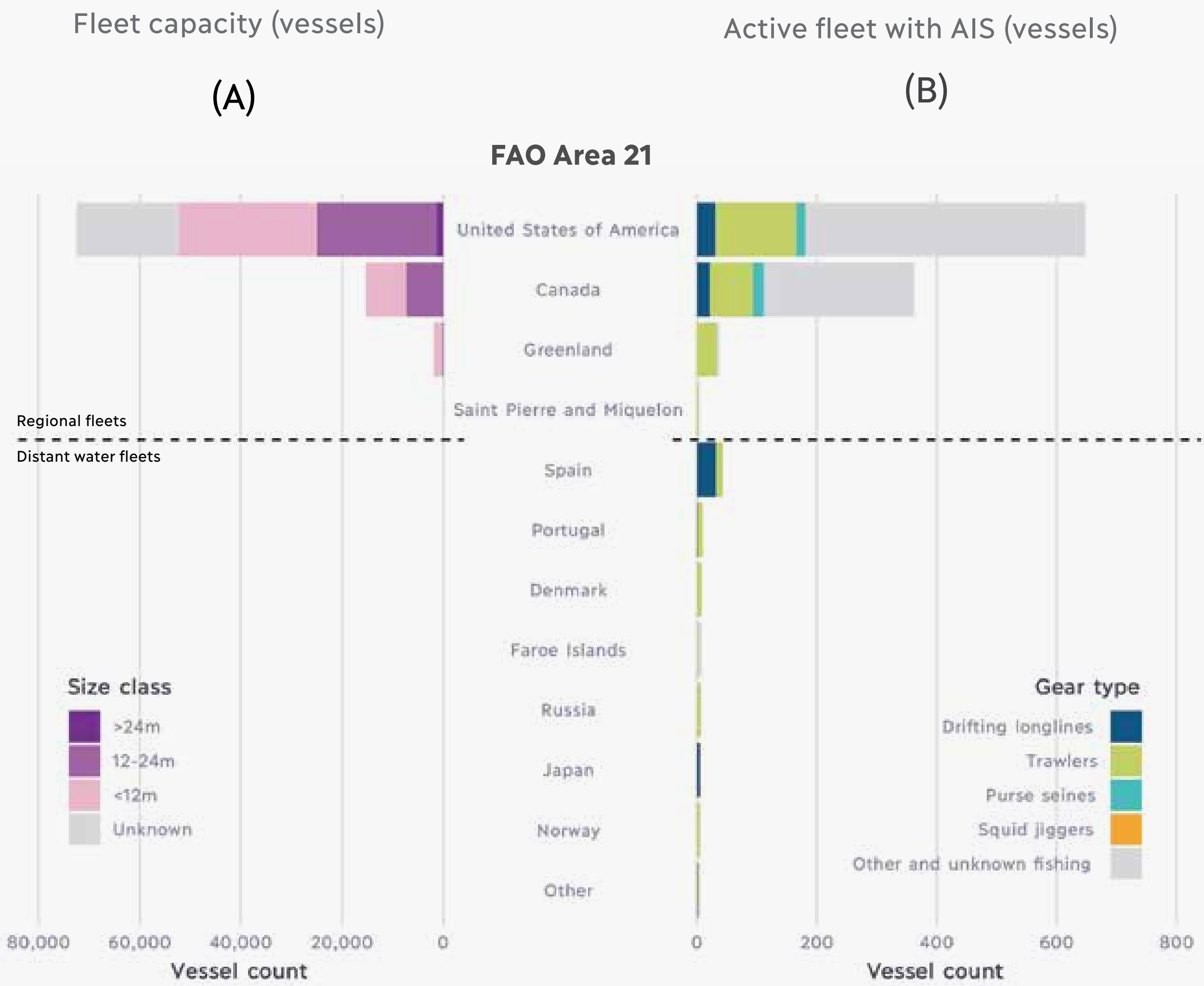


Figure 21. 4. Coastal and distant fleets summary based on FAO statistics and AIS data classification by GFW in FAO Area 21 during year 2017. A) Number of motorized vessels as reported to FAO (left panel). The entire fleets for United States of America, Canada, and Greenland are shown even though these countries/territories border multiple FAO areas. Source: FAO statistics. Statistics were not available for the following countries/territories within FAO Area 21: Pierre and Miquelon. B) AIS-identified number of fishing vessels broadcasting AIS during their operations in FAO Area 21 by gear type and flag state (right panel). Dashed lines separate regional fleets (top) from distant fleets (bottom). Only vessels that fished for at least 24 hours in the area are included. Source: GFW.

Figure 21. 4 shows the number of vessels by flag state using AIS in the Northwest Atlantic, and within each country the distribution of the number of vessels by gear type. Greenland fishing vessels show AIS activity mostly in the Greenland EEZ. Distant water fleets play a smaller role in this area than in some other FAO areas. Spanish drifting longline vessels make their contribution to fishing activity in the southeast corner of the area, and several other fleets with only a few vessels each are active in the high seas areas.

AIS RECEPTION AND FISHING VESSEL ACTIVITY IN THE NORTHWEST ATLANTIC

Figures 21.5a,b show all the operations of fishing vessels (fishing, searching, in transit) captured by AIS in FAO Area 21 (Class A and Class B AIS devices). A higher fraction of the vessels in the far north use Class A, and almost all the high seas longline fleet operating in the southeast corner of the area use Class A devices. In terms of AIS reception, the high-quality device Class A performs very well in the Northwest Atlantic, with good coverage across the Northwest Atlantic (Figure 21. 5c). However, in the Northwest Atlantic, three quarters of the fishing vessels broadcasting AIS use the lower-quality Class B devices, whose reception is poor in most of the area (Figure 21. 5d). The exception is in the northern area where only a few vessels using Class B devices operate. Class B devices perform slightly better very close to shore in the United States of America and Canada in some areas, likely due to the presence of coastal receivers, but the reception weakens with distance from the coastline (Figure 21. 5d). As a result, the AIS fishing activity of these vessels will be underestimated when they operate far from shore.

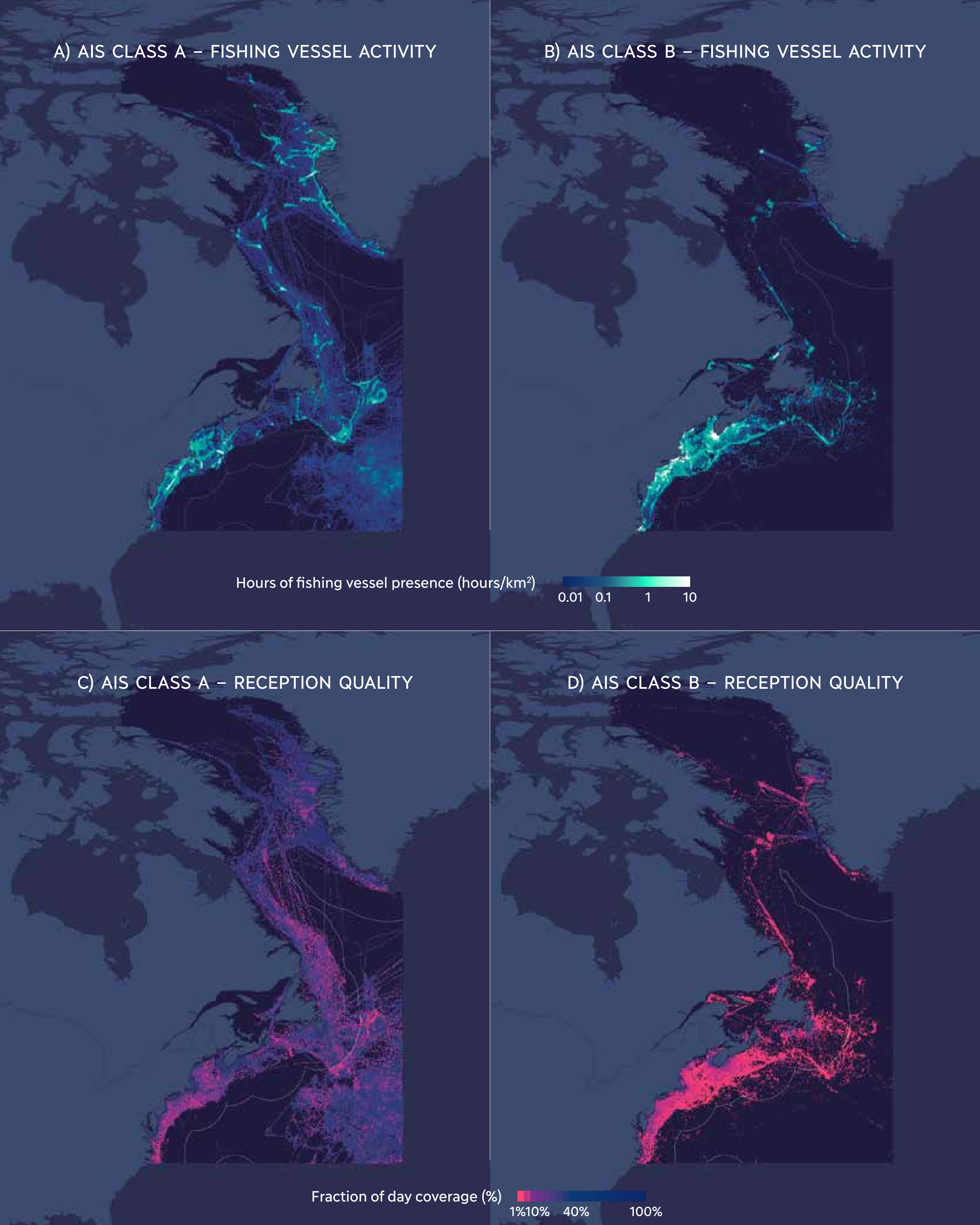
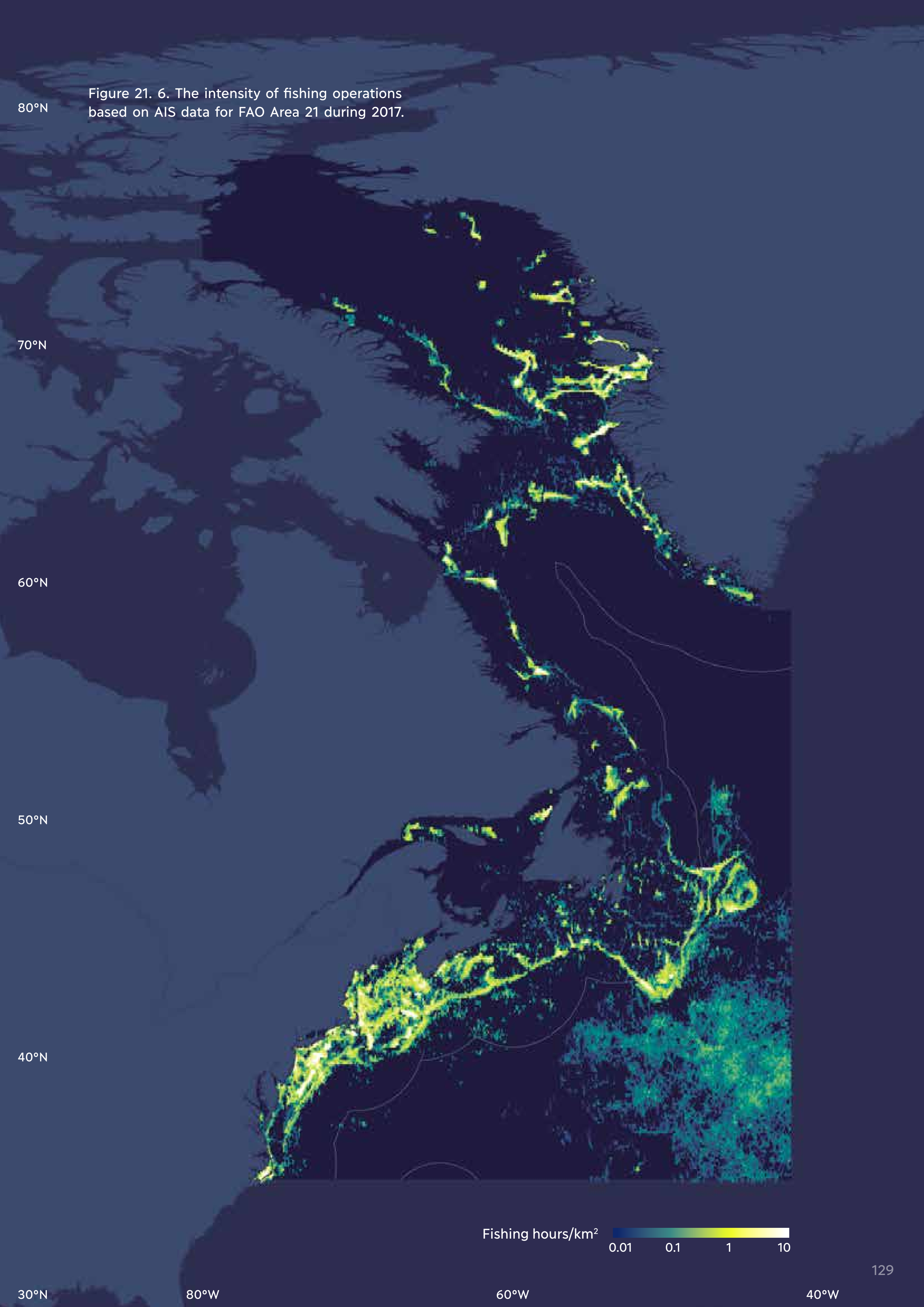


Figure 21. 5. Fishing vessel activity and quality of AIS reception for FAO Area 21 during 2017. Top row shows activity of vessels broadcasting using Class A devices (left panel) and Class B devices (right panel). The bottom row shows reception quality maps for devices Class A (left panel) and B (right panel). Blank spaces on the map (i.e. dark blue ocean background) mean that no signals from fishing vessels in this area were received, which is due to either no vessel activity or poor reception.

Figure 21. 6 shows the spatial distribution of fishing operations based on AIS across the Northwest Atlantic. The most intense fishing area is near the coast of the United States of America, followed by the edge of the continental shelf. The map shows low fishing intensity along the Canadian coastline, which may reflect the lower use of AIS by Canadian vessels operating along the coast. In the southeast part of FAO Area 21, the edge of the continental shelf extends beyond the EEZ for the Grand Banks of Newfoundland (divisions 3L, 3N and 3O) and a nearby plateau known as the Flemish Cap (division 3M), where fishing activity is also intense. Longliner fleets operate in the southeast corner of the Northwest Atlantic. Currently, the main deep-sea demersal fisheries take place on the continental slope of the Grand Banks in international waters – the so-called "nose" and "tail" of the Grand Banks – and on the Flemish Cap in depths ranging from 200 to 1 900 m. Some limited bottom fishing also occurs on seamount clusters in the high seas of the Northwest Atlantic (Bensch et al, 2009). This bottom fishing is detected by AIS and limited to alfonsino fishing by a Spanish vessel using pelagic trawl gear in the Kükenthal Peak in the Corner Rise Seamounts (NAFO, 2018). This vessel has fished on this peak an average of 12 days per year between 2014-2017 (NAFO, 2018). The most common distant fleets are European (Spanish, Portuguese and Estonian) trawlers targeting cod and redfish and Faroe Islands longliners mainly targeting Greenland halibut (NAFO, 2018). Cod is also caught as an associated species in the Portuguese and Russian trawl fisheries of redfish and in the Spanish trawl flatfish fishery. Cod is also caught in Flemish Cap (Division 3M) by Denmark (the Faroe Islands and Greenland), Norway and Russia.

Figure 21. 6. The intensity of fishing operations based on AIS data for FAO Area 21 during 2017.



FISHING VESSEL ACTIVITY AND OPERATIONS BY GEAR IN THE NORTHWEST ATLANTIC

This section reviews the spatial distribution patterns of the main fishing gears in FAO Area 21 as estimated by GFW based on 2017 AIS data. The most recent datasets available as of mid-2018 have been used to assess GFW capacity to provide an AIS based characterization of fishing activity by fishing gear in terms of presence/absence, intensity and hot spots. The Introduction chapter describes the rationale and challenges for use of contrasting data sources (e.g. Global Fisheries Landings database (GFLD; Watson, 2017)) for benchmarking AIS data classification.

When comparing fishing activity (Table 21. I) based on AIS data with the GFLD catches, it is observed that the percentage of trawlers' AIS-based fishing activity is higher than the percentage of activity based on catches by these vessels, whereas the activity of dredge and trap fishing is lower than the sum percentage for catches of dredges and traps (Table 21. I). Purse seiner activity (3 percent) detected by AIS seems to be underrepresented in relation to GFLD (17 percent), where purse seines represent the third most important fishing gear based on catches. It is also possible that the GFW fishing classification is misclassifying dredgers as trawlers, which could account for some of the under representation of dredging activity. FAO estimates that the most important catches in the last ten years are shrimps and scallops. The main gear used for fishing shrimps are trawls, and dredges are primarily used to target scallops. Dredges are not generally operated too far from the coastline as they must always be in "hard" contact with the bottom. The AIS data may be missing this gear because the fishing is conducted by vessels of medium size, which are less likely to be equipped with AIS, and/or because some vessels may have been misclassified as trawlers. Furthermore, longline activity (7 percent) seems to be overrepresented, in comparison with other gears, mainly because most of the longline activity detected by AIS is produced by distant fleets (Figure 21. 9) which usually broadcast AIS.

GEAR TYPES	Catches (GFLD) 2010–2014 average		Total fishing vessel activity (GFW-AIS) 2017	
	Tonnes of catch in 1000s	% of catch	Active days in 1000s	% of active days
Dredge fishing	513	31%	54.9	58%
Pots and traps	230	14%		
Set gillnets	79	5%		
Other	170	10%		
Trawls	379	23%	30.0	32%
Purse seines	276	17%	2.7	3%
Longlines	3	0%	7.1	7%
Total	1 650	100%	94.7	100%

Table 21. I. Summary table comparing average catch from GFLD during 2010–2014 with fishing vessel activity from GFW in FAO Area 21. Only vessels that fished for at least 24 hours in FAO Area 21 are included.

Trawler fishing activity estimated by AIS data and GFLD catches show a good agreement between both datasets. However, in the northeast part of FAO Area 21, mainly in the Division 1A along the coast of Greenland, GFLD shows high landings from trawlers, while AIS data from this area shows lower fishing activity than in southern coastal areas of Greenland. Overall it seems that the spatial distribution patterns of trawling are reasonably well represented by AIS, with uncertainty regarding trawling intensity further offshore, but within national waters. AIS should capture a higher fraction of the fishing occurring far from shore, as these vessels are larger and more likely to carry AIS. However, farther from shore, reception for Class B devices is poor once out of range of the terrestrial receivers. In the High Seas, the distribution of trawling intensity is expected to be fairly well represented since most of the activity concerns vessels equipped with AIS Class A devices which have good reception quality.

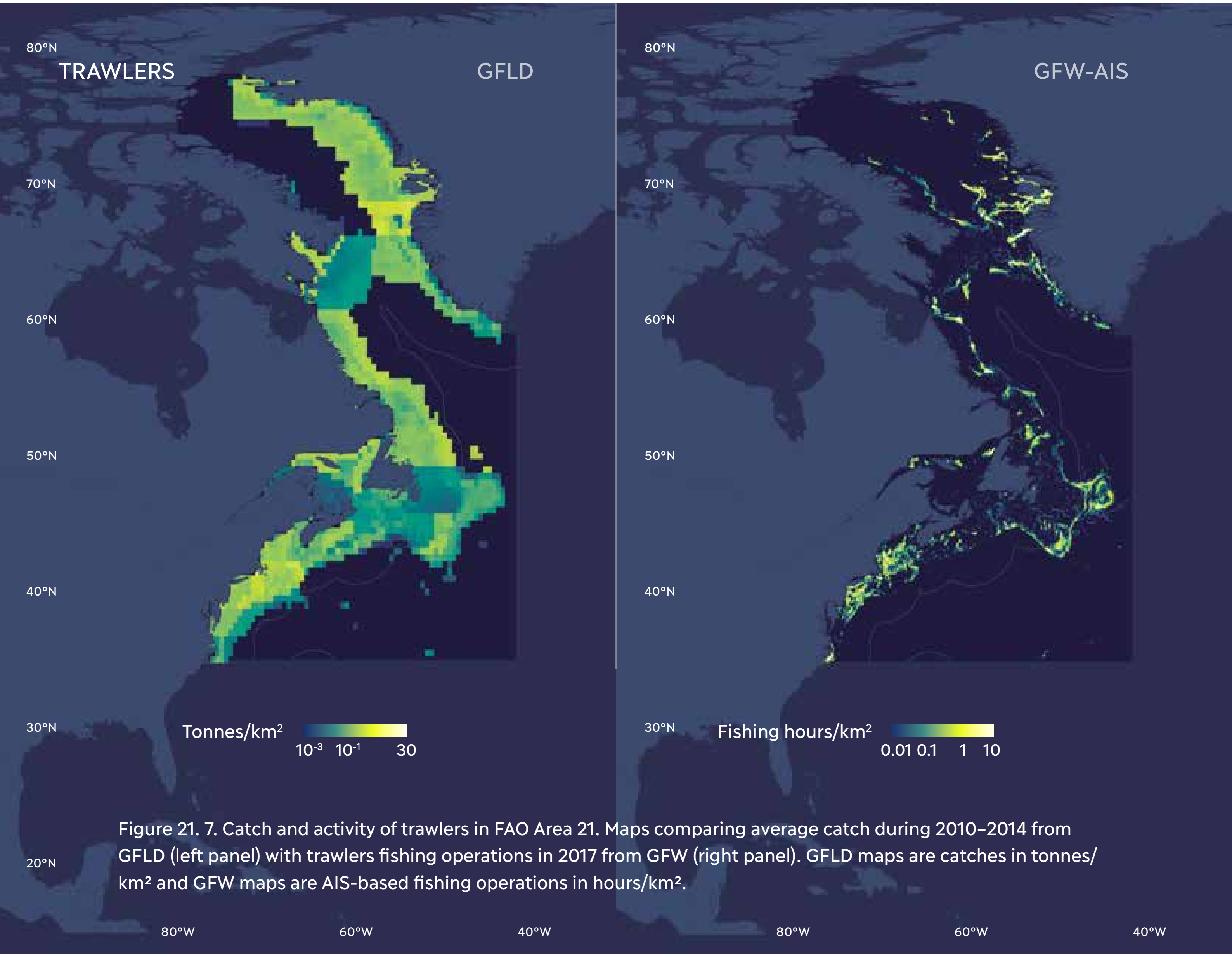


Figure 21. 7. Catch and activity of trawlers in FAO Area 21. Maps comparing average catch during 2010–2014 from GFLD (left panel) with trawlers fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

AIS fishing activity data presented for purse seiners only show some presence of activity in the south-western part of the FAO Area 21, in the United States of America coastal area and Division 3L (Figure 21. 8). Catch data for purse seiners (GFLD) showed that they seem to be present in broader areas, not only in the south-west, but also in the north-east. However, AIS data detect its sparse activity only in the south west of the area and purse seiner catches are reported in areas where AIS does not detect fishing activity.

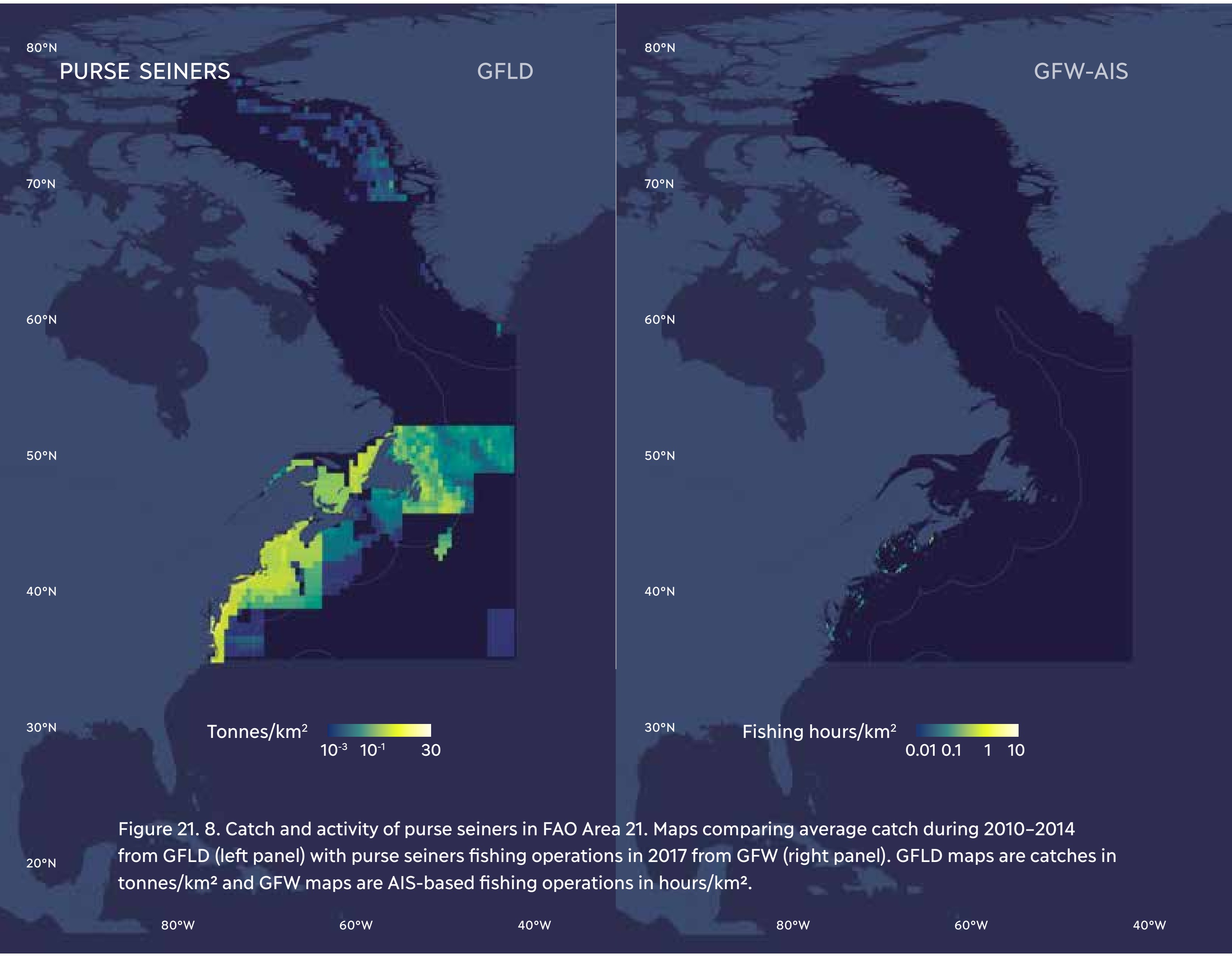


Figure 21. 8. Catch and activity of purse seiners in FAO Area 21. Maps comparing average catch during 2010–2014 from GFLD (left panel) with purse seiners fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

Figure 21.9 compares longline AIS fishing activity data and GFLD landings. In general, there seems to be good spatial agreement between AIS and GFLD information. There is a Faroe Islands longline fishery in the NAFO area which is focused on cod from the Flemish Cap and Grand Bank. Additionally, the Faroe Islands have smaller quotas for Greenland halibut and redfish in the area, so this could also be one of the significant longline fisheries. In addition, there are other fisheries not related to NAFO that use longlines targeting tuna and swordfish (monitored by ICCAT) and halibut. Overall, spatial distribution patterns of longliners as well as fishing intensity are well represented, except in the center of the southern area where GFLD shows lower catches and AIS data show almost no fishing activity, while Regional Fisheries Bodies (ICCAT) show a more evenly distributed longline activity across all the southern part of the area (Taconet *et al.*, 2018).

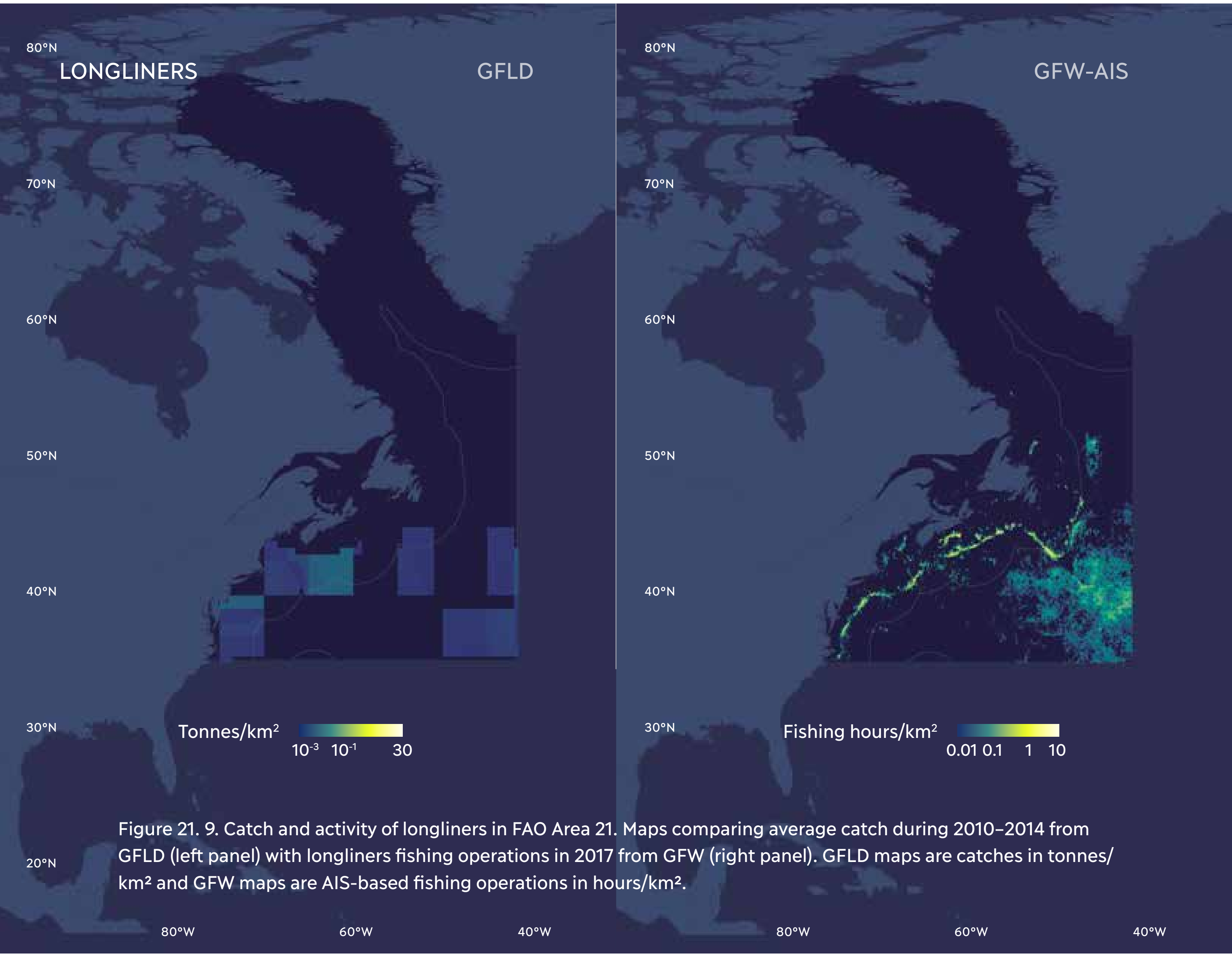


Figure 21. 9. Catch and activity of longliners in FAO Area 21. Maps comparing average catch during 2010–2014 from GFLD (left panel) with longliners fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

In Figure 21. 10 number of active vessels per day is shown. The number ranges from 50 vessels in January to around 300 vessels in July. AIS information from vessels in the Northwest Atlantic shows weekly patterns (e.g. weekend breaks) and a seasonal pattern, with fishing peaking in the warmer summer months, and reaching a low point during the winter months.

Fishing vessels in FAO Area 21

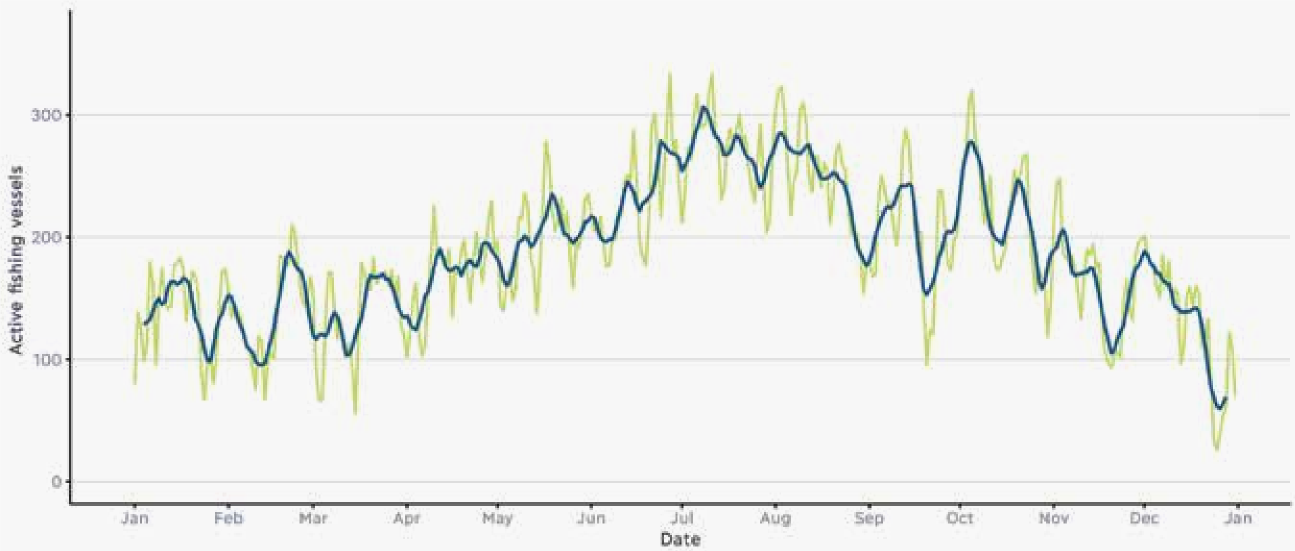


Figure 21. 10. Number of AIS-identified active fishing vessels per day in FAO Area 21 during 2017. Only vessels that fished at least 24 hours in the area over the course of the year are included. Dark blue line shows a 7-day rolling average.

ACKNOWLEDGEMENTS

The editors would like to thank Ricardo Alpoim and Ricardo Federizon for excellent comments and feedback during the elaboration of the chapter. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Required citation for this chapter:

Iriondo, A., Santiago, J., Granado, I., Kroodsma, D., Taconet, M., Fernandes, J. A. 2019. FAO Area 21 – AIS-based fishing activity in the Northwest Atlantic. *In* Taconet, M., Kroodsma, D., Fernandes, J.A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

Bensch, A., Gianni, M., Gréboval, D., Sanders, J.S., Hjort, A. 2009. *Worldwide review of bottom fisheries in the high seas.* FAO Fisheries and Aquaculture Technical Paper. No. 522, Rev.1. Rome, FAO. http://www.fao.org/tempref/docrep/fao/012/i1116e/i1116e01.pdf

FAO. 2011. *Food and Agriculture Organization of the United Nations. Review of The State of World Marine Fishery Resources.* FAO Fisheries and Aquaculture Technical Paper. No. 569. Rome, FAO. http://www.fao.org/3/i2389e/i2389e.pdf

FAO. 2019. *Food and Agriculture Organization of the United Nations. FAO Major Fishing Areas. Northwest Atlantic (Major Fishing Area 21).* http://www.fao.org/fishery/area/Area21/en

FishStatJ. 2018. Fisheries and aquaculture software. FishStatJ - software for fishery statistical time series. *In* FAO Fisheries and Aquaculture Department [online]. Rome. Updated 21 July 2018. [Cited 19 November 2018]. http://www.fao.org/fishery/statistics/software/fishstatj/en

Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F.,... & Woods, P. 2018. Tracking the global footprint of fisheries. *Science*, 359(6378), 904-908. https://doi.org/10.1126/science.aao5646

NAFO. 2018. *Northwest Atlantic Fisheries Organization. Report of the Scientific Council, 01-14 June 2018, Halifax, Canada.* NAFO SCS Doc. 18/19. https://www.nafo.int/Portals/0/PDFs/sc/2018/scs18-19.pdf

Taconet, P., Chassot, E., Barde, J. 2018. *Global monthly catch of tuna, tuna-like and shark species (1950-2015) aggregated by 1° or 5° squares (IRD level 2) (Version 1) [Data set]. Zenodo.* http://doi.org/10.5281/zenodo.1164128

Townsend, D. W., Thomas, A. C., Mayer, L. M., Thomas, M. A., Quinlan, J. A. 2006. Oceanography of the northwest Atlantic continental shelf (1, W). Chapter 5 *In* Robinson, A.R. and K.H. Brink (eds). 2004. *The Sea: The Global Coastal Ocean: Interdisciplinary Regional Studies and Syntheses.* Harvard University Press. ISBN 9780674021174.

Waller, R., Watling, L., Auster, P., Shank, T. 2007. Anthropogenic impacts on the Corner Rise seamounts, north-west Atlantic Ocean. *Journal of the Marine Biological Association of the United Kingdom*, 87(5), 1075-1076. https://doi.org/10.1017/S0025315407057785

Watson, R. A. 2017. A database of global marine commercial, small-scale, illegal and unreported fisheries catch 1950–2014. *Scientific data*, 4, 170039. https://doi.org/10.1038/sdata.2017.39

FAO AREA 27

AIS-based fishing activity in the Northeast Atlantic

Figure 27. 1. Location of FAO Area 27.

Maurizio Gibin, Steven Holmes, Antonella Zanzi, Igor Granado, David Kroodsma, Nathan A. Miller and Jose A. Fernandes

PREAMBLE

This chapter assesses, through a comparison with fleet statistics and public fisheries data, the capacity of Automatic Identification System (AIS) data and Global Fishing Watch (GFW) algorithms (Kroodsma *et al.*, 2018) to identify and quantify fishing vessel activity in the Northeast Atlantic. This assessment reviews fleet activity, main gear types and spatial distribution of fishing vessel activity and fishing operations.

SUMMARY AND CONCLUSIONS FOR THE NORTHEAST ATLANTIC

Most vessels over 15 m length in FAO Area 27 broadcast AIS mainly using Class A devices. Class A device reception is good along the coastline where a large network of terrestrial receivers enhances satellite coverage. However, several offshore regions beyond the coverage of terrestrial receivers have poorer reception. These areas are in the North Sea, the Bay of Biscay, and areas east of Ireland and the United Kingdom. Vessels with AIS Class B devices generally limit their operations to coastal areas and are well covered by terrestrial receivers. AIS and European Union effort data show similar spatial patterns and intensity of fishing activity on a broad scale. However, in detail observation can highlight substantial differences in patterns and intensities mainly due to an uneven spatiotemporal coverage and inadequate gear information in the AIS dataset. For example, AIS-based activity classification by GFW does not distinguish some of the main gears in the region such as dredge fishing and misclassifies some activity of purse seiners. This misclassification is likely due to lack of consideration of multi-gear activities by vessels in GFW's AIS.

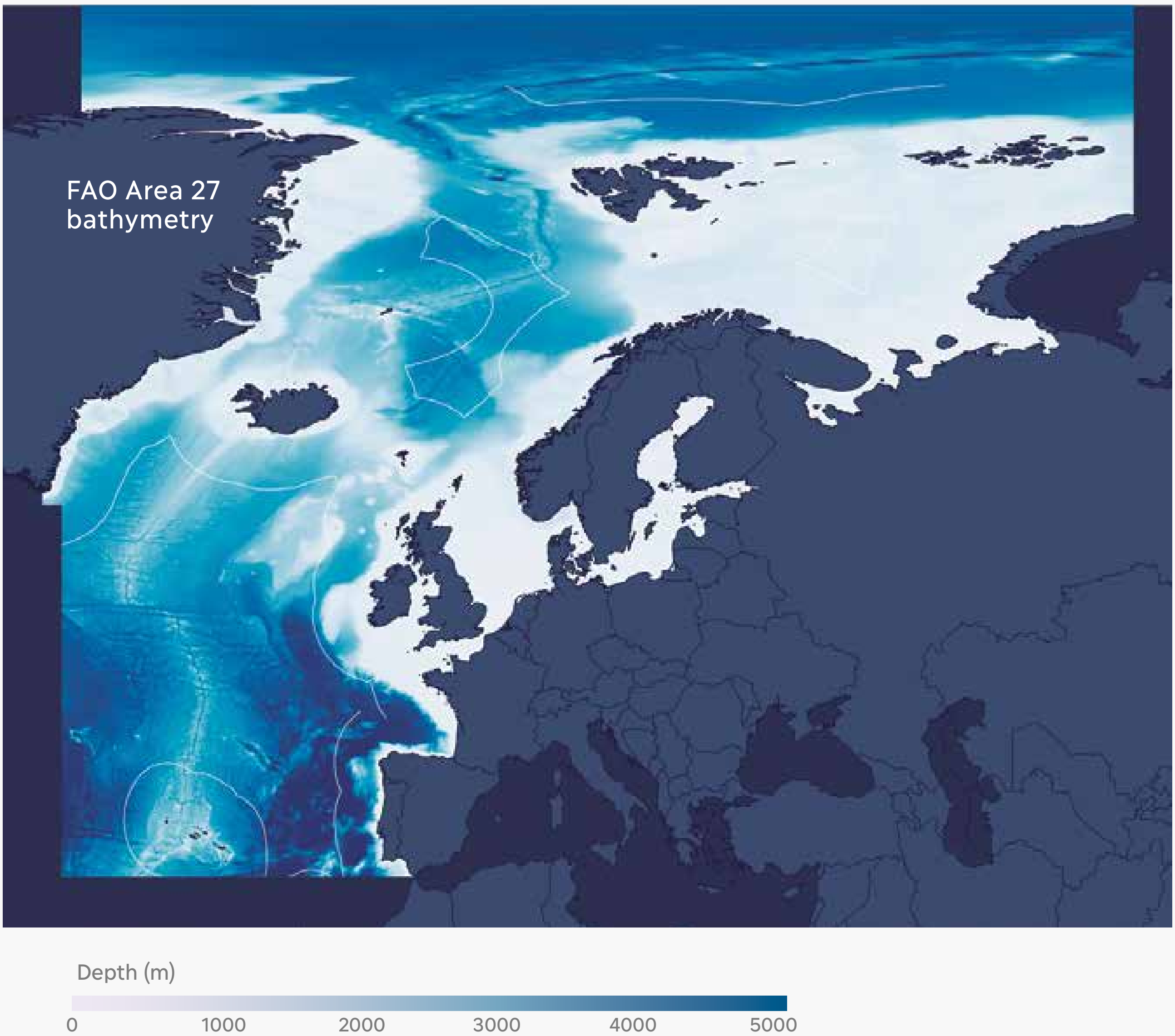


Figure 27. 2. FAO Area 27 bathymetry (depth) and 200 miles coastal arc.

INTRODUCTION TO THE NORTHEAST ATLANTIC

The Northeast Atlantic area (FAO Area 27; FAO, 2019) compromises all waters of the Atlantic and Arctic Oceans and their dependent seas bounded by the meridian of 40° W longitude in the west crossing Greenland and 68° 30' E longitude in the east. In the south it is bounded by 36° N latitude to the south of Azores, Portugal and Spain (Figure 27. 1). The following coastal countries/territories border FAO Area 27: Åland Islands, Belgium, Channel Islands, Denmark, Estonia, Faroe Islands, Finland, France, Germany, Greenland, Guernsey, Iceland, Ireland, Isle of Man, Jersey, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Russian Federation, Spain, Svalbard and Jan Mayen Islands, Sweden and UK (Figure 27. 2). In this region, about 62 percent of the marine waters are under national jurisdiction, with the complementary 38 percent being high seas, mostly in the western and northern parts. This proportion of high seas in FAO Area 27 is lower than the global average of FAO areas (54 percent), where minimum and maximum values range between 20 percent and 80 percent. Average sea temperatures range from 24 °C in Azores in the south to below freezing in the north at Spitzbergen and north Greenland (Peck and Pinnegar, 2018). In the Northwest Atlantic, the cold Labrador Current meets the warm Gulf Stream off the Grand Banks southeast of Newfoundland, influencing the entire FAO Area 27 (Peck and Pinnegar, 2018). FAO Area 27 is characterized by wide continental shelves mostly within national jurisdictions. Landing statistics from the International Council for the Exploration of the Sea (ICES) show that catches are dominated by small pelagic and demersal fish species (ICES, 2018). The largest catches were made of Atlantic herring, Atlantic cod, Atlantic mackerel, capelin, blue whiting, European sprat, haddock, saithe, sand lances, Atlantic horse mackerel, European pilchard and European plaice. These 12 species made up 80 percent of the reported catch in the period 2010–2014.

REGION FLEETS AND AIS USE IN THE NORTHEAST ATLANTIC

Vessels over 24 m make up 7.1 percent (Figure 27. 3), which is far above the global average of less than 1 percent. Vessels under 12 m represent 80.7 percent of the fleets which are less likely to use AIS. Iceland and Norway are the two countries with the highest fraction of vessels under 12 m using AIS. Out of roughly 2 500 fishing vessels in the world with AIS under 12 m, 60 percent or 1 500, belong to Norway and Iceland. Therefore, coastal AIS fishing in this region is probably the best represented in the world. For the European Union fleets, all fishing vessels over 15 m are equipped with AIS devices in accordance with the International Convention for the Safety of Life at Sea (SOLAS) 1974 (Chapter V, Regulation 19, section 2.4.5).

Fleets of coastal countries/territories in FAO Area 27

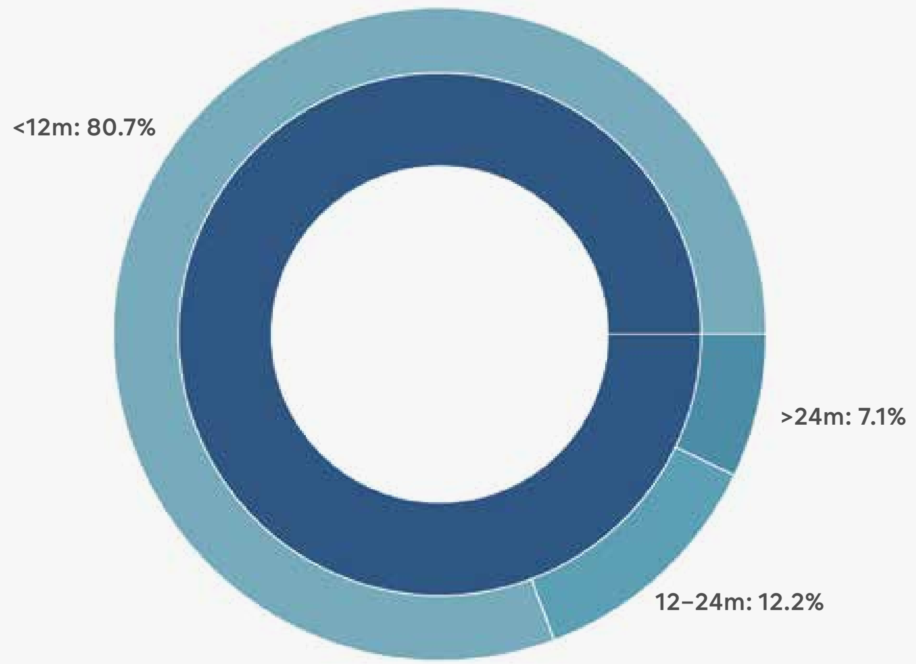


Figure 27. 3. Structural composition of fleets of coastal countries/territories in FAO Area 27. In dark blue motorized fishing vessels. Non-motorized vessels are not reported to FAO. Distant water fleets active in FAO Area 27 are not included (see next figure). Notice that France, Greenland, Russian Federation, Spain and Portugal are coastal states adjacent to more than one FAO area, yet their entire fleet size is included here. Sources: FAO statistics for year 2017. Statistics were not available for the following countries/territories within FAO Area 27: Åland Islands, Channel Islands, Faroe Islands, Isle of Man, Jersey and Svalbard and Jan Mayen.

This region also has rich data from official vessel registries. Almost 80 percent of the 8 351 fishing vessels with AIS were matched to registries, of which 44 percent had their gear type identified by these registries. A significant number of vessels used gears which were, for this Atlas, categorized as "other or unknown" (such as pots and traps, set gillnets, set longlines and others). This reflects the difficulty in verifying gear types other than purse seiners, drifting longliners and trawlers. Notice that many Spanish and Portuguese registered vessels operate in high seas of other FAO areas as distant fleets. This partially explains some of the mismatches between detection of active fleets based in AIS and European Union fleet registers (Figure 27. 4).

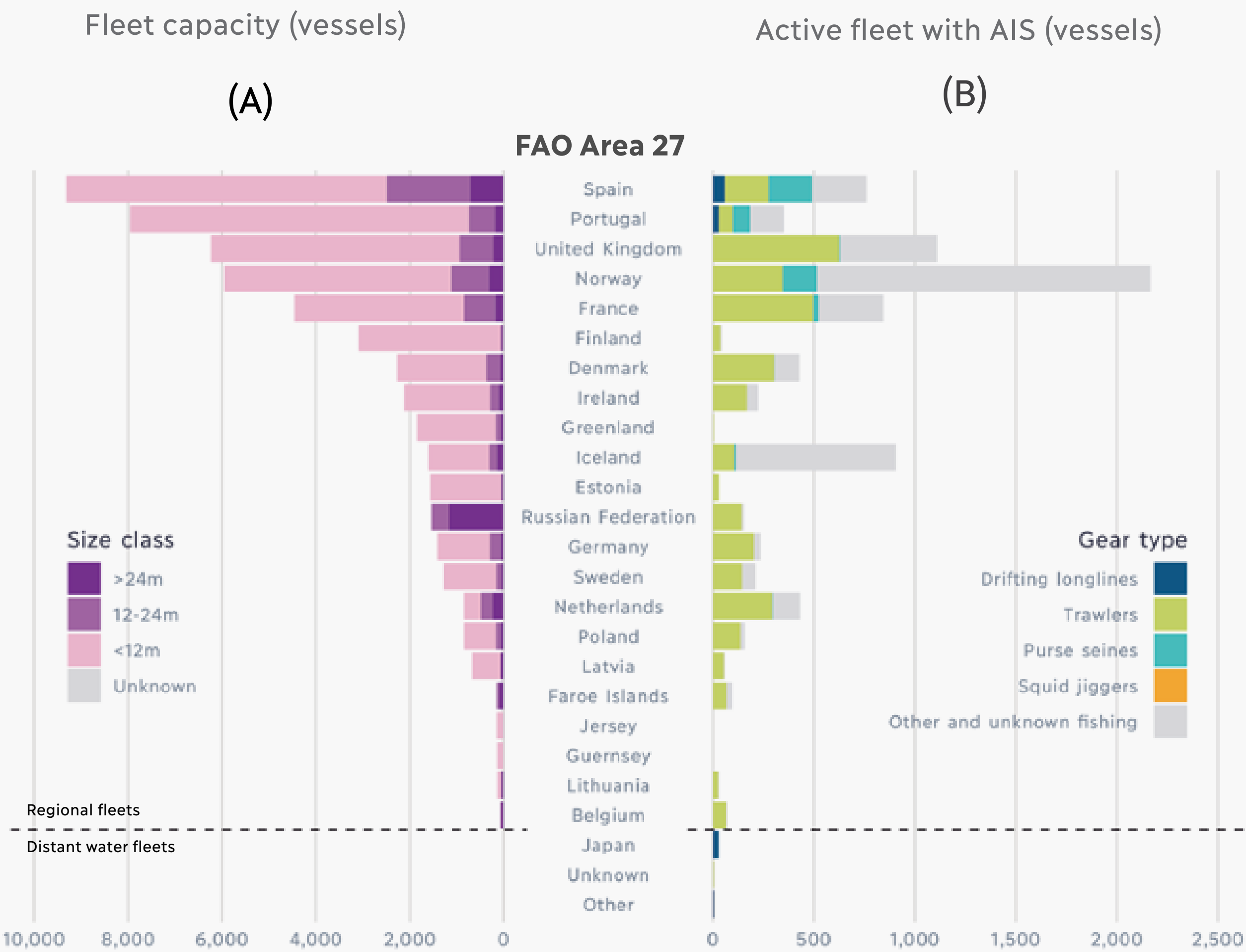


Figure 27. 4. Summary of coastal and distant fleets based on FAO statistics and AIS data classification by GFW in FAO Area 27 during year 2017. A) Number of motorized vessels as reported to FAO. Notice that France, Greenland, Russian Federation, Spain, Portugal are coastal states adjacent to more than one FAO area, yet their entire fleet size is included here. Source: FAO statistics for year 2017. Statistics were not available for the following countries/territories within FAO Area 27: Åland Islands, Channel Islands, Faroe Islands, Isle of Man, Jersey and Svalbard and Jan Mayen. B) AIS-identified number of fishing vessels broadcasting AIS during their operations in FAO Area 27 by gear type and flag state. Dashed lines separate regional fleets (top) from distant fleets (bottom). Only vessels that fished for at least 24 hours in the area are included. Source: GFW.

AIS RECEPTION AND FISHING VESSEL ACTIVITY IN THE NORTHEAST ATLANTIC

Figure 27. 5a,b panels show the activity of fishing vessels in the FAO Area 27 broadcasting Class A and Class B messages. About two thirds of the fishing vessels in the region use higher quality Class A AIS devices. For the vessels that use Class B devices, the average vessel length was 12 m, and stayed mostly close to shore, as shown in Figure 27. 5b. These vessels only accounted for about 10 percent of the fishing hours in the region.

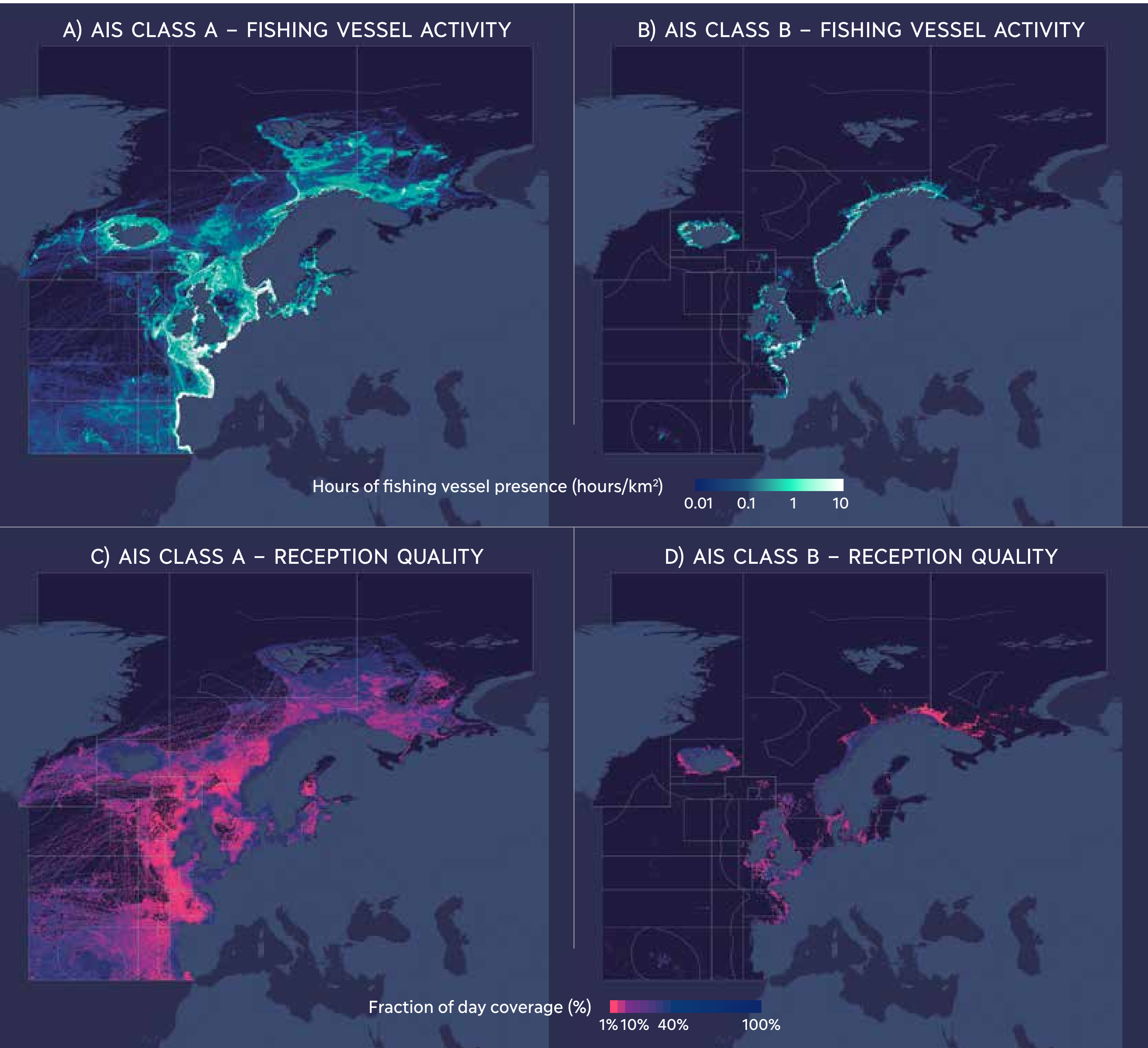


Figure 27. 5. Fishing vessel activity and quality of AIS reception for FAO Area 27 during 2017. Top row shows activity of vessels broadcasting Class A devices (left panel) and Class B devices (right panel). The bottom row shows reception maps for devices Class A (left panel) and B (right panel). Blank spaces on the map (i.e. dark blue ocean background) mean that no signals from fishing vessels in that region were received, which is due to either no vessel activity or poor reception.

A network of terrestrial receivers provides good reception along much of the European coastline (Figure 27. 5c,d), although there are some pockets along the coast where reception is worse (see Bay of Biscay comparison). As a result, vessels with Class B AIS devices, most operating near shore, are relatively well monitored with AIS. Offshore, out of the range of terrestrial receivers, there is poor reception in the North Sea, parts of the Bay of Biscay, east of Ireland and the United Kingdom. These poor reception areas have a high impact with nearly total absence of AIS-based fishing vessel activity (see the bright areas on the AIS fishing activity map in Figure 27. 5 corresponding to poor Class A coverage areas). Furthermore, analyses by Shepperson *et al.* (2018) showed that even in areas covered by terrestrial stations, gaps exist in the AIS data, as some vessels do not always turn on their AIS or may have the voltage reduced, which limits the AIS detection range.

The spatial distribution of fishing operations shows the importance of the continental shelf limits, except for total absence of fishing near northeastern of Greenland's continental shelf. Northern limits of activity are likely linked with the extent of ice coverage notably in winter (see Figure 18. 3). Low activity is shown along the coastal areas of Russia. In the high seas, activity is only observed south of Iceland (demersal fishing on seamounts and ridges) and west of Portugal (pelagic).

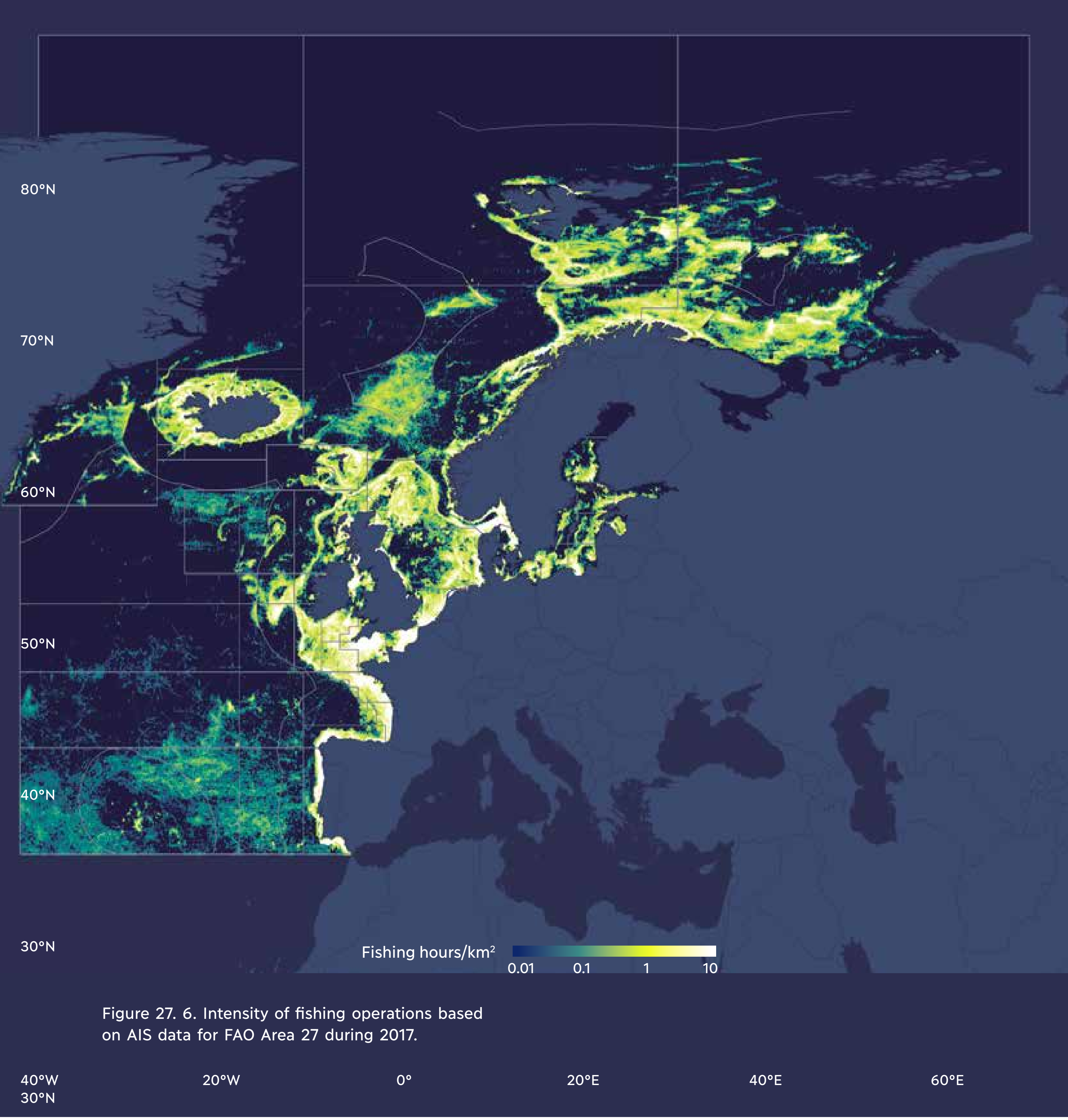


Figure 27. 6. Intensity of fishing operations based on AIS data for FAO Area 27 during 2017.

FISHING ACTIVITY COMPARISON WITH FISHERIES DEPENDENT INFORMATION (FDI) DATABASE

The official source of fishing vessels positions in this FAO area is VMS data, while logbooks provide additional information on fishing behavior and catches. VMS and logbook data are collected at national level and access to its raw data is limited to a few research institutes. For this reason, most of the comparison exercises published in literature cover limited areas (Shepperson *et al.*, 2018). The ICES Working Group on Spatial Fisheries Data (WGSFD) worked on a comparison of fishing activity calculated from AIS data, VMS and logbook data in 2016. VMS and logbook data were collected through an ICES data call and aggregated on a regular grid of 0.05 degrees. The comparison exercise extended to the OSPAR Commission area between October 2014 and September 2015. Exploratory data analysis showed that AIS data can improve VMS temporal resolution data and vessel track identification. However, AIS fishing activity data tended to underestimate total fishing activity in the comparison. When activity was disaggregated at gear level from the fleet register, AIS data tended to overestimate the share of bottom otter trawlers (OTB) as this is the main gear operated by multi-gear vessels (ICES, 2016).

In this section, GFW estimation of fishing hours during 2017 (Table 27. I) was compared to the most recent activity data available (2016 data) from the Fisheries Dependent Information (FDI) database held by the European Union Joint Research Centre. Comparison with FDI 2017 data was not possible as it was not yet available. This time delay in FDI data processing highlights AIS potential to provide a fast first estimate when official data based on VMS and logbooks is not yet available. In the AIS-GFW dataset however, gear information is obtained through registries and partly by observing the fishing vessels' track and characteristics.

While the AIS-GFW dataset is divided into 5 gear categories, the FDI data are collected for 11 gear types and specific analyses are in place to distinguish fishing activity for each category. As FDI dataset gear information is more detailed than the AIS-GFW, FDI gears were aggregated to match the fishing gear categories differentiated by AIS-GFW (Table 27. I). All gears matched directly or through aggregations, except for demersal seiners and set longliners. Demersal seiners were assigned to the trawler category rather than to purse seiners due to its bottom species targeting. In the rest of FAO area chapters, set longliners have been included in "other fishing" due to challenges in correctly identifying these vessels. However, in this chapter's comparison, set longliners and drifting longliners were combined into one category to compare them directly with the FDI category of longliners, which is a combination of these two gears. Unfortunately, AIS-GFW is unable to distinguish dredge gear which is also an important gear in Europe. The FDI data were collected under the European Union data collection framework and included activity (hours fished) by ICES statistical rectangle (0.5-degree latitude by 1.0-degree longitude). The FDI data were filtered to vessels over 15 m and GFW data filtered to countries supplying data to the FDI database and vessels over 15 m (Belgium, Denmark, Estonia, Finland, France, Germany, Ireland, Latvia, Lithuania, Netherlands, Poland, Portugal, Spain, Sweden and UK).

FDI	AIS-GFW	FDI - AIS
Otter	Trawlers	Trawlers
Longliner	Drifting_longliners and set_longliners	Longliners
Pelagic seine	Purse_seiners	Purse_seiners
Pelagic trawl	Trawlers	Trawlers
Demersal seine	Trawlers	Trawlers
Beam	Trawlers	Trawlers
None	Unknown_fishing	Other_and_unknown_fishing
Gill nets	Other_fishing (except set longliners)	Other_and_unknown_fishing
Trammel	Fixed_gear	Other_and_unknown_fishing
Pots	Fixed_gear	Other_and_unknown_fishing
Dredge	Other_fishing (except set longliners)	Other_and_unknown_fishing

Table 27. I. FDI gears allocation to match the AIS-GFW fishing gears and the final gear coding (right column) used in the comparison

Table 27. II compares the hours of fishing operations, or "fishing hours", between GFW and FDI. Overall, the GFW dataset recorded only 62 percent as many trawler fishing hours as the FDI data. This discrepancy could be because GFW were missing vessels (e.g. vessels operating in poor reception areas, misclassified activity), or FDI data were including activity, such as searching, that was absent in the AIS data. It is likely a combination of all the factors, as not all vessels have AIS, there are a few regions of poor reception, GFW algorithms are not perfect, and European Union Member States might overestimate the total number of hours fished (STECF, 2017).

Fishing hours AIS-GFW (2017)		Ratio AIS-GFW/FDI	Fishing hours FDI (2016 data)	
Trawlers	4 239 423	62%	Beam, otter, dem-seine, pel-trawl	6 791 905
Other and unknown	952 124	52%	Dredge, gill, trammel, pots, none (unknown)	1 829 315
Longliners and unknown fishing	473 841	68%	Longline	701 054
Purse seiners	116 858	117%	Pel-seine	99 974
Total	**6 449 397**	**62%**	Total	**9 422 248**

Table 27. II. Summary comparing fishing operations (expressed in fishing hours) by GFW gear categories during 2017 and equivalent gear type aggregations from the European Union Fisheries Dependent Information (FDI) database during 2016. GFW data limited to those countries supplying data to the FDI database.

All fishing activity categories were underestimated in the GFW data except for purse seiners, where the AIS data reported almost 20 percent more activity than FDI. This overestimation may be driven by the fact that GFW classifications do not account well for multi-gear vessels, and some of the GFW purse seiner activity is probably from other fishing gears. Given that the "other and unknown" fishing category is the most underestimated by AIS data, it is likely that some of the purse seining should really be in this category.

Comparing the overall fishing operation hour maps, GFW and FDI largely agree on the spatial extent of the fishing distribution (Figure 27. 7), but fishing intensity is lower in the GFW dataset. Activity is noticeably missing in the GFW data in the Bay of Biscay and the North Sea, both areas with poor satellite AIS reception.

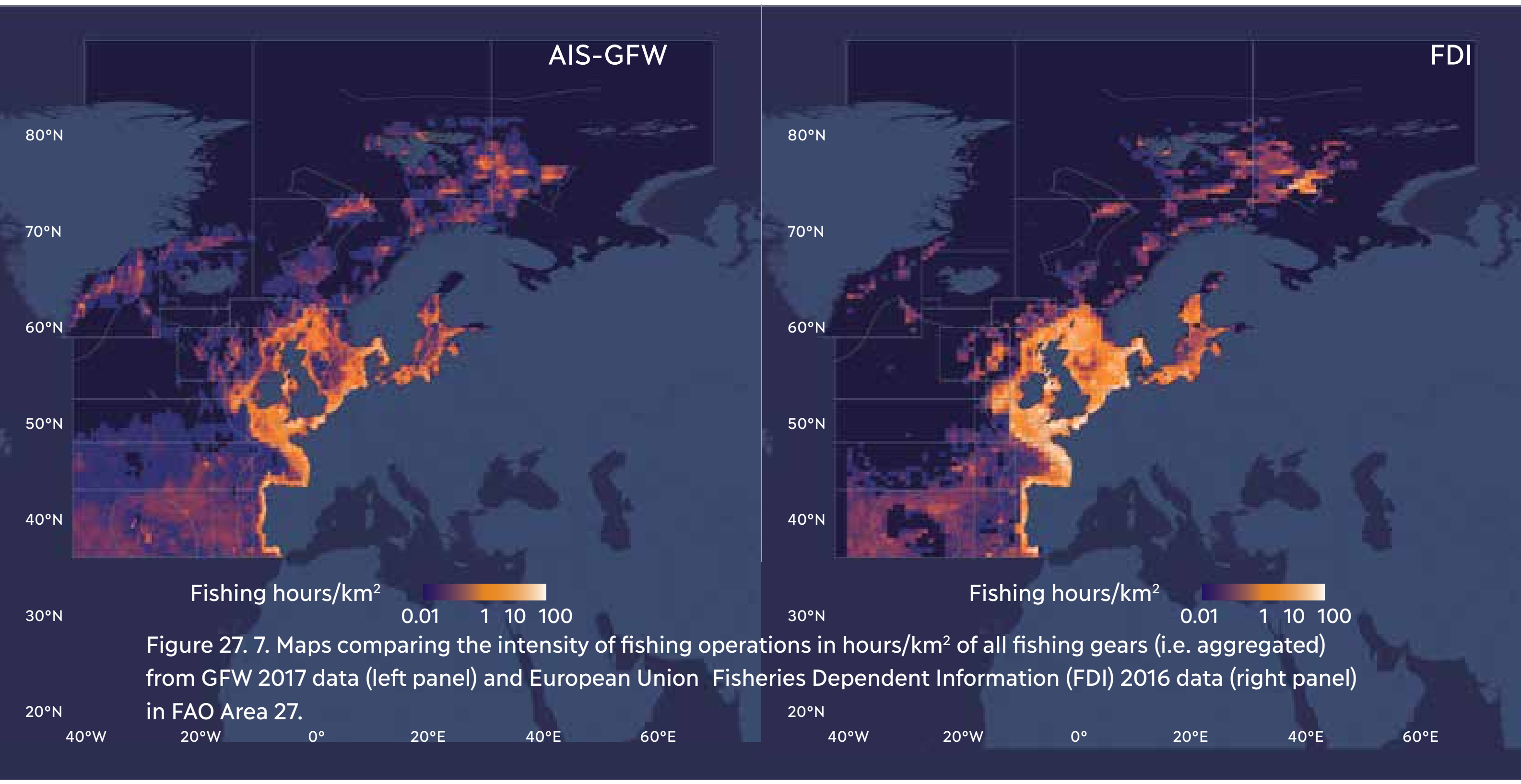


Figure 27. 7. Maps comparing the intensity of fishing operations in hours/km² of all fishing gears (i.e. aggregated) from GFW 2017 data (left panel) and European Union Fisheries Dependent Information (FDI) 2016 data (right panel) in FAO Area 27.

Overall, there is good consistency in the broad spatial pattern of relative trawler fishing hour intensities between the GFW and FDI data (Figure 27. 8). However, some higher intensity areas are underestimated in the AIS data, especially in poor AIS reception zones such as the North Sea.

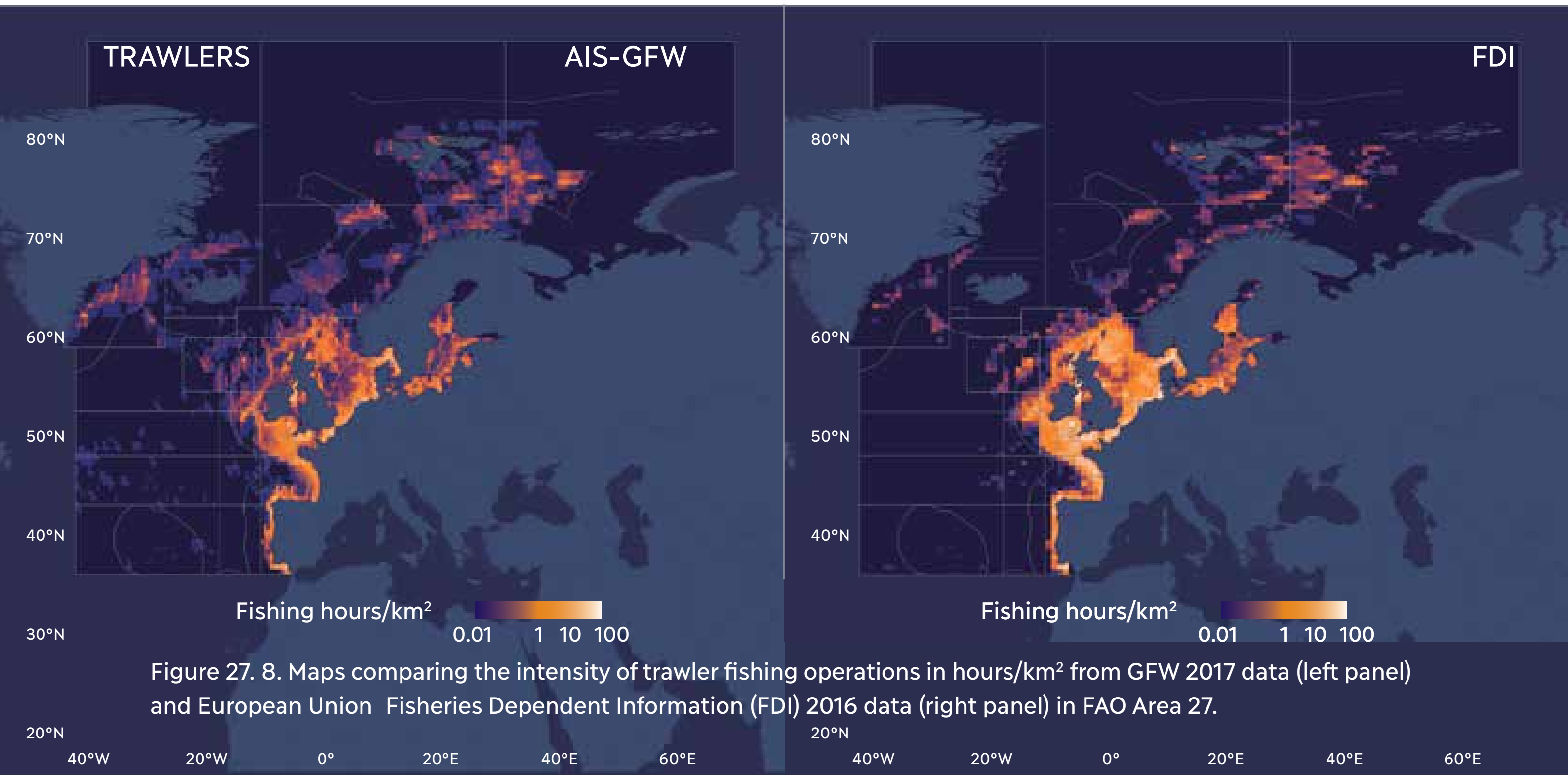


Figure 27. 8. Maps comparing the intensity of trawler fishing operations in hours/km² from GFW 2017 data (left panel) and European Union Fisheries Dependent Information (FDI) 2016 data (right panel) in FAO Area 27.

In general, the pattern of fishing hours between GFW and FDI data sets are similar (Figure 27. 9). Note that for this chapter, unlike for the rest of the Atlas, set longliners are not included in this category but are instead grouped with drifting longliners. The GFW data appear to be missing effort in the high seas pocket north of Russia, while spotting activity within Azores territorial waters which is absent in the FDI data. The fishing effort in the high seas pocket north of Russia does not appear in the map of all fishing activity, suggesting that these vessels are operating without AIS.

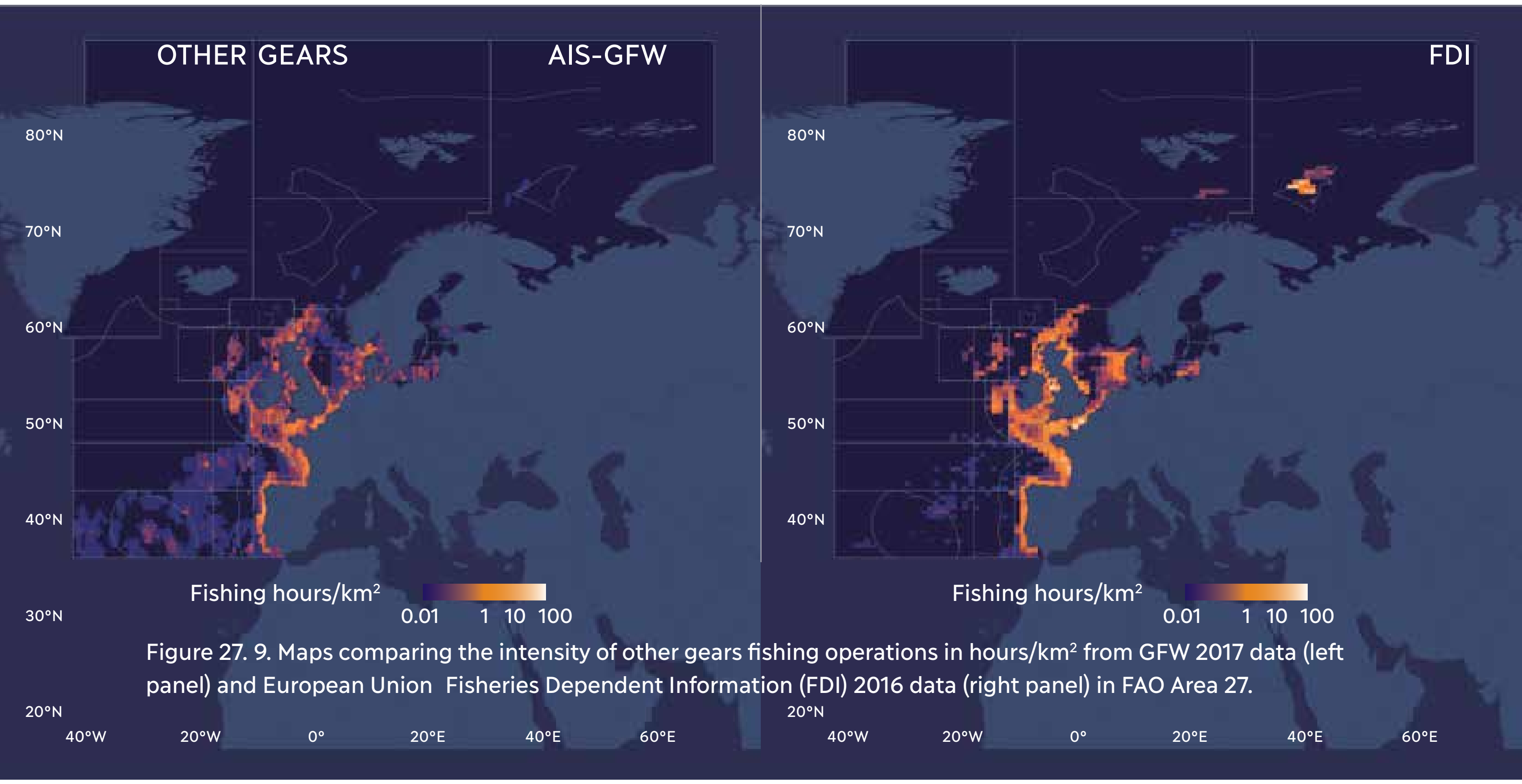


Figure 27. 9. Maps comparing the intensity of other gears fishing operations in hours/km² from GFW 2017 data (left panel) and European Union Fisheries Dependent Information (FDI) 2016 data (right panel) in FAO Area 27.

Demersal seiner activity was classified as part of trawler activity in the GFW data and thus excluded from these maps. This was supported by demersal seiner activity in the North Sea identified in the FDI data being absent in the GFW data classified as purse seiners. Because many purse seiners operate as multi gear vessels, GFW sometimes misclassifies vessels in this region. A few misclassified vessels were identified (and corrected) in the production of this Atlas (see the chapter on the Bay of Biscay). However, as the GFW predicts much more total purse seiner activity than the FDI dataset, it is likely that more vessels are misclassified in the GFW data (Figure 27. 10). While the two datasets agree on the presence of purse seining along the coasts of France, Spain, and Portugal, the GFW data are missing all pelagic purse seiner activity in the North Sea.

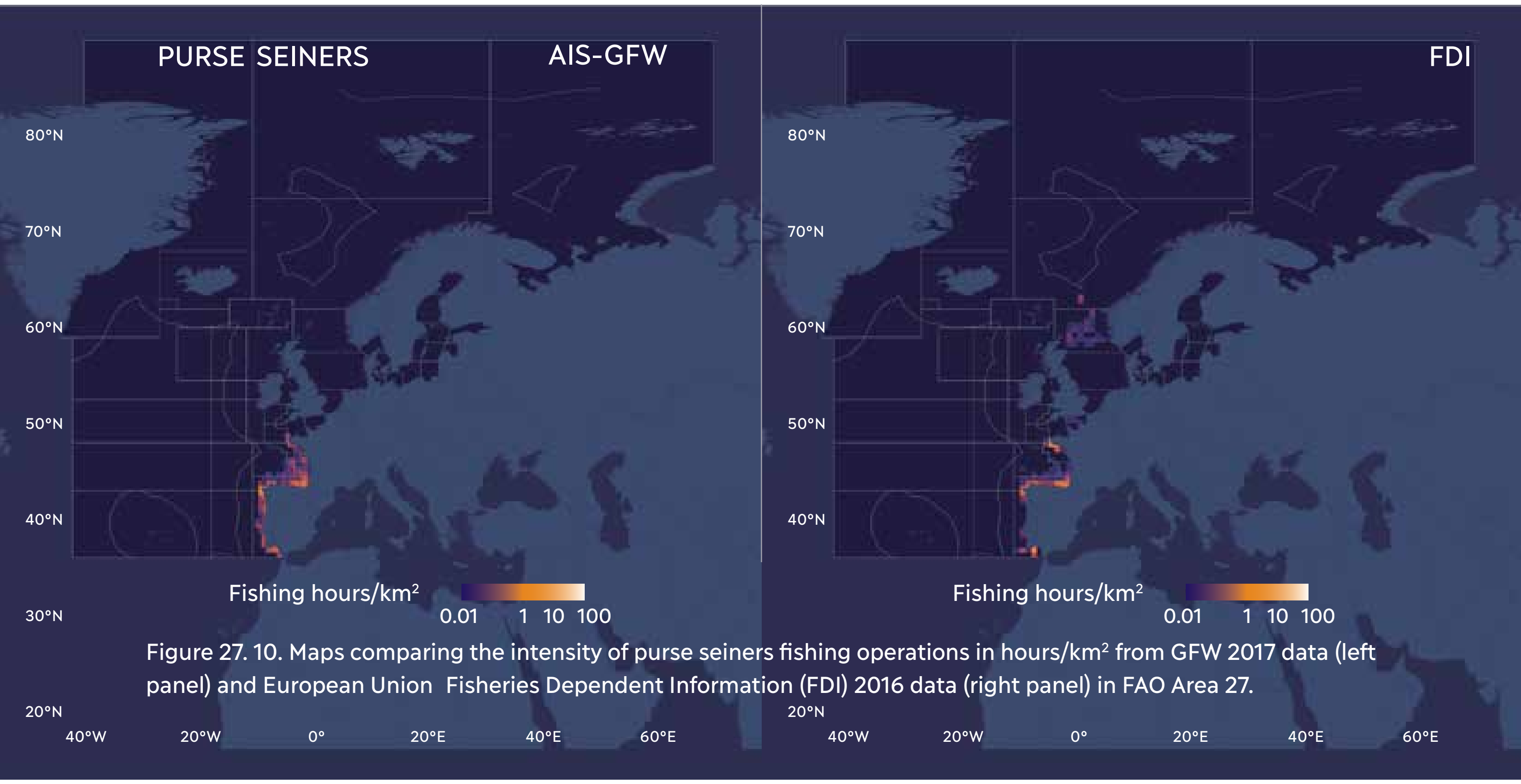


Figure 27. 10. Maps comparing the intensity of purse seiners fishing operations in hours/km² from GFW 2017 data (left panel) and European Union Fisheries Dependent Information (FDI) 2016 data (right panel) in FAO Area 27.

AIS-GFW and FDI show a broad agreement in the footprint of drifting and set longliners in in FAO Area 27, although the GFW shows lower intensity of fishing in almost every region (Figure 27. 11). Set longliners target various demersal fish species (Sistiaga *et al.*, 2018), especially European hake and other gadoids, which are more abundant on the continental shelf. Interestingly, the GFW shows some set longliner activity along the Greenland coast, also between Norway and Denmark, and some drifting longliner activity to the north of the Azores. These are all absent in the FDI data and likely due to misclassification of these vessels' operations as determined in the Bay of Biscay comparison chapter.

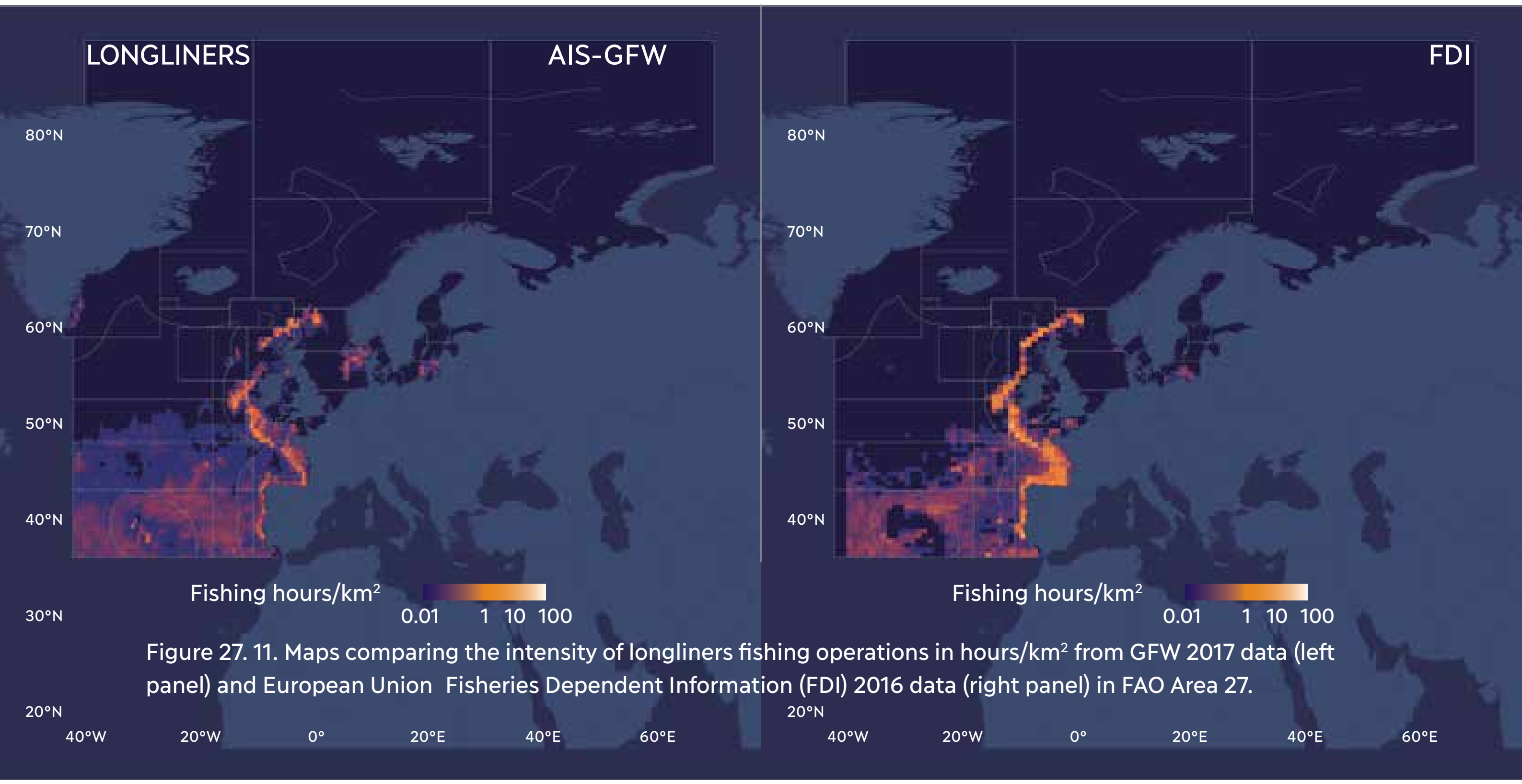


Figure 27. 11. Maps comparing the intensity of longliners fishing operations in hours/km² from GFW 2017 data (left panel) and European Union Fisheries Dependent Information (FDI) 2016 data (right panel) in FAO Area 27.

ACKNOWLEDGEMENTS

The editors would like to thank Hintzen Niels and Josefine Egekvist for excellent comments and feedback during the elaboration of the chapter. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Required citation for this chapter:

Gibin, M., Holmes, S., Zanzi, A., Granado, I., Kroodsma, D., Miller, N. A., Fernandes, J. A. 2019. FAO Area 27 - AIS-based fishing activity in the Northeast Atlantic. *In* Taconet, M., Kroodsma, D., Fernandes, J.A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

FAO. 2019. *Food and Agriculture Organization of the United Nations. FAO Major Fishing Areas. Northeast Atlantic (Major Fishing Area 27).* http://www.fao.org/fishery/area/Area27/en

ICES. 2016. Interim Report of the Working Group on Spatial Fisheries Data (WGSFD), 17–20 May 2016, Brest, France. *ICES CM* 2016/SSGEPI:18. 244 pp. http://ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/SSGEPI/2016/01%20WGSFD%20-%20Report%20of%20the%20Working%20Group%20on%20Spatial%20Fisheries%20Data.pdf

ICES. 2018. *Official Nominal Catches 2006-2016. Version 07-08-2018.* Accessed 26-04-2019 via http://ices.dk/marine-data/dataset-collections/Pages/Fish-catch-and-stock-assessment.aspx

Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F.,... & Woods, P. 2018. Tracking the global footprint of fisheries. *Science*, 359(6378), 904-908. https://doi.org/10.1126/science.aao5646

Peck, M., Pinnegar, J. K. 2018. Chapter 5: Climate change impacts, vulnerabilities and adaptations: North Atlantic and Atlantic Arctic marine fisheries. *In* Barange, M., Bahri, T., Beveridge, M., Cochrane, K., Funge-Smith, S., Poulain, F. (Eds.). 2018. *Impacts of Climate Change on fisheries and aquaculture: Synthesis of current knowledge, adaptation and mitigation options.* FAO Fisheries Technical Paper 627. Rome, FAO. http://www.fao.org/3/i9705en/i9705en.pdf

Shepperson, J. L., Hintzen, N. T., Szostek, C. L., Bell, E., Murray, L. G., & Kaiser, M. J. 2017. A comparison of VMS and AIS data: The effect of data coverage and vessel position recording frequency on estimates of fishing footprints. *ICES Journal of Marine Science*, 75(3), 988-998. https://doi.org/10.1093/icesjms/fsx230

Sistiaga, M., Herrmann, B., Rindahl, L., & Tatone, I. 2018. Effect of Bait Type and Bait Size on Catch Efficiency in the European Hake Merluccius merluccius Longline Fishery. *Marine and Coastal Fisheries*, 10(1), 12-23. https://doi.org/10.1002/mcf2.10007

STECF. 2017. *Scientific, Technical and Economic Committee for Fisheries. Fisheries Dependent Information - Classic (STECF-17-09) - Study.* Publications Office of the European Union, Luxembourg 2017, ISBN 978-92-79-67481-5. https://doi.org/10.2760/561459

FAO AREA 31

AIS-based fishing activity in the Western Central Atlantic

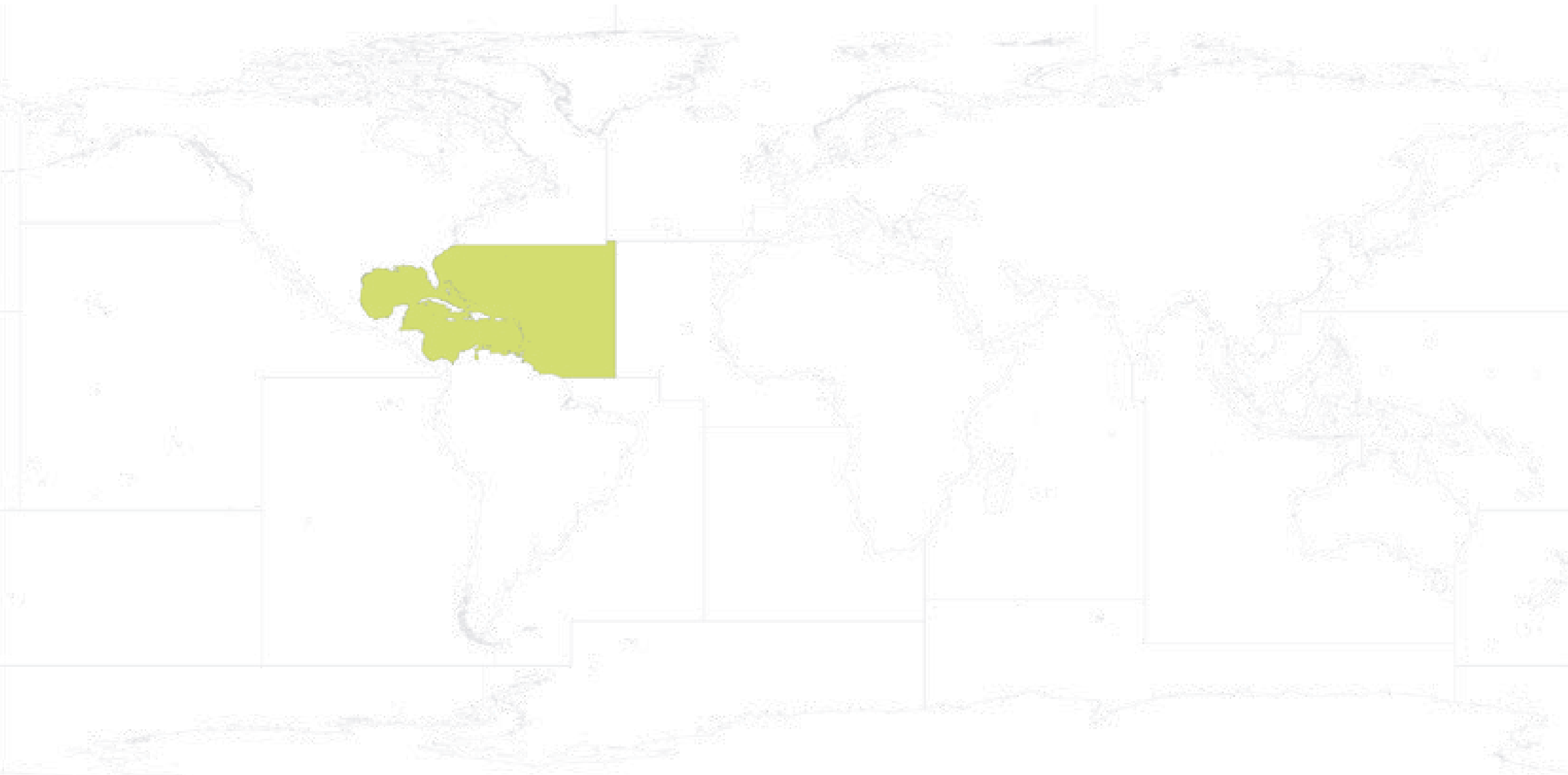


Figure 31. 1. Location of FAO Area 31.

Haritz Arrizabalaga, Josu Santiago, Hilario Murua, Igor Granado, David Kroodsma, Nathan A. Miller, Marc Taconet and Jose A. Fernandes

PREAMBLE

This chapter assesses, through a comparison with fleet statistics and public fisheries data, the capacity of Automatic Identification System (AIS) data and Global Fishing Watch (GFW) algorithms (Kroodsma *et al.*, 2018) to identify and quantify fishing vessel activity in the Western Central Atlantic Ocean. This assessment reviews fleet activity, main gear types and spatial distribution of fishing vessel activity and fishing operations.

SUMMARY AND CONCLUSIONS FOR THE WESTERN CENTRAL ATLANTIC

AIS use in this region is dominated by vessels from the United States of America (trawlers in their majority), largely because most other countries in the region have a very low use of AIS. Class A reception is poor in the Gulf of Mexico, missing much of the fishing activity in that zone, but better in the southern and eastern parts of the region. Reception for Class B, which is used by half of the detected vessels, is poor across the entire region, except close to some terrestrial receivers. Therefore, the spatial distribution is detected poorly in general, especially for the main fishing gears of the industrial vessels. The primary fishing gears detected by AIS in the region are trawls, drifting longlines and purse seines. Other important gears in the region, not identified by AIS data, are pots and traps, trolling lines, dredges and set gillnets.

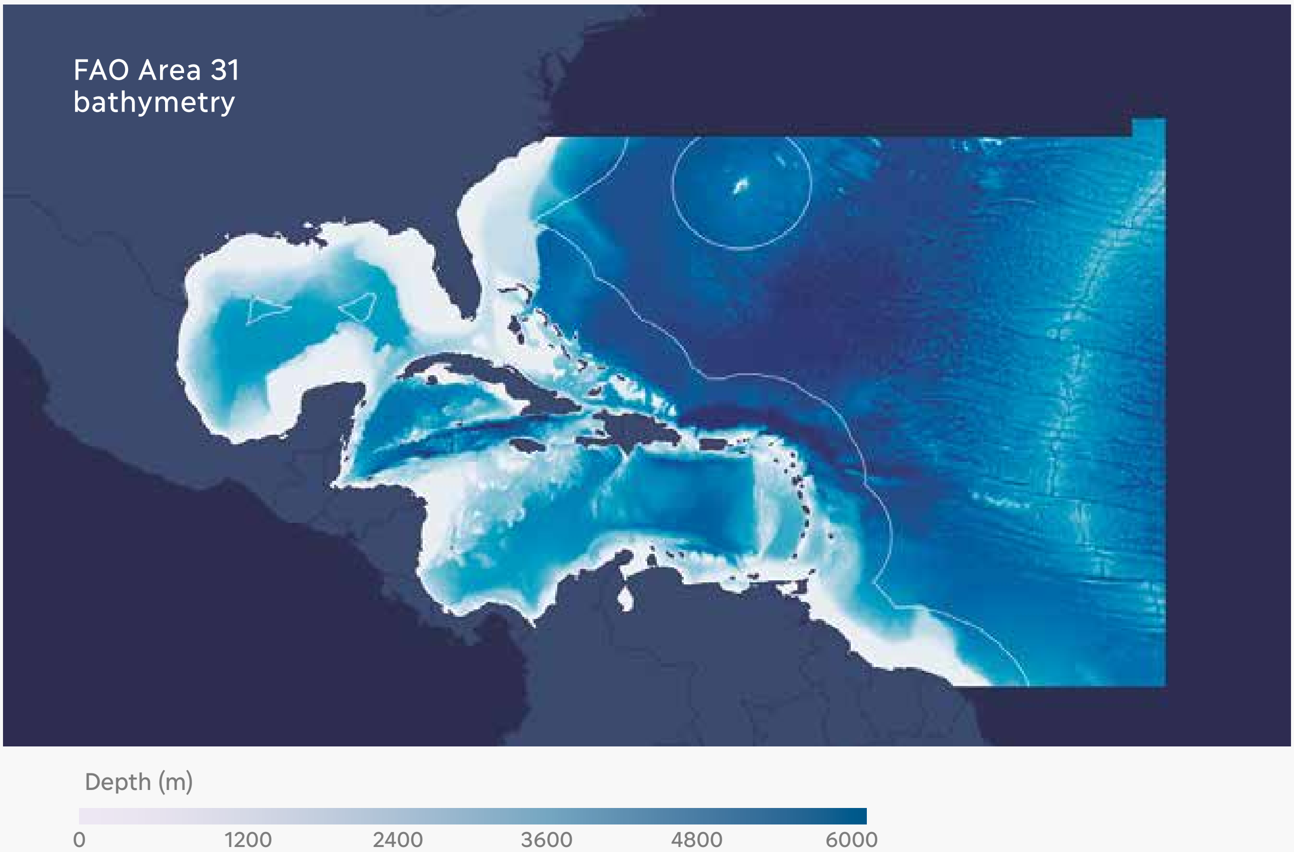


Figure 31.2. FAO Area 31 bathymetry (depth) and 200 miles coastal arc.

INTRODUCTION FOR THE WESTERN CENTRAL ATLANTIC

The Western Central Atlantic encompasses all marine waters bounded by latitudes 35° N and 5° N, longitude 40° W and the coast of the American continent (Figure 31. 1; FAO, 2019), comprising approximately 14.5 million km^2. The following coastal countries/territories are

border FAO Area 31: Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Bermuda, Bonaire, Sint Eustatius and Saba, British Virgin Islands, Cayman Islands, Colombia, Costa Rica, Cuba, Curaçao, Dominica, Dominican Republic, French Guyana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Montserrat, Nicaragua, Panama, Puerto Rico, Saint-Martin (French part), Sint Maarten (Dutch part), Saint Kitts and Nevis, Saint Lucia, Saint Vincent and Grenadines, Saint Barthélemy, Suriname, Trinidad and Tobago, Turks and Caicos Islands, US Virgin Islands, the United States of America, and Venezuela. All together, these coastal countries/territories constitute an area under national jurisdiction of 50 percent, while high seas, mostly in northeastern part, cover the remaining 50 percent of the FAO Area 31.

The continental shelf area (Figure 31. 2) covers 1.64 million km^2 and is widest around the Gulf of Mexico, Central America (Yucatan Peninsula, Honduras, Nicaracua), north of Guyana, Surinam, and French Guyana, and around some islands and offshore banks (e.g. The Bahamas, Cuba, Pedro Bank). The Western Central Atlantic also includes a large number of islands with very limited shelf area and large areas of deep ocean in the Caribbean Sea and the Atlantic. FAO Area 31 is one of the most bio-diverse marine areas in the world, exhibiting a wide range of oceanographic and hydrographic features, with a great diversity of tropical, subtropical, estuarine, coastal, shallow-shelf, deep-slope and oceanic habitats, coral reefs and seamounts (Oxenford and Monnereau, 2018).

The productivity of the region is heterogeneous, with alternating areas of high and low productivity. As a result, this area has a high diversity of marine species, especially in the Caribbean, which is considered a global hotspot of marine biodiversity (Roberts *et al.*, 2002). Species of interest to fisheries include molluscs, crustaceans (lobster, penaeid shrimps, crabs), coastal fishes occupying various substrata (soft bottom or reefs), large migratory fish species and deep-slope fish species (FAO, 2016). Recent catches in the Western Central Atlantic were around 1.6 million tonnes, which is considerably below the maximum of 2.5 million tonnes recorded in 1984 (WECAFC/FAO, 2018). In addition, it is estimated that illegal, unreported and unregulated (IUU) fishing equates to 20–30 percent of the reported landings, with a value of USD 700 to 930 million per year (FAO, 2018). FAO landings statistics (FishStatJ, 2018) show that catches were dominated by invertebrate and pelagic fish species from 2010 to 2014. The largest catches made were for gulf menhaden, American cupped oyster, northern brown shrimp, northern white shrimp, blue crab, round sardinella, stromboid conchs, Atlantic seabob, Caribbean spiny lobster, ark clams, common octopus, penaeid shrimps, yellowfin tuna and crevalle jack. These 14 species items made up 70 percent of the reported catch in that period. Among the diverse marine fishes that are caught, gulf menhaden is the most productive species, representing around 39 percent of recorded landings in the region (WECAFC/FAO, 2018).

REGION FLEETS AND AIS USE IN THE WESTERN CENTRAL ATLANTIC

The fleets of coastal states and territories in FAO Area 31 show that less than 10 percent of the vessels are non-motorized (Figure 31. 3), although this fraction is higher for many Caribbean nations. Less than one percent of the vessels are larger than 24 m, and thus likely to have AIS, and most of these are from the United States of America (Figure 31. 4). Almost two thirds of the fishing vessels are small motorized vessels under 12 m in length. This region is overwhelmingly characterized by small-scale fishing fleets operating within EEZs, often very close to shore (Oxenford and Monnereau, 2018) without using AIS devices.

Fleets of coastal countries/territories in FAO Area 31

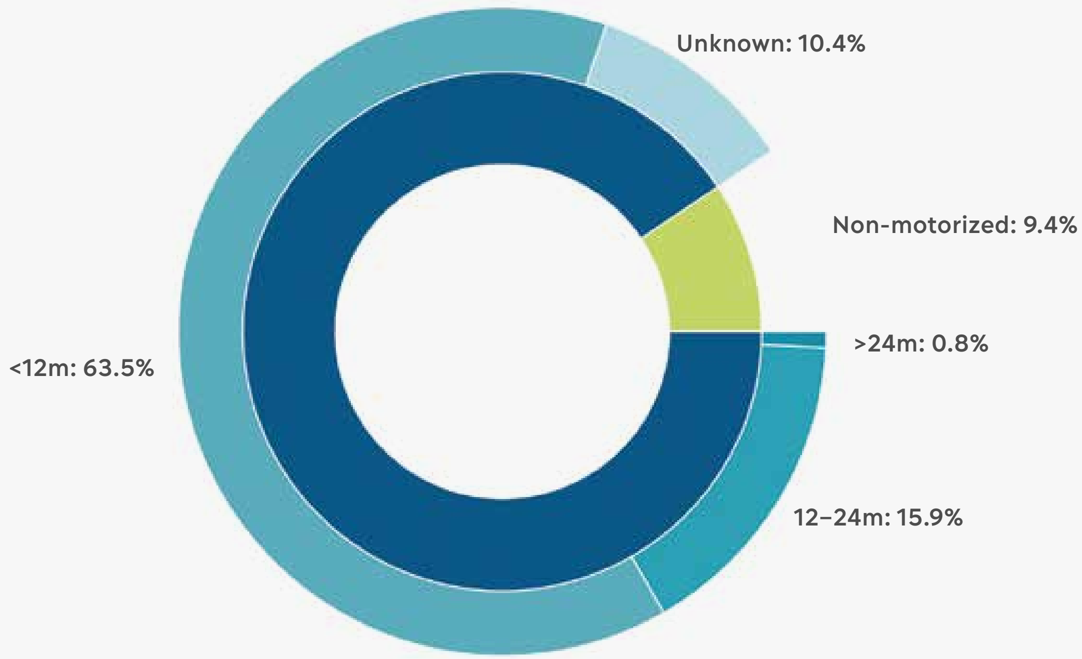


Figure 31. 3. Structural composition of fleets of coastal countries/territories in FAO Area 31. In dark blue motorized fishing vessels and in green non-motorized. Distant water fleets active in FAO Area 31 are not included (see next figure). Notice that some countries/territories (Mexico, countries of Central America, Colombia, United States of America) also borders more than one region, yet their entire fleet size is included here. Source: FAO statistics for year 2017. Statistics were not available for the following coastal countries/territories: British Virgin Islands, Cayman Islands, Haiti, Saint-Martin (French part), Sint Maarten (Dutch part), and Saint Barthélemy.

As shown in Figure 31. 4, AIS utilization by coastal fleets in this region is extremely low except for the United States of America. In the United States of America, almost all vessels larger than 24 m have AIS devices. No other nation in the region reports having more than 25 percent of their vessels larger than 24 m with AIS. Colombia, Venezuela, and Mexico all report some

degree of AIS use, while most Central American and Caribbean nations have almost no AIS use. Chinese and Spanish drifting longline vessels fish in the high seas in the eastern portion of the region. In 2017, 490 vessels with AIS fished in this region for at least 24 hours, with about 400 being from the United States of America. A total of 383 vessels in the region were matched to a registry, but only 95 of these were matched to registries that had gear type information. The gear types of the rest of vessels were inferred using GFW's vessel neural network classifier. The United States of America operates mainly with trawlers, but also with a range of other gears, including set longlines, set gears, purse seines, pots and traps, other fishing gears and drifting longlines. Spain and China operate only with drifting longlines in this region.

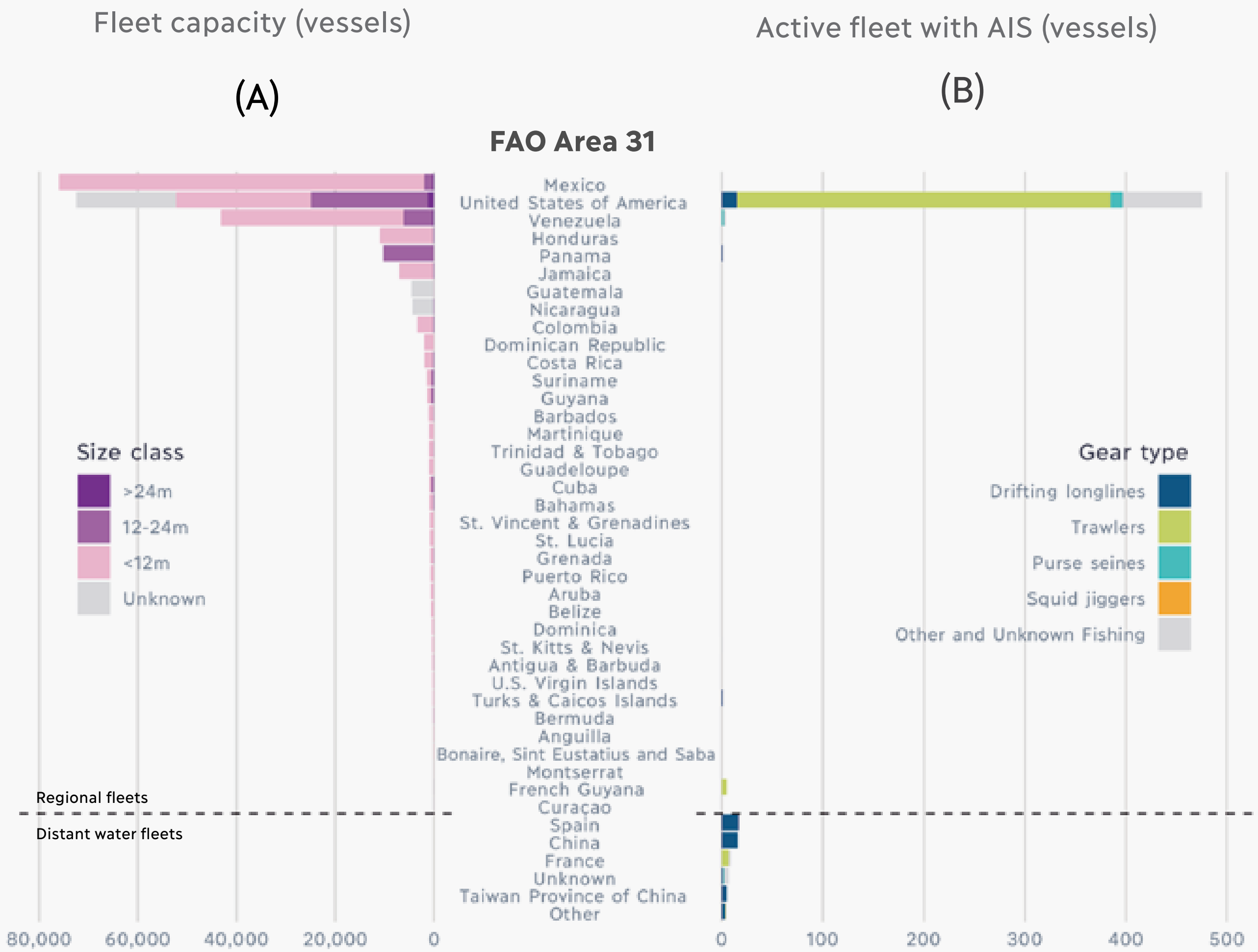


Figure 31. 4. Summary of coastal and distant fleets based on FAO statistics and AIS data classification by GFW in FAO Area 31 during year 2017. A) Number of motorized vessels as reported to FAO (left panel). The entire fleets for countries/territories are shown even though these may operate within multiple FAO areas. Source: FAO statistics. Statistics were not available for the following coastal countries/territories border FAO Area 31: British Virgin Islands, Cayman Islands, Haiti, Saint-Martin (French part), Sint Maarten (Dutch part), and Saint-Barthélemy. B) AIS-identified number of fishing vessels broadcasting AIS during their operations in FAO Area 31 by gear type and flag state (right panel). Dashed lines separate regional fleets (top) from distant fleets (bottom). Only vessels that fished for at least 24 hours in the area are included. Source: GFW.

AIS RECEPTION AND FISHING VESSEL ACTIVITY IN THE WESTERN CENTRAL ATLANTIC

About two-thirds of the vessels with AIS in this region use lower-quality Class B AIS devices. Figure 31. 5 shows the activity and reception quality of all fishing vessels broadcasting Class A and Class B AIS in the region. Class A is more common in Spanish longline fleets operating in the northeast corner of the region and for fleets operating along the northern edge of South America. Longliners in the southeastern part of the region, which include mainly Chinese and Taiwanese longline vessels, are split between using Class A and Class B. Class B is more common in most other regions. AIS reception is very poor in the Gulf of Mexico for both Class A and Class B vessels, largely because of high volumes of ship traffic broadcasting AIS in this region. Class A reception quality is good in the rest of FAO Area 31, but Class B is poor across the entire area. The maps in Figure 31. 5 shows not only the positions of fishing vessels, but also include many fishing vessels that merely transited through the region on their way to and from the Panama Canal without necessarily fishing in the area.

C) AIS CLASS A – RECEPTION QUALITY

D) AIS CLASS B – RECEPTION QUALITY

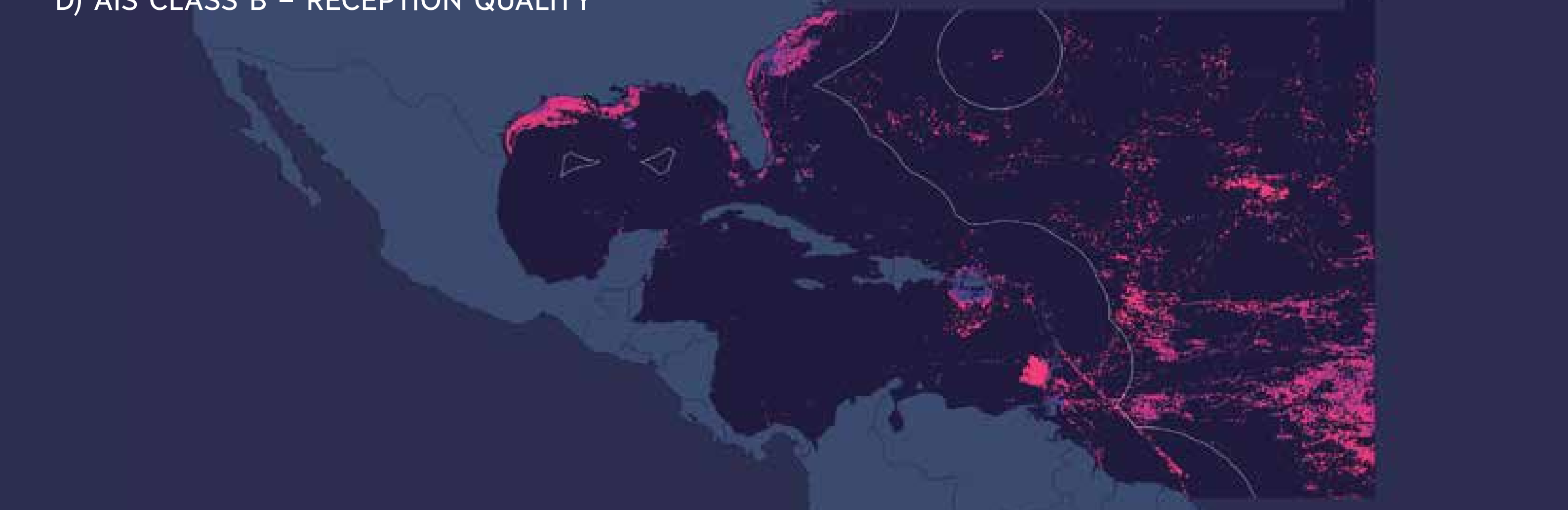


Figure 31. 5. Fishing vessel activity and quality of AIS reception for FAO Area 31 during 2017. (A) shows activity of vessels broadcasting using Class A devices and (B) shows the same for Class B devices. (C) and (D) show receptions quality maps for devices Class A and B. Blank spaces on the map (i.e. dark blue ocean background) mean that no signals from fishing vessels in that region were received, which is due to either no vessel activity or poor reception.

Figure 31. 6, shows fishing operations based on AIS data for all fishing gears in FAO Area 31. According to AIS data, the most intense fishing activity in the region is concentrated in the northwest area of the Gulf of Mexico. Other relatively intensive fishing areas are located along Florida and in its southern tip, north of Colombia, Venezuela and French Guyana. However, in general very low fishing activity is detected. While poor AIS reception is a challenge, the main reason for not observing fishing activity is the low use of AIS by fishing fleets. Excluding United States of America vessels, only 90 fishing vessels were identified by AIS data, and over half of these are fleets foreign to the region operating in the high seas. Most of FAO Area 31 EEZs show no fishing activity in the AIS data. In open seas, fishing activity is distributed mostly in the northeast (mainly by Spanish longliners) and southeast (mainly by Chinese and Taiwanese vessels) corners of the region.

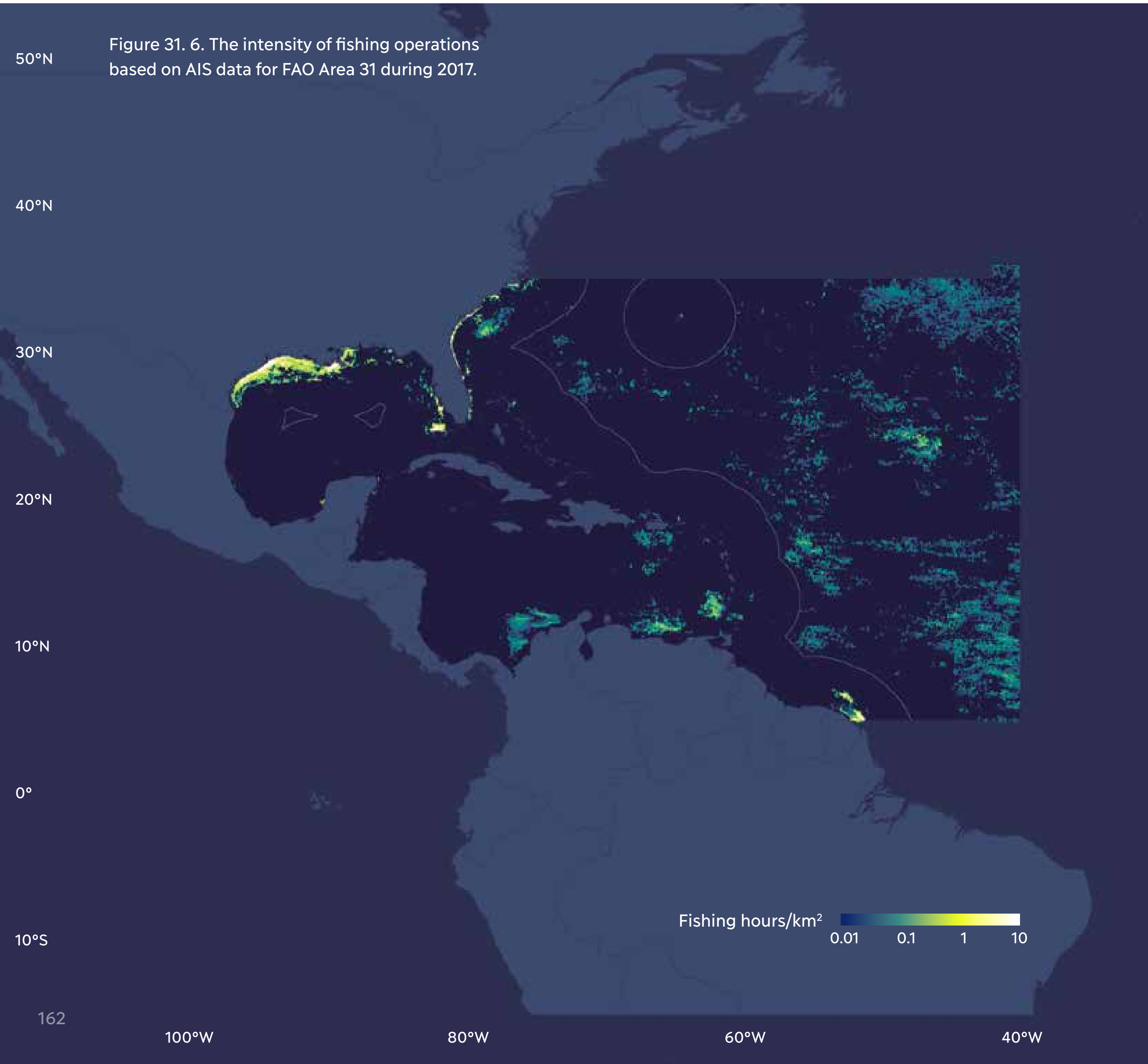


Figure 31. 6. The intensity of fishing operations based on AIS data for FAO Area 31 during 2017.

FISHING VESSEL ACTIVITY AND OPERATIONS BY GEARS IN THE WESTERN CENTRAL ATLANTIC

This section reviews the spatial distribution patterns of the main fishing gears in FAO Area 31 as estimated by GFW based on 2017 AIS data. The most recent datasets available as of mid-2018 have been used to assess GFW capacity to provide an AIS based characterization of fishing activity by fishing gear in terms of presence/absence, intensity and hot spots. The Introduction chapter describes the rationale and challenges for use of contrasting data sources (e.g. Global Fisheries Landings database (GFLD; Watson, 2017)) for benchmarking AIS data classification.

When comparing fishing activity (Table 31. I) based on AIS data with the GFLD catches, the relative importance of trawlers and longliners is overrepresented in the AIS activity estimates. This overrepresentation is because these larger vessels are more likely to broadcast AIS and also because of the high use of AIS by United States of America trawlers. Other fishing gears are likely underrepresented, particularly purse seiners, set gillnets, other gears and pots and traps.

GEAR TYPES	Catches (GFLD) 2010–2014 average		Total fishing vessel activity (GFW-AIS) 2017	
	Tonnes of catch in 1000s	% of catch	Active days	% of active days
Purse seines	546	46%	4 026	11%
Trawls	277	23%	25 076	70%
Pots and traps	85	7%	2 849	8%
Set gillnets	55	5%		
Other	201	17%		
Drifting longlines	17	1%	4 104	11%
Total	1 184	100%	36 055	100%

Table 31. I. Summary table comparing average catch from GFLD during 2010–2014 with fishing vessel activity from GFW in FAO Area 31. Only vessels that fished for at least 24 hours in FAO Area 31 are included.

Trawler activity identified by AIS is very limited and patchy, mostly concentrated on continental shelf areas in the northern part of the Gulf of Mexico, with some local spots in the southern tip of Florida, as well as French Guyana (Figure 31.7). This limited distribution is because of the lack of use of AIS by vessels and poor AIS coverage in the region (see above). GFLD shows a more realistic distribution of trawler activity along all the coastal areas of FAO Area 31 (Figure 31. 6). This indicates that AIS data can detect partially the United States of America trawlers activity, but is unable to detect the activity of other fleets.

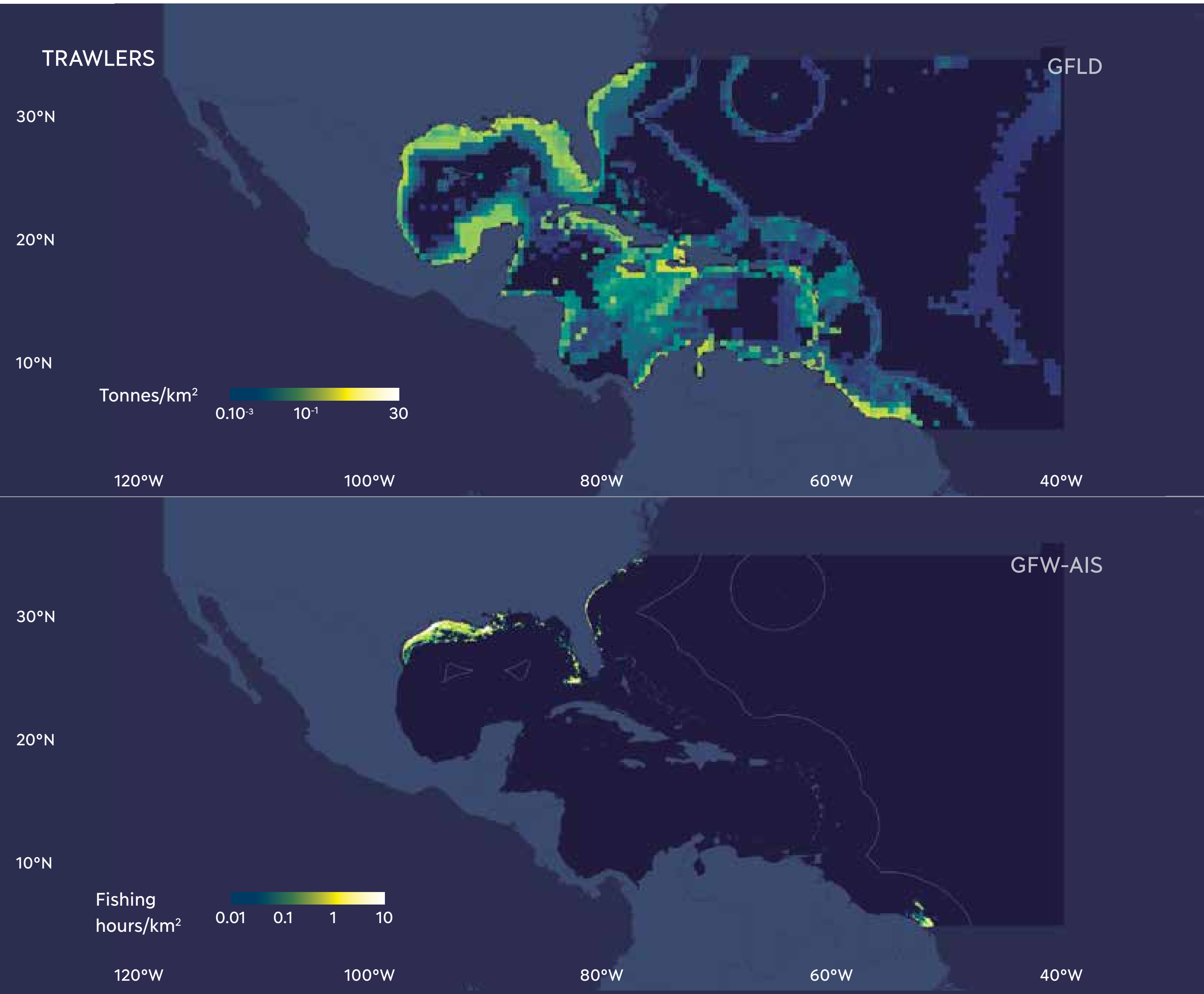


Figure 31. 7. Catch and activity of trawlers in FAO Area 31. Maps comparing average catch during 2010–2014 from GFLD (top panel) with trawler fishing operations in 2017 from GFW (bottom panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

The activity of the drifting longliners, operated mostly by the United States of America, China and Spain is best represented, using AIS, in the northeast and southeast corners of the region. This activity can be observed to extend into FAO Area 31, just to the east. Longline fishing activity spots are also detected south of Puerto Rico, west of Grenada and off northwest Colombia (Figure 31. 8). Overall, both GFLD and AIS suggest that this region is not heavily fished by longliners. However, GFLD and the AIS data differ in fishing activity in some regions. Both show some fishing activity in the southeastern corner, while GFLD is missing fishing activity in the northeast corner (mostly Spanish vessels). GFLD also shows activity in the western part of the Atlantic near Florida where AIS does not detect activity. This could be due to a combination of poor AIS reception and few vessels broadcasting AIS in this area.

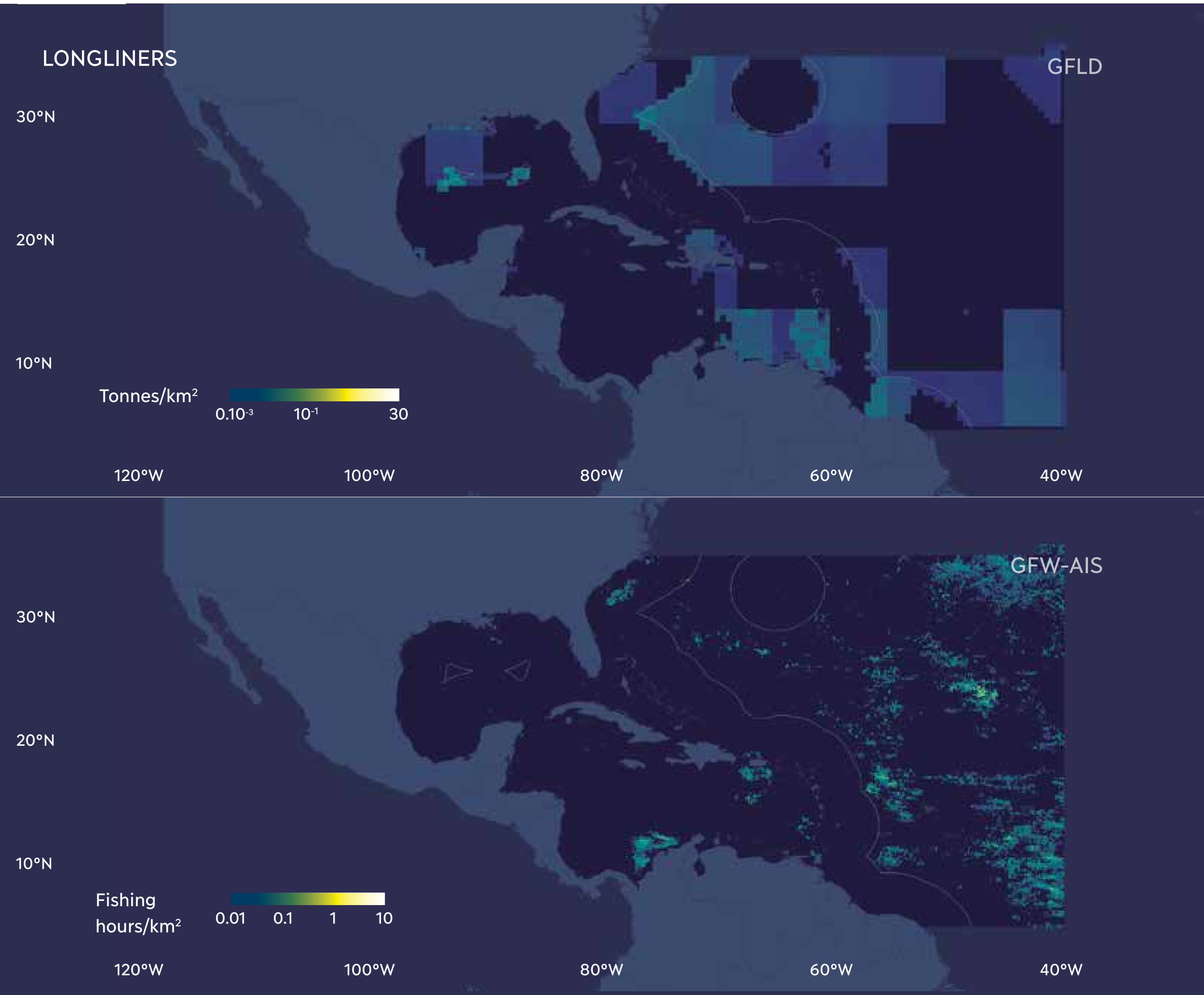


Figure 31. 8. Catch and activity of drifting longliners in FAO Area 31. Maps comparing average catch during 2010–2014 from GFLD (top panel) with drifting lonliners fishing operations in 2017 from GFW (bottom panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

According to the International Commission for the Conservation of Atlantic Tunas (ICCAT), longline fishing activity during the last decade extended over all the region, including the Gulf of Mexico (ICCAT, 2018), suggesting that the AIS data are missing some activity. While it may be possible that the differences are because AIS data only represents a single year of data (2017), it is also possible that some longliners operating in the western part of this region do not broadcast AIS or are small vessels not required to use.

Purse seiner activity is detected mainly off the north coast of Venezuela (Figure 31. 9) where purse seiner catches of yellowfin tuna and bigeye tuna are reported (ICCAT, 2018). In addition, some small amount of purse seiner activity is detected in coastal areas of the Gulf of Mexico. However, it is interesting to note that these two spots correspond to kernels of more extended areas of purse seiner catches estimated by GFLD. Considering the relative importance of small pelagic fisheries in this FAO region, as well as the increasing use of Fish Aggregating Devices (Erhardt *et al.*, 2017), it is likely that purse seiner activity distribution is poorly detected by AIS.

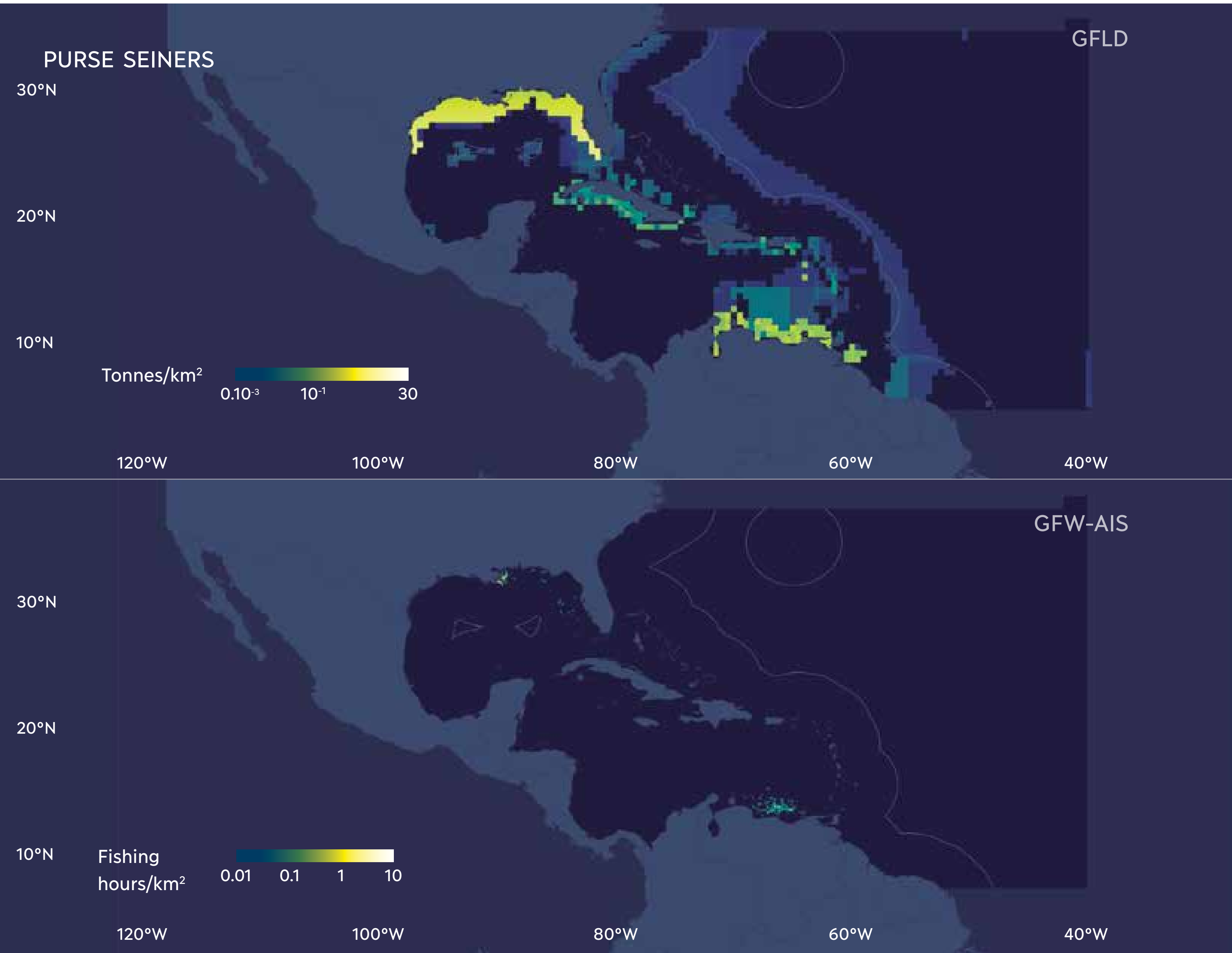


Figure 31. 9. Catch and activity of purse seiner in FAO Area 31. Maps comparing average catch during 2010–2014 from GFLD (top panel) with purse seiners fishing operations in 2017 from GFW (bottom panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

ACKNOWLEDGEMENTS

The editors would like to thank Hazel Oxenford and Nancie Cummings for excellent comments and feedback during the elaboration of the chapter. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Required citation for this chapter:

Arrizabalaga, H., Santiago, J., Murua, H., Granado, I., Kroodsma, D., Miller, N. A., Taconet, M., Fernandes, J. A. 2019. FAO Area 31 - AIS-based fishing activity in the Western Central Atlantic. *In* Taconet, M., Kroodsma, D., Fernandes, J.A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

Ehrhardt, N., Brown, J. E., Pohlot, B.G. 2017. *FADs fisheries development in the WECAFC region and the impact on stock assessments. Rosenstiel School of Marine and Atmospheric Science. University of Miami. Merida, 3 November.* http://www.fao.org/fi/static-media/MeetingDocuments/WECAFC/WECAFC17/Ref5e.pdf

FAO. 2016. *Food and Agriculture Organization of the United Nations. The State of World Fisheries and Aquaculture 2016. Contributing to food security and nutrition for all.* Rome. http://www.fao.org/3/a-i5555e.pdf

FAO. 2019. *Food and Agriculture Organization of the United Nations. FAO Major Fishing Areas. Western Central Atlantic (Major Fishing Area 31).* http://www.fao.org/fishery/area/Area31/en

WECAFC/FAO. 2018. *Western Central Atlantic Fishery Commission /Food and Agriculture Organization of the United Nations. Western Central Atlantic Fishery Commission. Report of the eighth session of the Scientific Advisory Group, Merida, Mexico, 3-4 November.* FAO Fisheries and Aquaculture Report Nº 1195, Bridgetown, Barbados. http://www.fao.org/3/i8745t/I8745T.pdf

FAO. 2018. *Western Central Atlantic Fishery Commission. Report of the first meeting of the regional working group on illegal, unreported and unregulated (IUU) fishing, Barbados, 1-2 March 2017.* FAO Fisheries and Aquaculture Report No. 1190, Bridgetown, Barbados. http://www.fao.org/3/i8292b/I8292B.pdf

FishStatJ. 2018. Fisheries and aquaculture software. FishStatJ - software for fishery statistical time series. *In* FAO Fisheries and Aquaculture Department [online]. Rome. Updated 21 July 2018. [Cited 19 November 2018]. http://www.fao.org/fishery/statistics/software/fishstatj/en

ICCAT. 2018. *The International Commission for the Conservation of Atlantic Tunas. Report of the standing committee on research and statistics (SCRS) (Madrid, Spain, 1 to 5 October 2018).* https://www.iccat.int/Documents/Meetings/Docs/2018/REPORTS/2018_SCRS_REP_ENG.pdf

Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F.,... & Woods, P. 2018. Tracking the global footprint of fisheries. *Science*, 359(6378), 904-908. https://doi.org/10.1126/science.aao5646

Oxenford, H.A. & Monnereau, I. 2018. Chapter 9: Climate change impacts, vulnerabilities and adaptations: Western Central Atlantic marine fisheries. Pp. 147-168 *In* Barange, M., Bahri, T., Beveridge, M., Cochrane, K., Funge-Smith, S., and Poulain, F. (eds.). 2018. *Impacts of Climate Change on fisheries and aquaculture: Synthesis of current knowledge, adaptation and mitigation options.* FAO Fisheries Technical Paper 627. http://www.fao.org/3/I9705EN/i9705en.pdf

Roberts, C. M., McClean, C. J., Veron, J. E., Hawkins, J. P., Allen, G. R., McAllister, D. E.,... & Vynne, C. 2002. Marine biodiversity hotspots and conservation priorities for tropical reefs. *Science*, 295(5558), 1280-1284. https://doi.org/10.1126/science.1067728

Watson, R. A. 2017. A database of global marine commercial, small-scale, illegal and unreported fisheries catch 1950–2014. *Scientific data*, 4, 170039. https://doi.org/10.1038/sdata.2017.39

FAO AREA 34

AIS-based fishing activity in the Eastern Central Atlantic

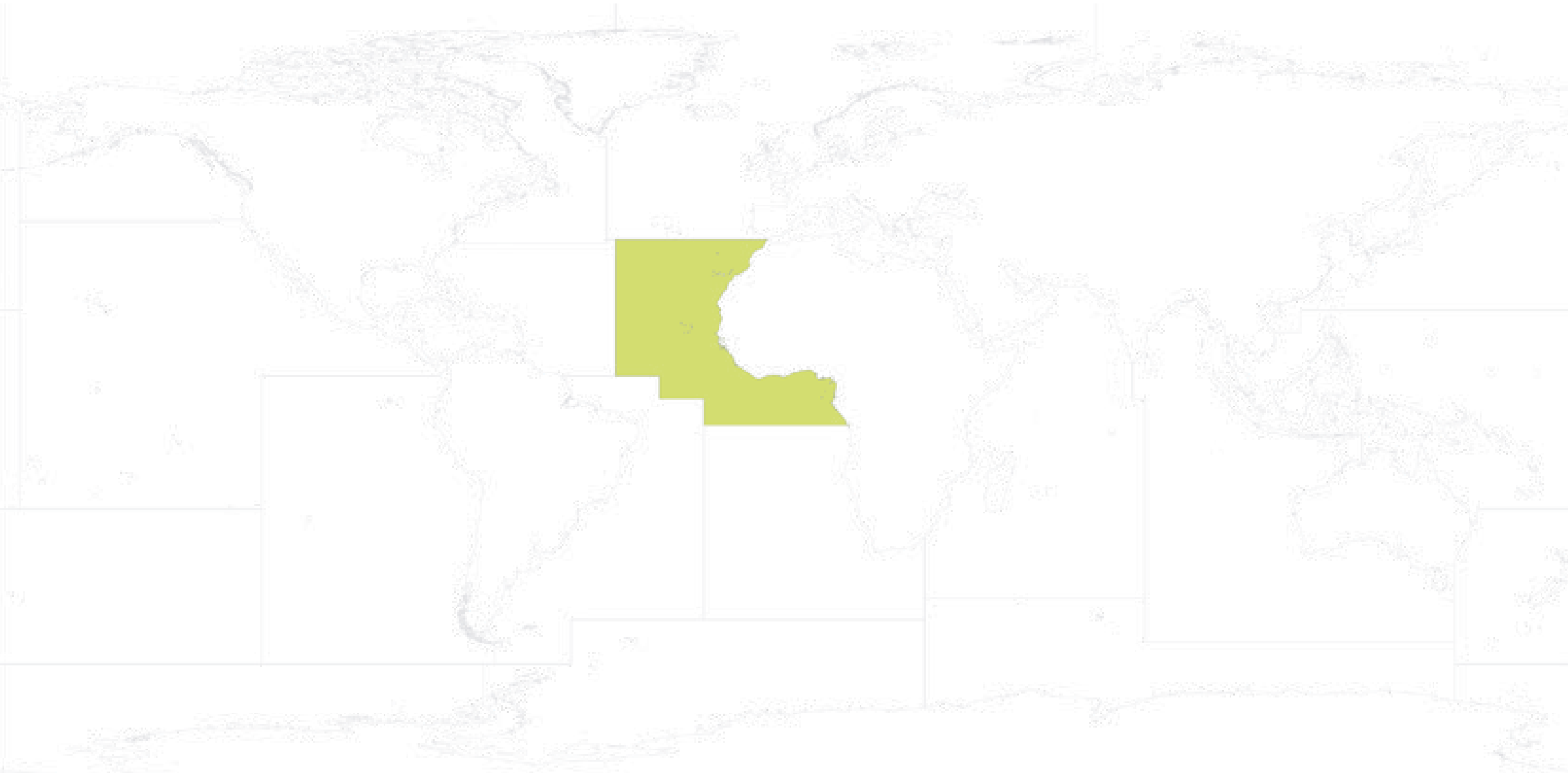


Figure 34. 1. Location of FAO Area 34.

Haritz Arrizabalaga, Hilario Murua, Igor Granado, David Kroodsma, Nathan A. Miller, Marc Taconet and Jose A. Fernandes

PREAMBLE

This chapter assesses, through a comparison with fleet statistics and public fisheries data, the capacity of Automatic Identification System (AIS) data and Global Fishing Watch (GFW) algorithms (Kroodsma *et al.*, 2018) to identify and quantify fishing vessel activity in the Eastern Central Atlantic Ocean. This assessment reviews fleet activity, main gear types and spatial distribution of fishing vessel activity and fishing operations.

SUMMARY AND CONCLUSIONS FOR THE EASTERN CENTRAL ATLANTIC

Most of the fishing activity detected by AIS included fleets from Morocco and distant water fleets from Europe and Asia. In contrast, little activity by west African nations was seen because few vessels in these fleets carry AIS. Trawling, the most important activity identified by AIS in the region, showed clear concentration patterns along the coast. However, GFW did not distinguish between pelagic and bottom trawling. Purse seining, especially by smaller scale vessels along the northwestern African coast, were poorly captured in the AIS data. Other gears such as set gillnets, pole and line and all artisanal gears were also poorly captured in the AIS data. Drifting longliner fleets are relatively well represented in the AIS data in the high seas, but possibly overrepresented in relation to other important gears in the area (purse seiners, trawlers and small-scale gears). In general, AIS identified the fishing footprint from Morocco, European Union or other foreign fishing vessels without identifying coastal states' fishing activities.

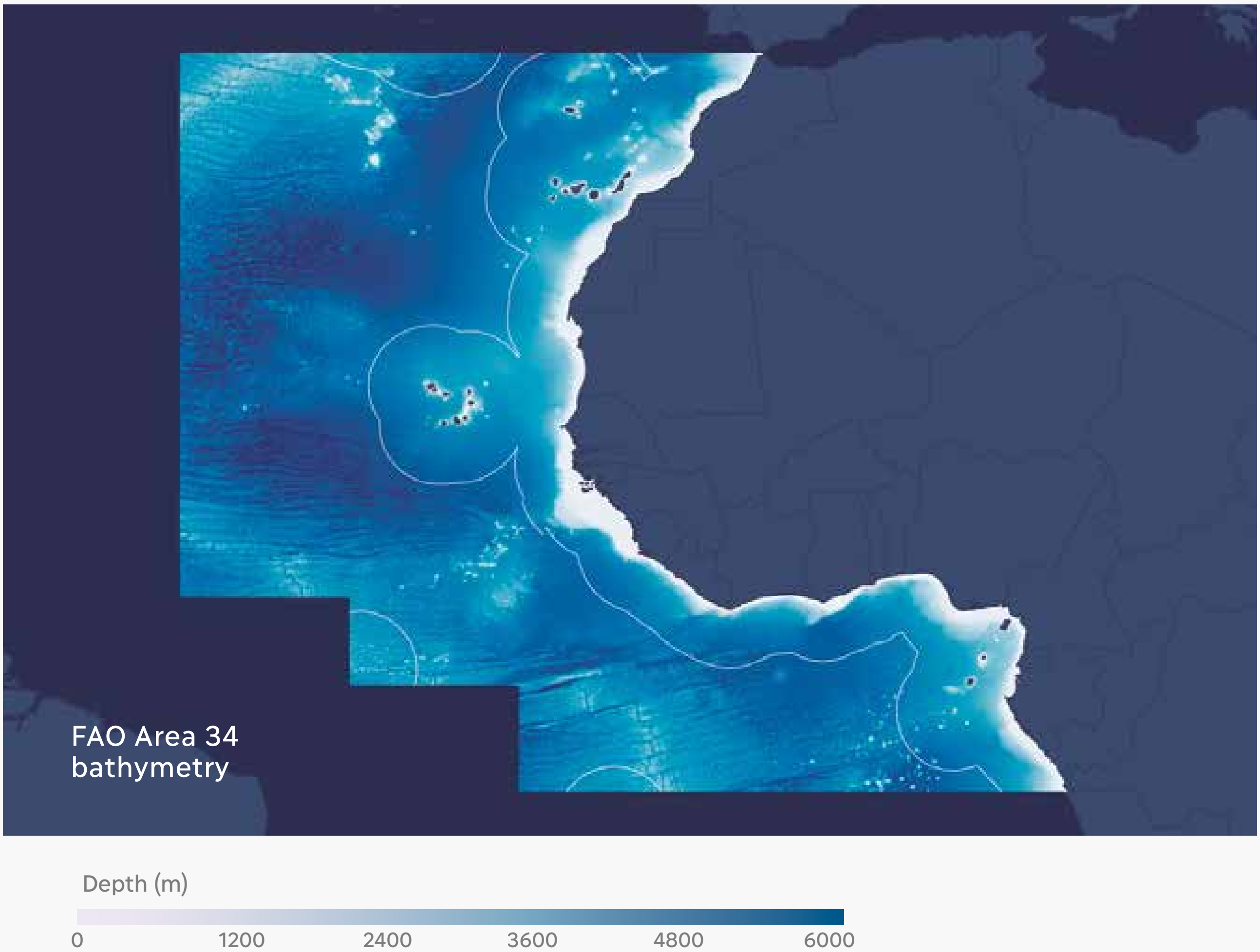


Figure 34. 2. FAO Area 34 bathymetry (depth) and 200 miles coastal arc.

INTRODUCTION FOR THE EASTERN CENTRAL ATLANTIC

The Eastern Central Atlantic (FAO Area 34; FAO, 2019) comprises waters of the eastern central Atlantic Ocean bounded by the African coast, ranging from the Strait of Gibraltar in the north to the Democratic Republic of the Congo in the south (Figure 34. 1). The following coastal countries/territories border FAO Area 34: Benin, Cabo Verde, Cameroon, Côte d'Ivoire, Democratic Republic of the Congo, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mauritania, Morocco, Nigeria, Portugal, Sao Tome and Principe, Republic of the Congo, Senegal, Sierra Leone, Spain, Togo and Western Sahara (Figure 34. 2). In this region 36 percent of the marine waters are under national jurisdiction, leaving 64 percent in the high seas. This high seas proportion is higher than the average for all FAO areas (54 percent). FAO Area 34 falls under several regional fisheries organizations and advisory bodies such as The International Commission for the Conservation of Atlantic Tunas (ICCAT), the Fishery Committee for the Eastern Central Atlantic (CECAF), the Sub-Regional Fisheries Commission (SRFC), the Fisheries Committee for the West Central Gulf of Guinea (FCWC), the Regional Commission of Fisheries of Gulf of Guinea (COREP) and the Ministerial Conference on Fisheries Cooperation Among African States Bordering the Atlantic (ATLAFCO, or COMHAFAT).

Most of the area lies in tropical and subtropical latitudes and encompasses several marine biogeochemical provinces (Longhurst, 1998; Kifani *et al.*, 2018). The continental shelf (Figure 34. 2) varies in width, with areas where it extends further offshore especially between 28° N and 30° N, 19° N and 26° N, 7° N and 14° N, in the Canary current region, as well as along the Ghanaian, Nigerian and Gabonese coasts, and in the Guinea current region. These wide continental shelf areas benefit from a strong upwelling current and coastal nutrient enrichment, supplied via tropical river networks, supporting some of the richest fishing grounds in the world. Small pelagic species are the most abundant resources of the area, providing more than 60 percent of the region's marine catches (Kifani *et al.*, 2018). These species are mainly composed of European sardine (*Sardina pilchardus*), round sardinella (*Sardinella aurita*), flat sardinella (*S. maderensis*), bonga shad (*Ethmalosa fimbriata*), anchovy (*Engraulis encrasicolus*), Atlantic chub mackerel (*Scomber colias*), Atlantic horse mackerel (*Trachurus trachurus*), Cunene horse mackerel (*T. trecae*) and false scad (*Caranx rhonchus*), amounting to around 2.1 million tonnes per year (Kifani *et al.*, 2018; FishStatJ, 2018). Tuna and tuna-like species are also important with around 400 000 tonnes in FAO Area 34. Coastal demersal fisheries harvest mainly cephalopods, shrimps, hake and other species, which make a relatively small proportion of the total catch volume, but a significantly larger one of the catch value (Mallory 2013; Pauly *et al.*, 2014; Fernandes *et al.*, 2017). According to the FAO database, about 4.8 million tonnes were caught in total in the Eastern Central Atlantic in 2016 (FAO, 2018).

According to Agnew *et al.* (2009), illegal and unreported fishing in this region in the mid-2000s was over 30 percent of the reported catches. Despite improvements in industrial trawler monitoring and licensing, the figure currently might still remain high. However, it is unlikely that AIS can help to detect illegal fishing as many IUU vessels are unlikely to use AIS or may manipulate it to broadcast misleading activity.

REGION FLEETS AND AIS USE IN THE EASTERN CENTRAL ATLANTIC

The regional fleets of coastal countries/areas in FAO Area 34 are dominated by non-powered vessels, which make up 58.8 percent of all fishing vessels of reported fleets (Figure 34. 3). This figure is much higher than the global average of 39 percent (SOFIA, 2018). The proportion of vessels over 24 m, which are the vessels most likely to have AIS, is about 0.6 percent.

Fleets of coastal countries/territories in FAO Area 34

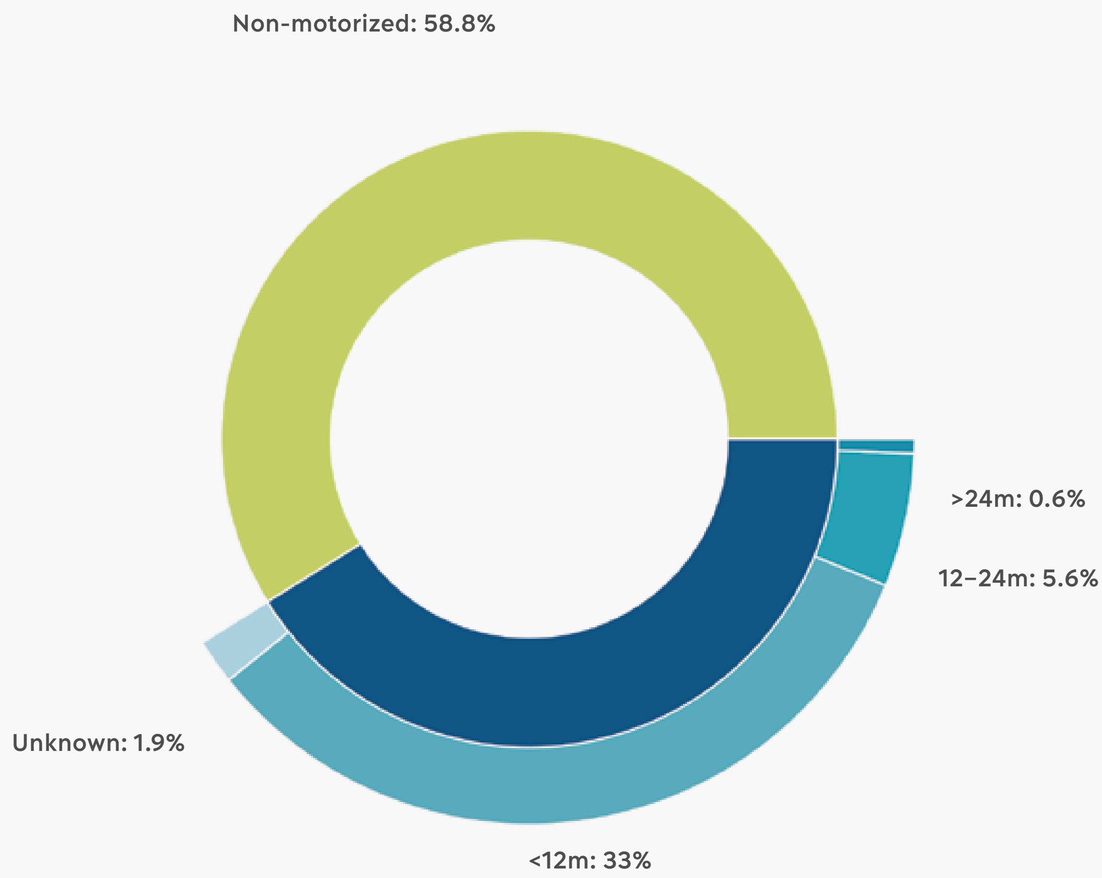


Figure 34. 3. Structural composition of fleets of coastal countries/territories in FAO Area 34. In dark blue motorized fishing vessels and in green non-motorized. Distant water fleets active in FAO Area 34 are not included (see next figure). Note that although Morocco, Portugal and Spain border more than one FAO Area, their entire fleet size is included here. Sources: FAO statistics for 2017.

Vessels between 12 and 24 m are also a small proportion (2.4 percent). A large component of the coastal countries' artisanal fleet is not identified by AIS due to small vessel size. For example, Nigeria and Congo reported respectively about 30 000 and 26 000 vessels, which are almost exclusively below 12 m. Furthermore, in countries such as Ghana, canoes represent over 90 percent of the total number of vessels (Nunoo *et al.*, 2015) and 60 percent of the national catches (FC, 2015), a significant amount of which are for domestic consumption (Ameyaw, 2017). These canoes operate mainly in rivers, deltas and in a nearshore area called the Inshore Exclusion Zone (IEZ), which comprises coastal waters where industrial vessels cannot operate (Nunoo *et al.*, 2015). Similar IEZs are common throughout countries of the region (Alder and Sumaila, 2004; OECD, 2008; Pauly *et al.*, 2014).

The coastal countries/territories with larger number of active vessels detected by AIS were Spain, Ghana, Portugal, Morocco and Senegal, in that order (Figure 34. 4). Additionally, AIS detected that the largest distant water active fleets were China, Japan and Taiwan Province of China, followed by more than ten other flag states. Almost 200 vessels from Spain, a large part of which operate in the Canary Islands, and over 100 vessels from China are active in the region operating within the EEZs of African countries likely under Fisheries Partnership Agreements. The largest African fleet detected with AIS was Ghana, the third largest according to AIS data. Except for Morocco and Ghana, and to a lesser extent Senegal, AIS use was low among West African countries. This low utilization may be partly due to these countries having few vessels larger than 24 m. Nonetheless, a significant portion of catches come from large industrial vessels of distant water fleets from Asia and Europe which do have relatively high AIS coverage. A high percentage of these vessels (613 out of 828 likely fishing vessels) were matched to vessel registries, and 476 matched to registries with listed gear types. AIS use by African nations is likely to increase in the future for larger vessels. Mauritania, Senegal, Cabo Verde, Guinea, Guinea Bissau, Sierra Leone, Liberia and Ghana now all have the USA-supplied Seavision AIS viewer active in their Monitoring, Control and Surveillance (MCS) control centres. Exact Earth technology has been supplied periodically by the West Africa Regional Fisheries Programme for trial activities.

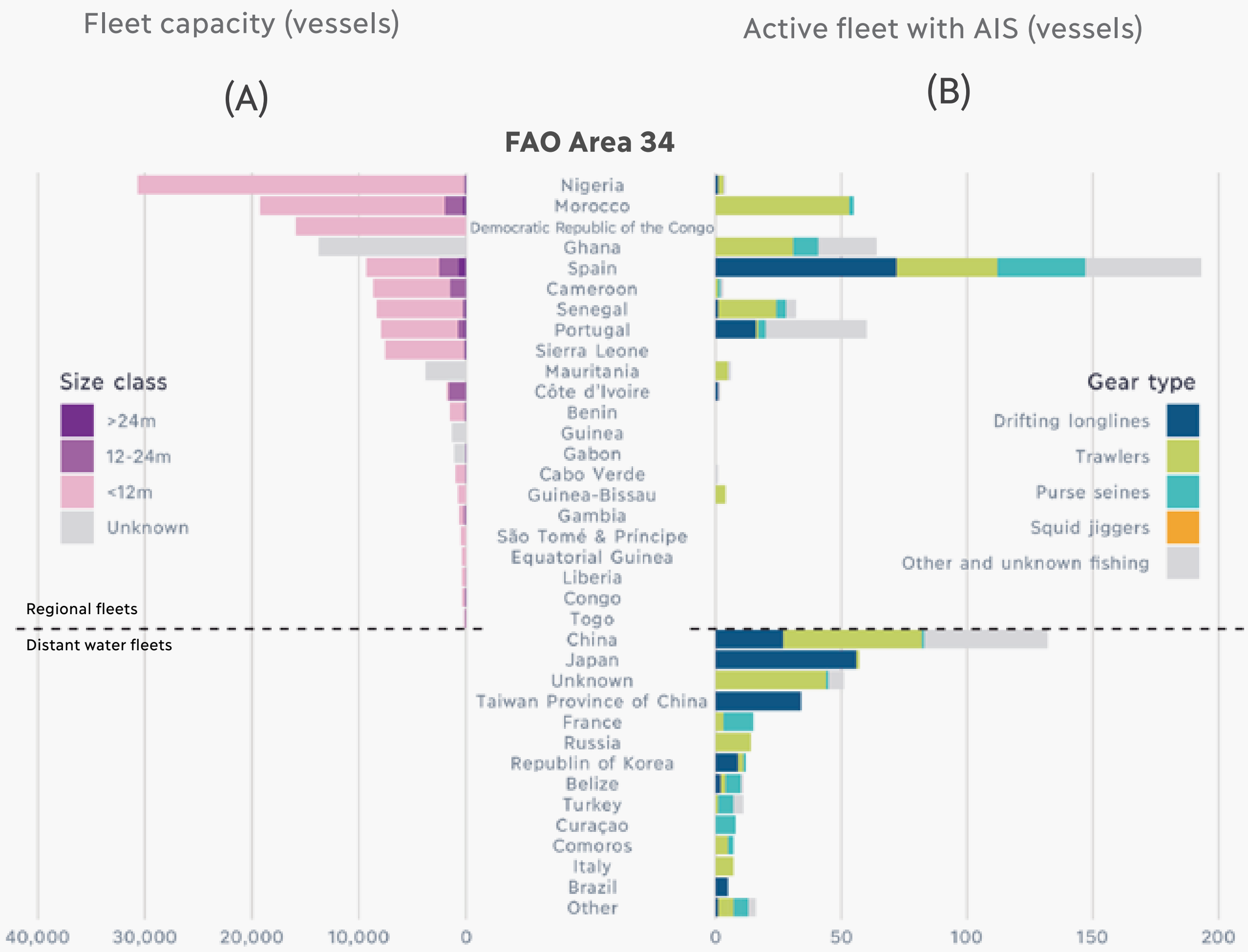


Figure 34. 4. Coastal and distant fleets summary based on FAO statistics and AIS data classification by GFW in FAO Area 34 during year 2017. A) Number of motorized vessels as reported to FAO (left panel). The entire fleets of Morocco, Spain and Portugal are shown even though these countries border multiple FAO areas. Source: FAO statistics. B) AIS-identified number of fishing vessels broadcasting AIS during their operations in FAO Area 34 by gear type and flag state (right panel). Dashed lines separate regional fleets (top) from distant fleets (bottom). Only vessels that fished for at least 24 hours in the area are included. Source: GFW.

Figure 34. 4b shows the gear type by flag state in the region. Some countries/areas (e.g. Spain, China and Portugal) use a variety of fishing gears, while others (e.g. Japan, Morocco and Taiwan Province of China) focus mostly on one single fishing gear (pelagic longline, trawl and pelagic longline, respectively).

AIS RECEPTION AND FISHING ACTIVITY IN THE EASTERN CENTRAL ATLANTIC

Figure 34. 5 shows the use and reception quality of Class A and Class B across the region. Most vessels use Class A AIS devices, while Class B AIS is common among the Taiwanese and Chinese fleets. About two thirds of the 828 fishing vessels in the region use Class A AIS devices. Reception quality is good for Class A across almost the entire region, but medium to poor for Class B except near some coastlines with terrestrial receivers (basically Morocco, Canary Islands, and Senegal).

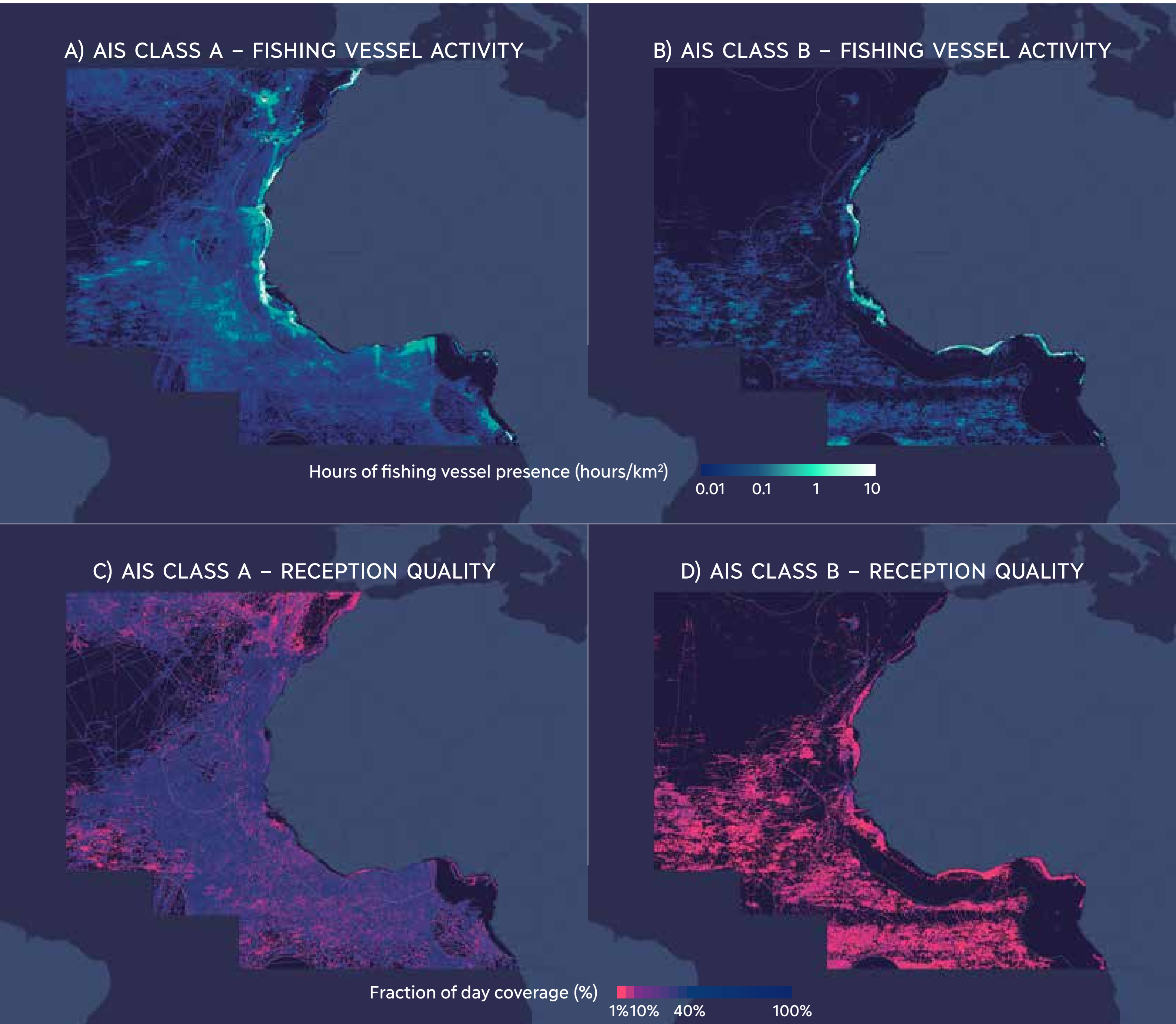
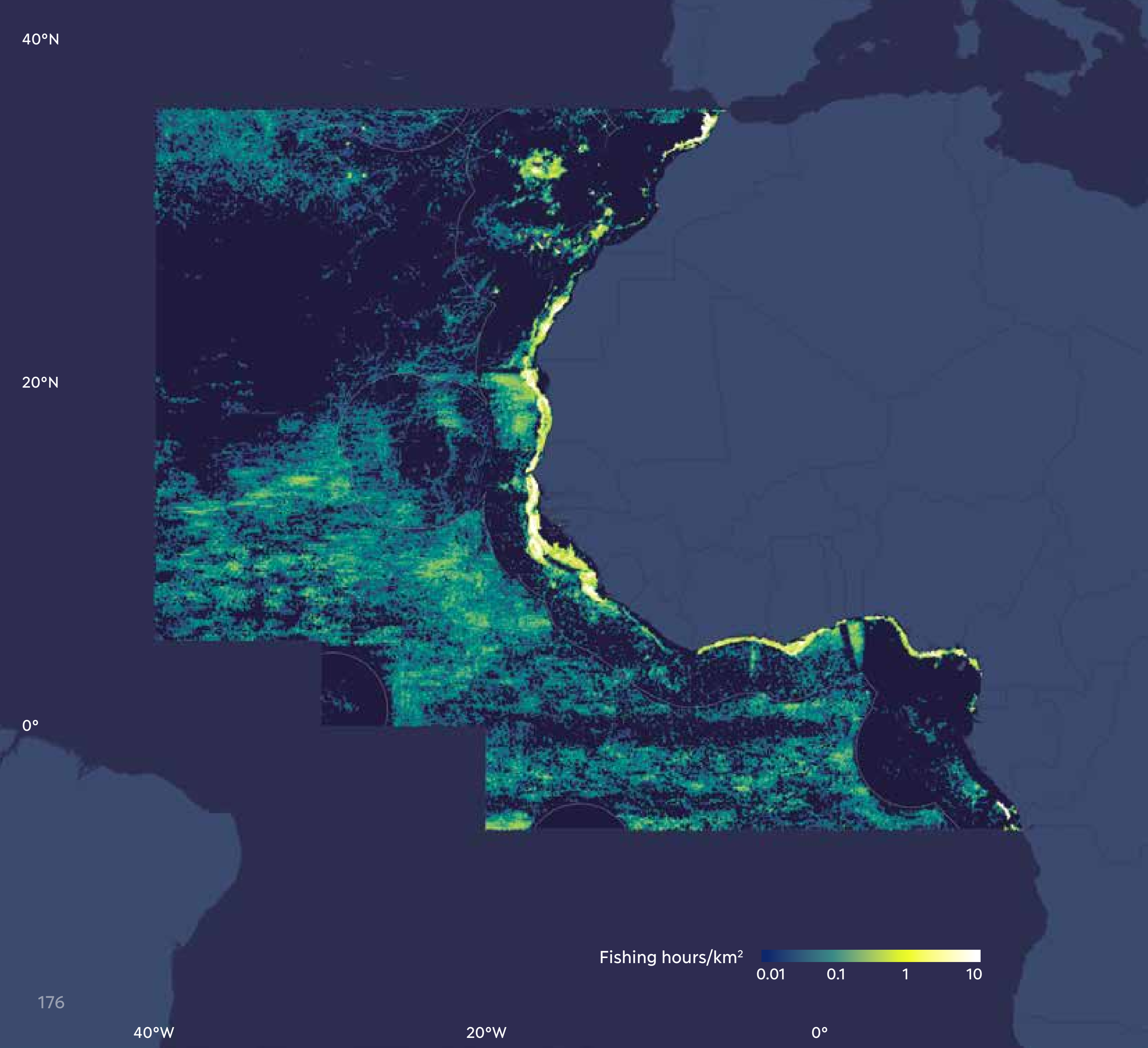


Figure 34. 5. All activity of fishing vessels based on AIS data for FAO Area 34 during 2017. Top row shows activity of vessels broadcasting using Class A devices (left panel) and Class B devices (right panel). The bottom row shows reception quality maps for AIS devices Class A (left panel) and B (right panel). Blank spaces on the map (i.e. dark blue ocean background) mean that no signals from fishing vessels in that region were received, which is due to either no vessel activity or poor reception.

Figure 34. 6 shows the distribution of fishing operations for all fishing gears operating in FAO Area 34. According to AIS data, coastal areas of African countries/areas (from Western Sahara to Sierra Leone) show the highest fishing intensity in the region, which corresponds with expected high productivity over the continental shelf. The coastal areas in the Atlantic Morocco, as well as Côte d'Ivoire, Ghana, Canary Islands and Madeira also show high fishing intensity. Towards the edge of the EEZs fishing intensity decreases, but is substantial again in open oceanic waters, especially between the equator and 15° N. Meanwhile, little fishing activity is detected in oceanic waters between 15° N and 30° N.

Figure 34. 6. Intensity of fishing operations based on AIS data for FAO Area 34 during 2017.



FISHING VESSEL ACTIVITY AND OPERATIONS BY GEAR IN THE EASTERN CENTRAL ATLANTIC

This section reviews the spatial distribution patterns of the main fishing gears in FAO Area 34 as estimated by GFW based on 2017 AIS data. The most recent datasets available as of mid-2018 have been used to assess GFW capacity to provide an AIS based characterization of fishing activity by fishing gear in terms of presence/absence, intensity and hotspots. The Introduction chapter describes the rationale and challenges for use of contrasting data sources (e.g. Global Fisheries Landings Database (GFLD; Watson, 2017) for benchmarking AIS data classification.

Based on GFLD, FAO Area 34 activity is dominated by purse seiners and trawlers, while according to AIS, purse seiners would be less important (Table 34. I). This discrepancy likely stems from the lack of AIS use by coastal purse seiners, especially those operating near the northwestern African coast, and industrial purse seiners operating in the Gulf of Guinea where there are high catches but almost no AIS coverage (see Figure 34.8). Drifting longliner activity seems to be overrepresented given the high activity reported by AIS and the low catches in GFLD. This overrepresentation is likely caused by AIS use being higher in this sector than in other fishing gears. Also, their relative contribution to the catch might be underestimated in GFLD 2010–2014 data: RFMO total catch estimate data for 2015 shows twice as much catch for longliners than that reported in GFLD (Taconet *et al.*, 2018). AIS does not detect set gillnets and pole and line properly despite their importance in the region, most likely because the gillnets are mostly used by local African smaller boats that do not have AIS.

GEAR TYPES	Catches (GFLD) 2010–2014 average		Total fishing vessel activity (GFW-AIS) 2017	
	Tonnes of catch in 1000s	% of catch	Active days in 1000s	% of active days
Purse seines	1 667	39%	12.8	12%
Trawls	1 267	30%	45.6	44%
Set gillnets	735	17%		
Pole and line	231	5%	19.3	19%
Other	311	7%		
Drifting longlines	46	1%	25.6	25%
Total	4 258	100%	103.4	100%

Table 34. I. Summary table comparing average catch from GFLD during 2010–2014 with fishing vessel activity from GFW in FAO Area 34. Only vessels that fished for at least 24 hours in FAO Area 34 are included.

GFLD catch data and GFW AIS data roughly agree on the spatial distribution of trawling, although AIS shows this activity more concentrated closer to shore and is also missing activity in a few regions, notably in coastal Western Sahara and off the coast of Liberia. Within EEZs of local countries, demersal fishing targets mostly cephalopods, shrimps, hake and other demersal fish (FAO, 2018). The main local countries using this gear are Mauritania, Morocco, Ghana and Senegal, the latter two often through joint ventures. VMS for Guinea and Sierra Leone shows a similar intensity of demersal trawling to Ghana and maybe higher than Senegal, some of which is reflected in AIS because such trawling is licensed to foreign countries (Virdin *et al.*, 2019). Foreign countries like Spain and China also use this fishing gear in the EEZs of coastal African countries, under Sustainable Fisheries Partnership Agreement (SFPA) in the case of Spain between the European Union and the coastal state. Some Spanish fishing trawlers are also fishing under "direct authorizations", but these are a minority. Also detected by AIS are a few Korean vessels which have been known to get licenses in the past for fishing in the waters of Guinea-Bissau, Guinea, Sierra Leone and Liberia. It appears that AIS data can identify trawling activity distributed along the coast and its intensity depends on actual adoption and use by vessels of these countries (Figure 34. 7).

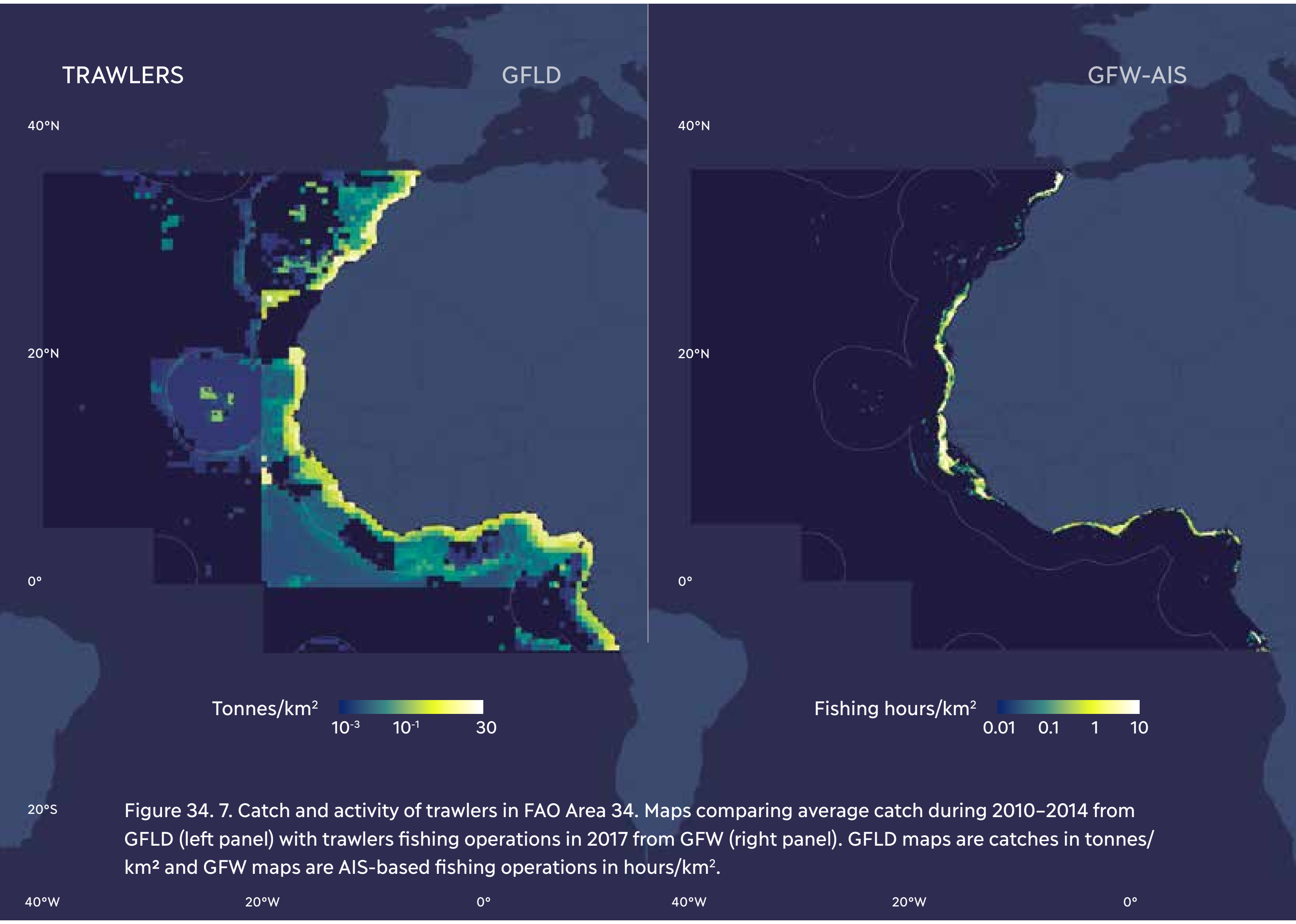


Figure 34. 7. Catch and activity of trawlers in FAO Area 34. Maps comparing average catch during 2010–2014 from GFLD (left panel) with trawlers fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

Use of Class B by some foreign vessels may result in lower intensity of fishing activity estimated from AIS. Some bordering country fleets comprise pelagic trawlers (equipped with Refrigerated Sea Water (RSW) systems tanks) and some foreign fleets also include pelagic freezer trawlers operating in the region under fishing agreements. However, currently those are not differentiated in AIS data classification by GFW nor in vessel registries. Their activity was low in 2017, but there is an important fleet of European Union pelagic trawlers mainly operating in waters of coastal Western Sahara and Mauritania fishing under Sustainable Fisheries Partnership Agreements (SFPAs) between the European Union and Morocco and Mauritania, respectively. These are vessels from Poland, the Netherlands, Lithuania, Latvia and Germany.

North of 20° N, AIS data do not show purse seiner activity except in very coastal areas around Dakhla or Tanger. There are some European Union purse seiners operating around Tanger under European Union - Morocco agreements. South of 20° N, the spatial patterns of purse seiner activity observed by AIS show clear concentrations off the edges of the continental shelf from northern Mauritania (e.g. there are 19 small pelagic purse seiners under Turkish flag in Mauritania detected in AIS data) down to Gabon (with some noticeable exceptions off Gambia, Côte d'Ivoire, Ghana and Togo), and in the equatorial high seas between 5° N and 5° S (Figure 34. 7) consistent with that reported in ICCAT (2018).

These patterns are quite different those shown by GFLD which indicates that purse seiner activity is highest in coastal waters of most coastal countries, but is also significant in international waters, especially in the southern part of the region (<10° S), where fishing intensity is at the same level as in coastal regions in similar latitudes. On one hand, the high intensity of coastal purse seiner activity is not well identified by AIS, mostly because it is conducted by small boats not using AIS targeting small pelagics. On the other hand, the AIS fishing concentrations are based on a limited proportion of large purse seiners using AIS targeting tropical tunas. This activity of larger purse seiners, mostly from Spain, France, Ghana and Senegal, is identified both in international waters and within EEZs above the 200 m isobath, as tunas are oceanic species whose distribution is not as close to the shallow coastline as important small pelagic resources. The AIS data show clear concentrations within EEZs where this industrial purse seiner activity is conducted by distant water fleets under bilateral fishing agreements, with spatial patterns which demarcate clearly the edge of the continental shelf: offshore for Gabon and between Mauritania down to Guinea, but close to shore regarding Benin. However, overall fishing intensity identified by AIS seems to be underestimating real fishing activity based on ICCAT reports (ICCAT, 2018).

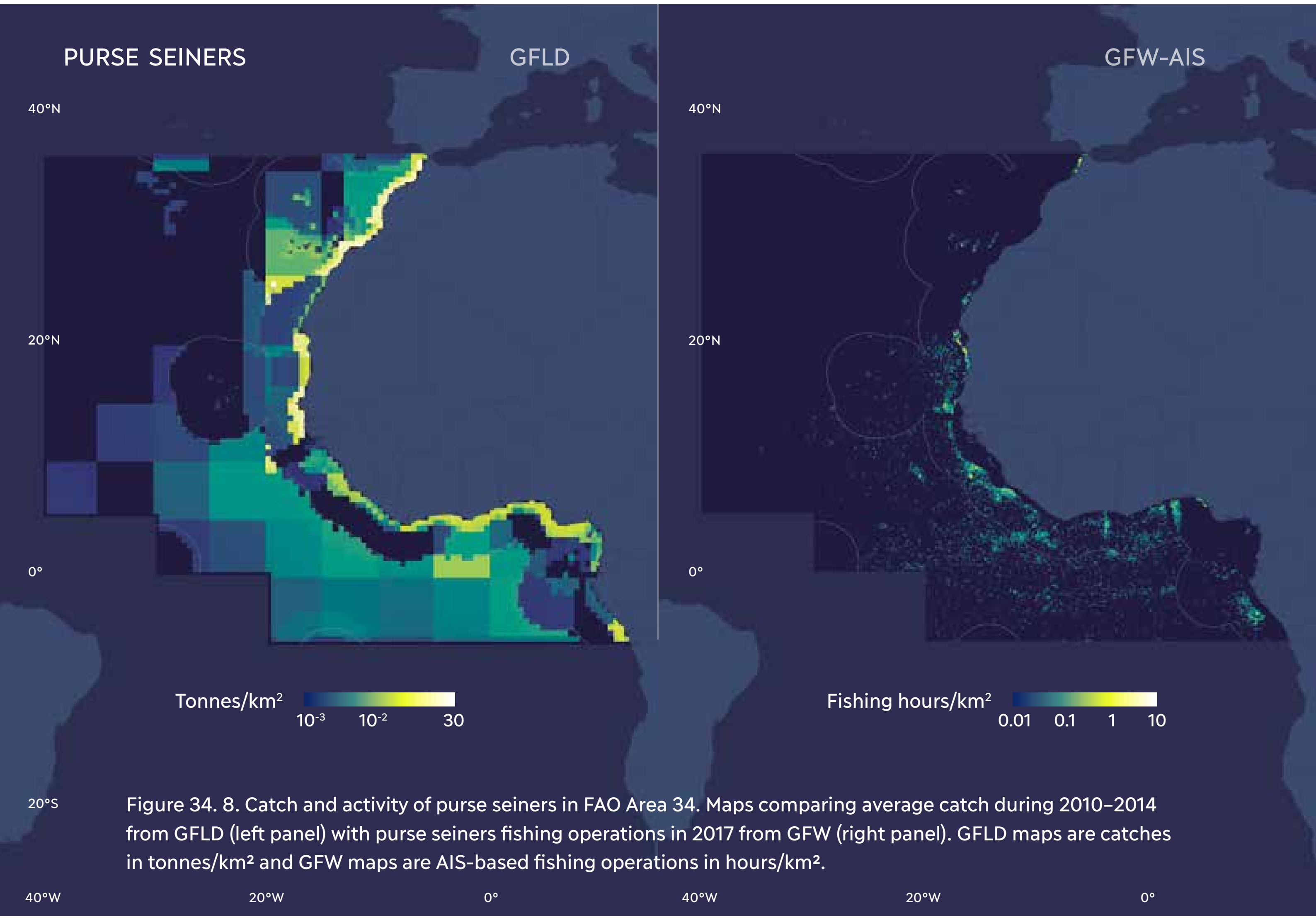


Figure 34. 8. Catch and activity of purse seiners in FAO Area 34. Maps comparing average catch during 2010–2014 from GFLD (left panel) with purse seiners fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

The fishing activity of drifting longliners is dominated by foreign countries/territories (Spain, Japan, Taiwan Province of China, China, Portugal and the Republic of Korea) and occurs mainly in international waters, although in some cases also within local EEZs (e.g. Mauritania, outer part of the Cabo Verde archipelago). There is a lack of activity in the western part of the region between 15° N and 30° N. Overall, longliner spatial activity patterns seem well represented by AIS data, taking into account the fact that European fleets operating in the northern half of the region are almost all equipped with Class A AIS devices. However, many of the vessels in the Chinese and Taiwanese longliner fleets use Class B AIS devices, and some activity may be underrepresented due to incomplete AIS reception. Considering that GFLD seems to underestimate drifting longliner catches, which according to ICCAT are around 100 000 tonnes (ICCAT, 2018), the AIS map appears to be more realistic. Nonetheless, some pelagic longliners do not have AIS, and Class B used by the Chinese and Taiwanese fleets may result in underestimation of this gear's fishing activity. Bottom longliners are also active in the region, but not detected by AIS since these are small vessels not using AIS devices.

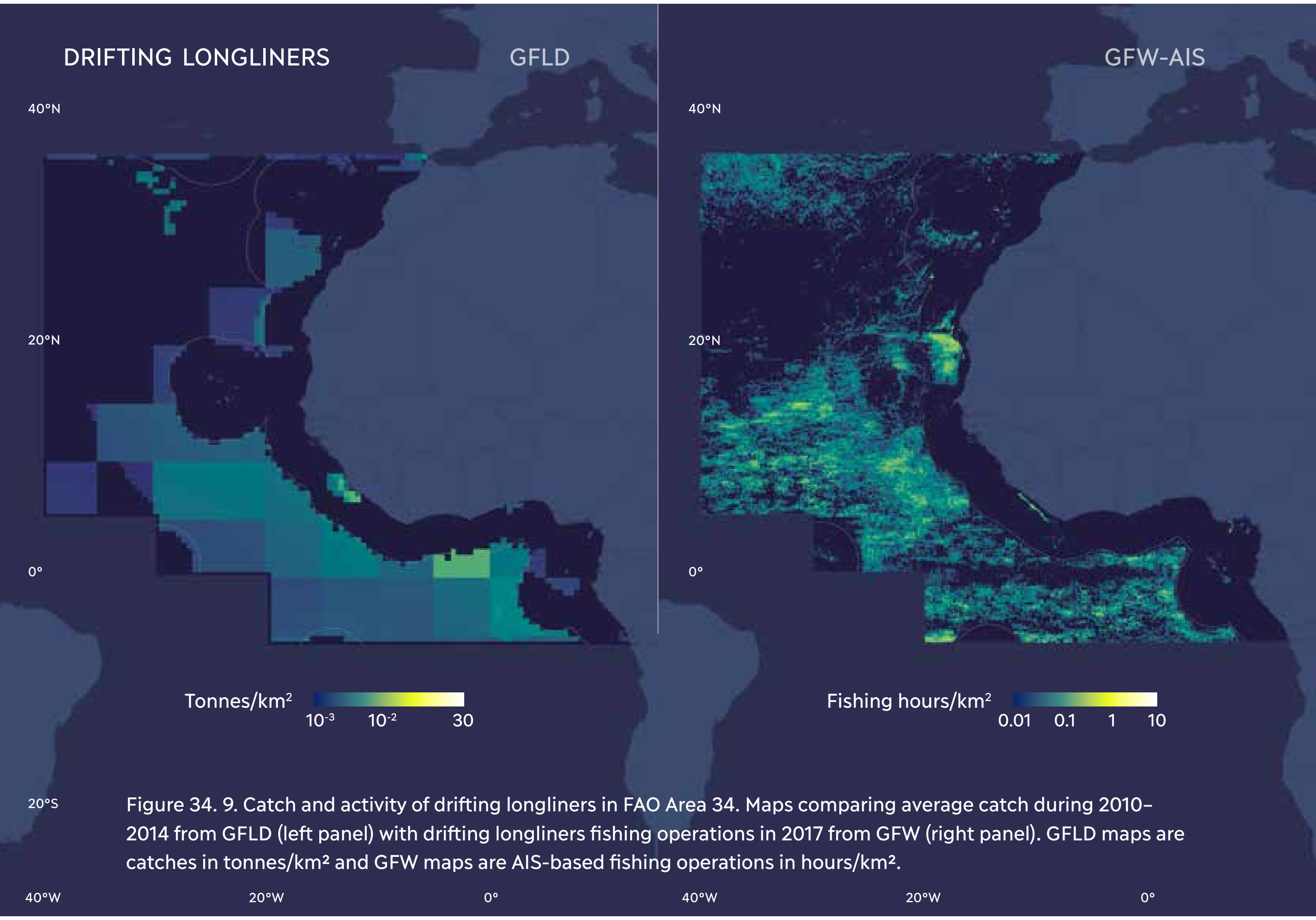


Figure 34. 9. Catch and activity of drifting longliners in FAO Area 34. Maps comparing average catch during 2010–2014 from GFLD (left panel) with drifting longliners fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

ACKNOWLEDGEMENTS

The editors would like to thank Stephen Akester, Eva Garcia Isarch, Souad Kifani and John Virdin for excellent comments and feedback during the elaboration of the chapter. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Required citation for this chapter:

Arrizabalaga, H., Murua, H., Granado, I., Kroodsma, D., Miller, N. A., Taconet, M., Fernandes, J. A. 2019. FAO Area 34 - AIS-based fishing activity in the Eastern Central Atlantic. *In* Taconet, M., Kroodsma, D., Fernandes, J.A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

Agnew DJ, Pearce J, Pramod G, Peatman T, Watson R, Beddington JR, et al. 2009. Estimating the Worldwide Extent of Illegal Fishing. *PLoS ONE* 4(2): e4570. https://doi.org/10.1371/journal.pone.0004570

Alder, J., & Sumaila, U. R. 2004. Western Africa: a fish basket of Europe past and present. *The Journal of Environment & Development*, 13(2), 156-178. https://doi.org/10.1177/1070496504266092

Ameyaw, G. A. 2017. *Managing conflicts in the marine fisheries sectors in Ghana.* Thesis, University of Wollongong. https://ro.uow.edu.au/theses1/102/

ICCAT. 2018. *International Commission for the Conservation of Atlantic Tunas. Report of the Standing Committee on Research and Statistics (SCRS). 2018 SCRS Report. Madrid, Spain, 1 to 5 October 2018.* https://www.iccat.int/Documents/Meetings/Docs/2018/REPORTS/2018_SCRS_REP_ENG.pdf

Kifani, S., Quansah, E., Masski, H., Houssa, R., Hilmi, K. 2018. Chapter 8: Climate change impacts, vulnerabilities and adaptations: Eastern Central Atlantic marine fisheries. *In* Barange, M., Bahri, T., Beveridge, M., Cochrane, K., Funge-Smith, S., Poulain, F. (Eds.). *Impacts of Climate Change on fisheries and aquaculture: Synthesis of current knowledge, adaptation and mitigation options.* FAO Fisheries Technical Paper 627. http://www.fao.org/3/i9705en/i9705en.pdf

FAO. 2016. *Food and Agriculture Organization of the United Nations. The State of World Fisheries and Aquaculture 2016 (SOFIA). Contributing to food security and nutrition for all.* Rome, FAO. http://www.fao.org/3/a-i5555e.pdf

FAO. 2018. *Food and Agriculture Organization of the United Nations. The State of World Fisheries and Aquaculture 2018. Meeting the sustainable development goals.* Rome, FAO. http://www.fao.org/3/i9540en/I9540EN.pdf

FAO/CECAF. 2018. *Food and Agriculture Organization of the United Nations / Fishery Committee for the Eastern Central Atlantic. Report of the FAO/CECAF Working Group on the Assessment of Demersal Resources – Subgroup North. Tenerife, Spain, from 6 to 15 June 2017.* CECAF/ECAF Series/COPACE/PACE Séries. No. 18/78. Rome, FAO. http://www.fao.org/3/ca1003b/CA1003B.pdf

FAO. 2019. *Food and Agriculture Organization of the United Nations. FAO Major Fishing Areas. Eastern Central Atlantic (Major Fishing Area 34).* http://www.fao.org/fishery/area/Area34/en

FCG. 2015. *Fisheries Commission of Ghana. The National Marine Fisheries Management Plan (2015-2019) towards a sustainable fishery.* Ministry of Fisheries and Aquaculture Development (MOFAD), Fisheries Commission, Accra, Ghana. http://extwprlegs1.fao.org/docs/pdf/gha160291.pdf

Fernandes, J. A., Papathanasopoulou, E., Hattam, C., Queirós, A. M., Cheung, W. W., Yool, A.,... & Calosi, P. 2017. Estimating the ecological, economic and social impacts of ocean acidification and warming on UK fisheries. *Fish and Fisheries*, 18(3), 389-411. https://doi.org/10.1111/faf.12183

FishStatJ. 2018. Fisheries and aquaculture software. FishStatJ - software for fishery statistical time series. *In* FAO Fisheries and Aquaculture Department [online]. Rome. Updated 21 July 2018. [Cited 19 November 2018]. http://www.fao.org/fishery/statistics/software/fishstatj/en

Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F.,... & Woods, P. 2018. Tracking the global footprint of fisheries. *Science*, 359(6378), 904-908. https://doi.org/10.1126/science.aao5646

Mallory, T. G. 2013. China's distant water fishing industry: Evolving policies and implications. *Marine Policy*, 38, 99-108. https://doi.org/10.1016/j.marpol.2012.05.024

Nunoo, F.K.E., Berchie, A., Amador, K., Belhabib, D., & Pauly, D. 2015. *Reconstruction of marine fisheries catches for Ghana, 1950-2010*. Fisheries Centre, The University of British Columbia, working paper series No. 2015-10. http://www.seaaroundus.org/doc/publications/wp/2014/Nunoo-et-al-Ghana.pdf

OECD. 2008. *Organización para la Cooperación y el Desarrollo Económicos. Fishing for Coherence in West Africa: Policy Coherence in the Fisheries Sector in Seven West African Countries.* Paris, OECD. https://read.oecd-ilibrary.org/development/fishing-for-coherence-in-west-africa_9789264040595-en

Pauly, D., Belhabib, D., Blomeyer, R., Cheung, W. W., Cisneros-Montemayor, A. M., Copeland, D.,... & Österblom, H. 2014. China's distant-water fisheries in the 21st century. *Fish and Fisheries*, 15(3), 474-488. https://doi.org/10.1111/faf.12032

Taconet, P., Chassot, E., Barde, J. 2018. *Global monthly catch of tuna, tuna-like and shark species (1950-2015) aggregated by 1° or 5° squares (IRD level 2) (Version 1) [Data set].* Zenodo. http://doi.org/10.5281/zenodo.1164128

Virdin, J., Kobayashi, M., Akester, S., Vegh, T., & Cunningham, S. 2019. West Africa's coastal bottom trawl fishery: Initial examination of a trade in fishing services. *Marine Policy,* 100, 288-297. https://doi.org/10.1016/j.marpol.2018.11.042

Watson, R. A. 2017. A database of global marine commercial, small-scale, illegal and unreported fisheries catch 1950–2014. *Scientific data*, 4, 170039. https://doi.org/10.1038/sdata.2017.39

FAO AREA 37

AIS-based fishing activity in the Mediterranean and Black Sea

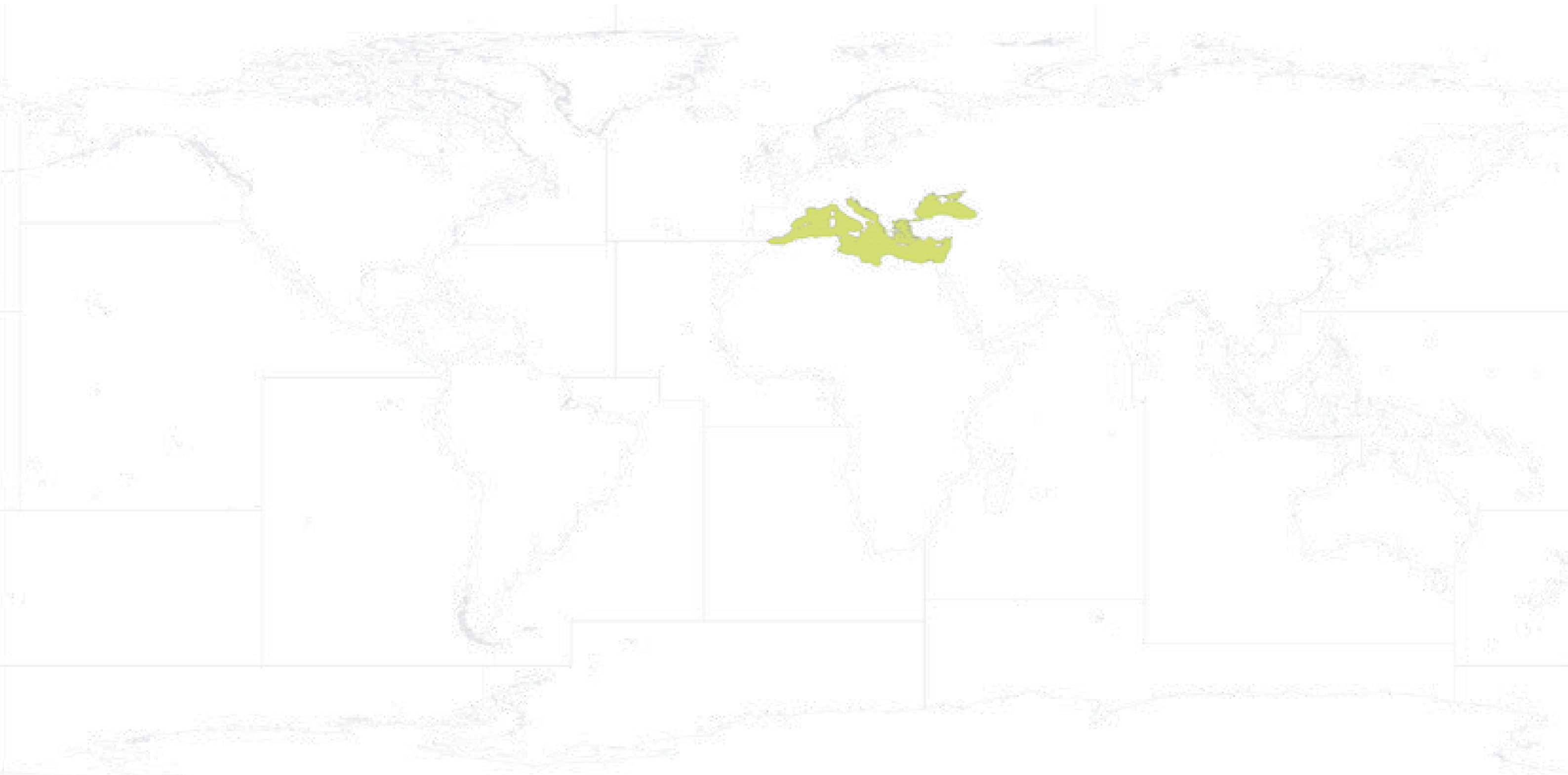


Figure 37. 1. Location of FAO Area 37.

Gorka Merino, Marta Coll, Igor Granado, Jennifer Gee, David Kroodsma, Nathan A. Miller and Jose A. Fernandes

PREAMBLE

This chapter assesses, through a comparison with fleet statistics and public fisheries data, the capacity of Automatic Identification System (AIS) data and Global Fishing Watch (GFW) algorithms (Kroodsma *et al.*, 2018) to identify and quantify fishing vessel activity in the Mediterranean Sea and in the Black Sea. This assessment reviews fleet activity, main gear types, and spatial distribution of fishing vessel activity and fishing operations.

SUMMARY AND CONCLUSIONS FOR THE MEDITERRANEAN AND BLACK SEA

European fleets in the northern half of FAO Area 37 have adopted AIS for almost 100 percent of vessels larger than 15 m, whereas African and Middle East countries have extremely low AIS use in southern and eastern areas where AIS reception is also poor. Most vessels broadcasting AIS in the area use high quality Class A AIS devices, and the AIS reception for Class A is good in the northern Mediterranean. AIS appears to capture a large fraction of trawlers and purse seiners but fails to capture set gillnets and other gears.

INTRODUCTION FOR THE MEDITERRANEAN AND BLACK SEA

The Mediterranean and Black Sea (FAO Area 37; FAO, 2019) comprises all the marine waters bounded, to the west, by the Strait of Gibraltar and, to the southeast, by the northern entrance to the Suez Canal (Figure 37. 1). The following coastal countries/territories border FAO Area 37: Albania, Algeria, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Egypt, France, Georgia, Gibraltar, Greece, Israel, Italy, Lebanon, Libya, Malta, Monaco, Montenegro, Morocco, Palestine, Romania, Russian Federation, Slovenia, Spain, Syria, Tunisia, Turkey and Ukraine (Figure 37. 2). Altogether, 53 percent of the area is under national jurisdiction, while high seas/open areas cover 47 percent of the total marine waters. Notice that the whole Black Sea is under national jurisdiction, therefore all the high seas/open areas concentrate in the Mediterranean Sea. This proportion is slightly lower than the world average for FAO areas (54 percent). The proportion of high seas/open areas in FAO areas ranges between 20 percent and 80 percent.

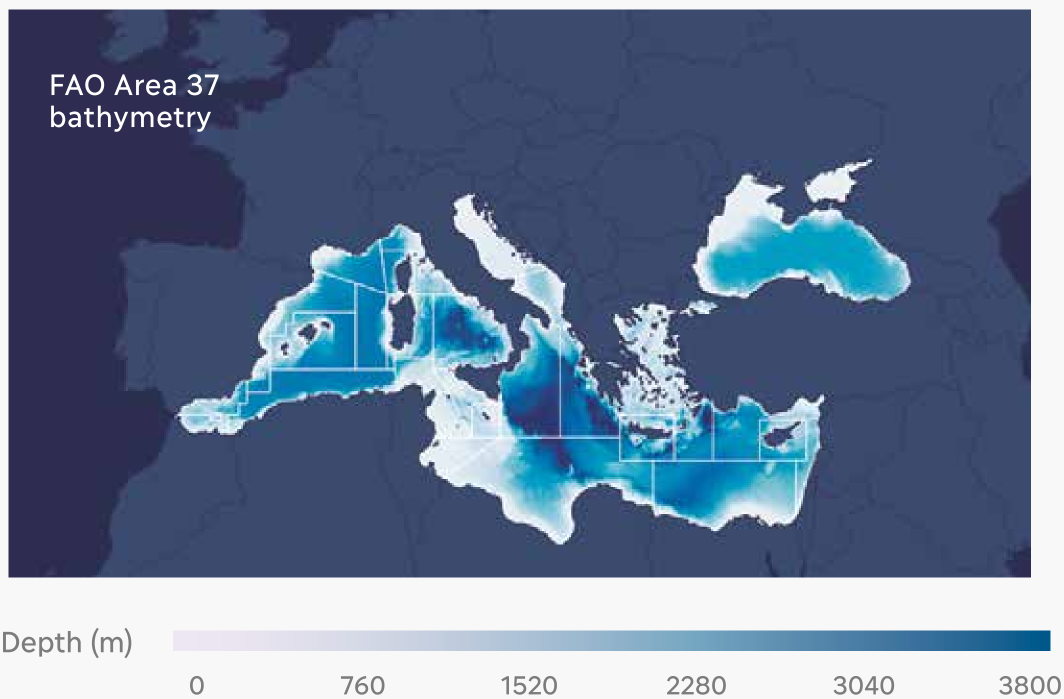


Figure 37. 2. FAO Area 37 bathymetry (depth). Light blue represents shallow waters and dark blue represent deep sea areas.

The Mediterranean Sea is the largest (2 969 000 km^2) and deepest (average 1 460 m and maximum 5 267 m) enclosed sea in the world (Coll *et al.*, 2010). The Mediterranean Sea connects through the Strait of Gibraltar to the Atlantic Ocean in the west and through the Dardanelles to the Sea of Marmara and the Black Sea in the northeast. In the southeast, the Suez Canal links the Mediterranean to the Red Sea and the Indian Ocean. Overall, the Mediterranean Sea is considered oligotrophic (Basterretxea *et al.*, 2018) with some local regions having enhanced productivity such as the Adriatic Sea, Gulf of Lions and areas with a good extent of continental shelf between Tunisia and Sicily. Biological productivity decreases from north to south and from west to east, while salinity and temperature increase from the northwest to the southeast (Coll *et al.* 2010). The Black Sea has an area of 436 400 km^2 which represents 12 percent of FAO Area 37 (FAO, 2016). The Black Sea is distinguished by a low salinity surface layer and a significant anoxic layer below 200 m depth, making it the largest anoxic body of water on the planet (Srour, 2017).

FAO landings statistics (FishStatJ, 2018) for the Mediterranean and Black Sea show that in the period from 2010 to 2014 catches were dominated by small pelagic fishes and a miscellaneous mix of coastal invertebrates and fishes. The largest catches made were for European anchovy, European sardine (*Sardina pilcardus*), European sprat (*Sprattus sprattus*), striped venus (*Chamelea gallina*), round sardinella (*Sardinella aurita*), jack and horse mackerels (*Trachurus picturatus* and *T. trachurus*), bogue (*Boops boops*), Mediterranean horse mackerel (*T. mediterraneus*), European hake (*Merluccius merluccius*), Atlantic bonito (*Sarda sarda*), red mullets and surmullet (*Mullus barbatus and M. surmuletus*), deep-water rose shrimp (*Parapenaeus longirostris*) and various gobies. These species and groups made up 70 percent of the reported catch in the period 2010–2014.

REGION FLEETS AND AIS USE IN THE MEDITERRANEAN AND BLACK SEA

According to FAO statistics, the fleet of coastal states and territories in FAO Area 37 is estimated at around 72 820 fishing vessels (FAO, 2016). Figure 37. 3 shows the distribution of these fleets by vessel size. Vessels over 24 m, which are the vessels most likely to have AIS, account for 2.4 percent of the region's fleets and vessels between 12 and 24 m represent 8.5 percent of the region's fleets in FAO statistics (Figure 37. 3). Most of the vessels under 12 m and non-motorized vessels (respectively 50.9 percent and 23.5 percent of the total fleet) are not likely to have AIS.

Fleets of coastal countries/territories in FAO Area 37

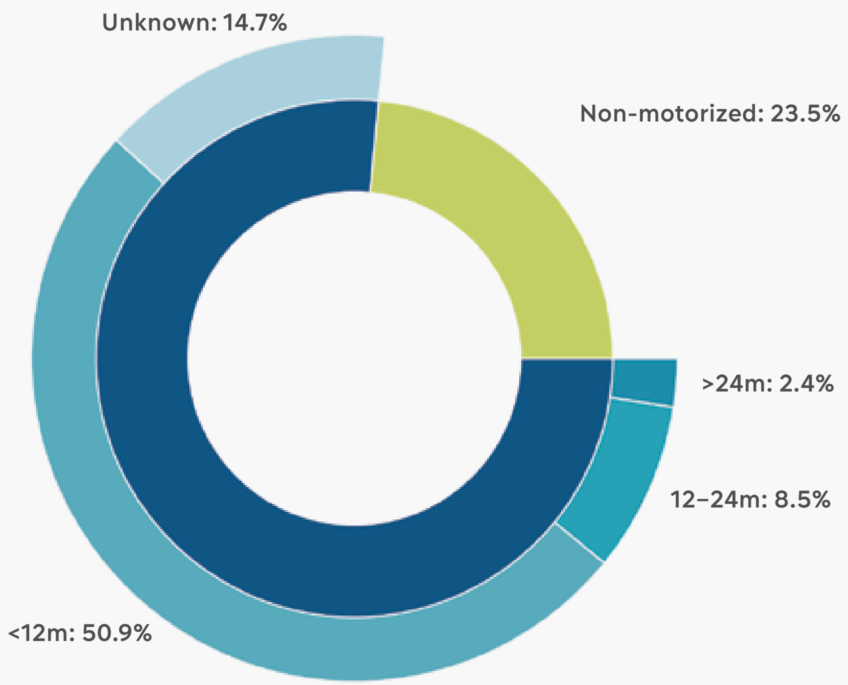


Figure 37. 3. Structural composition of fleets of coastal countries/territories in FAO Area 37. In dark blue motorized fishing vessels and in green non-motorized. Distant water fleets active in FAO Area 37 are not included (see next figure). Notice that Spain is a coastal state adjacent to three FAO areas (27, 34 and 37), France is a coastal state adjacent to two FAO areas (27 and 37) and Morocco is adjacent to two FAO areas (34 and 37). Sources: FAO-GFCM statistics for year 2017. Statistics were not available for the following countries/territories within FAO Area 37: Bosnia and Herzegovina, Monaco, Palestine and Ukraine.

AIS use can be divided into the northern and southern areas of the Mediterranean Sea (Figure 37. 4). In the northern Mediterranean, European fleets have adopted AIS for almost 100 percent of vessels larger than 15 m. By contrast, North African countries have extremely low AIS use, with almost no vessels using this technology. As a result, AIS cannot currently be used to estimate the fishing activity by the African nations in the area (mostly in the southern parts of the Mediterranean Sea) where most of the AIS estimated activity is due to European vessels. This lack of use in northern Africa is due to the poor use of transmitters on board and, to a lesser extent, the lack of terrestrial receptors to capture the AIS signal (Kroodsma *et al.*, 2018). FAO Area 37 also has relatively accessible vessel registries, and out of the 3 588 likely fishing vessels in the area that are broadcasting AIS, 3 132 (83 percent) have been matched to a registry, including information on gear type for 2 687 of them (73 percent). By fleet, Italy has the most vessels broadcasting AIS, followed by Spain and Turkey. Trawlers appear in the AIS registries as being the primary vessels by gear for all fleets except Turkey, where purse seiners dominate.

With regards to vessels over 15 m identified by AIS (Figure 37. 4) trawlers and purse seiners are dominant across Mediterranean Sea subareas (mostly off northeast Spain, in the Gulf of Lions, off Liguria, and in the Tyrrhenian and Adriatic seas). At a lower scale, drifting longliners operate in the eastern and western edges of the Mediterranean (Levantine sea, Northern Spain and Alboran sea). In the Black Sea, Russian and Ukrainian trawlers operate in the west and purse seiners in the east, with few operations from dredgers. Some activity is also found in the Azov sea. Trawler activity in this area can be overestimated when relying in the European Union Fleet Register due to misidentification of primary and secondary gears reported (Ferrà *et al.*, 2018).

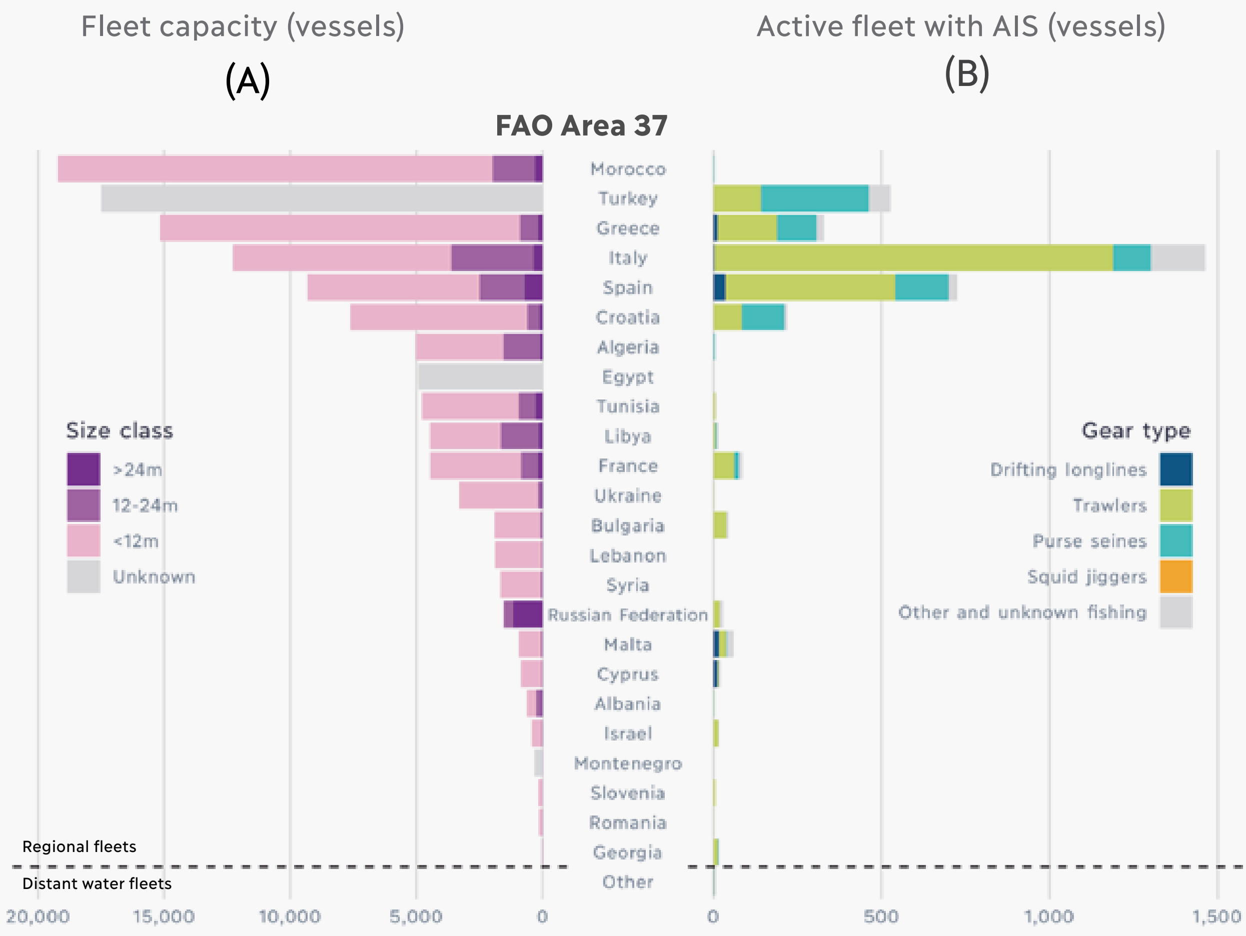


Figure 37. 4. Summary of coastal and distant fleets based on FAO statistics and AIS data classification by GFW in FAO Area 37 during year 2017. A) Number of motorized vessels as reported to FAO (left panel). The entire fleets of coastal countries/territories are displayed, even though these fleets may be active in other FAO areas. Sources: FAO-GFCM statistics. Statistics were not available for the following coastal countries/territories within FAO Area 37: Bosnia and Herzegovina, Gibraltar, Monaco, Palestine and Ukraine. B) AIS-identified number of fishing vessels broadcasting AIS during their operations in FAO Area 37 by gear type and flag state (right panel). Dashed lines separate regional fleets (top) from distant fleets (bottom). Only vessels that fished for at least 24 hours in the area are included. Source: GFW.

AIS RECEPTION AND FISHING VESSEL ACTIVITY IN THE MEDITERRANEAN AND BLACK SEA

Figure 37. 5 shows all operations of fishing vessels (fishing, searching, in transit) captured by AIS in FAO Area 37 (Class A and Class B AIS devices). Most of the vessels in this area use high-quality Class A devices, with only around 500 of over 3 500 vessels using lower quality Class B devices. The top row of Figure 37. 5 shows the presence of vessels using Class A and Class B. Almost no vessels from northern Africa broadcast AIS. In terms of AIS reception (bottom row of Figure 37.5), Class A performs relatively well in the northern Mediterranean. Class A reception is worse in the southern Mediterranean, especially in the eastern central region. Class B reception is more difficult to assess across the area, because vessels using Class B devices account for less than 10 percent of the fishing hours in the area.

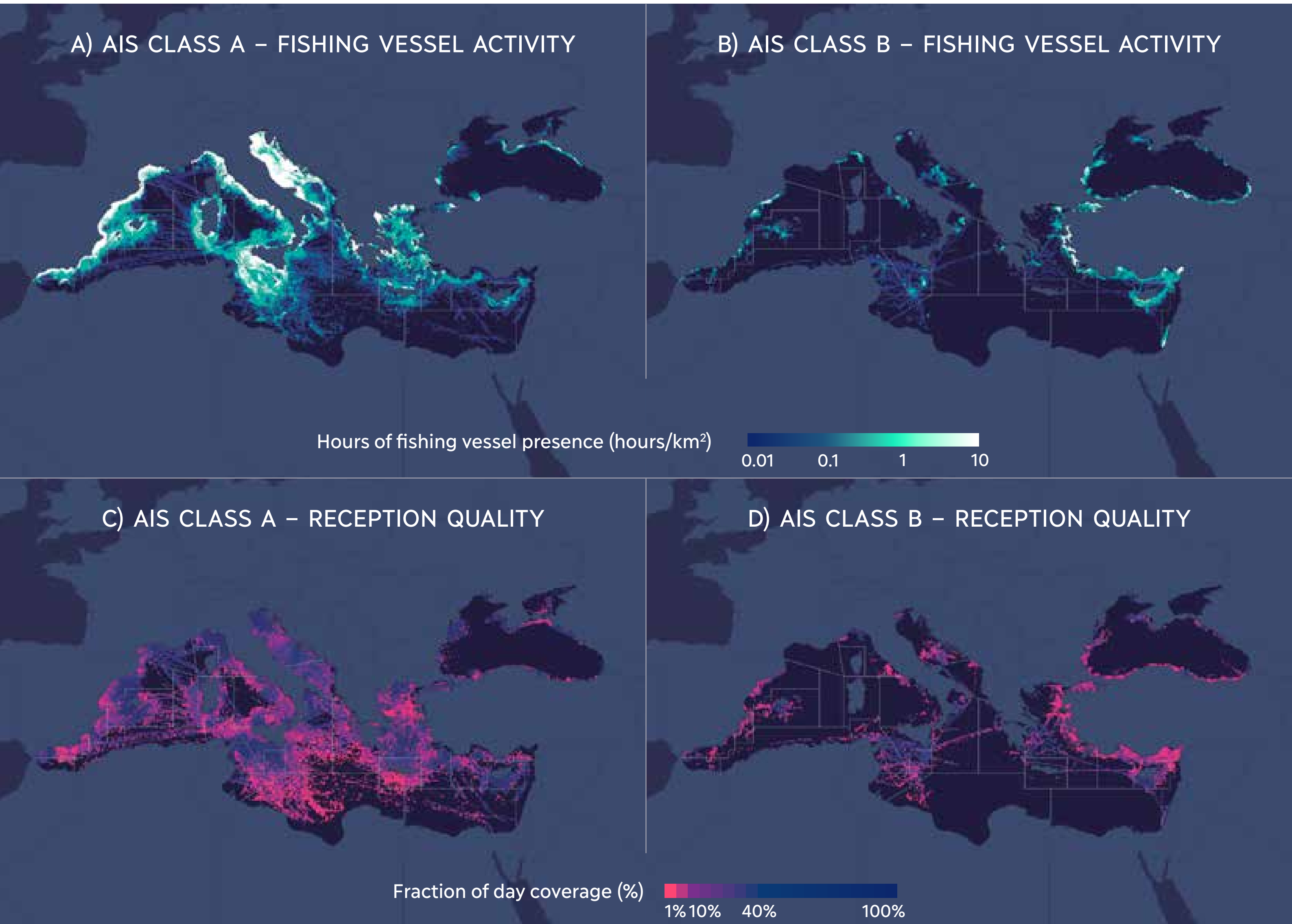


Figure 37. 5. Fishing vessel activity and quality of AIS reception for FAO Area 37 during 2017. Top row shows activity of vessels broadcasting using Class A devices (left panel) and Class B devices (right panel). The bottom row shows reception quality maps for devices Class A (left panel) and B (right panel). Blank spaces on the map (i.e. dark blue ocean background) mean that no signals from fishing vessels in this area were received, which is due to either no vessel activity or poor reception.

The AIS fishing operations (Figure 37. 6) show the European fishing activity recorded by the AIS mainly in the coastal areas of the North and North western Mediterranean. As mentioned earlier, vessels operating in the Mediterranean southern areas are not equipped with AIS and have poor signal reception. However, it is well known that Mediterranean vessels, specifically trawlers, operate in coastal and shelf areas and nearby canyons targeting demersal species. Purse seiners generally operate in coastal areas targeting small pelagic fish.

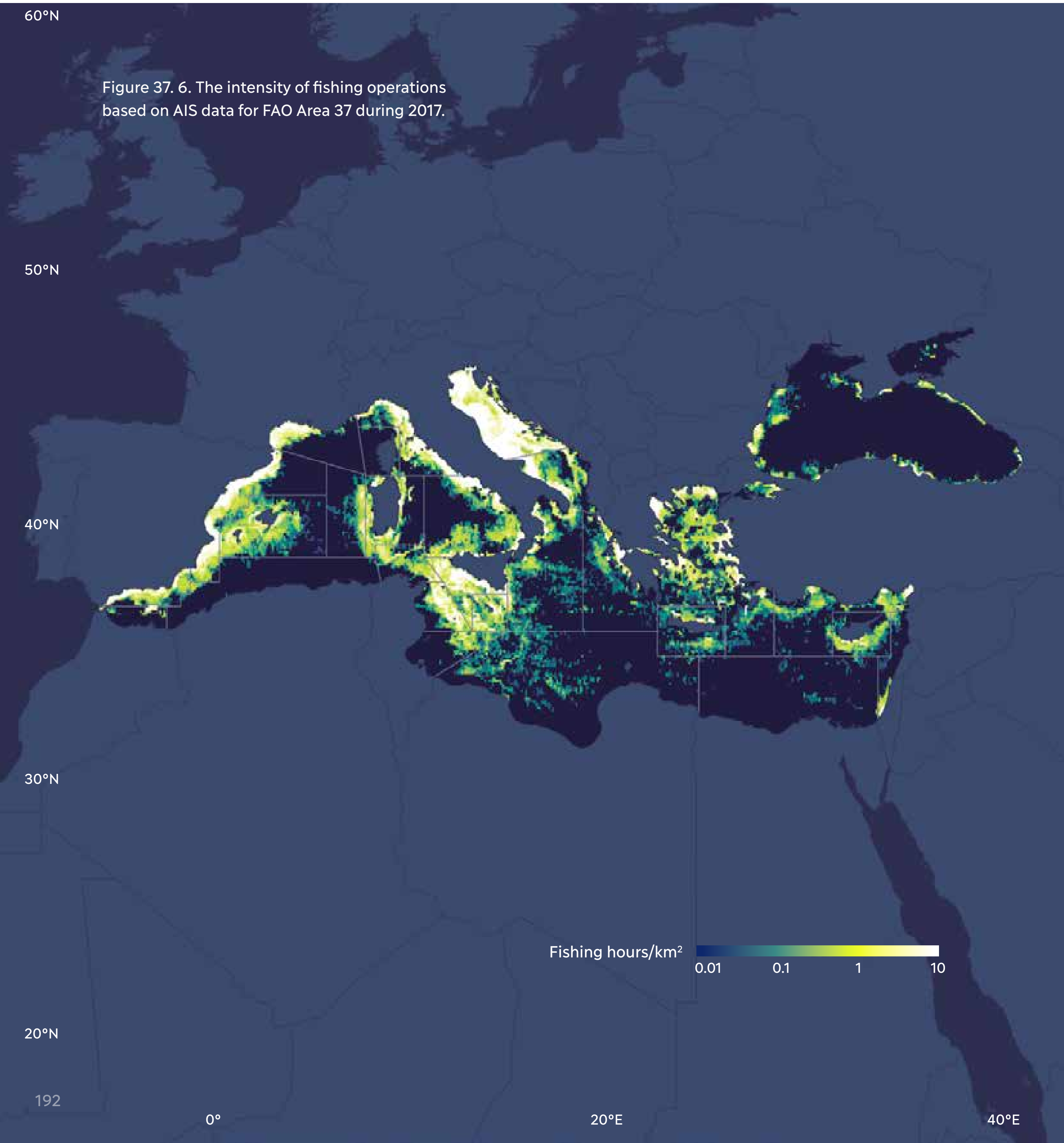


Figure 37. 6. The intensity of fishing operations based on AIS data for FAO Area 37 during 2017.

FISHING VESSEL ACTIVITY AND OPERATIONS BY GEAR IN THE MEDITERRANEAN AND BLACK SEA

This section reviews the spatial distribution patterns of the main fishing gears in FAO Area 37 as estimated by GFW based on 2017 AIS data. The most recent datasets available at mid-2018 were used to assess GFW capacity to provide an AIS based characterization of fishing activity by fishing gear in terms of presence/absence, intensity and hotspots. The Introduction chapter describes the rationale and challenges for the use of contrasting data sources (e.g. Global Fisheries Landings database (GFLD; Watson, 2017)) for benchmarking AIS data classification.

Table 37. I. compares the activity percentage for each fishing gear in this area and shows that AIS detects the main fishing gears: trawlers and purse seiners. However, the fraction of trawler fishing activity detected by GFW based on AIS data is much higher than that of the catch data (GFLD). In contrast, AIS seems to underrepresent set gillnets and other gears' activity.

GEAR TYPES	Catches (GFLD) 2010–2014 average		Total fishing vessel activity (GFW-AIS) 2017	
	Tonnes of catch in 1000s	% of catch	Active days in 1000s	% of active days
Trawls	415	38%	336.3	71%
Purse seines	327	29%	100.1	21%
Set gillnets	116	11%	31,1	6%
Other	246	21%		
Drifting longlines	11	1%	7.5	2%
Total	1 115	100%	474.1	100%

Table 37. I. Summary table comparing average catch from GFLD during 2010–2014 with fishing vessel activity from GFW in FAO Area 37. Only vessels that fished for at least 24 hours in FAO Area 37 are included.

Trawling is the major fishing activity method in the northern area of the Adriatic Sea and the coasts of northeastern Spain, the Aegean Sea, southern Sicily and Alboran areas, and is also well represented in the northern part of the Black Sea. However, AIS data fail to describe the fishing activity off southern Levant. AIS also misses important fishing vessel activity in the continental shelves of the North African countries, such as the Gulf of Gabes, where an important fishing activity exists (Hattab *et al.*, 2013).

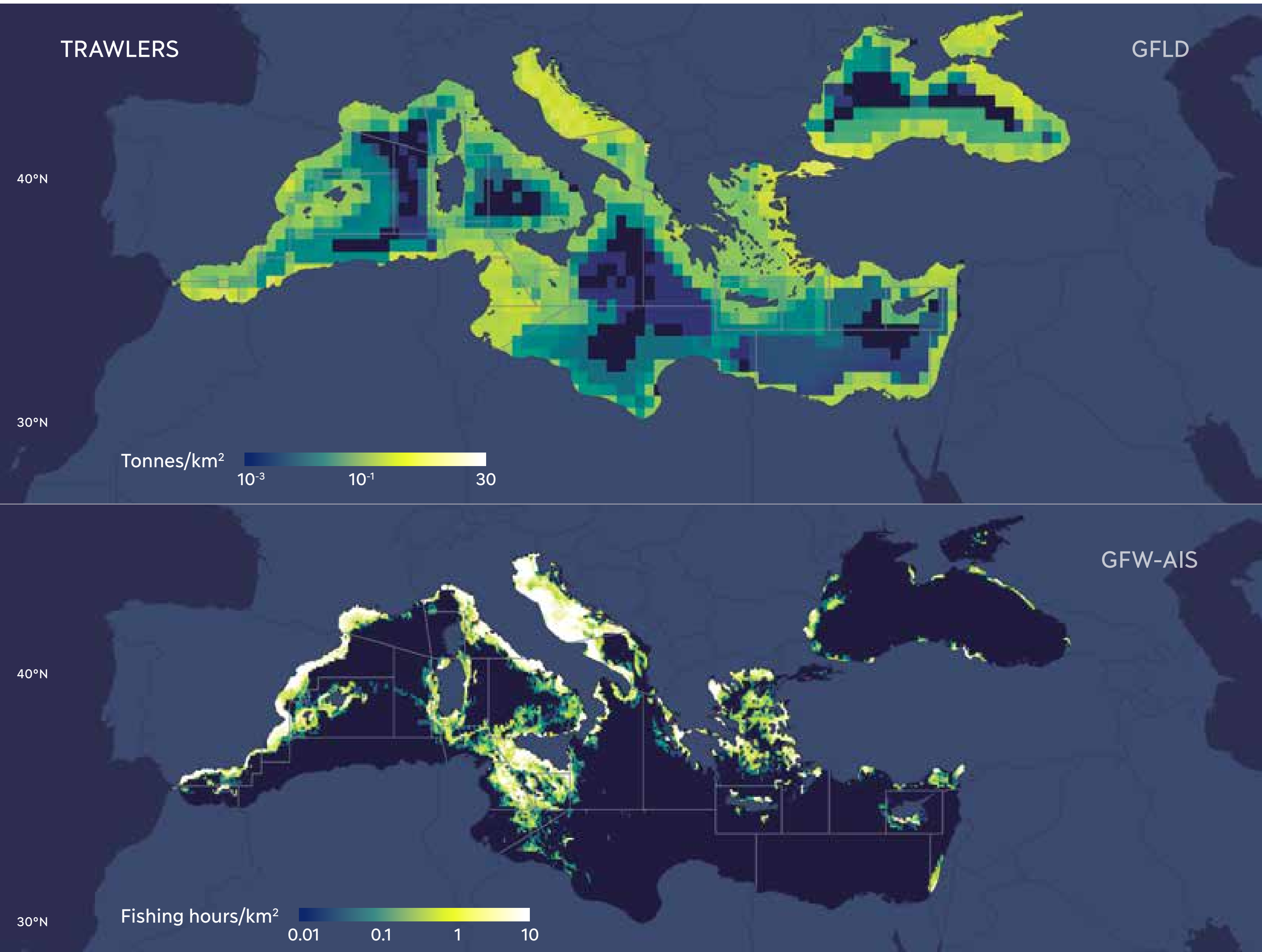


Figure 37. 7. Catch and activity of trawlers in FAO Area 37. Maps comparing average catch during 2010–2014 from GFLD (top panel) with trawlers fishing operations in 2017 from GFW (bottom panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

The AIS detects drifting longline activity in the western and eastern areas of the Mediterranean basin as well as in the areas south of Sicily despite GFLD showing activity in almost all the Mediterranean Sea. This mismatch is likely due to the fact that operating drifting longliners are mostly small-scale vessels not using AIS. Another possible explanation is that there might be an overrepresentation of drifting longline activity off the Spanish coasts where other gears' activity is misclassified as drifting longliners. On the other hand, there is an underrepresentation in the Tyrrhenian area, in the Ionian Sea and in the Central and Southern Adriatic Sea where the activity of this gear is excluded due to a mis-codification of longliners in the vessel registry classification, which in turn impacts the classification of the GFW algorithm. The observed pattern may also reflect, at least partially, the main concentration areas of large pelagic fish in the Mediterranean Sea (Druon *et al.*, 2016) and suitable survival habitat (Reglero *et al.*, 2018) where drifting longliners target swordfish (*Xiphias gladius*), bluefin tuna (*Thunnus thynnus*) and albacore (*T. alalunga*), (Tserpes and Peristeraki, 2015; FAO, 2016). Longliners also target demersal species in this area (FAO, 2016).

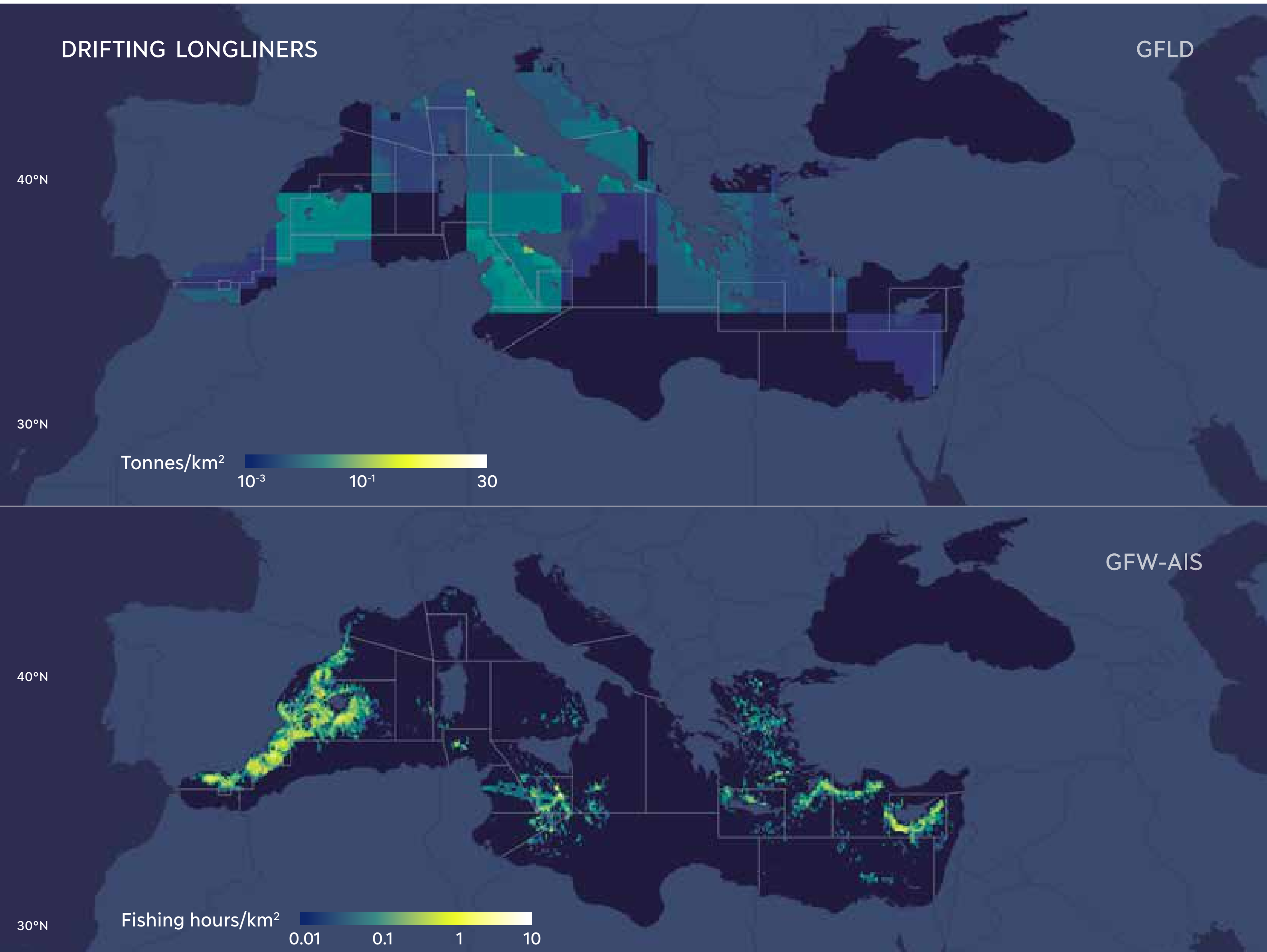


Figure 37. 8. Catch and activity of longliners in FAO Area 37. Maps comparing average catch during 2010–2014 from GFLD (top panel) with longliners fishing operations in 2017 from GFW (bottom panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

The purse seine activity detected by AIS corresponds to European fleets operating in the coastal areas of the eastern and western Mediterranean and all along the Italian and Greek coasts, due to the coastal distribution of most of the small pelagic fish species targeted by purse seiners (Palomera *et al.*, 2007). The French coast shows little fishing activity in AIS despite French purse seiners historically operating in the area and targeting small pelagic species. This lack of activity is probably explained by the collapse of this fishery in the Gulf of Lion (van Beveren *et al.*, 2016). Other areas where AIS seems to miss fishing activity are the Ebro Delta area and the central and northern Adriatic Sea.

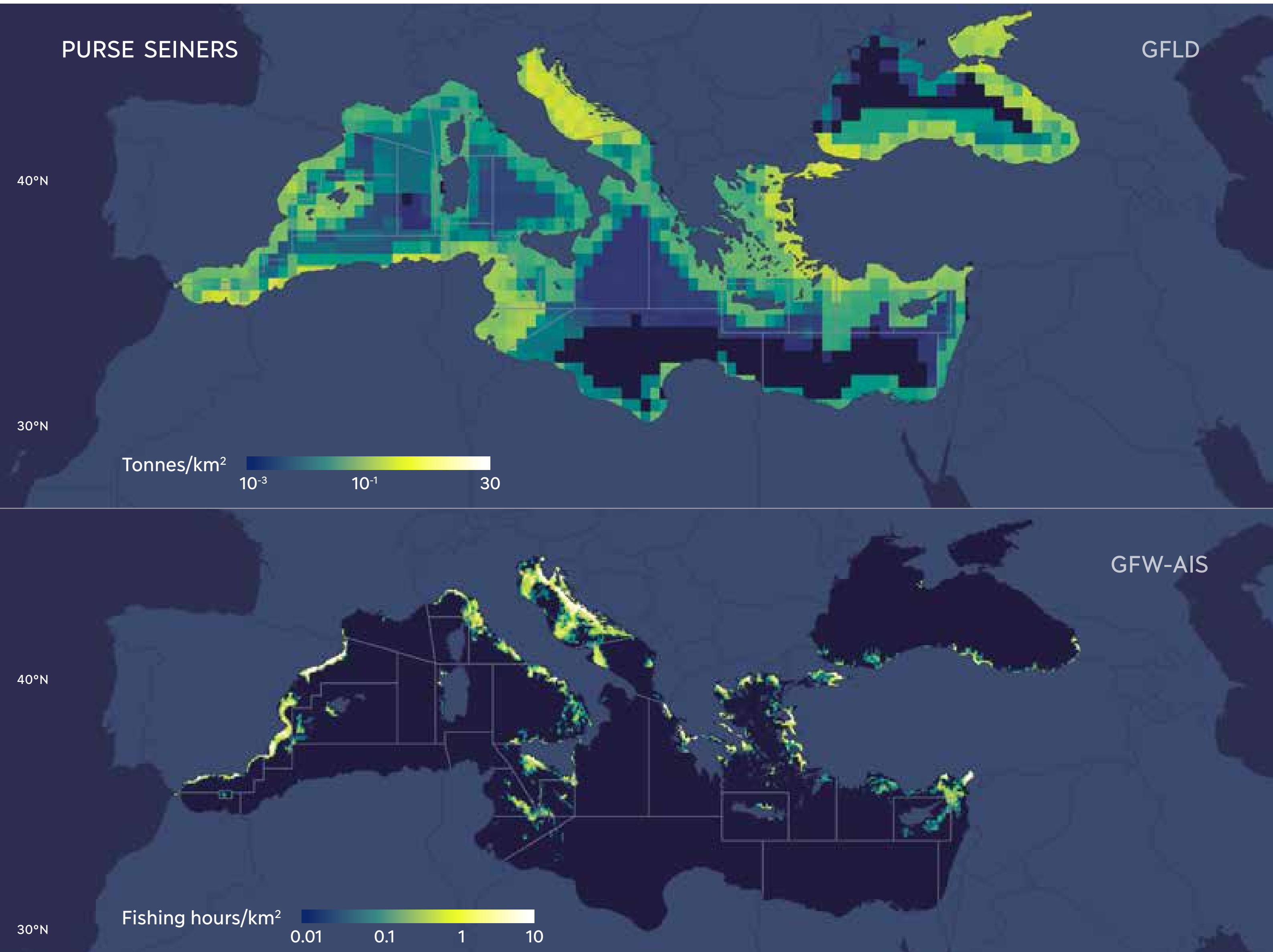


Figure 37. 9. Catch and activity of purse seiners in FAO Area 37. Maps comparing average catch during 2010–2014 from GFLD (top panel) with purse seiners fishing operations in 2017 from GFW (bottom panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

ACKNOWLEDGEMENTS

The editors would like to thank Manuel Hidalgo and Dario Pinello for excellent comments and feedback during the elaboration of the chapter. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Required citation for this chapter:

Merino, G., Coll, M., Granado, I., Gee, J., Kroodsma, D., Miller, N. A., Fernandes, J. A. 2019. FAO Area 37 - AIS-based fishing activity in the Mediterranean and Black Sea. *In* Taconet, M., Kroodsma, D., Fernandes, J.A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

Basterretxea, G., Font-Muñoz, J. S., Salgado-Hernanz, P. M., Arrieta, J., & Hernández-Carrasco, I. 2018. Patterns of chlorophyll interannual variability in Mediterranean biogeographical regions. *Remote Sensing of Environment*, 215, 7-17. https://doi.org/10.1016/j.rse.2018.05.027

Coll, M., Piroddi, C., Steenbeek, J., Kaschner, K., Lasram, F. B. R., Aguzzi, J.,... & Danovaro, R. 2010. The biodiversity of the Mediterranean Sea: estimates, patterns, and threats. *PloS one,* 5(8), e11842. https://doi.org/10.1371/journal.pone.0011842

Druon, J. N., Fromentin, J. M., Hanke, A. R., Arrizabalaga, H., Damalas, D., Tičina, V.,... & Reglero, P. 2016. Habitat suitability of the Atlantic bluefin tuna by size class: An ecological niche approach. *Progress in oceanography*, 142, 30-46. https://doi.org/10.1016/j.pocean.2016.01.002

FAO. 2016. *The State of Mediterranean and Black Sea Fisheries 2016.* General Fisheries Commission for the Mediterranean. Rome, FAO. http://www.fao.org/3/a-i5496e.pdf

FAO. 2019. *Food and Agriculture Organization of the United Nations. FAO Major Fishing Areas. Mediterranean and Black Sea (Major Fishing Area 37).* http://www.fao.org/fishery/area/Area37/en

Ferrà, C., Tassetti, A. N., Grati, F., Pellini, G., Polidori, P., Scarcella, G., & Fabi, G. 2018. Mapping change in bottom trawling activity in the Mediterranean Sea through AIS data. *Marine Policy*, 94, 275-281. https://doi.org/10.1016/j.marpol.2017.12.013

FishStatJ. 2018. Fisheries and aquaculture software. FishStatJ - software for fishery statistical time series. *In* FAO Fisheries and Aquaculture Department [online]. Rome. Updated 21 July 2018. [Cited 19 November 2018]. http://www.fao.org/fishery/statistics/software/fishstatj/en

Hattab, T., Lasram, F. B. R., Albouy, C., Romdhane, M. S., Jarboui, O., Halouani, G.,... & Le Loc'h, F. 2013. An ecosystem model of an exploited southern Mediterranean shelf region (Gulf of Gabes, Tunisia) and a comparison with other Mediterranean ecosystem model properties. *Journal of Marine Systems*, 128, 159-174. https://doi.org/10.1016/j.jmarsys.2013.04.017

Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F.,... & Woods, P. 2018. Tracking the global footprint of fisheries. *Science*, 359(6378), 904-908. https://doi.org/10.1126/science.aao5646

Palomera, I., Olivar, M. P., Salat, J., Sabatés, A., Coll, M., García, A., & Morales-Nin, B. 2007. Small pelagic fish in the NW Mediterranean Sea: an ecological review. *Progress in Oceanography*, 74(2-3), 377-396. https://doi.org/10.1016/j.pocean.2007.04.012

Reglero, P., Balbín, R., Abascal, F. J., Medina, A., Alvarez-Berastegui, D., Rasmuson, L.,... & de la Gándara, F. 2018. Pelagic habitat and offspring survival in the eastern stock of Atlantic bluefin tuna. *ICES Journal of Marine Science*, fsy135. https://doi.org/10.1093/icesjms/fsy135

Srour, A., Massa, F., Bernal, M., Ferri, N., Sessa, M., Bourdenet, D.,... & Siliman, A. 2017. *GFCM High-level conference towards enhanced cooperation on Black Sea fisheries and aquaculture: a declaration to boost regional cooperation in the sector. 24-25 October 2016,* Bucharest, Romania. FAO. http://www.fao.org/3/a-i7109e.pdf

Tserpes, G., & Peristeraki, P. 2015. *Temporal CPUE trends of the Greek drifting longline swordfish fisheries in the east Mediterranean.* Collect. Vol. Sci. Pap. ICCAT, 71(5), 2015-2020. https://www.iccat.int/Documents/CVSP/CV071_2015/n_5/CV071052015.pdf

Van Beveren, E., Fromentin, J. M., Rouyer, T., Bonhommeau, S., Brosset, P., & Saraux, C. 2016. The fisheries history of small pelagics in the Northern Mediterranean. *ICES Journal of Marine Science*, 73(6), 1474-1484. https://doi.org/10.1093/icesjms/fsw023

Watson, R. A. 2017. A database of global marine commercial, small-scale, illegal and unreported fisheries catch 1950–2014. *Scientific data*, 4, 170039. https://doi.org/10.1038/sdata.2017.39

FAO AREA 41

AIS-based fishing activity in the Southwest Atlantic

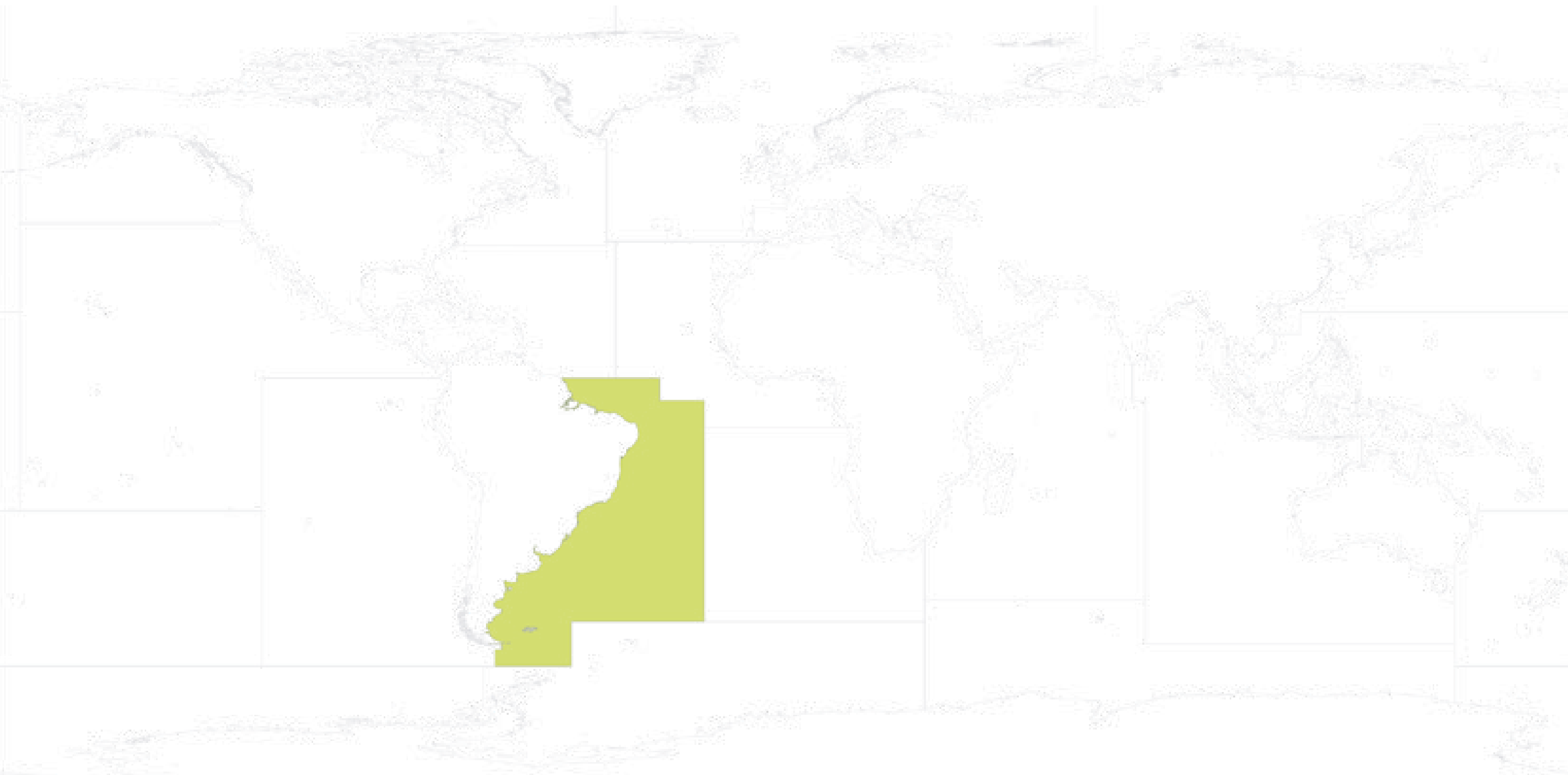


Figure 41. 1. Location of FAO Area 41.

Haritz Arrizabalaga, Igor Granado, David Kroodsma, Nathan A. Miller, Marc Taconet and Jose A. Fernandes

PREAMBLE

This chapter assesses, through a comparison with fleet statistics and public fisheries data, the capacity of Automatic Identification System (AIS) data and Global Fishing Watch (GFW) algorithms (Kroodsma *et al.*, 2018) to identify and quantify fishing vessel activity in the Southwest Atlantic Ocean. This assesment reviews fleet activity, the main gear types, and the spatial distribution and intensity of fishing.

SUMMARY AND CONCLUSIONS FOR THE SOUTHWEST ATLANTIC

AIS use is high by Argentina, Uruguay, the Falkland Islands and foreign fleets fishing in the southern half of the area. Farther north, in the Brazilian EEZ, AIS provides a poor assessment of activity due to low use of AIS. The AIS reception for class A is excellent across the area, while it is poor for class B. There is a high number of distant fleets operating in the area. AIS data identify well the high importance of the fishing activity by trawlers. AIS shows that the area has an important activity by squid jiggers and to a lesser extent longliners. However, these might be overrepresented in relation to other gears used by smaller vessels not using AIS.

Figure 41. 2. FAO Area 41 bathymetry (depth) and 200 miles coastal arc.

INTRODUCTION FOR THE SOUTHWEST ATLANTIC

The Southwest Atlantic (FAO Area 41) comprises all the marine waters bounded by the South American coast, specifically by the coastlines of Brazil, Uruguay and Argentina (Figure 41. 1). In addition to the above mentioned three countries, the Falkland Islands (Malvinas) also border FAO Area 41 (Figure 41. 2). Just one third of the area's waters are under national jurisdiction, leaving over two thirds in the high seas. The fraction of ocean in the high seas is slightly higher than all the FAO areas' average (about 54 percent).

The continental shelf is narrow in the north (except near the Amazon river estuary) and widens southwards with gentle slopes and low relief becoming very extended and spanning into the high seas at the southeastern end of South America. The soft sand bottom predominates in 65 percent of its surface off Argentina, while rocky, hard bottoms are very limited in area (Villasante *et al.*, 2015). FAO Area 41 encompasses four distinctly different biogeographic areas considered as different large marine ecosystems (LMEs): the northeast coast of South America (North Brazil Shelf), the East Brazil Shelf, the South Brazil Shelf and the Patagonian Shelf, as well as a large area of high seas linked by major ocean currents.

FAO landings statistics (FishStatJ, 2018) show that in the period from 2010 to 2014, catches were dominated by invertebrate and pelagic fish species. The largest catches have been made of Argentine shortfin squid *(Illex argentinus)*, Argentine hake *(Merluccius hubbsi)*, Whitemouth croaker *(Whitemouth croaker)*, Argentine red shrimp *(Pleoticus muelleri)*, Patagonian grenadier *(Macruronus magellanicus)*, Brazilian sardinella *(Sardinella brasiliensis)*, Patagonian squid *(Doryteuthis gahi)*, Antarctic rockcods, Patagonian toothfish *(Dissostichus eleginoides)*, unspecified marine fishes, Patagonian scallop (*Zygochlamys patagonica*), Rays/stingrays/mantas, Sea catfishes and Skipjack tuna. These species items made up 70 percent of the reported catch in that period. This is one of the FAO Statistical Areas where capture fisheries grew rapidly until the late 1990s. In the last decade, total catches from Area 41 have stabilized, although with marked interannual fluctuations. According to the FAO database, total catches have fluctuated between 1.7 – 2.6 million tonnes (after a period of increase that ended in the mid-1980s), reaching 2.4 million tonnes in 2015 and decreasing to 1.5 million tonnes in 2016 (Sofia, 2018). According to Agnew et al (2009), illegal fishing in this area shows an increasing trend and it was estimated to be equivalent to over 30 percent of reported catches in the early 2000's. The coverage of international Regional Fisheries Bodies RFBs) or Regional fisheries management organisations (RFMOs) seem to be lower than in other FAO areas. In this area there is a RFB, the Joint Technical Commission of the Maritime Front (CTMFM), and a RFMO, the Commission for the Conservation of Southern Bluefin Tuna (CCSBT).

FLEETS AND AIS USE IN THE SOUTHWEST ATLANTIC

The fleets are dominated by non-motorized vessels (Figure 41. 3), almost all of which are from Brazil (Fig 41.4). The proportion of non-motorized vessels, over 60 percent, is much higher than the global average of 39 percent (based on SOFIA, 2018). Brazil has more than 90 percent of the vessels among the coastal fleets, reporting no large vessels but many smaller ones. Vessels over 24 m, which are the vessels most likely to have AIS, are mainly from Argentina and to a minor extent from Uruguay and the Falkland Islands (Malvinas), and account for 0.6 percent of fishing vessels in the region (Figure 41.3).

Fleets of coastal countries/territories in FAO Area 41

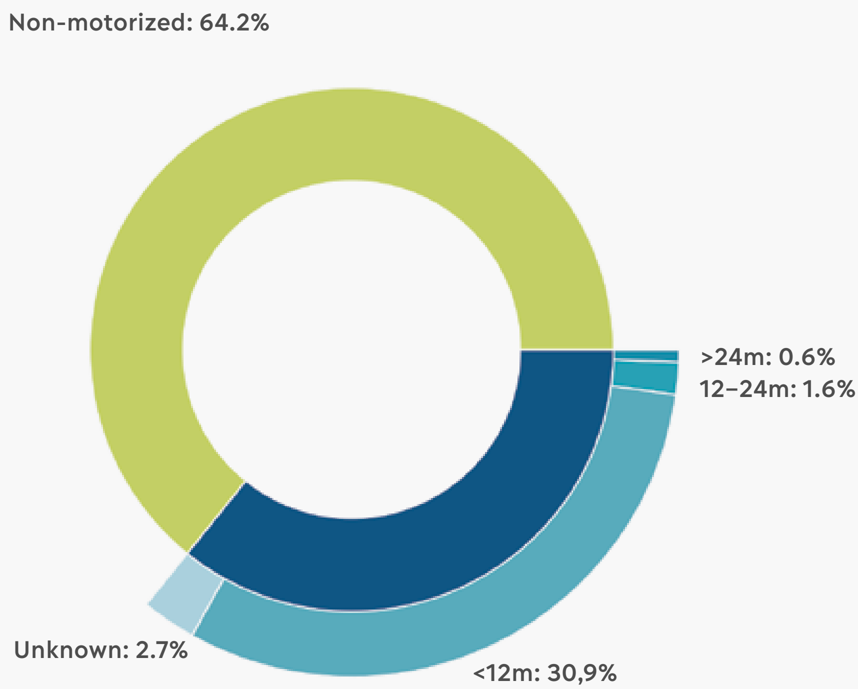


Figure 41. 3. Structural composition of fleets of coastal countries/territories in FAO Area 41. In dark blue motorized fishing vessels and in green non-motorized. Distant water fleets active in FAO Area 41 are not included (see next figure). Note that although some Brazilian vessels may fish outsige Area 41, its entire fleet size is included here. Source: FAO statistics for year 2017.

AIS use is high in Argentina and Uruguay, with about 80 percent of the vessels over 24 m broadcasting AIS in Argentina and almost 100 percent in Uruguay. The Falkland Islands (Malvinas) small fleet also has very good AIS use and almost all vessels larger than 24 m have AIS. AIS use is much lower in Brazil where only about a third of the nation's large vessels broadcast AIS. In the south of Brazil (States of Rio Grande do Sul and Santa Catarina) there is an important fleet of boats between 14 and 24 m length (mainly gillnet, but also trawlers and some

longliners). China and Taiwan Province of China are both very active, and these high seas fleets are estimated to have a high proportion of the vessels broadcasting AIS. Over three quarters of the 1 050 vessels operating in the area have been matched to registries, and just under two thirds broadcast Class A AIS. Figure 41. 4 shows the number of vessels by flag state, as well as the composition of gear types within each flag state during 2017. In terms of vessels fishing in the area, Argentina and China are the dominant flags, followed by Brazil, Taiwan Province of China, the Republic of Korea and Uruguay. Trawlers operate mainly in EEZs of coastal South American countries (Argentina, Brazil, and Uruguay). Asian countries use mostly squid jiggers, and to a lesser extent, drifting longlines. These longlines operate in international waters, while some Brazilian longliners also operate in EEZs (Figure 41. 1). The continental South American countries (Argentina, Brazil, and Uruguay) use mostly trawlers, but also a wide range of other fishing gears. These countries have high number of vessels of unknown gear type, largely due to the neural net classifier having low confidence in the classification of these vessels. The low confidence is partially because there is not much training data for this part of the world (registries with gear type were not available for Argentina, Uruguay and Brazil). Many of these "unknown" vessels are likely trawlers, based both on the neural net (the most likely category for many of these vessels is trawler, although the confidence is low) and based on catch statistics (see later section).

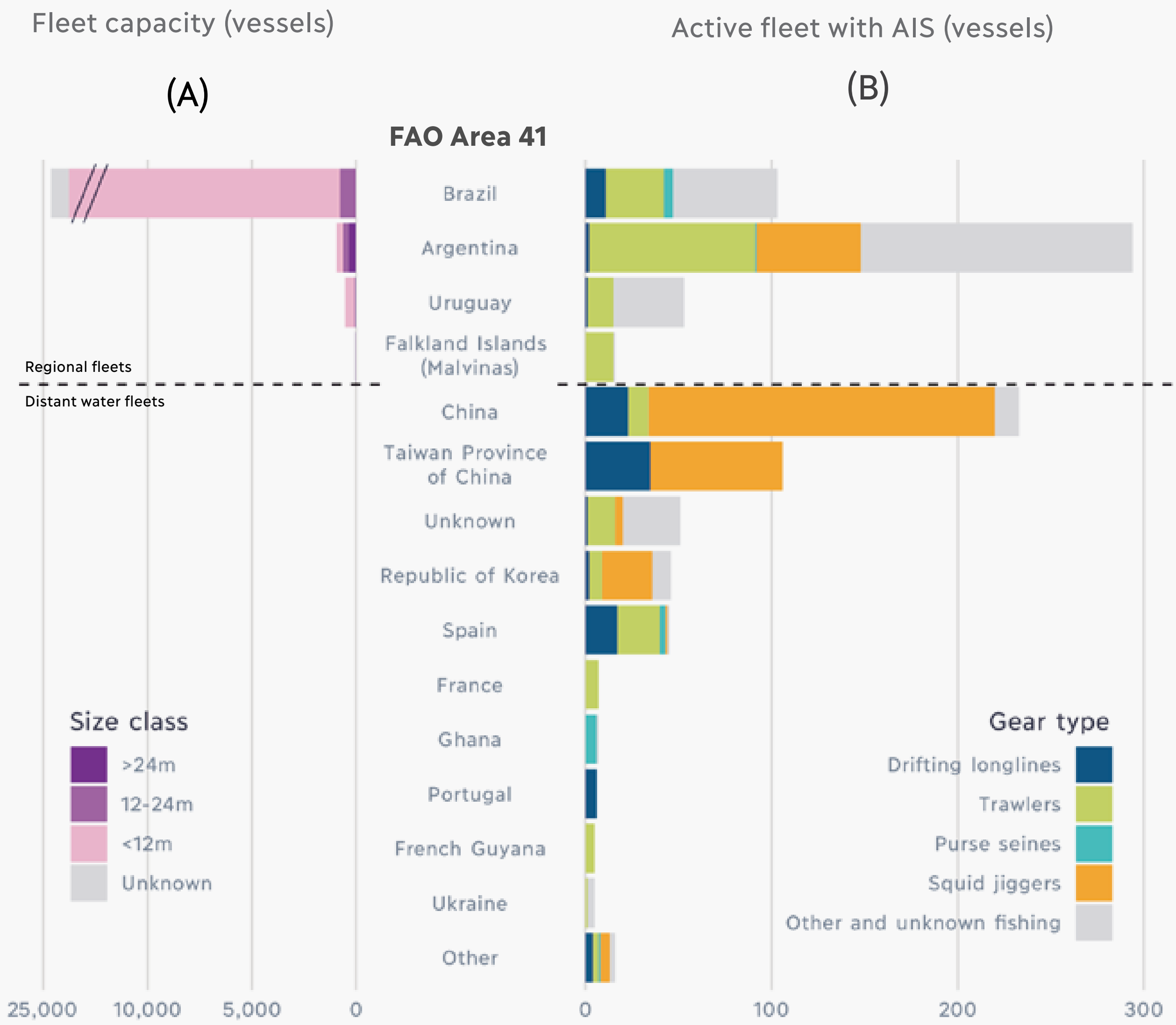
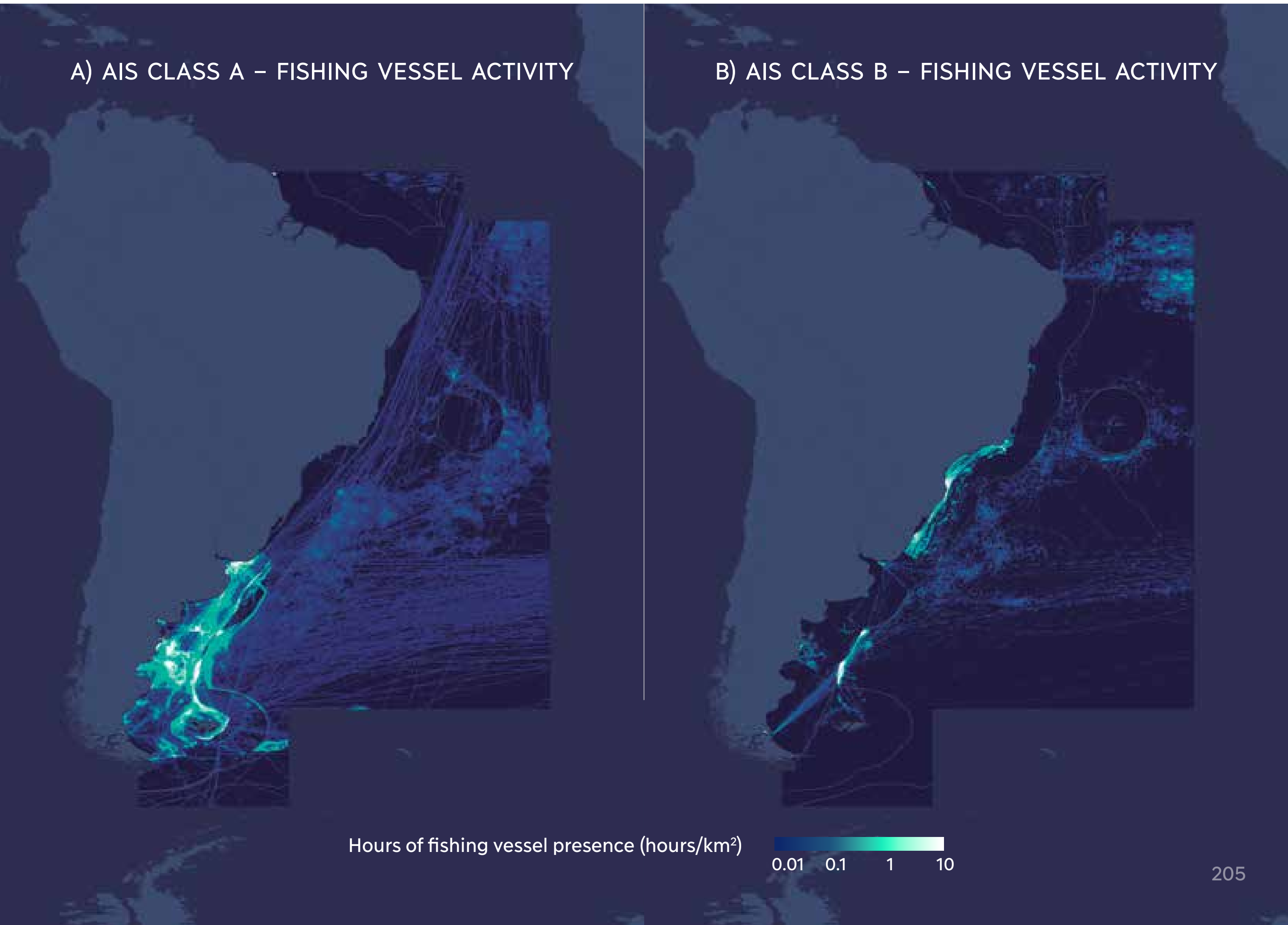


Figure 41.4 Coastal and distant fleets summary based on FAO statistics and AIS data classification by GFW in FAO Area 41 during year 2017. A) Number of motorized vessels as reported to FAO (left panel). The entire fleets are shown even though Brazzilian vessels may fish in other FAO areas. Source: FAO statistics. B) AIS-identified number of fishing vessels broadcasting AIS during their operations in FAO Area 41 by gear type and flag state (right panel). Slashed lines separate regional fleets (top) from distant fleets (bottom). Only vessels that fished for at least 24 hours in the area are included. Source: GFW.

AIS RECEPTION AND FISHING VESSEL ACTIVITY IN THE SOUTHWEST ATLANTIC

Figures 41. 5a,b show all the operational activities of fishing vessels (fishing, searching, in transit) captured by AIS in FAO Area 41 (class A and class B AIS devices). In this area, about 80 percent of vessels use high quality Class A devices. Lower quality Class B devices are, though, more common in the Brazilian fleet and in the Chinese fleet operating in the high seas. The AIS reception for class A is excellent across the area (Figure 41. 5c), while it is generally poor for class B except in southern parts of the area (Figure 41. 5d). The intense activity by vessels just outside the boundary with Argentina's EEZ to the north of the Falkland Islands (Malvinas), where many vessels cluster, has poor Class B reception and activity by vessels in this area thus is likely underestimated.



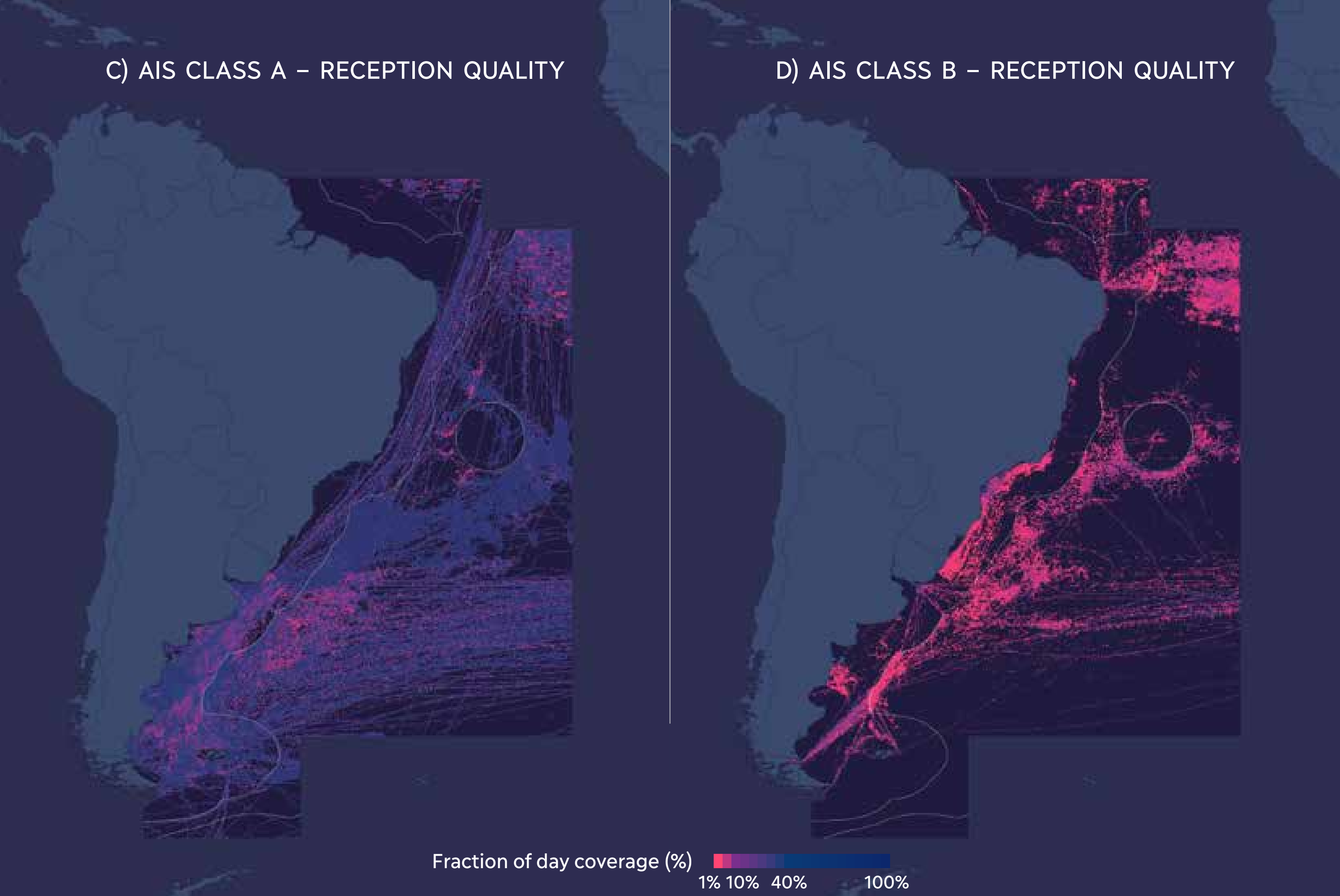
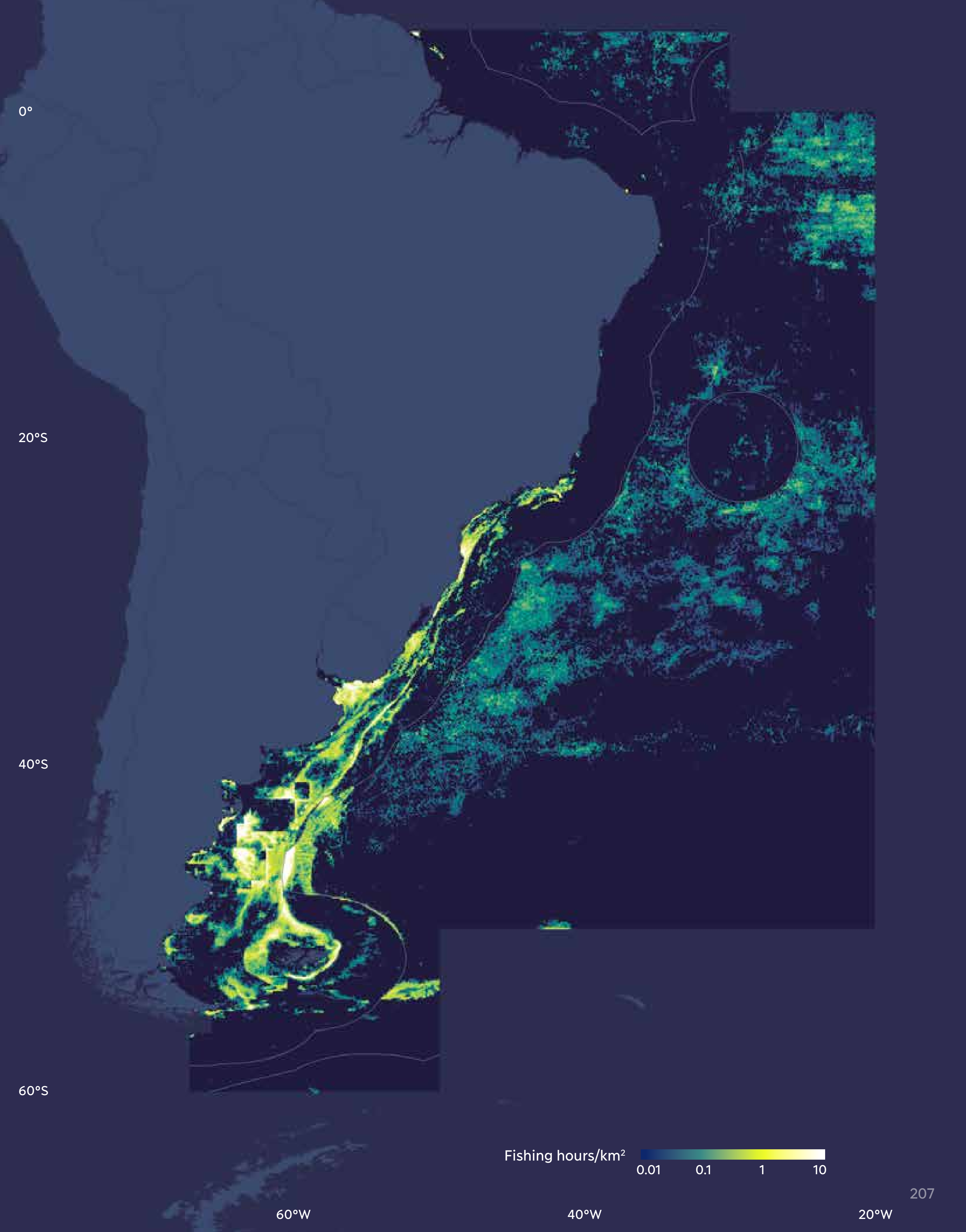


Figure 41. 5. All activity of fishing vessels based on AIS data for FAO Area 41 during 2017 without discriminating between different activities (e.g. fishing, searching, in transit). Top row shows activity of vessels broadcasting using Class A devices (left panel) and Class B devices (right panel). The bottom row shows receptions quality maps for devices class A (left panel) and B (right panel). Blank spaces on the map (i.e. dark blue ocean background) mean that no signals from fishing vessels in that area were received even though vessels might be present.

AIS data detects more of the fishing operations in the southern countries' EEZs (Figure 41. 6), namely Uruguay, Argentina and the Falkland Islands (Malvinas). This is not the case in Brazil, where fishing activity is hardly detected both within the Brazilian EEZ as well as around the Trindade and Martin Vaz Islands. In the south of Brazil (States of Rio Grande do Sul and Santa Catarina) there is an important fleet of boats between 14 and 24 m in length that are active. Many of them are gillnetters, but there are also trawlers and some longliners. In the high seas outside of the EEZs, the fishing activity is of lesser intensity and distributed towards the northeast of the area, north of 40° S.

Figure 41. 6. The intensity of fishing operations based on AIS data for FAO Area 41 during 2017.



FISHING VESSEL ACTIVITY AND OPERATIONS BY GEARS IN THE SOUTHWEST ATLANTIC

This section reviews the spatial distribution patterns of the main fishing gears of FAO Area 41 as estimated by Global Fishing Watch (GFW) based on 2017 AIS data. The most recent datasets available at mid-2018 are used to assess GFW capacity to provide an AIS based footprint of fishing activity by fishing gear in terms of presence/absence, intensity and hot spots. The Introduction chapter describes the rationale and challenges for use of contrasting data sources (e.g. Global Fisheries Landings database (GFLD; Watson, 2017)) for benchmarking AIS data classification.

When comparing fishing activity (Table 41. I) based on AIS data with the GFLD catches, it is observed that the GFLD shows that the majority of vessels in the area are trawlers (Table 41. I), while the AIS data has "other and unknown." It is quite likely, however, that many of the "unknown" fishing vessels classified by AIS (vessels that we did not have complete confidence in their gear type) here are actually trawlers, and some set longliners. The AIS data also show substantial activity by squid jiggers in 2017 (about a quarter of the activity) which is more realistic than GFLD, the latter showing almost no activity between 2010 and 2014. The number of active days by drifting longliners is higher than might be expected considering the catch reported by GFLD, and drifting longliners might be overrepresented in AIS data. Although it is likely that some longline activity is misclassified in AIS data (see below) it is also likely GFLD 2010–2014 data has underestimated catch, as many of the longliners (mostly from China, Taiwan Province of China and Spain) have been identified as drifting longlines through registries. Total tuna and tuna-like catches estimated from RFMO data for 2015 show twice as much catch for longlines as reported in GFLD (Taconet *et al.*, 2018). The importance of purse seiners is higher in the GFLD (6 percent) than the AIS (1 percent), although some of the "unknown" fishing vessels may also be purse seiners.

GEAR TYPES	Catches (GFLD) 2010–2014 average		Total fishing vessel activity (GFW-AIS) 2017	
	Tonnes of catch in 1000s	% of catch	Active days in 1000s	% of active days
Trawls	1 283	70%	33.5	27%
Other	362	20%	44.3	36%
Set gillnets	52	3%		
Purse seines	115	6%	0.8	1%
Drifting longlines	19	1%	12.9	10%
Squid jigger	1	0%	32.5	26%
Total	1 835	100%	124.1	100%

Table 41. I. Summary table comparing average catch from GFLD during 2010–2014 with fishing vessel activity from GFW in FAO Area 41. Only vessels that fished for at least 24 hours in FAO Area 41 are included.

The spatial distribution of trawlers shows clear patterns in the southern part of the area, namely the EEZs of Uruguay, Argentina and the Falkland Islands. However, AIS data does not represent the trawling activity off the coast of Brazil, especially in the Amazon area because few Brazilian vessels broadcast AIS signal. GFLD also identified some activity outside the EEZs in the high seas, especially off southern Brazil and east of the Falkland Islands (Malvinas), whereas this activity is not detected by AIS. As example, the GFLD trawl catches in the high seas east southeast of the Falkland Islands (Malvinas) is not identified as trawling by AIS, most probably rightly; of the significantly caught species with geographic distribution in this area and their associated fishing techniques, the activity identified in this area (Fig.41. 6) by AIS is likely to be mostly for Patagonian toothfish longlining using set longlines. AIS can determine well the trawling distribution for countries which have a high number of vessels broadcasting AIS (Argentina, Uruguay and the Falkland Islands (Malvinas)), but the fishing intensity is, as in most areas, underestimated because most vessels do not carry AIS (Figure 41. 3).

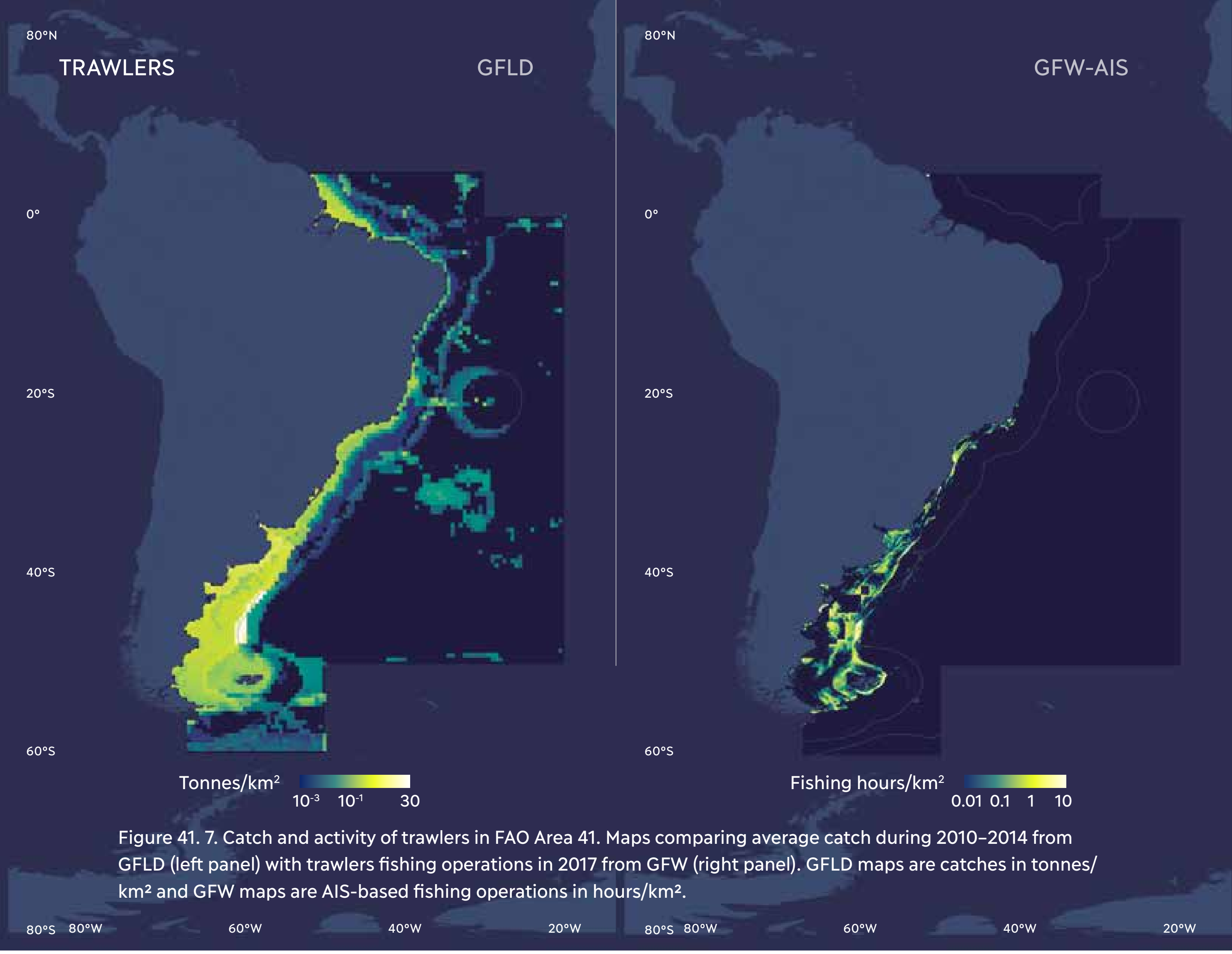


Figure 41. 7. Catch and activity of trawlers in FAO Area 41. Maps comparing average catch during 2010–2014 from GFLD (left panel) with trawlers fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

According to GFLD, squid jigger activity is very modest for 2010–2014, and is mostly near the limits of EEZs and further offshore. AIS data, however, reveals clear patterns of this important activity also within the EEZs of Argentina and the Falkland Islands (Malvinas) during 2017. This mismatch in activity in the southern portion of the area most likely suggests that GFLD is missing squid activity because the Argentina shortfin squid is the most important species in landings, with half a million tonnes produced in 2013 (FAO 2016). The AIS also doesn’t identify any of the fishing activity that GFLD identifies around the Brazilian EEZ, which could be due to vessels not having AIS or due to a squid activity being spatially misallocated in the GFLD dataset. Squid jiggers with AIS are mostly from Asian countries (China, Taiwan province of China and Republic of Korea). Argentina is the only country in the area using a substantial number of squid jiggers using AIS.

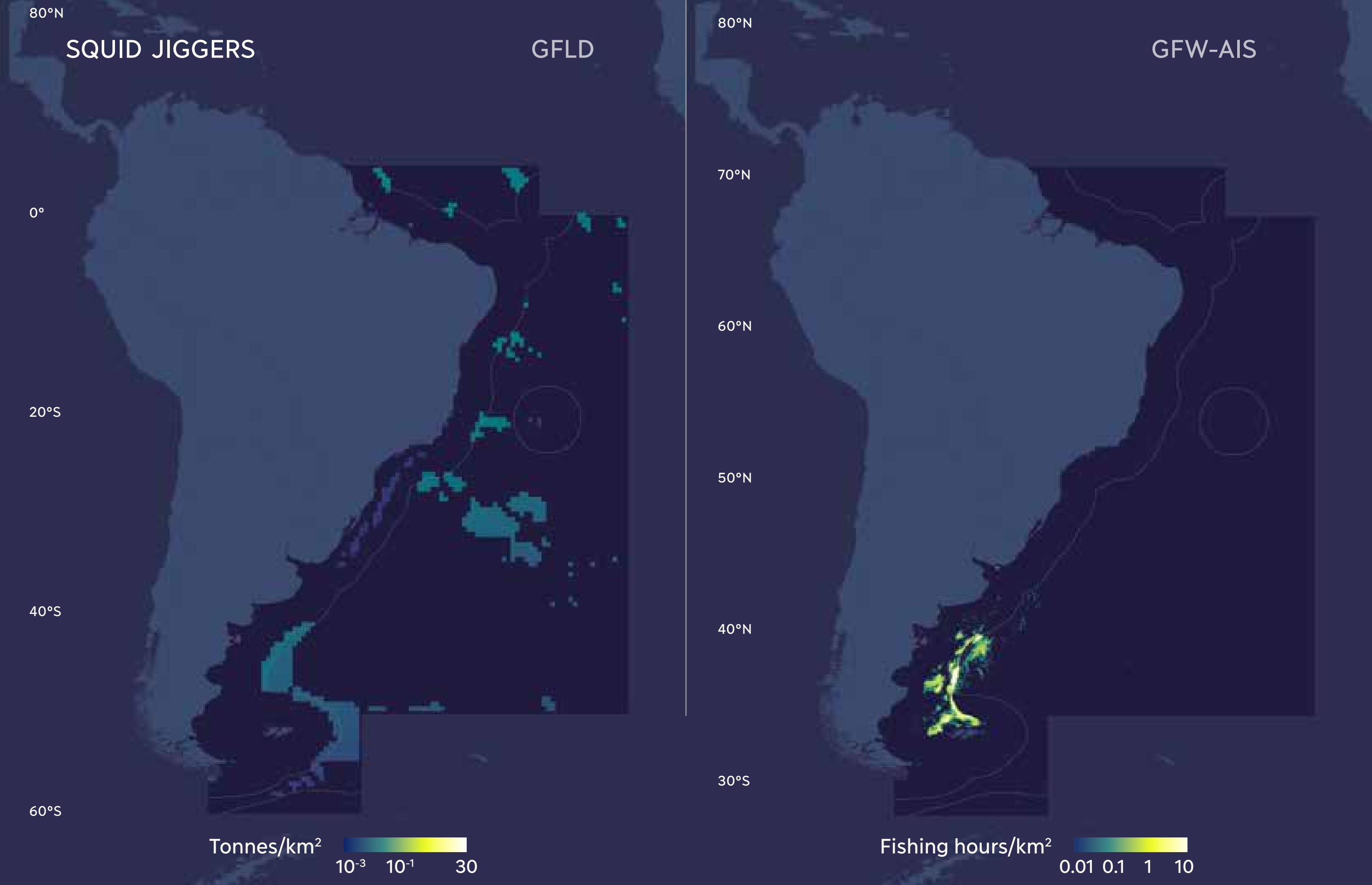


Figure 41. 8. Catch and activity of squid jiggers in FAO Area 41. Maps comparing average catch during 2010–2014 from GFLD (left panel) with squid jiggers fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

Squid jiggers show the strongest seasonality, with the bulk of the activity concentrated in the first half of the year, peaking in April-May. This peak is linked to favourable weather conditions and the squid productivity regime in the area.

Squid jiggers in FAO Area 41

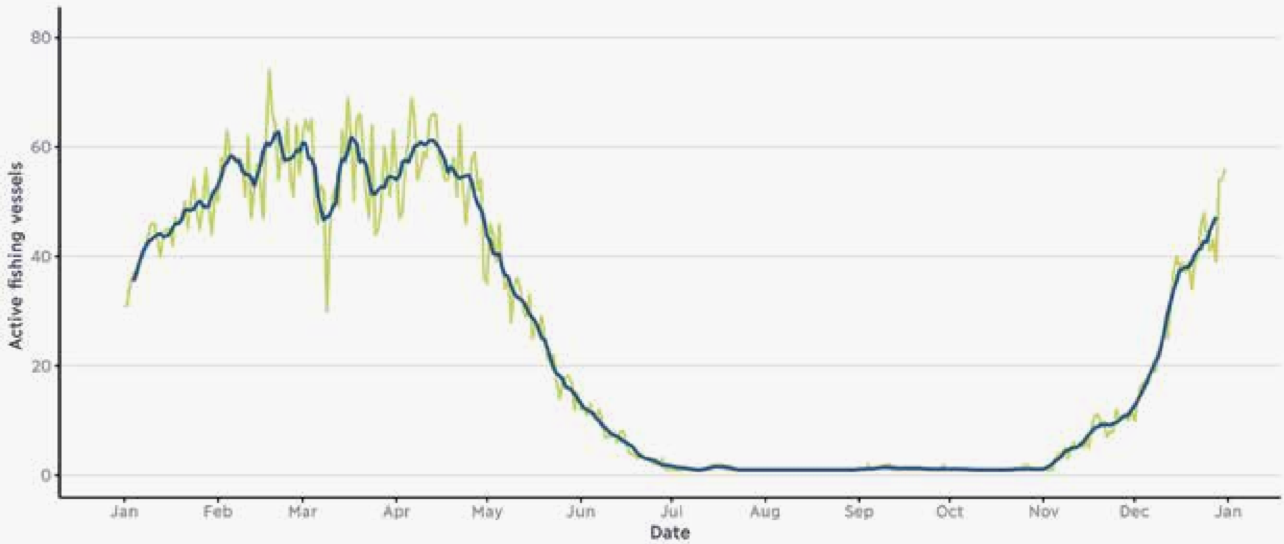


Figure 41. 9. Number of AIS-identified active squid jiggers per day in FAO Area 41 during 2017. Only vessels that fished at least 24 hours in the area over the course of the year are included. Dark blue line shows a 7-day rolling average.

Drifting longliners operate mostly in international waters, where AIS data provide more detailed spatial distribution compared to Watson (2017). Moreover, AIS data also identify fishing activity in areas not identified by Watson (2017), e.g. around the Falkland Islands (Malvinas) and in coastal areas off southern Brazil. It is likely that some of the drifting longline activity in the high seas north of the Falkland Islands (Malvinas) is misclassified since it is an area of high vessel en-route density (see Fig.41.5), and it is unlikely that vessels could set long drifting lines in this high-traffic area. Many squid jiggers are also operating in this area and there is also a fleet of bottom longlines targeting hake, which this drifting longline activity could be instead. The likely misclassified longline activity, though, is only a small fraction of the total drifting longline activity in the area. The majority of longlines in the area are from distant water fleets operating in the high seas, namely China, Taiwan Province of China, Spain and Portugal, targeting swordfish, bigeye, yellowfin, albacore tuna, toothfish and blue shark in the area (ICCAT, 2018). All these countries are members of the International Commission for the Conservation of Atlantic Tunas (ICCAT), with the exception of Argentina. For fleets from countries and territories within the area, Brazil is the most important country using drifting longlines.

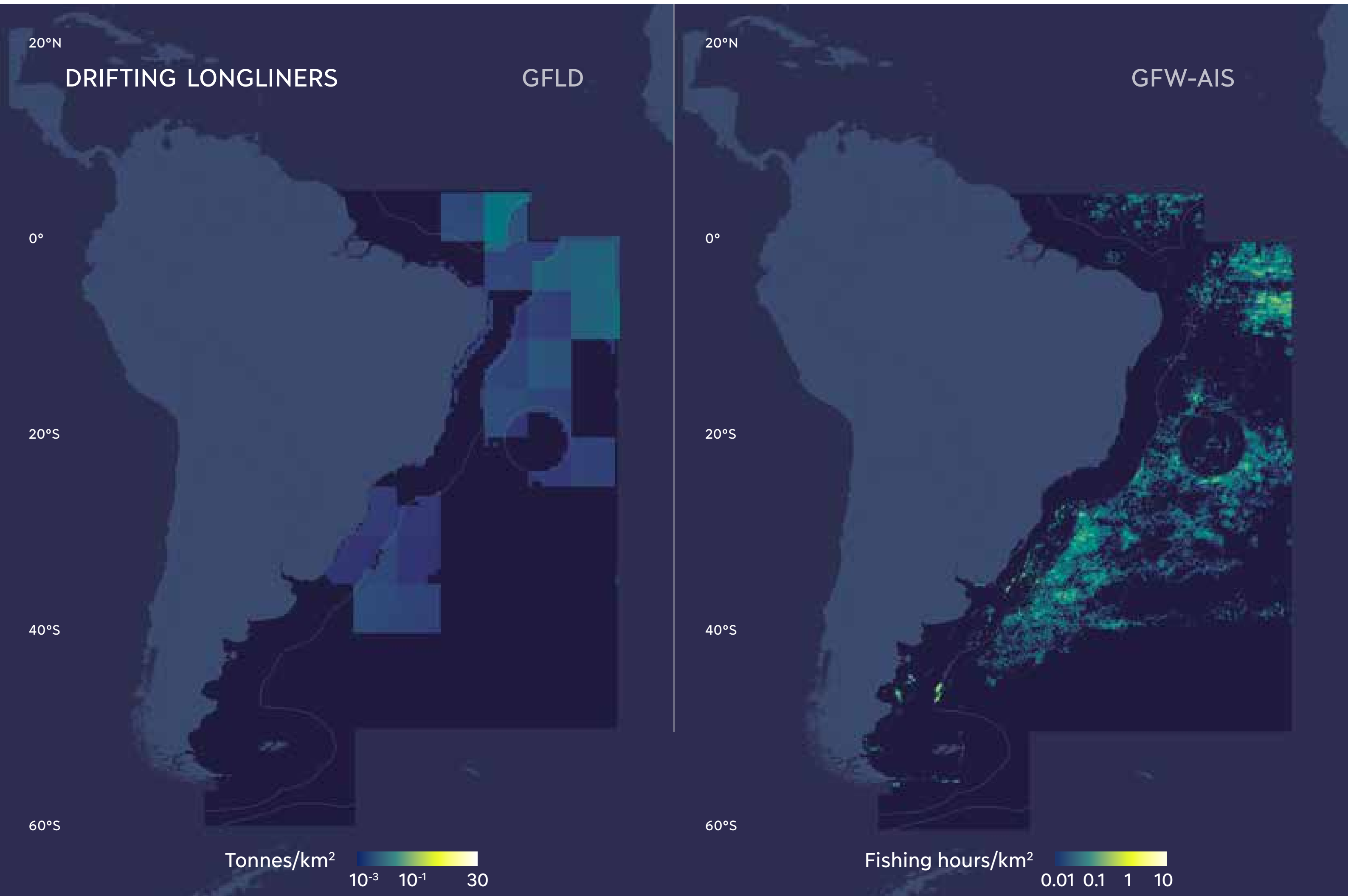


Figure 41. 10. Catch and activity of drifting longliners in FAO Area 41. Maps comparing average catch during 2010–2014 from GFLD (left panel) with drifting longliners fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

ACKNOWLEDGEMENTS

The editors would like to thank Andrés Domingo and Daniel Gilardoni for excellent comments and feedback during the elaboration of the chapter. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Required citation for this chapter:

Arrizabalaga, H., Granado, I., Kroodsma, D., Miller, N. A., Taconet, M., Fernandes, J. A. 2019. FAO Area 41 - AIS-based fishing activity in the Southwest Atlantic. *In* Taconet, M., Kroodsma, D., Fernandes, J.A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

Agnew, D. J., Pearce, J., Pramod, G., Peatman, T., Watson, R., Beddington, J. R., & Pitcher, T. J. 2009. Estimating the worldwide extent of illegal fishing. *PloS one*, 4(2), e4570. https://doi.org/10.1371/journal.pone.0004570

FAO. 2011. *Food and Agriculture Organization of the United Nations. Review of The State of World Marine Fishery Resources.* FAO Fisheries and Aquaculture Technical Paper. No. 569. Rome, FAO. http://www.fao.org/3/i2389e/i2389e.pdf

FAO. 2016. *Food and Agriculture Organization of the United Nations. The State of World Fisheries and Aquaculture 2016 (SOFIA). Contributing to food security and nutrition for all.* Rome. http://www.fao.org/3/a-i5555e.pdf

FAO. 2019. *Food and Agriculture Organization of the United Nations. FAO Major Fishing Areas. Southwest Atlantic (Major Fishing Area 41).* http://www.fao.org/fishery/area/Area41/en

Freire, K. M. F., Aragão, J. A. N., Araújo, A. R. R., Ávila-da-Silva, A. O., Bispo, M. C. S., Canziani, G. V.,... & Moro, P. S. 2015. *Reconstruction of catch statistics for Brazilian marine waters (1950-2010). Fisheries Catch Reconstructions for Brazil's Mainland and Oceanic Islands.* Fisheries Centre Research Reports, 23, 3-30. https://open.library.ubc.ca/media/download/pdf/52383/1.0354313/5

ICCAT. 2018. *International Commission for the Conservation of Atlantic Tunas. Report of the Standing Committee on Research and Statistics (SCRS). Madrid, Spain, 1 to 5 October 2018.* https://www.iccat.int/Documents/Meetings/Docs/2018/REPORTS/2018_SCRS_REP_ENG.pdf

Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F.,... & Woods, P. 2018. Tracking the global footprint of fisheries. *Science*, 359(6378), 904-908. https://doi.org/10.1126/science.aao5646

Oxenford, H. A., Monnereau, I. 2018. Chapter 9: Climate change impacts, vulnerabilities and adaptations: Western Central Atlantic marine fisheries. *In* Barange, M., Bahri, T., Beveridge, M., Cochrane, K., Funge-Smith, S., Poulain, F. (Eds.). *Impacts of Climate Change on fisheries and aquaculture: Synthesis of current knowledge, adaptation and mitigation options.* FAO Fisheries Technical Paper 627. Rome, FAO. http://www.fao.org/3/i9705en/i9705en.pdf

Taconet, P., Chassot, E., Barde, J. 2018. *Global monthly catch of tuna, tuna-like and shark species (1950-2015) aggregated by 1° or 5° squares (IRD level 2) (Version 1) [Data set].* Zenodo. http://doi.org/10.5281/zenodo.1164128

Villasante, S., Macho, G., de Isusu Rivero, J., Divovich, E., Zylich, K., Harper, S., & Pauly, D. 2015. *Reconstruction of marine fisheries catches in Argentina (1950–2010). Working Paper 2015-50.* Fisheries Centre, University of British Columbia, Vancouver. http://www.seaaroundus.org/doc/publications/wp/2015/Villasante-et-al-Argentina.pdf

Watson, R. A. 2017. A database of global marine commercial, small-scale, illegal and unreported fisheries catch 1950–2014. *Scientific data*, 4, 170039. https://doi.org/10.1038/sdata.2017.39

FAO AREA 47

AIS-based fishing activity in the Southeast Atlantic

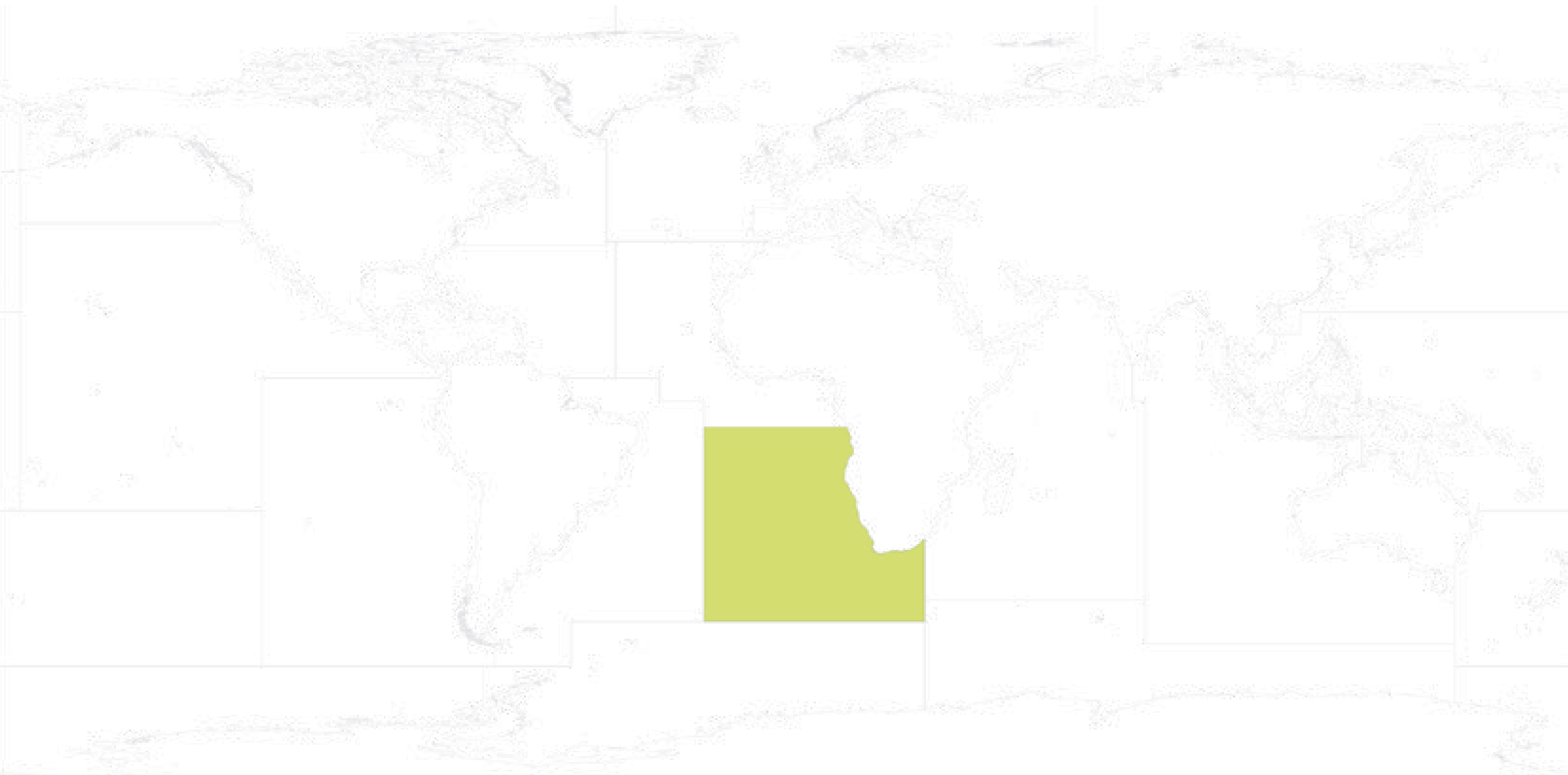


Figure 47. 1. Location of FAO Area 47.

Haritz Arrizabalaga, Josu Santiago, Igor Granado, David Kroodsma, Nathan A. Miller and Jose A. Fernandes

PREAMBLE

This chapter assesses, through a comparison with fleet statistics and public fisheries data, the capacity of Automatic Identification System (AIS) data and Global Fishing Watch (GFW) algorithms (Kroodsma *et al.*, 2018) to identify and quantify fishing vessel activity in the Northwest Atlantic. This assessment reviews fleet activity, main gear types, and spatial distribution of fishing vessel activity and fishing operations.

SUMMARY AND CONCLUSIONS FOR THE SOUTHEAST ATLANTIC

Among coastal countries/territories, AIS use is low for Angola and Saint Helena, Ascension and Tristan da Cunha, but significant for South Africa and Namibia. For distant water fleets, with several operating in the region, AIS use is high. AIS Class A and B device reception is good except in northern areas for Class B devices. Trawler intensity and spatial distribution is well captured by AIS in coastal areas, but poor in the high seas. The second most important gear, purse seiners, is underrepresented. Set gillnets, the third most important fishing gear, is very poorly represented in the data, as few of these vessels carry AIS in the region. Regarding longliners, AIS data overrepresented their importance because a much higher fraction of pelagic longliners carry AIS than coastal vessels and vessels handling other gears. Despite this overrepresentation, spatial patterns of longliners outside territorial waters seem to be well captured.

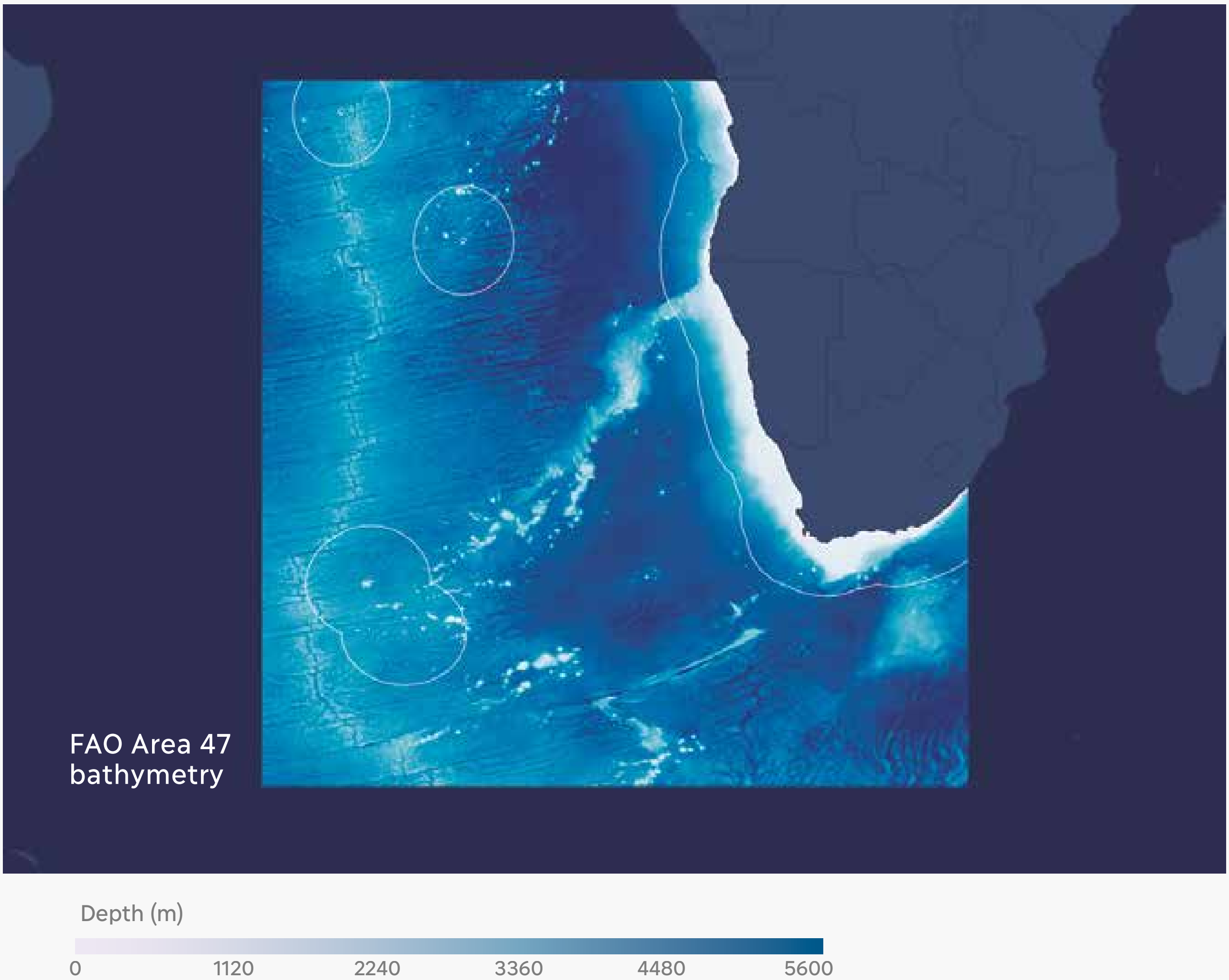


Figure 47. 2. FAO Area 47 bathymetry (depth) and 200 miles coastal arc.

INTRODUCTION FOR THE SOUTHEAST ATLANTIC

The Southeast Atlantic (FAO Area 47; FAO, 2019) comprises all the marine waters bounded by latitudes 6° S and 50° S, longitudes 20° W and 30° E, and the African continent in the northeast (Figure 47. 1). The following coastal countries/territories are within FAO Area 47: Angola, Namibia, South Africa and Saint Helena, Ascension and Tristan da Cunha (Figure 47. 2). These four countries/territories determine an area under national jurisdiction of 29 percent along the continent and Saint Helena, Gough, Ascension and Tristan da Cunha islands, while the high seas mostly in south and west parts cover 71 percent of the total marine waters (Figure 47. 2). This proportion of high seas is higher than the average for FAO areas (54 percent). In this region, fisheries are managed at least by two Regional Fishery Bodies (RFBs): the South East Atlantic Fisheries Organization (SEAFO) and The International Commission for the Conservation of Atlantic Tunas (ICCAT).

FAO Area 47 is characterized by a narrow continental shelf (very narrow at South Lobito in Angola), large seamounts and deep waters in most of the area. The region can be sub-divided into the following oceanographic regimes (van der Lingen and Hampton, 2018): 1) a subtropical zone north of the Angola/Benguela front, which is essentially a transition zone between the wind-driven Benguela Current upwelling system to the south and the Equatorial Atlantic, from where the seasonal cycle is remotely driven; 2) the Benguela Upwelling System, which lies roughly between 14°S and 37°S and extends in a broad sense to include the western Agulhas Bank, and is divided into northern and southern systems by strong perennial upwelling in the region of Lüderitz, at approximately 26°S; and 3) the central and eastern Agulhas Bank on the South African south coast, which has characteristics of both an upwelling and a warm temperate shallow shelf system, and is increasingly influenced by the strong southward flow and meanders of the Agulhas Current as the shelf narrows to the east. There is also influence of the sub-Antarctic front.

The Southeast Atlantic has shown a decreasing trend in catches, from a total production of 3.3 million tonnes in the early 1970s to 1.3 million tonnes in 2013 (FAO, 2016). Horse mackerel and hake represent the most important species in terms of landings, with 25 and 22 percent, respectively (FAO, 2016). FAO landings statistics (FishStatJ, 2018) show that in the period from 2010 to 2014, catches were dominated by invertebrate and pelagic fish species. The largest catches have been made of Cape horse mackerel *(Trachurus capensis)*, Cape hakes, Southern African anchovy *(Engraulis encrasicolus)*, Southern African pilchard *(Sardinops sagax)*, sardinellas *(Sardinella aurita)*, Cunene horse mackerel *(Trachurus trecae)* and Whitehead's round herring *(Etrumeus whiteheadi)*. These species made up about 60 percent of the reported catch in that period.

REGION FLEETS AND AIS USE IN THE SOUTHEAST ATLANTIC

Region fleets of coastal states and territories in FAO Area 47 show a very high portion of non-motorized fishing vessels (47.7 percent) and motorized vessels under 12 m (33.9 percent), neither of which are likely to have AIS (Figure 47. 3). Motorized vessels of 12-24 m represent 1 percent (mostly from Angola and Saint Helena, Ascension and Tristan da Cunha) and vessels of more than 24 m were 1.4 percent (mostly from Angola) of the total vessels in the coastal fleets of this region. Size classes were not reported for the South African fleet, while very few vessels were reported for Saint Helena, Ascension and Tristan da Cunha and no reporting was available for Namibia, which likely means that the actual fraction of large vessels is slightly higher than reported here (Figure 47. 4).

Fleets of coastal nations/territories in FAO Area 47

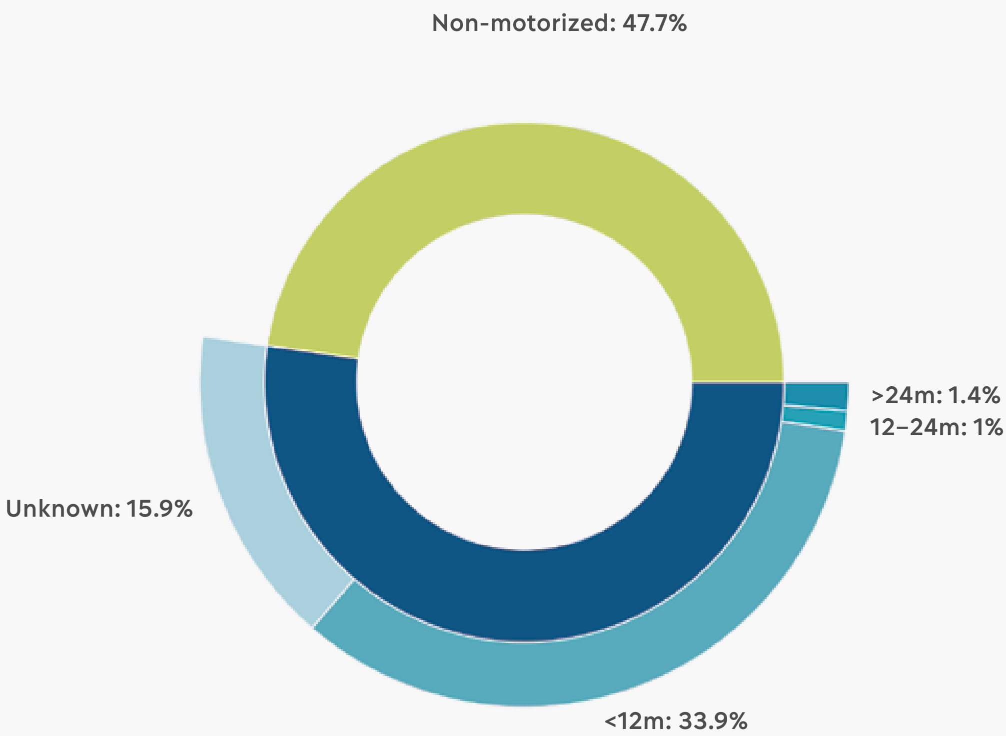


Figure 47. 3. Structural composition of fleets of coastal countries/territories in FAO Area 47. In dark blue motorized fishing vessels and in green non-motorized vessels. Distant water fleets active in FAO Area 47 are not included (see next figure). Note that South Africa borders more than one FAO area, yet its entire fleet size is included here. Source: FAO statistics for year 2017. Statistics were not available for the following coastal countries/territories within FAO Area 47: Namibia.

The use of AIS by coastal nations in FAO Area 47 is relatively low except for South Africa and Namibia. However, there is a significant presence of distant water fleets mostly from Asia and a few European countries. These fleets generally have high AIS use, especially in the high seas (Sala *et al.*, 2018). Most non-South African vessels have been matched to vessel registries,

confirming their identities, while for South African vessels the only means of identification was the GFW's vessel classification algorithm. The figure below (Figure 47. 4) shows the AIS identified number of vessels by flag state, as well as the composition of gear types within each flag state during the 2017 year. South Africa is clearly the dominant flag, followed by Taiwan Province of China, Japan, Namibia, Spain, China and Angola. African coastal countries/territories mainly use trawling gear, but also a diversity of other fishing gears. In the case of South Africa, these include purse seines, other fishing gears (troll and pole and line), set gears, set longlines and drifting longlines. On the other hand, the main Asian countries (Taiwan Province of China and Japan) operating in this area use almost exclusively drifting longlines. This fishing gear is almost exclusively used in international waters, but also in the South African EEZ.

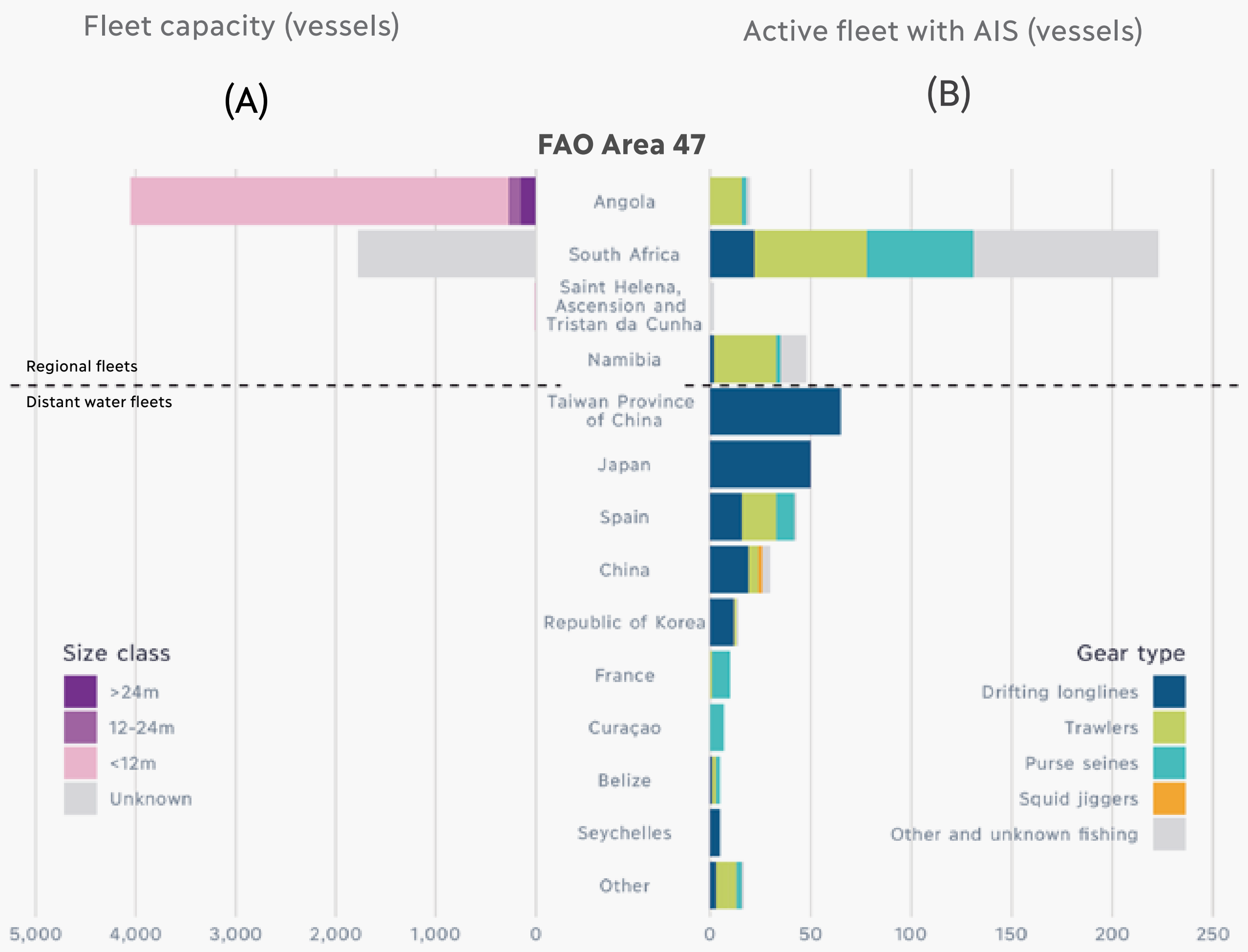
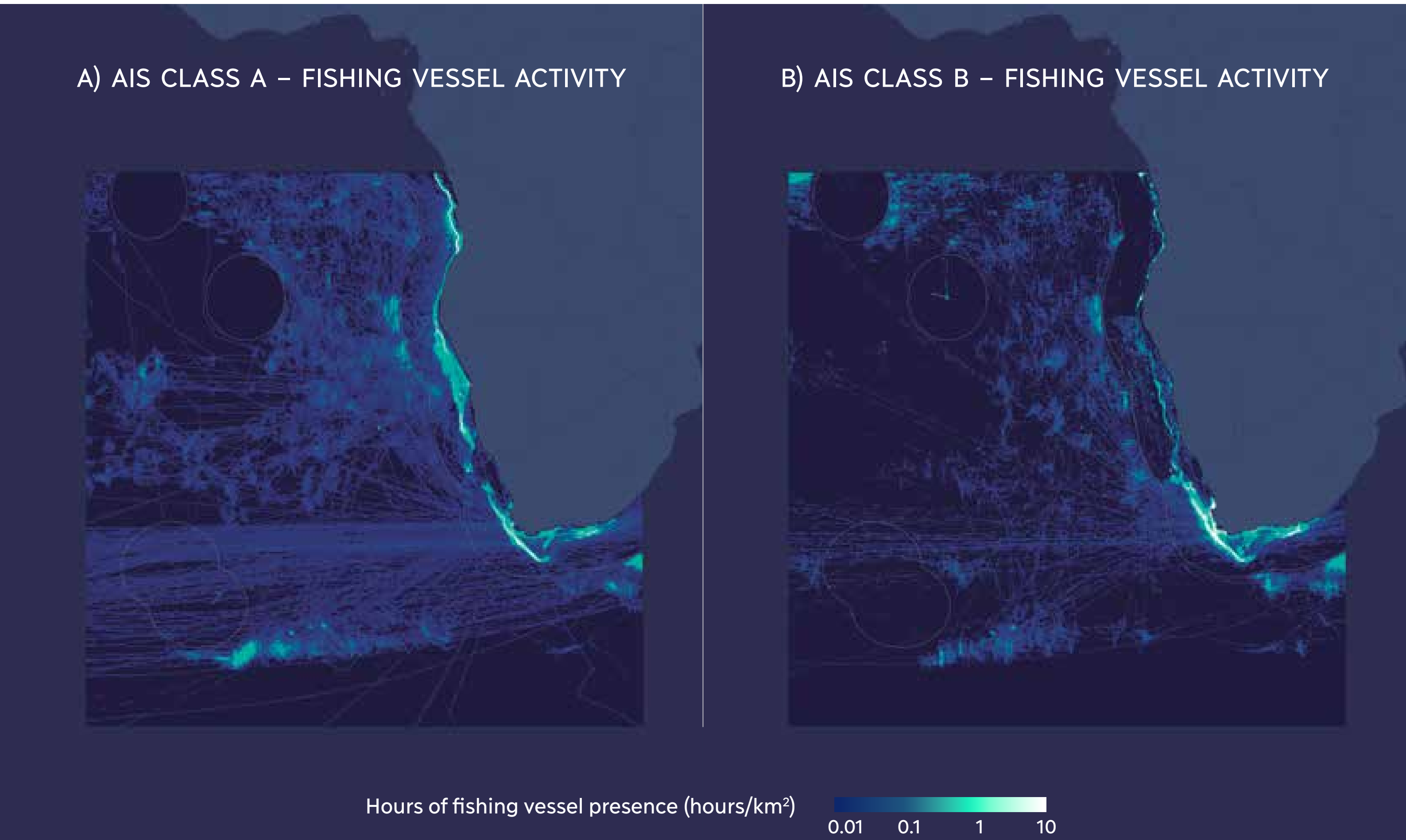


Figure 47. 4. Summary of coastal and distant fleets based on FAO statistics and AIS data classification by GFW in FAO Area 47 during year 2017. A) Number of motorized vessels as reported to FAO. The entire national South African fleet is displayed, even though the country borders more than one FAO area. Source: FAO statistics. Statistics were not available for the following coastal countries/territories within FAO Area 47: Namibia. B) AIS-identified number of fishing vessels broadcasting AIS during their operations in FAO Area 47 by gear type and flag state. Slashed lines separate regional fleets (top) from distant fleets (bottom). Only vessels that fished for at least 24 hours in the region are included.

AIS RECEPTION AND FISHING VESSEL ACTIVITY IN THE SOUTHEAST ATLANTIC

Fishing activity detected by AIS occurs throughout the region, with higher presence in northern and eastern areas (Figure 47. 6), and with the highest intensities concentrated close to EEZ boundaries or along the edge of the African continental shelf. Note the islands' EEZs are without AIS fishing activity, which may be due to less fishing activity or to smaller vessels without AIS operating in these areas. For example, Saint Helena jurisdictional waters have been designated a Marine Protected Area where only local vessels below 24 m operate. In addition, longliners have been banned and only handliners and similar are allowed since the beginning of 2017.



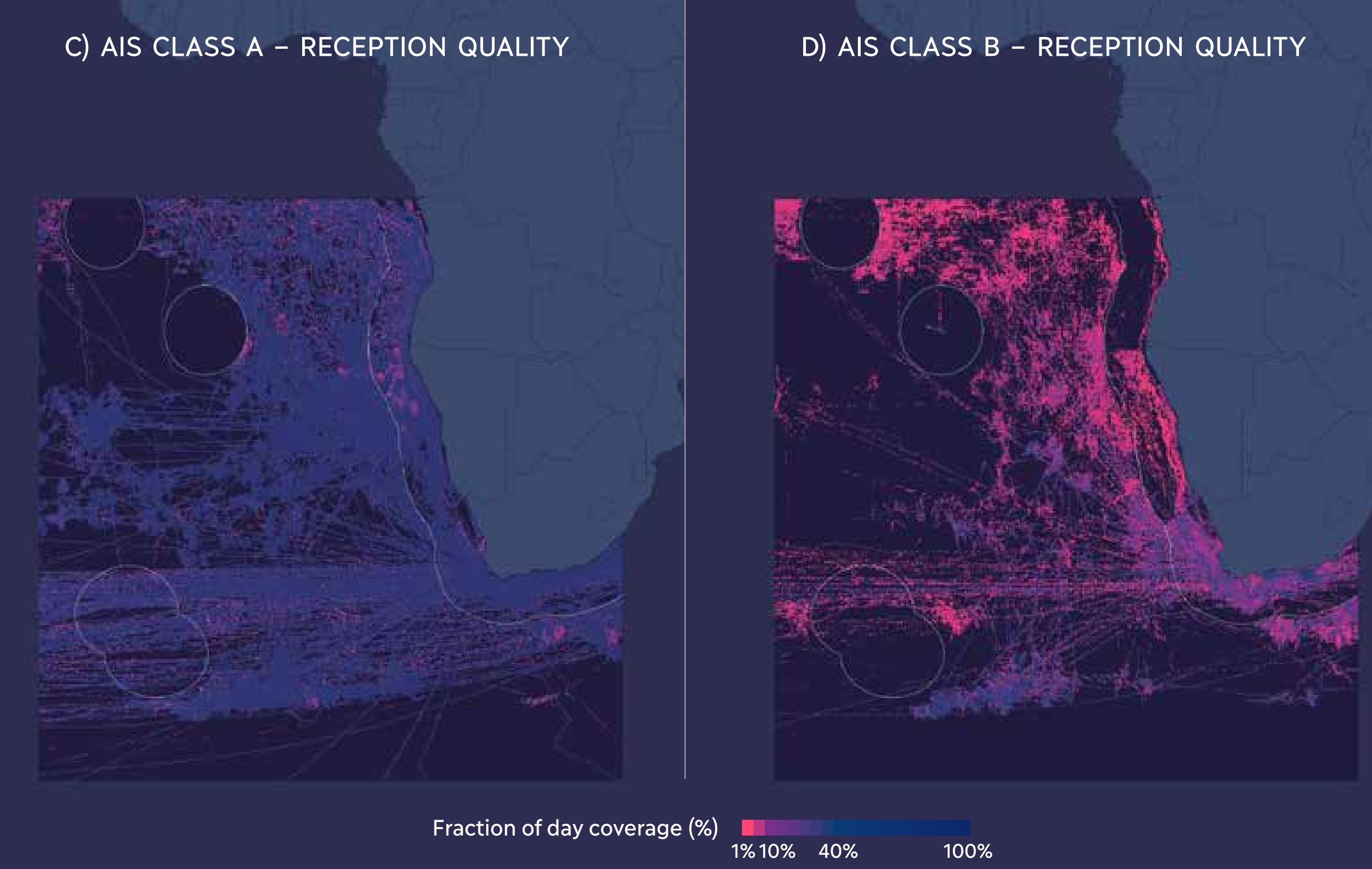
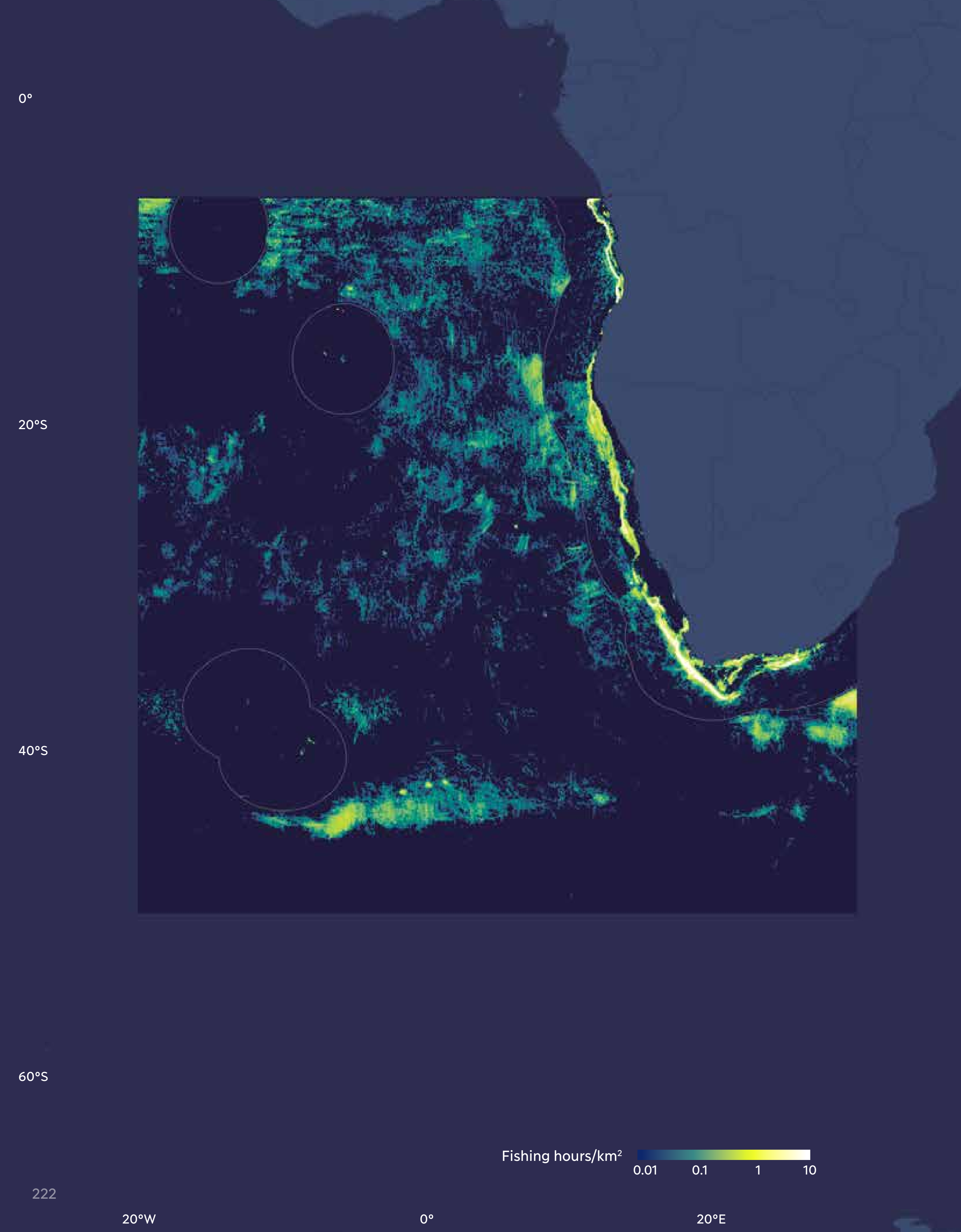


Figure 47. 5. Fishing vessel activity and quality of AIS reception for FAO Area 47 during 2017. Top row shows activity of vessels broadcasting using Class A devices (left panel) and Class B devices (right panel). The bottom row shows reception quality maps for devices Class A (left panel) and B (right panel). Blank spaces on the map (i.e. dark blue ocean background) mean that no signal from fishing vessels in that region were received, which is due to either no vessel activity or poor reception.

AIS Class A reception across the FAO Area 47 is good. AIS Class B reception is good across most of the region except in its northern part. About half of the vessels in the region use AIS Class A.

Figure 47. 6. The intensity of fishing operations based on AIS data for FAO Area 47 during 2017.



FISHING VESSEL ACTIVITY AND OPERATIONS BY GEAR IN THE SOUTHEAST ATLANTIC

This section reviews the spatial distribution patterns of the main fishing gears in FAO Area 47 as estimated by Global Fishing Watch (GFW) based on 2017 AIS data. The most recent datasets available at mid-2018 are used to assess GFW capacity to provide an AIS based footprint of fishing activity by fishing gear in terms of presence/absence, intensity, and hotspots. The Introduction chapter describes the rationale and challenges for use of contrasting data sources (e.g. Global Fisheries Landings database (GFLD; Watson, 2017) for benchmarking AIS data classification.

FAO Area 47 activity is dominated by large vessels like trawlers, purse seiners, set gillnetters and other gears (mainly traps) as can be inferred from Table 47. I. When comparing fishing activity (Table 47. I) based on AIS data with from GFLD average annual catches during the period 2010–2014, it is observed that drifting longliner fishing activity percentage based on AIS data by GFW is much higher than the catch percentage by these vessels in the region, whereas the fishing activity of purse seiners based on AIS data is lower than the catch percentage (Table 47. I). Set gillnetters, which account for about 10 percent of the catch, are also underrepresented and it seems that detection of fishing activity using AIS for this fishing gear is negligible. This is probably because this gear is used in small local boats that do not use AIS. Other fishing gears are mostly troll line and pole and line operating off Namibia and South Africa. The squid resource or 'chokka' *Loligo reynaudii* and *Todarodes sagittatus* generates important fisheries from Namibia to the Wild Coast of the Eastern Cape; squid are caught mostly by squid jiggers which have nowadays replaced the trawlers which used to fish them in the 1970s (DAFF, 2016; de Moor *et al.*, 2015).

GEAR TYPES	Catches (GFLD) 2010–2014 average		Total fishing vessel activity (GFW-AIS) 2017	
	Tonnes of catch in 1000s	% of catch	Active days in 1000s	% of active days
Trawls	607	44%	26.2	39%
Drifting longlines	28	2%	20.0	30%
Other	171	13%	139	21%
Set gillnets	137	10%		
Purse seines	426	31%	6.7	10%
Total	1 372	100%	66.8	100%

Table 47. I. Summary table comparing average catch from GFLD during 2010–2014 with fishing vessel activity from GFW in FAO Area 47. Only vessels that fished for at least 24 hours in FAO Area 47 are included.

Trawler fishing activity distribution with AIS data clearly delineate areas of high intensity along the edge of the continental shelf, probably representing well the activity of large trawlers. AIS data fail to show activity in areas far from shore in deeper waters, while GFLD shows activity spread farther out to sea. Trawlers target mainly hake (*Merluccius capensis and M. paradoxus*), kingklip (*Genypterus capensis*) and horse mackerel species (*Trachurus capensis, T. tracea and T. delagoa*) (DAFF, 2016) as well as monkfish (*Lophius sp.*).

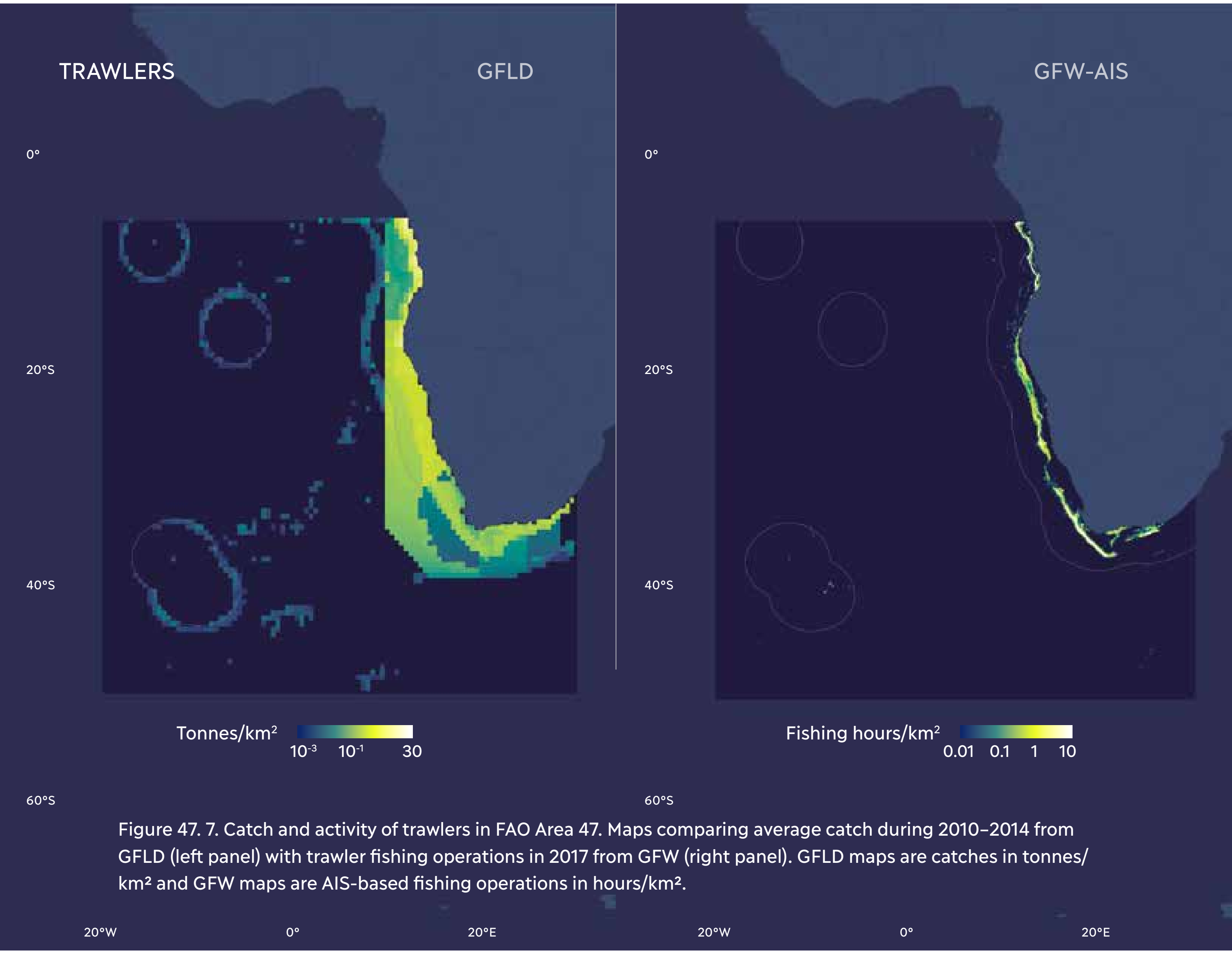


Figure 47. 7. Catch and activity of trawlers in FAO Area 47. Maps comparing average catch during 2010–2014 from GFLD (left panel) with trawler fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

Purse seiner fishing activity distribution based on AIS shows reasonably good agreement between GFLD and GFW classification with higher intensity in coastal areas and in the northern border of the region. Purse seiners target small pelagic forage fish, consisting predominantly of anchovy (*Engraulis encrasicolus*), sardine (*Sardinops sagax*) and redeye round herring (*Etrumeus whiteheadi*) (DAFF, 2016). However, there is tuna purse seiner activity in the northern high seas of this FAO area that is poorly represented by both GFLD and GFW (Taconet *et al.*, 2018) which target also tuna species.

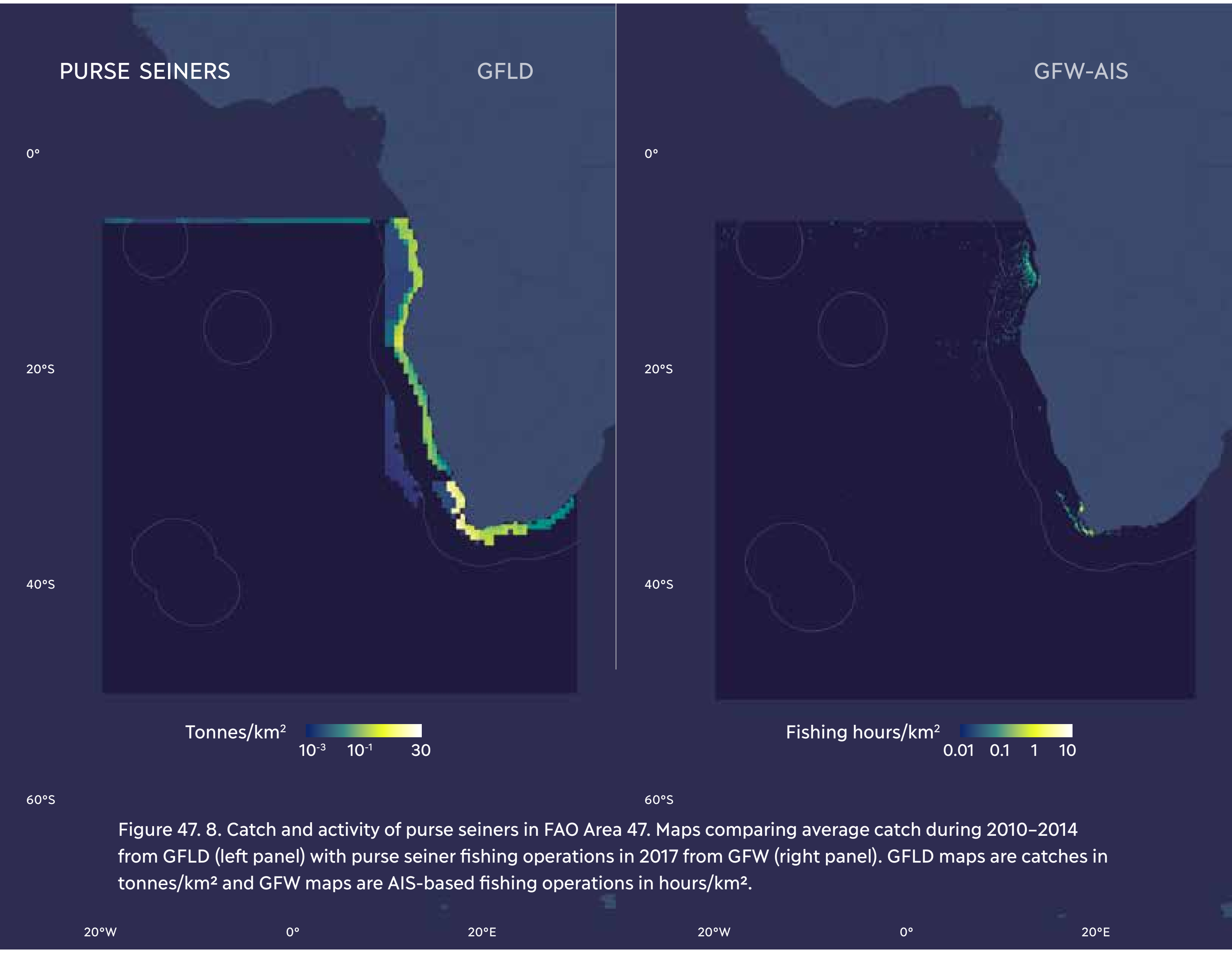


Figure 47. 8. Catch and activity of purse seiners in FAO Area 47. Maps comparing average catch during 2010–2014 from GFLD (left panel) with purse seiner fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

Spatial patterns of drifting longliner fishing activity in the high seas seem to be well captured by AIS, whereas GFLD missed much of the southern and western activity (Figure 47. 8). High seas longliners target swordfish (*Xiphias gladius*) and tuna species (temperate albacore *Thunnus alalunga)* and southern bluefin (*T. maccoyii)*, tropical yellowfin (*T. albacares)* and bigeye (*T. obesus*). Within national jurisdiction waters of the African continent where longliners operating in coastal areas target mainly hake and sharks (DAFF, 2016), there is no agreement between GFLD and AIS. For example, along the coast of Namibia and South Africa where vessels have high AIS use, AIS shows longliner activity which GFLD misses; on the contrary, AIS does not capture longliner activity shown by GFLD along the coast of Angola, probably because these longliners are usually semi-industrial vessels below 24 m not broadcasting AIS.

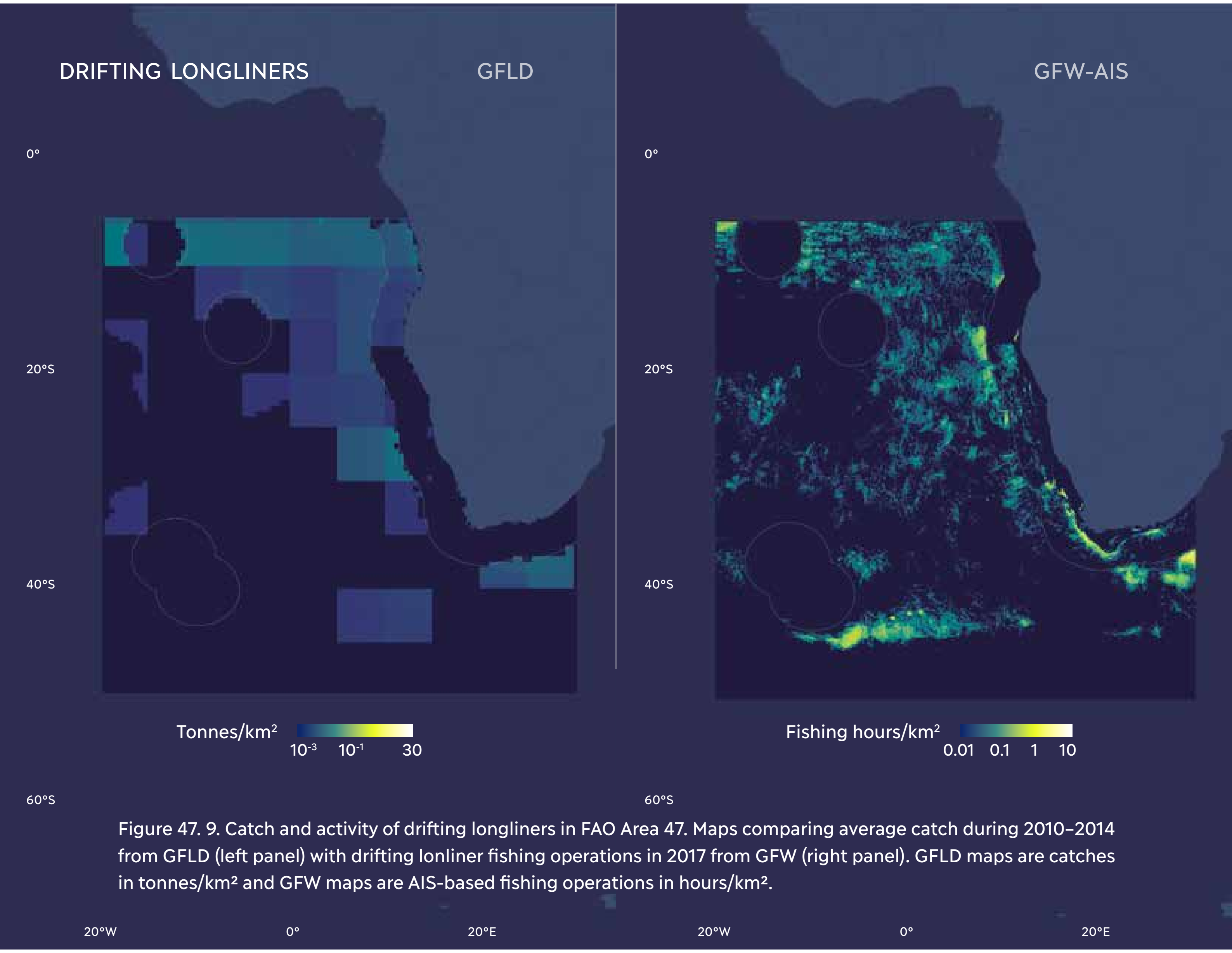


Figure 47. 9. Catch and activity of drifting longliners in FAO Area 47. Maps comparing average catch during 2010–2014 from GFLD (left panel) with drifting lonliner fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

Other gears' fishing activity is detected by AIS only in Namibian and South African waters due to high use of AIS in these vessels. These gears are mainly trolls and pole and lines targeting linefish species (e.g. *Chrysoblephus laticeps*, *Pachymetopon blochii* and *Chrysoblephus puniceus*) as well as yellowfin tunas and albacore tuna (DAFF, 2016). Fishing intensity is likely spread along the entire coastline, as reflected in GFLD.

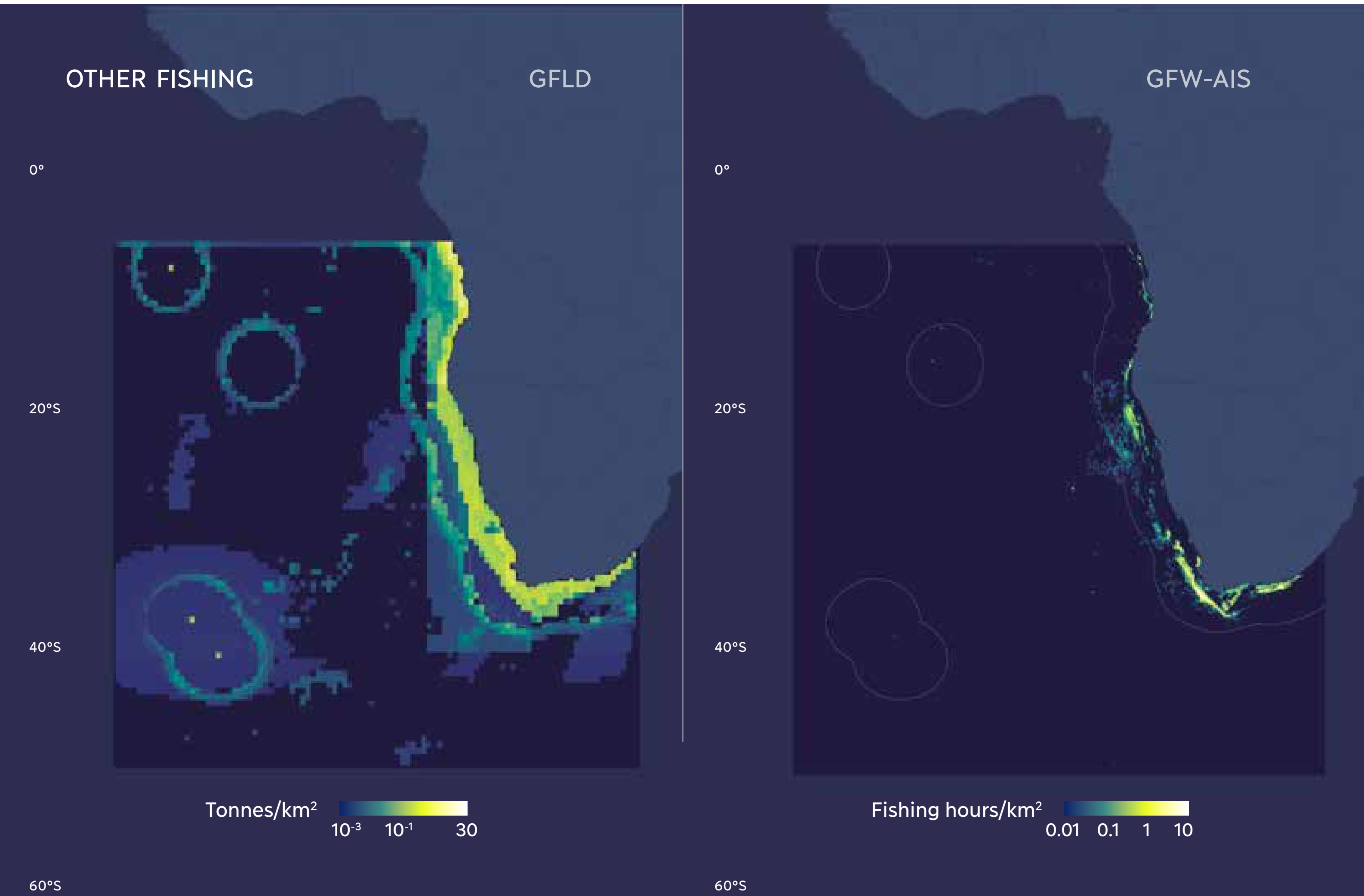


Figure 47. 10. Catch and activity of other gears in FAO Area 47. Maps comparing average catch during 2010–2014 from GFLD (left panel) with other gears fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

ACKNOWLEDGEMENTS

The editors would like to thank Jennifer Gee, Paulus Kainge, Dean Hurholtz and Luis J. López Abellán for excellent comments and feedback during the elaboration of the chapter. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Required citation for this chapter:

Arrizabalaga, H., Santiago, J., Granado, I., Kroodsma, D., Miller, N. A., Fernandes, J. A. 2019. FAO Area 47 - AIS-based fishing activity in the Southeast Atlantic. *In* Taconet, M., Kroodsma, D., Fernandes, J.A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

DAFF. 2016. *Department of Agriculture, Forestry and Fisheries. Status of the South African marine fishery resources 2016.* Republic of South Africa, Cape Town. https://www.nda.agric.za/doaDev/sideMenu/fisheries/fisheriesresearch%20and%20development/docs/STATUS%20REPORT%202016.pdf

De Moor, C. L., Johnston, S. J., Brandão, A., Rademeyer, R. A., Glazer, J. P., Furman, L. B., & Butterworth, D. S. 2015. A review of the assessments of the major fisheries resources in South Africa. *African Journal of Marine Science*, 37(3), 285-311. https://doi.org/10.2989/1814232X.2015.1070201

FAO. 2016. *Food and Agriculture Organization of the United Nations. The State of World Fisheries and Aquaculture 2016 (SOFIA). Contributing to food security and nutrition for all.* Rome. **http://www.fao.org/3/a-i5555e.pdf**

FAO. 2019. *Food and Agriculture Organization of the United Nations. FAO Major Fishing Areas. Southeast Atlantic (Major Fishing Area 47).* http://www.fao.org/fishery/area/Area47/en

FishStatJ. 2018. Fisheries and aquaculture software. FishStatJ - software for fishery statistical time series. *In* FAO Fisheries and Aquaculture Department [online]. Rome. Updated 21 July 2018. [Cited 19 November 2018]. http://www.fao.org/fishery/statistics/software/fishstatj/en

Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F.,... & Woods, P. 2018. Tracking the global footprint of fisheries. *Science*, 359(6378), 904-908. https://doi.org/10.1126/science.aao5646

Sala, E., Mayorga, J., Costello, C., Kroodsma, D., Palomares, M. L., Pauly, D.,... & Zeller, D. 2018. The economics of fishing the high seas. *Science advances*, 4(6), eaat2504. http://doi.org/10.1126/sciadv.aat2504

Taconet, P., Chassot, E., Barde, J. 2018. *Global monthly catch of tuna, tuna-like and shark species (1950-2015) aggregated by 1° or 5° squares (IRD level 2) (Version 1) [Data set].* Zenodo. http://doi.org/10.5281/zenodo.1164128

Van der Lingen C., Hampton, I., 2018. Chapter 11: Southeast Atlantic and Southwest Indian Ocean marine fisheries. *In* Barange, M., Bahri, T., Beveridge, M., Cochrane, K., Funge-Smith, S., Poulain, F. (Eds.). *Impacts of Climate Change on fisheries and aquaculture: Synthesis of current knowledge, adaptation and mitigation options.* FAO Fisheries Technical Paper 627. http://www.fao.org/3/i9705en/i9705en.pdf

Watson, R. A. 2017. A database of global marine commercial, small-scale, illegal and unreported fisheries catch 1950–2014. *Scientific data*, 4, 170039. https://doi.org/10.1038/sdata.2017.39

FAO AREAS 48, 58 AND 88

AIS-based fishing activity in the Southern Ocean

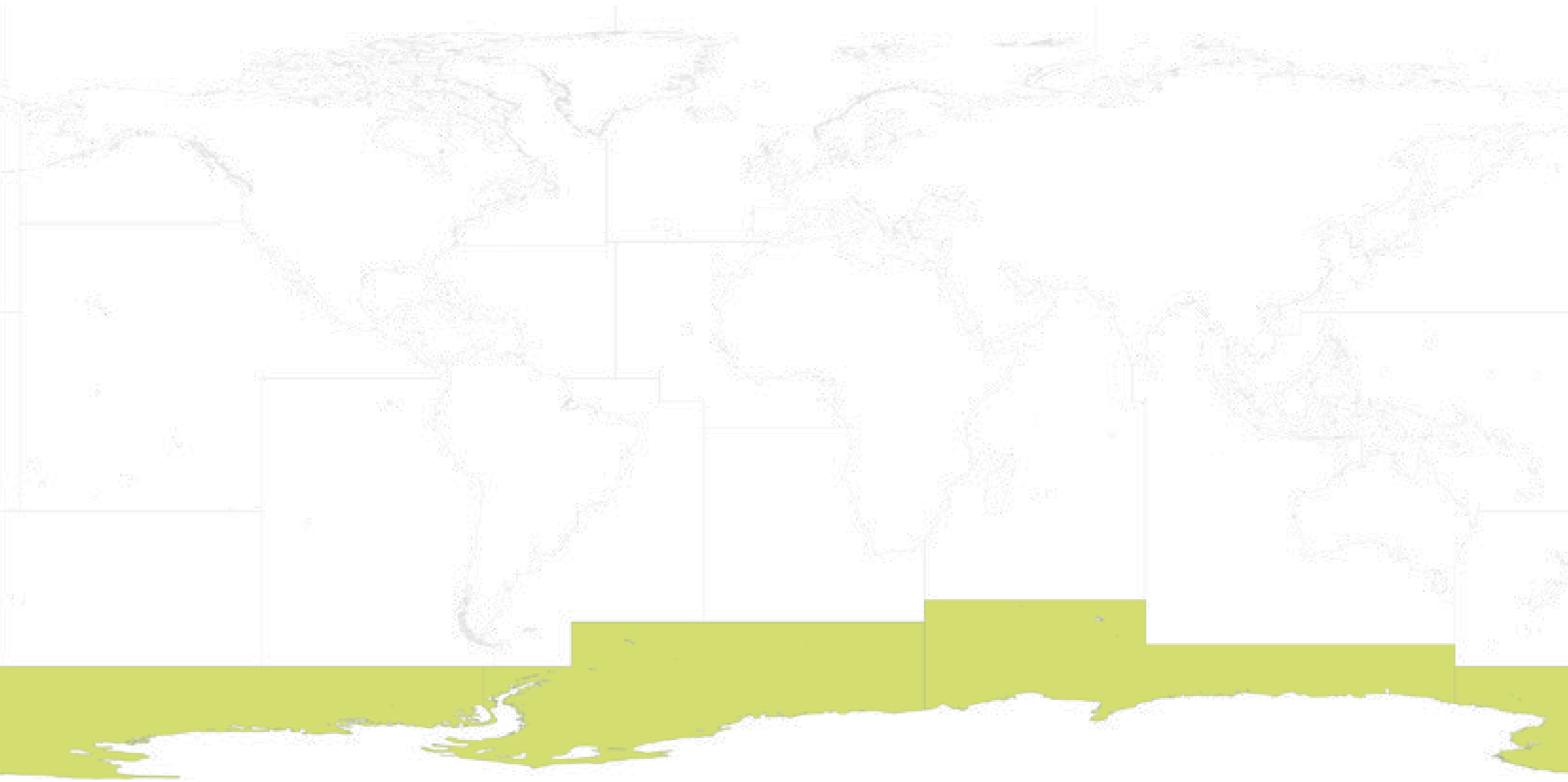


Figure 48-58-88. 1. Location of FAO Areas 48, 58 and 88.

Hilario Murua, David Ramm, Igor Granado, David Kroodsma, Nathan A. Miller, Marc Taconet and Jose A. Fernandes

PREAMBLE

This chapter assesses the degree to which Automatic Identification System (AIS) data can be used to identify fishing vessel activity in the Southern Ocean through a comparison with fleet statistics and fisheries data. Specifically, this assessment documents fleet AIS use in the Southern Ocean and the ability of Global Fishing Watch (GFW) algorithms (Kroodsma *et al.*, 2018) to correctly identify the primary fishing gear types operating in this region, as well as the spatial distribution and intensity of fishing.

SUMMARY AND CONCLUSIONS FOR THE SOUTHERN OCEAN

Based on AIS data, most fishing in the Southern Ocean is conducted by distant water fleets using Class A devices with good reception quality across the region. CCAMLR fishery data reports show that bottom-set longliners and mid-water trawlers are predominant, accounting for 68 percent and 32 percent of fishing days in 2016, respectively. Fishing activity predicted from AIS data successfully identified the fishing activity of trawlers and longliners (initially classified by GFW as other fishing gear).

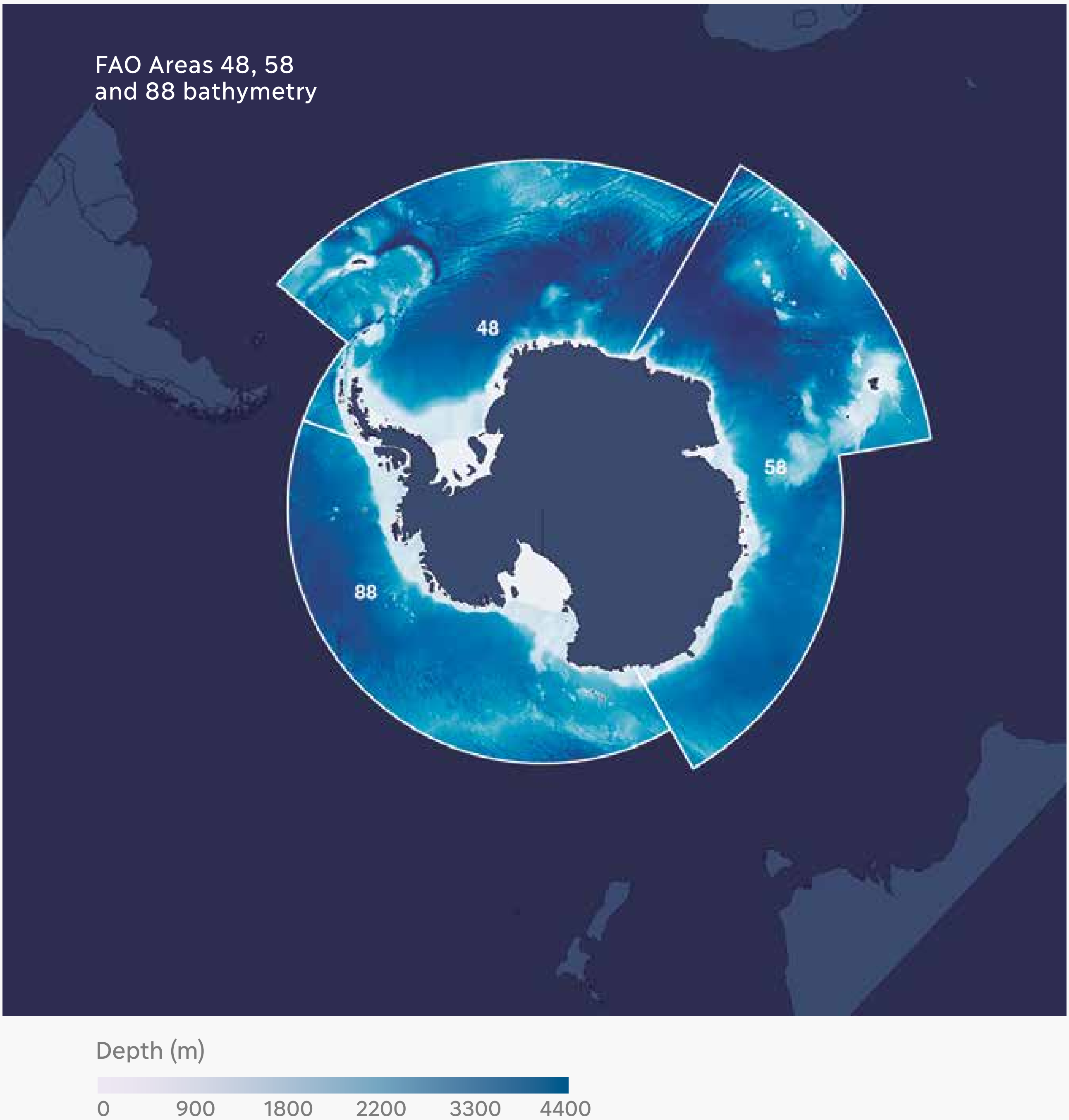


Figure 48-58-88. 2. Bathymetry (depth) and boundaries of FAO Areas 48, 58 and 88.

INTRODUCTION FOR THE SOUTHERN OCEAN

The Southern Ocean (FAO Areas 48, 58 and 88; FAO, 2019a, 2019b, 2019c) comprises all the waters around Antarctica (Figure 48-58-88. 1). The following sub-Antarctic islands are within the Southern Ocean area: Bouvet Island, Crozet Islands and Kerguelen Islands, Heard and McDonald Islands, Prince Edward and Marion Islands and South Georgia and the South Sandwich Islands. Sub-Antarctic islands provide several Exclusive Economic Zones (EEZs) managed by their respective countries. There are also non-solved claims over the Antarctic 200 nautical miles made by several countries which have proposed EEZs over their national jurisdiction.

The continental shelf surrounding Antarctica is generally narrow and deep, its edge lying at depths averaging 500 m (the shelf mean depth is around 100 m), with troughs extending as deep as 2 000 m (Riffenburgh, 2007). Southern Ocean marine life conservation is managed by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), established in 1982 as part of the Antarctic Treaty System. The CCAMLR Convention Area does include the EEZs of the Sub-Antarctic islands. The Southern Ocean, which is one of the largest, oldest, and coldest deep-water marine systems, has the deepest continental shelf, the largest wind-driven oceanic current, the highest number of endemic species and the largest seasonal variation in ice cover (Bargagli 2005). Its waters encircle Antarctica in a 2 500-km-wide region where minimum water temperatures are near freezing point (about -1.9 °C). The Antarctic marine ecosystem is influenced by the mostly unrestricted flow of water masses, the seasonal formation of sea ice which covers an area larger than the continent in winter, retreating during summer (Bargagli, 2005). The upwelling of warmer water from lower latitudes in the austral summer and spring favours the growth of phytoplankton providing for the short food chain of diatoms-krill-top predators (such as whales, seals and penguins) (Bargagli, 2005). Krill (*Euphausia superba*) is the dominant species and plays an essential role in the Antarctic marine ecosystem due to its abundance and large biomass (Bargagli, 2005). Fishing activity in this area targets mainly krill, patagonian toothfish (*Dissostichus eleginoides*), antarctic toothfish (*Dissostichus mawsoni*), and mackerel icefish (*Champsocephalus gunnari*) (Watson *et al.*, 2017; CCAMLR, 2018). Krill and mackerel icefish are targeted by midwater trawlers while toothfish are caught predominantly using bottom-set longlines (CCAMLR, 2018).

REGION FLEETS AND AIS USE IN THE SOUTHERN OCEAN

Available information on fishing vessels authorized by CCAMLR (Figure 48-58-88. 3) to fish during the calendar year 2017 indicated that there were 47 vessels (13 trawlers and 34 bottom longliners). Two vessels authorized to fish in the 2017 season re-flagged during the season and thus each vessel appeared under two countries in the list (CCAMLR, 2019). In the 2017 AIS data, 53 vessels were observed fishing in the FAO Areas 48, 58 and 88. AIS detected a higher vessel number operating within the area than in the CCAMLR list of authorized vessels. This discrepancy may be attributed to the following: a) French-flagged vessels fishing in French EEZs are exempted from CCAMLR Conservation Measures and therefore not all are on the CCAMLR authorised vessel list; b) one vessel authorised by CCAMLR operated mixed fishing gears (trawl and longline), c) various vessels were re-flagged during 2017 in order to fish in EEZs, notably vessels registered in Saint Helena, Ascension and Tristan da Cunha and the Falkland Islands (Malvinas) which were authorised to fish in Subareas 48.3 and 48.4 (in FAO Area 48) under UK flag. In addition, it is possible that research vessels deploying scientific trawls are not included in the CCAMLR list of authorised fishing vessels, and AIS data from those vessels may have been classified by GFW as trawling activity. Within FAO Areas 48, 58 and 88, GFW observed 22, 15 and 19 vessels, respectively, using AIS, where 21, 6 and 14 were matched to a vessel registry with a known gear type. The gear type of the vessels not matched to registries was assigned using a neural network classifier based on vessel movement patterns. Although earlier versions of the GFW model incorrectly classified some vessels as “other gears” or “drifting longlines”, the newest version correctly identified them as set longliners based on their behaviour (Figure 48-58-88. 3). AIS data indicated vessels operating within national jurisdictions and in the high seas (e.g. French-flagged vessels within and outside the EEZ of the Kerguelen Islands).

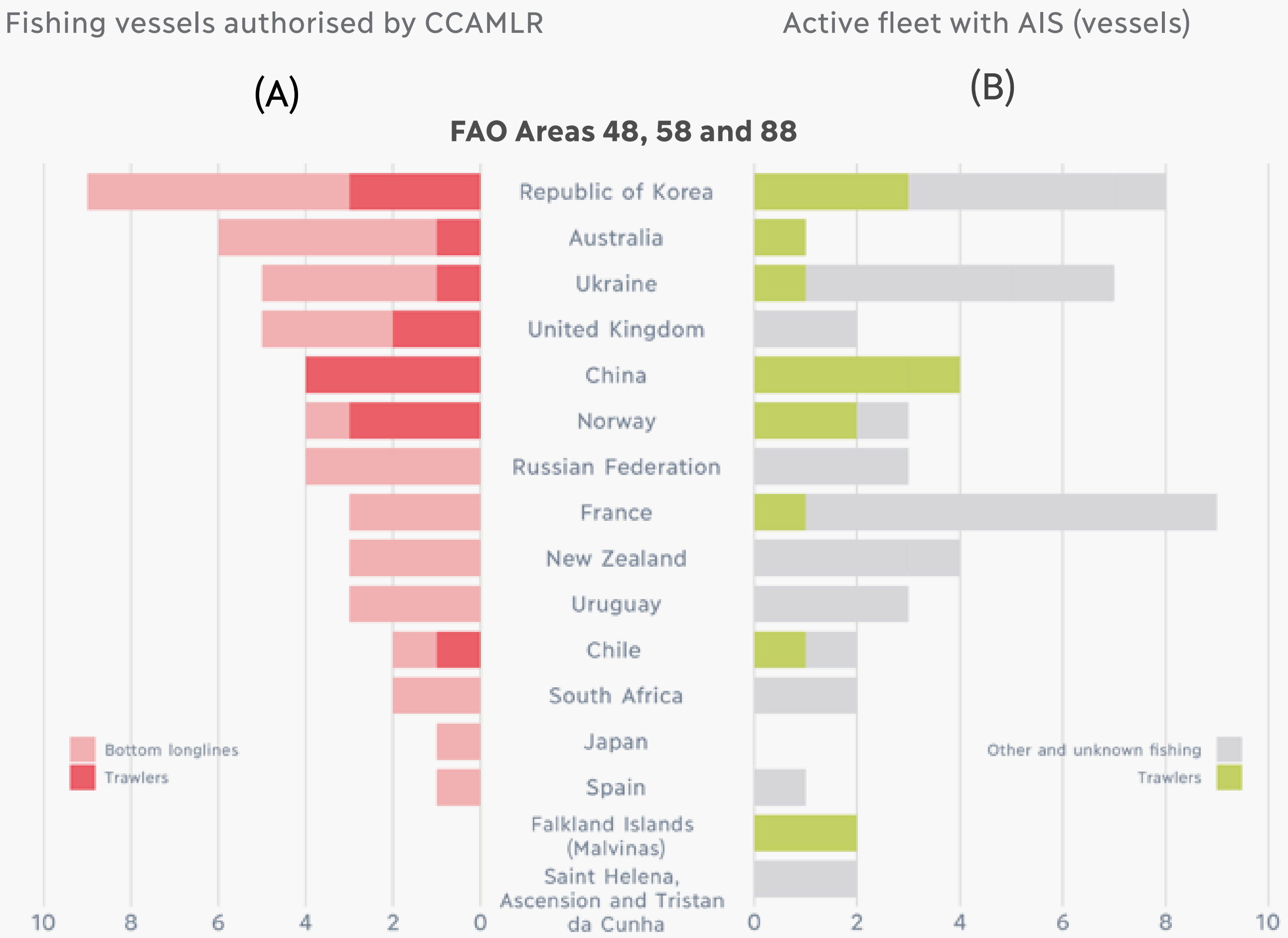


Figure 48-58-88. 3. Fleets summary based on CCAMLR statistics and AIS data classification for FAO Areas 48, 58 and 88 in 2017, by fishing gear type and vessel flag. A) Number of fishing vessels authorized by CCAMLR to fish inside the Convention Area by gear type and flag. B) AIS-identified number of fishing vessels broadcasting AIS by gear type and flag. Note that the number of vessels authorised by CCAMLR in 2017 was derived from the list of authorised vessels for the 2017 fishing season (1 December 2016 to 30 November 2017) and in December 2017 (i.e. the start of the 2018 fishing season). Only vessels that fished for at least 24 hours in the regions are included in the GFW analysis.

AIS RECEPTION AND FISHING VESSEL ACTIVITY IN THE SOUTHERN OCEAN

Figure 48-58-88. 4 shows fishing vessel activity presence and reception quality of AIS signals. Vessels in this area seem to be using only Class A devices. AIS reception is very good for high-quality AIS devices (Class A). Only vessels broadcasting Class A were seen in the region.

A) AIS CLASS A - FISHING VESSEL ACTIVITY

B) AIS CLASS A – RECEPTION QUALITY

Figure 48-58-88. 4. Fishing vessel activity and quality of AIS reception. All operations of fishing vessels are based on AIS data for FAO Areas 48, 58 and 88 during 2017. Top row shows activity of vessels broadcasting using Class A devices. The bottom row shows receptions quality maps for AIS Class A devices. Blank spaces on the map (i.e. dark blue ocean background) mean that no signals from fishing vessels in this area were received, which is due to either no vessel activity or poor reception.

Fishing operations estimated from AIS data indicated hotspots of activity occurring in specific areas such as the northern part of the Antarctic Peninsula, South Georgia and the South Sandwich Islands, Bouvet Island, Heard and McDonald Islands and Crozet and Kerguelen Islands among other islands (Figure 48-58-88. 5). The distribution of fishing activity identified by AIS generally corresponds with the fishing areas reported by CCAMLR (2018).

Figure 48-58-88. 5. The intensity of fishing operations based on AIS data for FAO Areas 48, 58 and 88 during 2017.

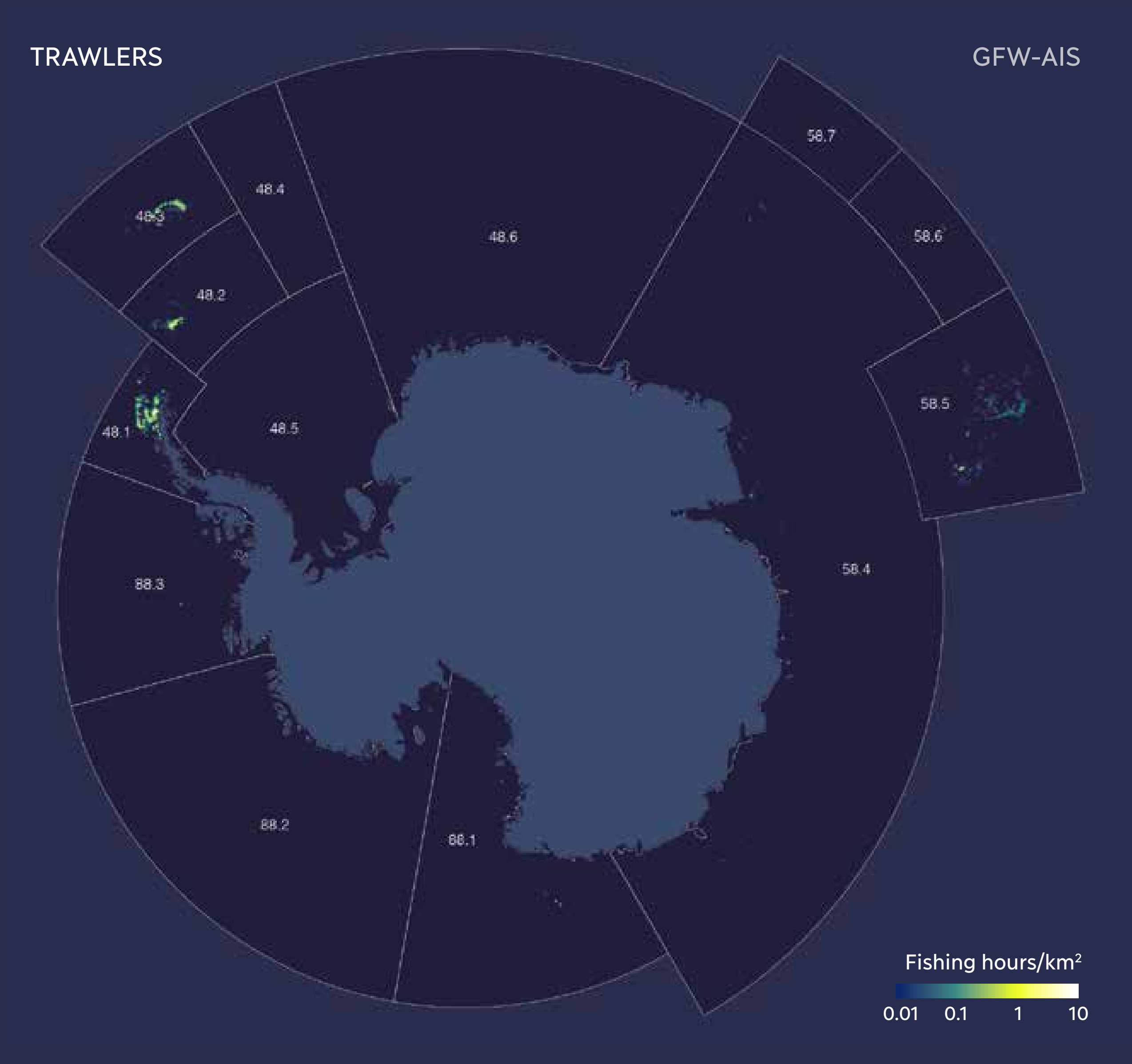
FISHING VESSEL ACTIVITY AND OPERATIONS BY GEAR IN THE SOUTHERN OCEAN

CCAMLR fishery statistics were used to assess AIS data and GFW capacity to provide a rapid method to footprint fishing activity by fishing gear in this region. When comparing fishing activity based in AIS data with fishing days reported by CCAMLR (CCAMLR, 2018) in the calendar year 2017, GFW identified "other" gear group as the major fishing activity (64 percent of total activity detected), which was comparable to the relative activity reported by CCAMLR for set longliners (69 percent of the total activity reported) (Table 48-58-88. I). The relative trawler fishing activity detected by GFW (36 percent) was similar to that reported by CCAMLR (31 percent). Overall, GFW estimation of fishing activity for different gear types is comparable to fishing activity reported by CCAMLR.

Fishing activity (GFW-AIS)			Fishing activity (CCAMLR)		
Gear types	**Active days**	**% of active days**	**Fishing days**	**(%)**	**Gears types**
Other and unknown fishing	3 064	64%	2 910	69%	Set longlines
Trawlers	1 736	36%	1 299	31%	mid-water trawls
All gears	4 800	100%	4 209	100%	All gears

Table 48-58-88. I. Summary of fishing activity in FAO Areas 48, 58 and 88 in 2017 based on AIS data using GFW and data reported by CCAMLR. "Active days" are defined as calendar days when a vessel is not in port. Only vessels that fished for at least 24 hours in FAO Areas 48, 58 and 88 were included. The initially GFW-defined gear type "Other" is reported by CCAMLR as longliners.

A comparison between trawler fishing operations detected by GFW and the fishing activity reported by CCAMLR (2018) indicated a good correspondence in the spatial distribution of trawler fishing activities in FAO Areas 48, 58 and 88 in 2017 (Figure 48-58-88. 6). Based on the gear type, target species and fishing effort in CCAMLR data, trawler fishing was focused in Subareas 48.1, 48.2 and 48.3, where krill was targeted using mid-water otter trawls and beam trawls. Some krill fishing also occurred in Divisions 58.4.1 and 58.4.2. Mid-water otter trawls were also used to target icefish in Subarea 48.3 and Divisions 58.5.1 and 58.5.2 and bottom otter trawls were used to target toothfish in Division 58.5.2.



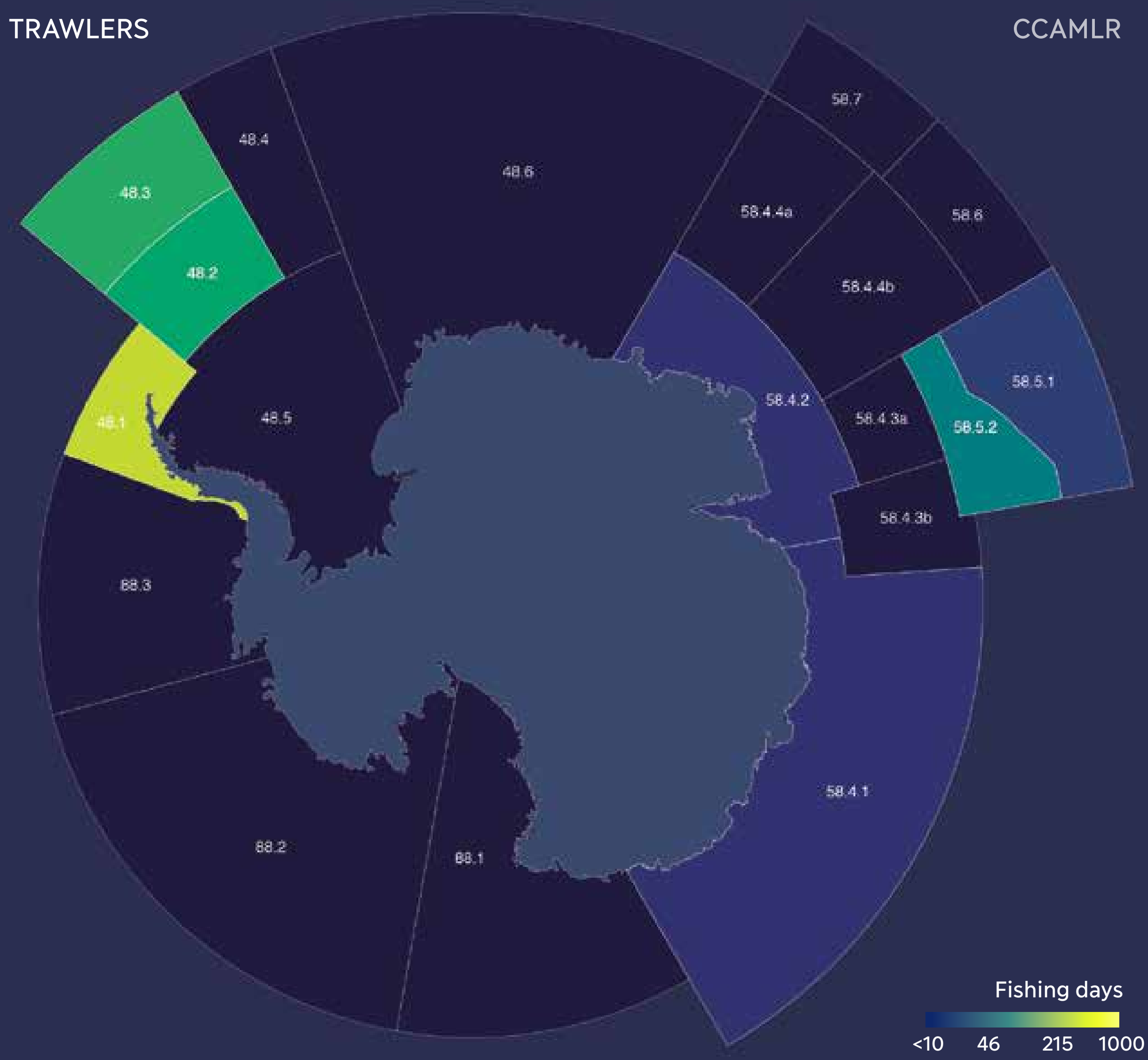


Figure 48-58-88. 6. Maps comparing the intensity of trawler fishing operations from AIS (top panel) in 2017 with fishing activity as reported to CCAMLR (bottom panel) in 2017 for FAO Areas 48, 58 and 88.

Trawler fishing activity occurred mostly between January and August 2017 depending on the region, especially in FAO Area 48 (Figure 48-58-88. 7).

Trawlers fishing in FAO Areas 48, 58 and 88

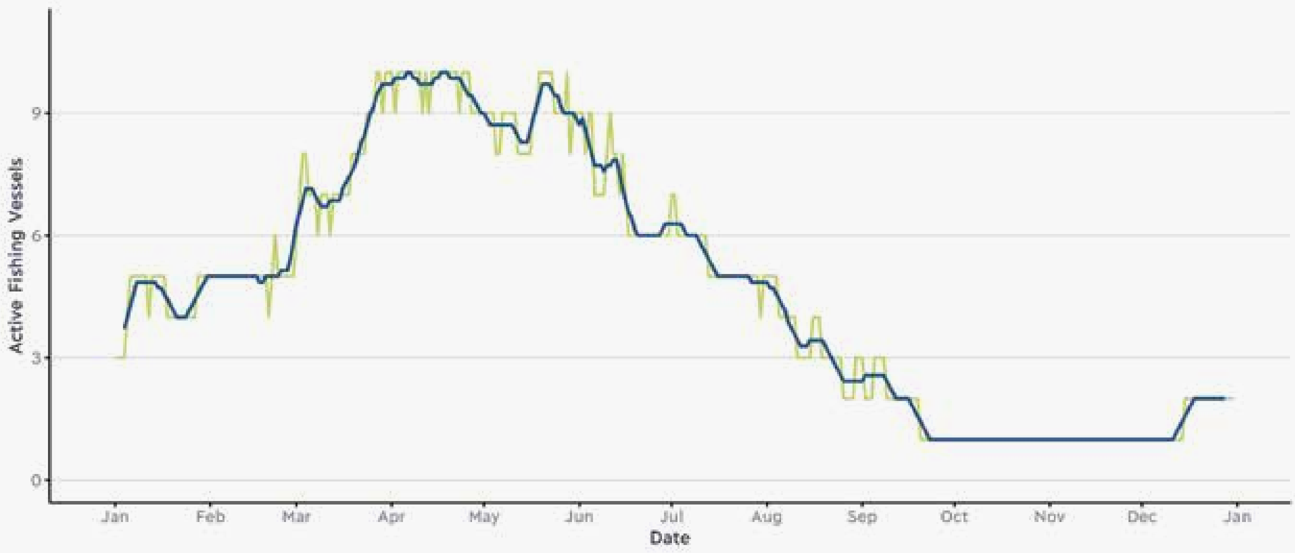
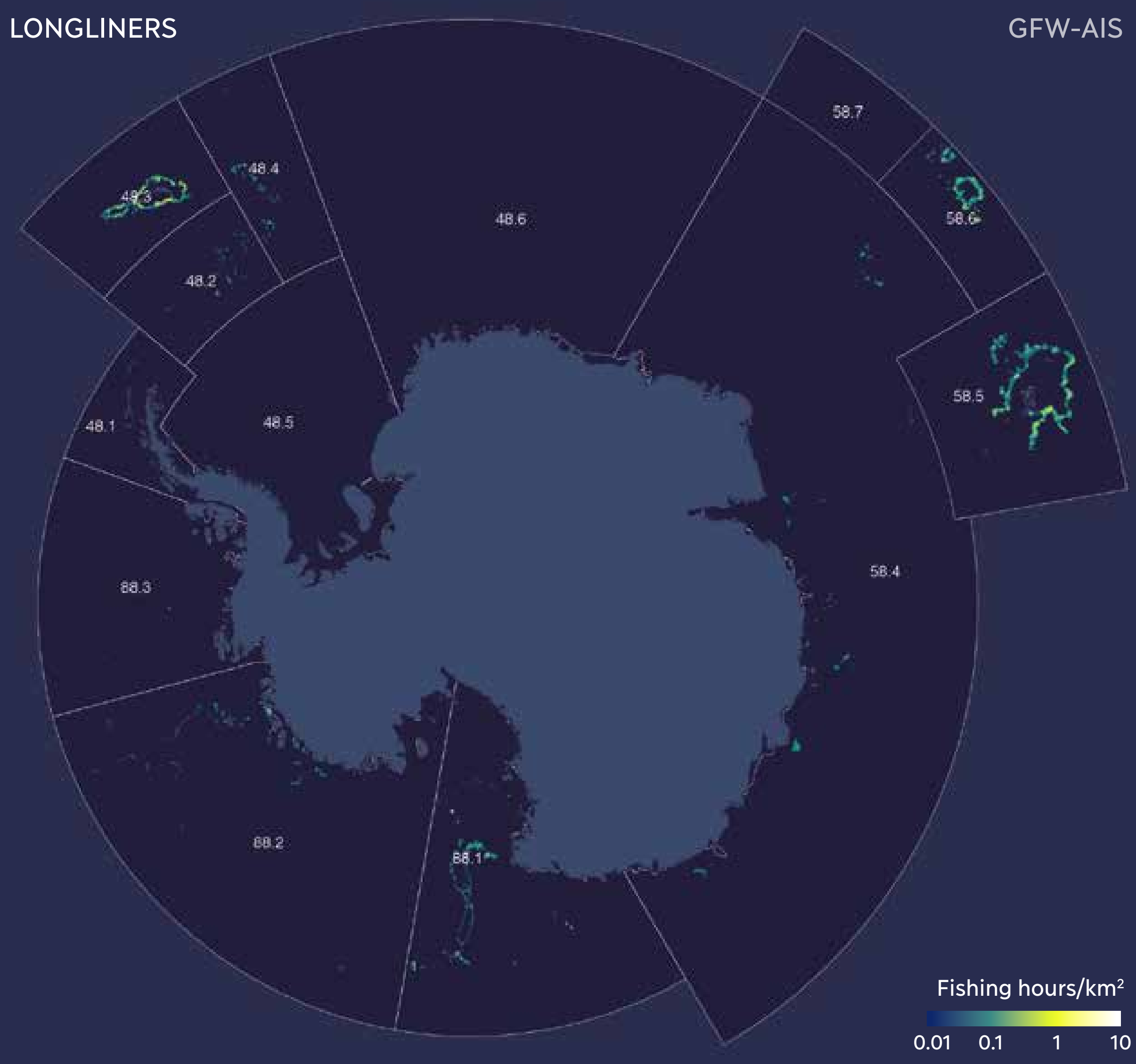


Figure 48-58-88. 7. Number of AIS-identified active trawlers per day in FAO Areas 48, 58 and 88 during 2017. Only vessels that fished at least 24 hours in the area over the course of the year are included. Dark blue line shows a 7-day rolling average.

A similar comparison between set longliner fishing activity detected by GFW (initially labelled as 'other' gear) and fishing effort reported by CCAMLR (2018) indicated a good correspondence in the spatial distribution of longliner fishing activities in FAO Areas 48, 58 and 88 in 2017 (Figure 48-58-88. 8). Based on the fishing effort reported by CCAMLR, longliner fishing activity targeted toothfish in all three FAO Antarctic areas except in Subareas 48.1 and 48.5 and Divisions 58.4.3b and 58.4.4a (Figure 48-58-88. 8). However, longliner fishing effort was mostly distributed in Subarea 48.3 and in Divisions 58.5.1 and 58.5.2, with high levels also reported in Subareas 48.6 and 58.6.



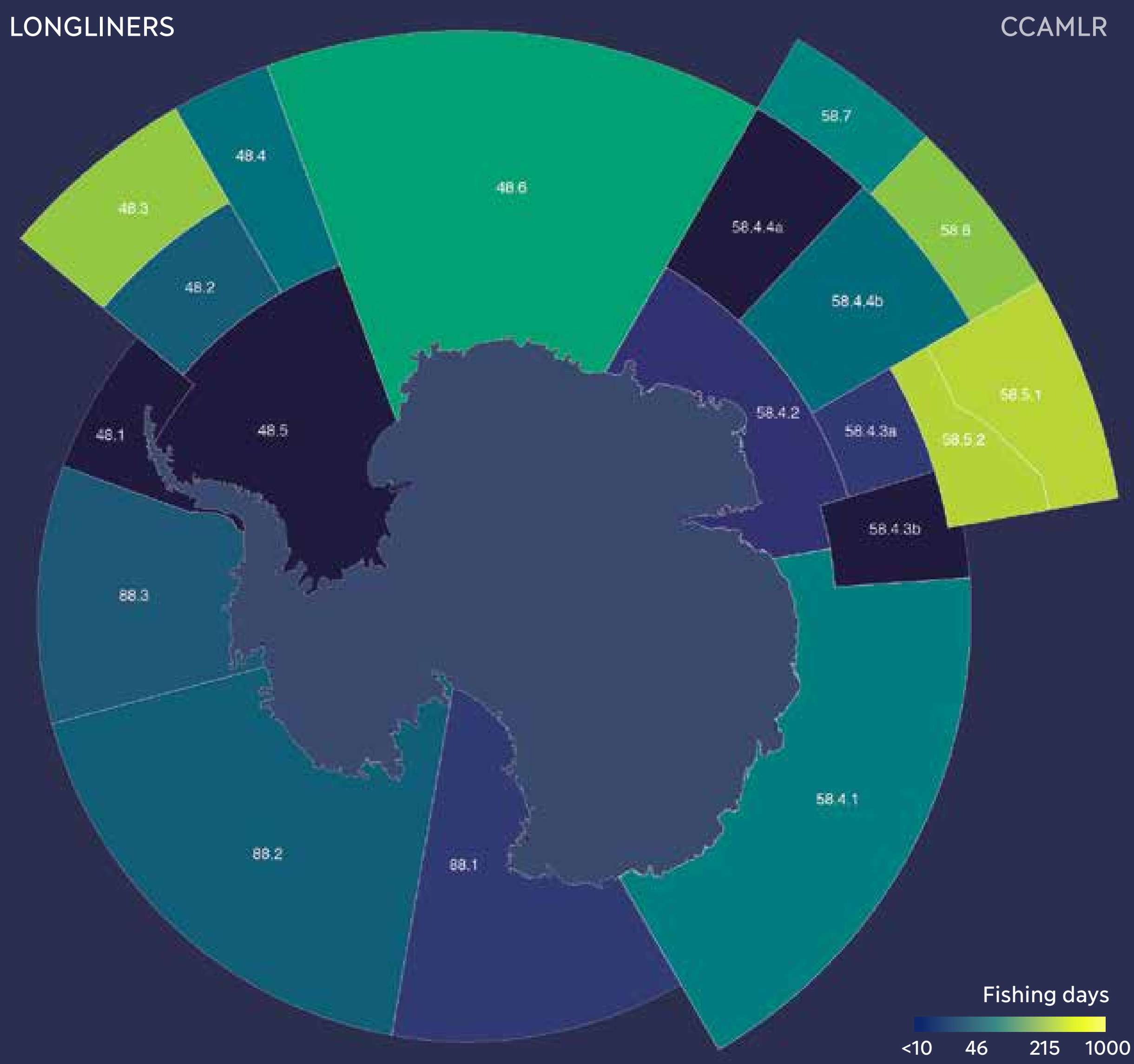


Figure 48-58-88. 8. Maps comparing the intensity of longliner fishing operations from AIS (top panel) in 2017 with fishing activity as reported to CCAMLR (bottom panel) in 2017 for FAO Areas 48, 58 and 88.

These fishing effort intensity spatial distribution patterns seem to be well represented in AIS data, both for the established fisheries around the islands of Kerguelen, La Possession (Crozet Islands), and South Georgia, and for the exploratory longline fisheries targeting toothfish in FAO Area 88. Indeed, the bottom-set longlines used in the toothfish fisheries are generally set at depths of 1 200-1 800 m, which is well reflected by the AIS spatial pattern of longliner fishing activity closely following the bathymetry contours at those depths, especially around sub-Antarctic islands (CCAMLR, 2013).

The AIS-based fishing activity pattern for longliners reflects well the fishing activity of longline fisheries, which occurred mainly in January, April-July and December 2017 (Figure 48-58-88. 9). The fishing activity peaked in January, during the austral summer, when around 20 longlining vessels were active and was lowest during August-September (austral winter). In addition, some CCAMLR fisheries may be closed seasonally during September-November (CCAMLR, 2019a).

Longliners in FAO Areas 48, 58 and 88

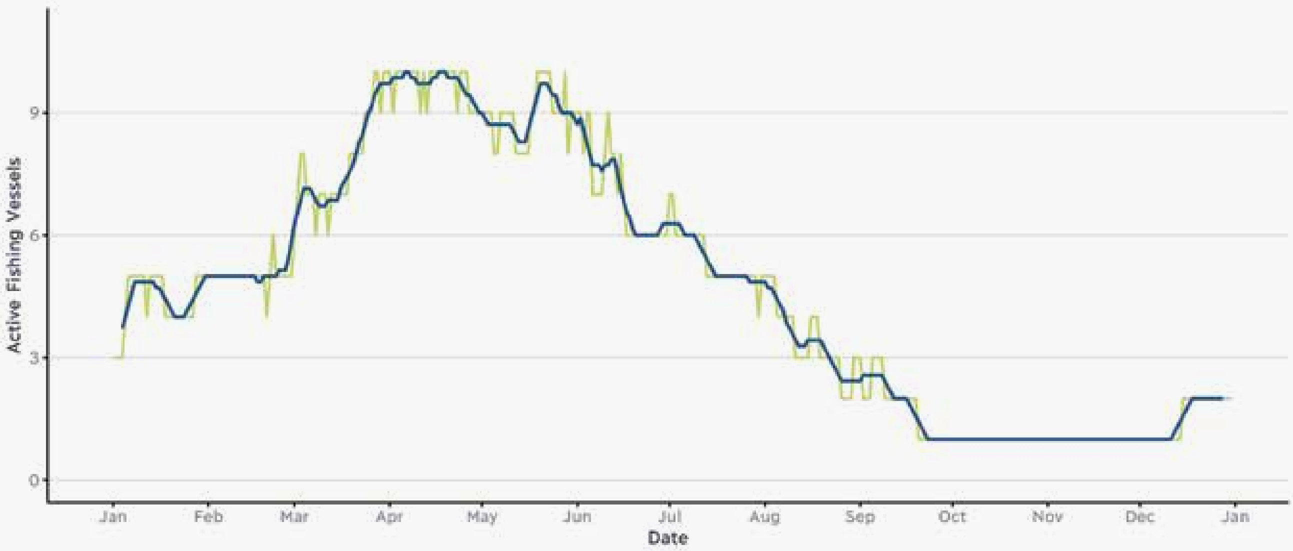


Figure 48-58-88. 9. Number of AIS-identified active longliners per day in FAO Areas 48, 58 and 88 during 2017. Only vessels that fished at least 24 hours in the area over the course of the year are included. Dark blue line shows a 7-day rolling average.

ACKNOWLEDGEMENTS

The editors would like to thank Roberto Sarralde, Carolina Minte-Vera, Keith Reid and Marta Soffker for excellent comments and feedback during the elaboration of the chapter. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Required citation for this chapter:

Murua, H., Ramm, D., Granado, I., Kroodsma, D., Miller, N. A., Taconet, M., Fernandes, J. A. 2019. FAO Areas 48, 58 and 88 - AIS-based fishing activity in the Southern Ocean. *In* Taconet, M., Kroodsma, D., Fernandes, J.A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

CCAMLR. 2013. *Commission for the Conservation of Antarctic Marine Living Resources. Report on bottom fisheries and vulnerable marine ecosystems.* https://www.ccamlr.org/en/system/files/VMEs_1.pdf

CCAMLR. 2018. *Commission for the Conservation of Antarctic Marine Living Resources.* Statistical Bulletin, Vol. 30. http://www.ccamlr.org

CCAMLR. 2019. *Commission for the Conservation of Antarctic Marine Living Resources. List of authorised vessels.* https://www.ccamlr.org/en/compliance/list-vessel-authorisations

Bargagli, R. 2005. *Antarctic Ecosystems: Environmental Contamination, Climate Change, and Human Impact.* Berlin, Springer-Verlag. ISBN 978-3-540-26465-1.

FAO. 2019a. *Food and Agriculture Organization of the United Nations. FAO Major Fishing Areas. Atlantic, Antarctic (Major Fishing Area 48).* http://www.fao.org/fishery/area/Area48/en

FAO. 2019b. *Food and Agriculture Organization of the United Nations. FAO Major Fishing Areas. Antarctic and Southern Indian Ocean (Major Fishing Area 58).* http://www.fao.org/fishery/area/Area58/en

FAO. 2019c. *Food and Agriculture Organization of the United Nations. FAO Major Fishing Areas. Pacific, Antarctic (Major Fishing Area 88).* http://www.fao.org/fishery/area/Area88/en

Riffenburgh, B. 2007. *Encyclopedia of the Antarctic,* Vol. 1. ISBN: 978-0415970242.

Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F.,... & Woods, P. 2018. Tracking the global footprint of fisheries. *Science*, 359(6378), 904-908. https://doi.org/10.1126/science.aao5646

FAO AREA 51

AIS-based fishing activity in Western Indian Ocean

Figure 51. 1. Location of FAO Area 51.

Hilario Murua, Igor Granado, Jennifer Gee, David Kroodsma, Nathan A. Miller, Marc Taconet and Jose A. Fernandes

PREAMBLE

This chapter assesses, through a comparison with fleet statistics and public fisheries data, the capacity of Automatic Identification System (AIS) data and Global Fishing Watch (GFW) algorithms (Kroodsma *et al.*, 2018) to identify and quantify fishing vessel activity in the Western Indian Ocean. This assessment reviews fleet activity, main gear types, and spatial distribution of fishing vessel activity and fishing operations.

SUMMARY AND CONCLUSIONS FOR THE WESTERN INDIAN

In the northern portion of the Western Indian Ocean region, the ability to map fishing activity through AIS data is limited by poor AIS reception and low levels of AIS use in artisanal and semi-industrial fleets from coastal countries. Throughout the region, gillnet is one of the main fishing gears for the artisanal and semi-industrial fleets, but this activity cannot be mapped as most of these vessels are under 12 m without AIS. Larger vessels in the region, however, also show relatively low use of AIS. Less than 50 percent of coastal country/territory vessels over 24 m use AIS. The exceptions are Bahrain, Seychelles and distant water longliner fleets with higher AIS use. Therefore, longliner activity appears to be well represented by the AIS data and GFW classification, particularly in the southern part where AIS reception quality is good. In contrast, the spatial distribution of trawler and purse seiner activity is poorly captured by AIS, and noticeably the industrial pelagic purse seiner fleet makes limited use of AIS.

FAO Area 51 bathymetry

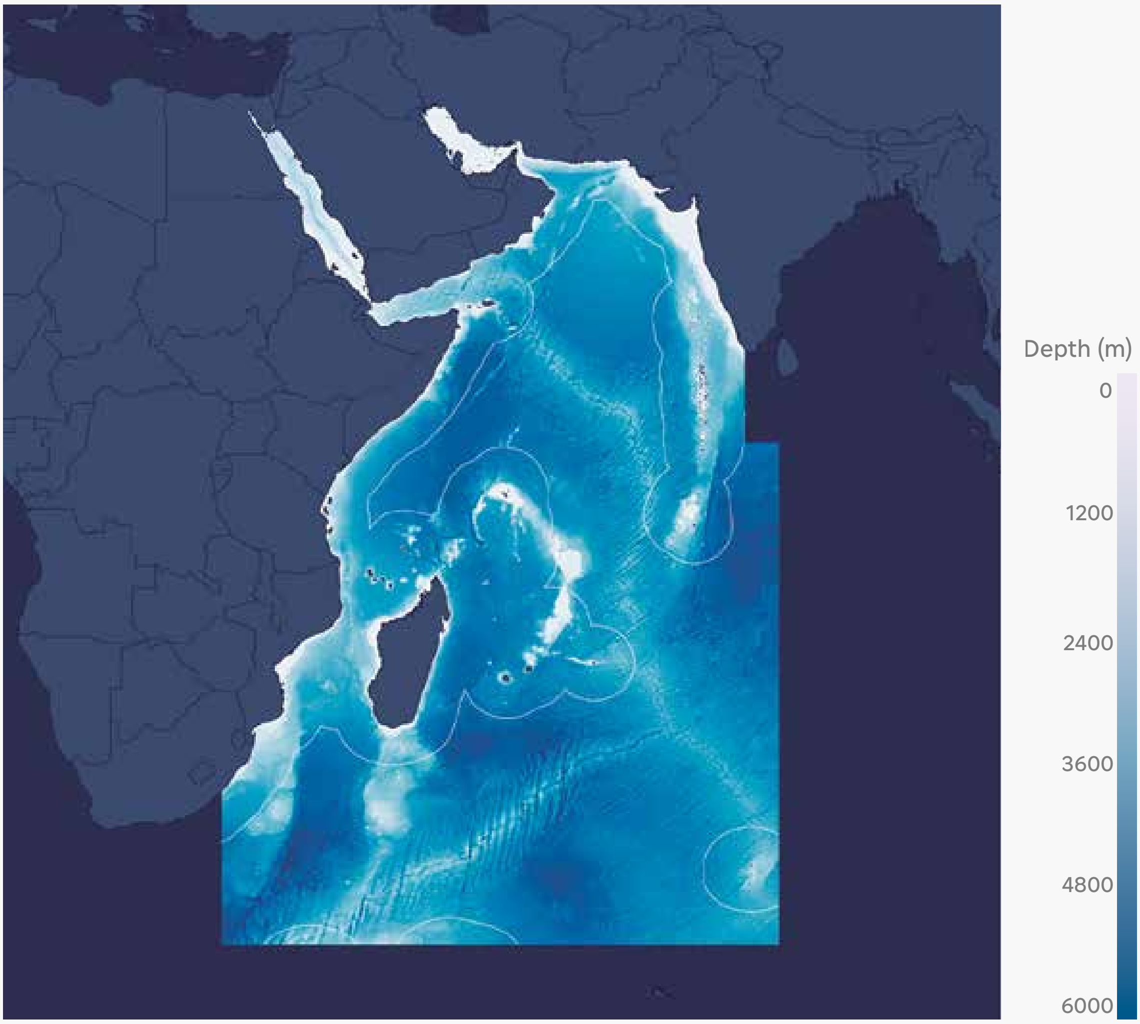


Figure 51. 2. FAO Area 51 bathymetry (depth) and 200 nautical miles arc.

INTRODUCTION FOR THE WESTERN INDIAN

The Western Indian Ocean FAO Area encompasses all marine waters of the western Indian Ocean bounded on the west and north by the coastline from southern Africa to the south of India, and extending eastwards to 80°E and southwards to 45°S. The following coastal countries/territories border FAO Area 51: Bahrain, British Indian Ocean Territories, Comoros, Djibouti, Egypt, Eritrea, Ethiopia, Ethiopia PDR, French Southern Territories, India, Iran, Iraq, Israel, Jordan, Kenya, Kuwait, Madagascar, Maldives, Mauritius, Mozambique, Oman, Pakistan, Qatar, Saudi Arabia, Seychelles, Somalia, South Africa, Sudan, United Republic of Tanzania, United Arab Emirates, Yemen and and the United Republic of Tanzania, Zanzibar. About 42 percent of the region's waters are under national jurisdiction, with the high seas accounting for 58 percent of the total marine waters (the proportion of high seas in all FAO areas ranges between 20 and 80 percent).

In this region, fisheries are managed by two Regional Fishery Management Organizations: the Indian Ocean Tuna Commission (IOTC), which is responsible for the management of tuna and tuna-like species in the Indian Ocean, and the Southern Indian Ocean Fisheries Agreement (SIOFA), which is responsible for the management of high seas deep seas non-highly migratory species. In addition, the Southwest Indian Ocean Fisheries Commission (SWIOFC) is a Regional Fishery Body providing advice on coastal resources of Eastern African States.

The continental shelf is generally narrow along east Africa, but wider along the north western coast of India, and covers the entire Gulf and Red Sea. Along mid-ocean ridges and fracture zones occur extended strips of islands and relatively shallow banks, while large seamounts occur particularly in the western part (Gershanovich and Dubinets, 1991). Seamounts contribute to the biodiversity of the Indian Ocean (Wafar *et al.*, 2011). During summer monsoon the productivity of the Indian Ocean is driven by the upwelling systems along Somalia, Oman, and the southwest coast of India and is spread across the Arabian Sea. In contrast, during winter monsoon, productivity is driven by convective mixing and is mostly limited to northern Arabian Sea (Jayaram and Kumar, 2018). FAO landings statistics (FishStatJ, 2018) show that in the period from 2010 to 2014, catches were dominated by small and large pelagic species. The largest catches have been made of Indian oil sardine, Yellowfin tuna, Skipjack tuna, Croakers, Bombay-duck, Indian mackerel *(Rastrelliger kanagurta)*, Natantian decapods, Hairtails, Longtail tuna *(Thunnus tonggol)*, Giant tiger prawn *(Penaeus monodon)*, Cephalopods, Sea catfishes, Anchovies, Narrow-barred Spanish mackerel *(Scomberomorus commerson)*, Carangids, Clupeoids, and Kawakawa *(Euthynnus affinis)*. These species and groups made up 70 percent of the reported catch in that period (FishStatJ, 2018).

REGION FLEETS AND AIS USE IN THE WESTERN INDIAN

Assessing fleets capacity in FAO Area 51 is challenging because countries in this region often lack accurate fleet reporting for FAO statistics (Figure 51. 3), including absence of vessel length information. Many countries/territories (e.g. Bahrain, Réunion and Mozambique) did not report vessels over 24 m (Figure 51. 4a) despite vessels of this size class being detected in the AIS data (Figure 51. 4b).

Coastal fleets in this region have a high proportion of small vessels, both powered and unpowered, which are not tracked in the AIS data (Figure 51. 3). According to these fleet statistics, non-motorized vessels account for 44.2 percent of the fishing vessels in this region, being higher than the global average of 39 percent (based on SOFIA, 2018). Coastal countries/territories in this region report very few vessels larger than 24 m. This number may be a reporting error, but may also reflect that many are developing countries with a low proportion of large vessels (McCauley *et al.* 2018). Also, two of the top three fleets, India and Yemen, lack reporting on the number of fishing vessels by size, explaining the high fraction of motorized vessels with unknown lengths and making it difficult to assess how many large fishing vessels should have AIS data.

Fleets of coastal countries/territories in FAO Area 51

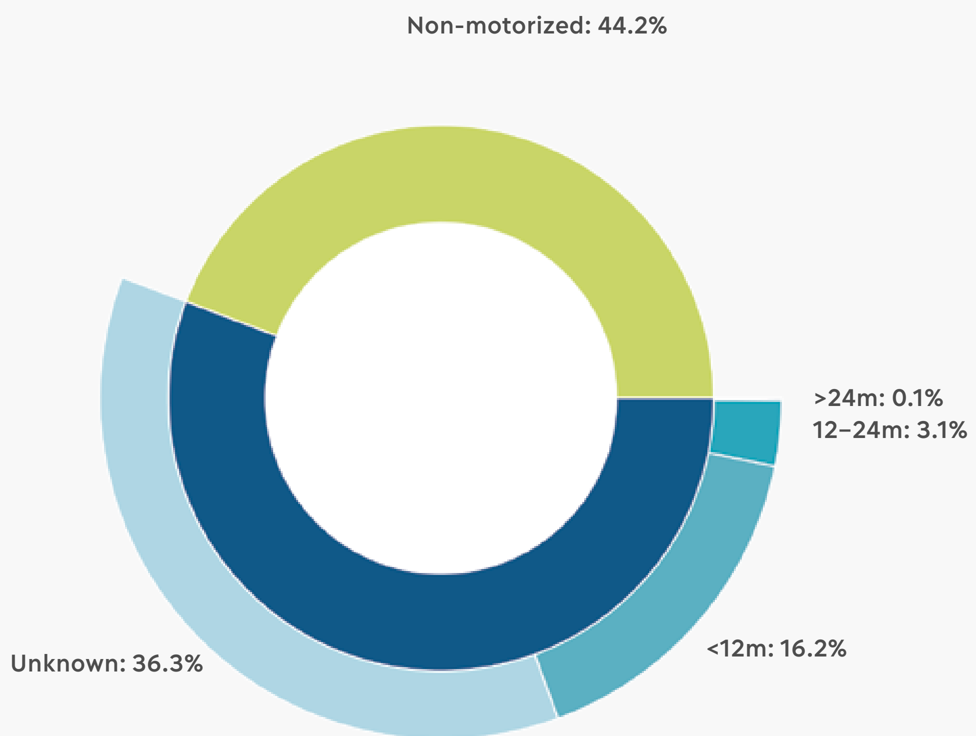


Figure 51. 3. Structural composition of fleets of coastal countries/territories in FAO Area 51. In dark blue motorized fishing vessels and in green non-motorized vessels. Distant water fleets active in FAO Area 51 are not included (see next Figure). Notice that India and South Africa border more than one FAO area, yet their entire fleet size is included here. Source: FAO statistics for 2017. Statistics were not available for the following coastal countries/territories within FAO Area 51: British Indian Ocean Territories, Ethiopia and Somalia.

Figure 51. 4.a shows that the coastal country with the largest number of reported motorized vessels was India, followed by Pakistan, Yemen and Oman. Correspondingly, India accounts for 50 percent of total captures across all species in the FAO Area 51 (FishStatJ, 2018). The AIS data for FAO Area 51 provided a very different picture of fishing activity, largely because it was dominated by the distant water fleets which have a relatively high adoption of AIS compared to coastal territories. Figure 51. 4.b shows the number of fishing vessels, by fleet, operating in the region and broadcasting AIS. About half the vessels broadcasting AIS are from distant water fleets, where Taiwan Province of China had the largest number of vessels using AIS in the region. China, Japan, Republic of Korea, Malaysia and Spain also had sizeable fleets, mostly operating in the high seas. Despite this higher use of AIS by distant fleets in the region, Sala *et al.* (2018) estimated that in the IOTC, less than half of Chinese longliners and only just over half of the Taiwanese Province of China ones broadcast AIS, and that these fractions were lower than in the Pacific or Atlantic Ocean high seas. For regional fleets, AIS data severely underrepresent the number of vessels.

Within coastal territories, Bahrain had the highest vessel number represented in the AIS data. This high representation is a result of Bahrain's national regulations requiring AIS use for its entire fleet including small vessels. India was the second largest regional fleet from the AIS data, even though it likely has by far the most vessels operating in the region and accounts for around 1.8 million tonnes of catch per year (FishStatJ, 2018). Other coastal fleets with some vessels broadcasting AIS were the Islamic Republic of Iran, Seychelles, Mauritius, Qatar, Réunion and other Indian Ocean Tuna Commission (IOTC) members that operate tuna fisheries in the region. In most countries the fraction of large vessels that broadcast AIS was well below 50 percent, and negligible in relation to total vessels. There were many semi-industrial vessels in the 12-24 m length class which did not appear to be using AIS. These would include thousands of gillnetters from Pakistan, Iran, Sri Lanka and possibly India; thousands of longliners from Indonesia; or, baitboats from Maldives, India and Indonesia. Finally, as shown by Figure 51. 3, the region has a high number of small, non-powered vessels from the coastal fleets.

Fishing gears identified by AIS data showed that foreign fleets are dominated by longliners, while coastal fleets are a mix of gear types with trawlers and purse seiners being the most common. China also had over 15 squid jiggers, which operated mostly in international waters near the Arabian Peninsula. These AIS results were based on 968 identified likely fishing vessels active in the region, from all fleets, 387 of which could be matched to registries with gear type information, thus confirming their identity. Meanwhile the other vessels' gear types were identified through the neural net classifier and flag states were assigned based on their AIS broadcast. Almost all vessels matched to public vessel registries were from distant water fleets and not regional fleets.

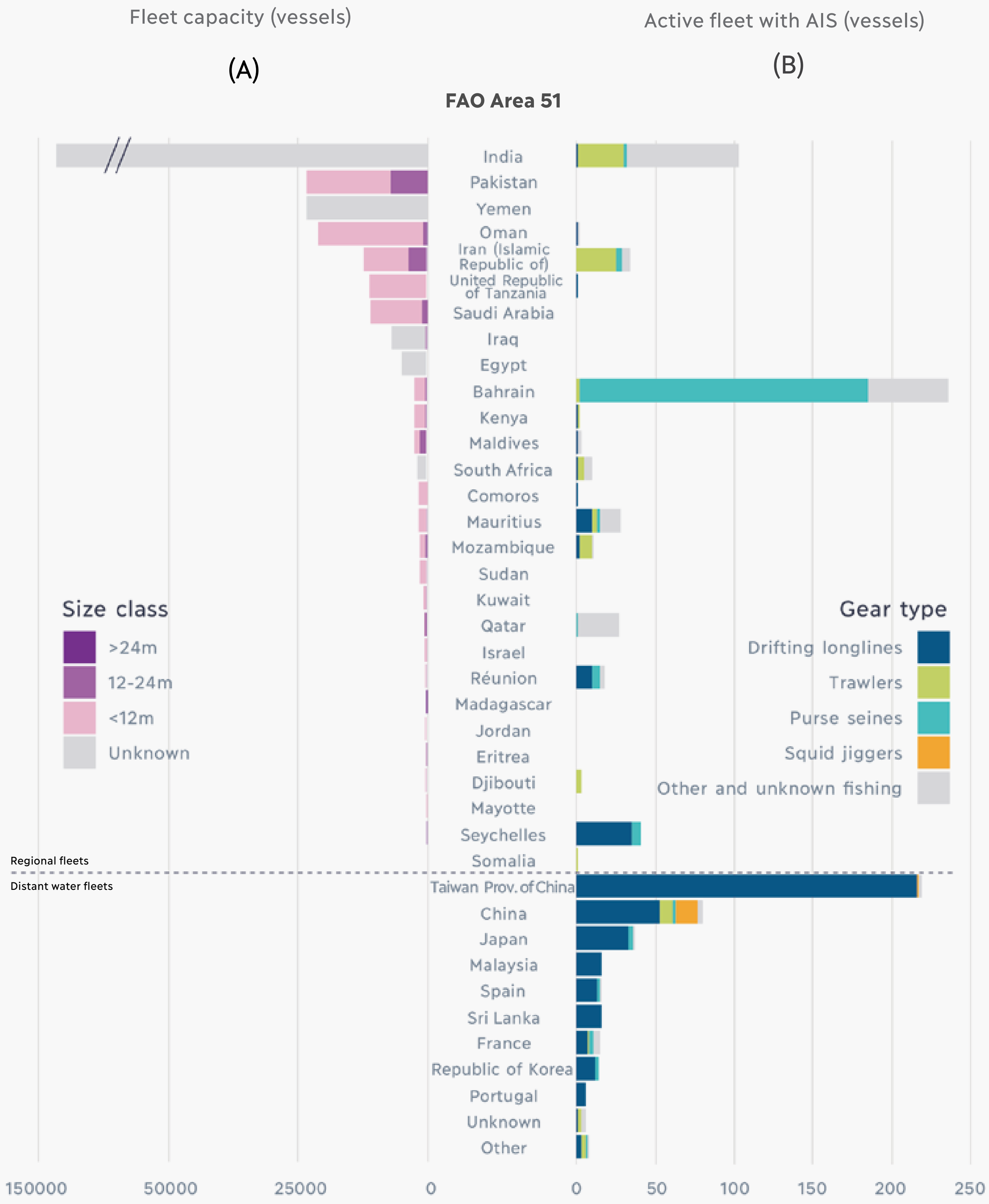


Figure 51. 4. Coastal and distant fleets summary based on FAO statistics and AIS data classification by GFW in FAO Area 51 for 2017. A) Number of motorized vessels as reported to FAO (left panel). The entire national Indian and South African fleets are shown, even though both countries border more than one FAO area. Source: FAO statistics. Statistics were not available for the following coastal countries/territories border FAO Area 51: British Indian Ocean Territories, Ethiopia, Somalia. B) AIS-identified number of fishing vessels broadcasting AIS during their operations in FAO Area 51 by gear type and flag state (right panel). Dashed lines separate regional fleets (top) from distant fleets (bottom). Only vessels that fished for at least 24 hours in the area are included. Source: GFW.

AIS RECEPTION AND FISHING VESSEL ACTIVITY IN THE WESTERN INDIAN

Figures 51. 5a,b show all fishing vessel activity captured by AIS in FAO Area 51 (Class A and Class B AIS devices). About three quarters of AIS operating fishing vessels in the region used the lower quality Class B devices. It appears that India's entire fleet uses Class B, as does most of the Iran and Bahrein fleets. The squid fleet, which is mostly Chinese, operating in the high seas near the Arabian Peninsula generally used Class A. The reception of high-quality Class A devices is good across the region, except in the Arabian Sea and near Pakistan and India (Figure 51. 5c). The reception of Class B devices was poor in the northern half of the region, which is a productive fishing zone, and relatively good in the southern half of the region (Figure 51. 5d).

Figure 51. 5. Fishing vessel activity and quality of AIS reception for FAO Area 51 during 2017. Top row shows activity of vessels broadcasting using Class A devices (left panel) and Class B devices (right panel). The bottom row shows reception quality maps for devices Class A (left panel) and B (right panel). About two thirds of the fishing vessels in this region broadcast Class B. Blank spaces on the map (i.e. dark blue ocean background) mean that no signals from fishing vessels in this area were received, which is due to either no vessel activity or poor reception.

The spatial pattern of vessel fishing operations depicted by AIS showed that most fishing concentrates in the south western part and is mostly exerted by distant nation fishing fleets (Figure 51. 6). This is because the AIS data is biased toward longliner distant water fleets, and because AIS reception is better in the southern half of the basin. The northern area, in contrast, shows little AIS-monitored fishing activity. Despite weak reception, northern India's coastal fishing activity was high in some located spots. The Red Sea showed, incorrectly, almost no activity.

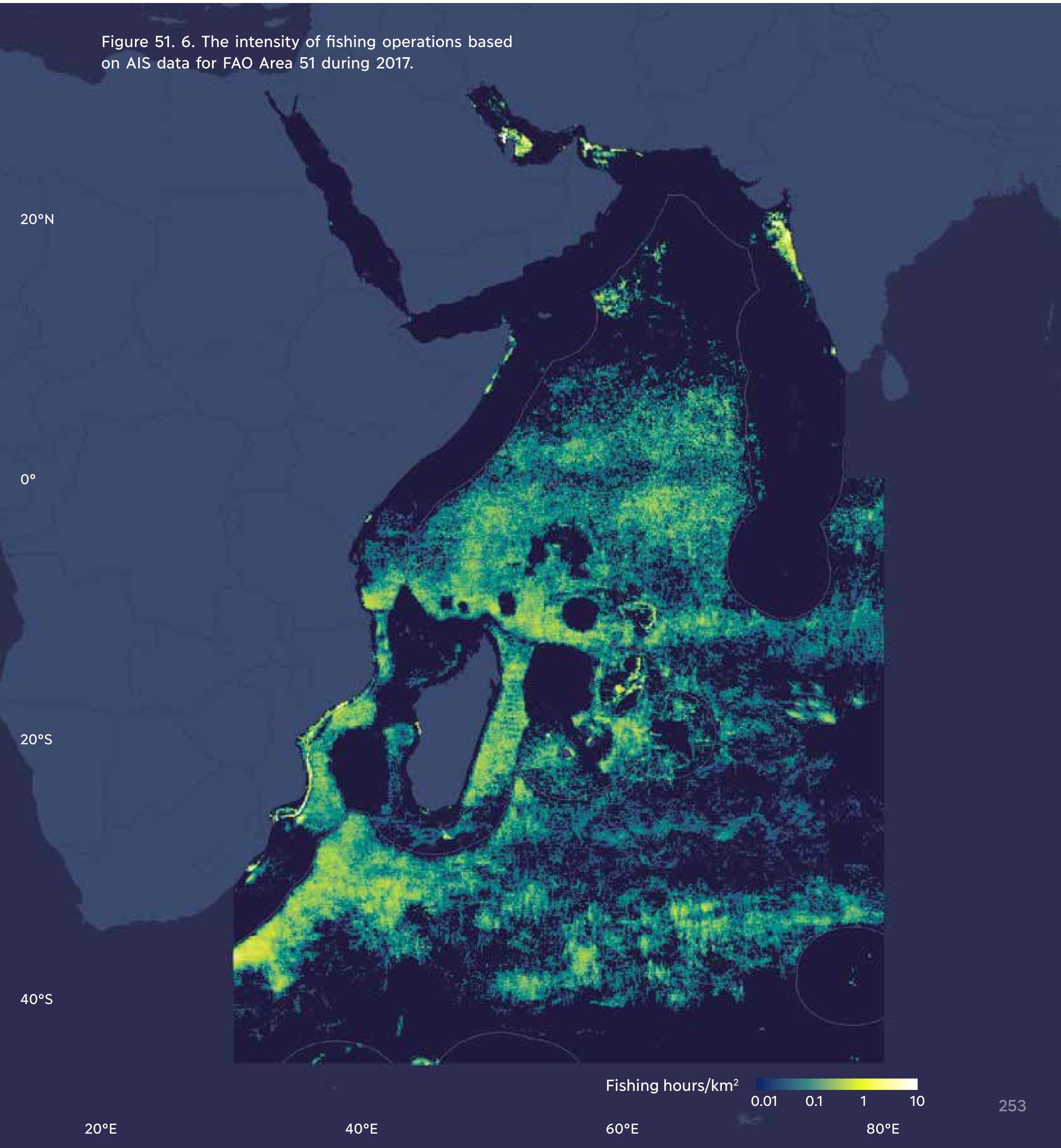


Figure 51. 6. The intensity of fishing operations based on AIS data for FAO Area 51 during 2017.

FISHING VESSEL ACTIVITY AND OPERATIONS BY GEAR IN THE WESTERN INDIAN

This section reviews the spatial distribution patterns of the main fishing gears in FAO Area 51 as estimated by Global Fishing Watch (GFW) based on 2017 AIS data. The most recent datasets available as of mid-2018 were used to assess GFW capacity to provide an AIS based characterization of fishing activity by fishing gear in terms of presence/absence, intensity and hotspots. The Introduction chapter describes the rationale and challenges for use of contrasting data sources (e.g. Global Fisheries Landings database (GFLD; Watson, 2017)) for benchmarking AIS data classification.

GEAR TYPES	Catches (GFLD) 2010–2014 average		Total fishing vessel activity (GFW-AIS) 2017	
	Tonnes of catch in 1000s	% of catch	Active days in 1000s	% of active days
Trawls	1 601	38%	8.3	7%
Other	923	22%	16.9	13%
Set gillnets	925	22%		
Purse seines	606	14%	18.2	15%
Longlines	154	4%	83.8	66%
Total	4 211	100%	123.0	100%

Table 51. I. Summary table comparing average catch from GFLD during 2010–2014 with fishing vessel activity from GFW in FAO Area 51. Only vessels that fished for at least 24 hours in FAO Area 51 are included.

AIS-based fishing activity estimated by GFW suggests that the main fishing gear in the region are longliners (Table 51. I). In contrast, some of the highest catches in GFLD are associated with the gillnet fleets. AIS could not detect most of their activity because almost no gillnetters broadcast AIS. According to Williams *et al.* (2018) (Figure 51. 7), these gillnetters are active mostly in the northern part of the region, where AIS use and reception are poor.

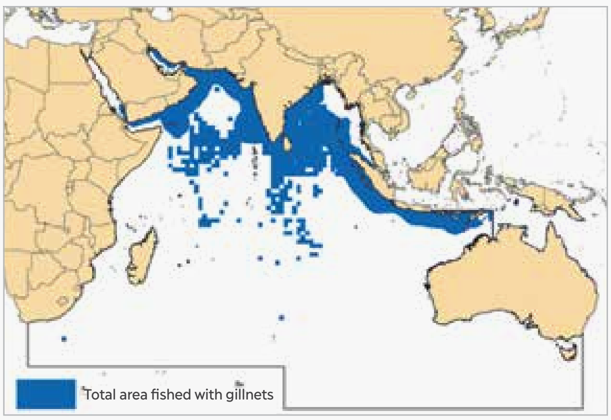


Figure 51. 7. Figure reproduced from report by Williams *et al.* (2018). Distribution of gillnet fishing activity in the IOTC area the years 2012-2016. Note that reported gillnet fishing is grossly underestimated in the IOTC area and in this map gillnet fishing was assumed to occur within the entire Exclusive Economic Zones (EEZs) of the main gillnet countries (Islamic Republic of Iran, Oman, Pakistan, Yemen, India, Sri Lanka and Indonesia).

AIS depicts drifting longliners as mostly operating in international waters, although some activity was observed within EEZs, including those of Kenya, Mozambique, United Republic of Tanzania, Seychelles, Madagascar and Réunion, where the activity was conducted either by local vessels or by foreign vessels licensed through fishing agreements. These longliners were mostly large deep-freezing vessels from Taiwan Province of China, China, Japan and the Seychelles targeting tuna and tuna-like species. The spatial distribution of fishing activity and number of vessels captured by AIS for these longline fleets seemed to correspond with the data of larger deep-freezing vessels for these countries and territories as provided by the IOTC (2017). However, there were also many fresh tuna longliners under 24 m which were not identified in the AIS characterization (IOTC, 2017). The Global Fisheries Landings database (GFLD; Watson, 2017) suggests that fishing activity from longliners cover a broader geographic coverage than depicted by the AIS characterization (Figure 51. 8). This wider characterization is especially marked in the northwestern Indian Ocean, where the vessels may turn off the AIS signal for security reasons or may not be detected because of poor AIS reception quality (Figure 51. 5).

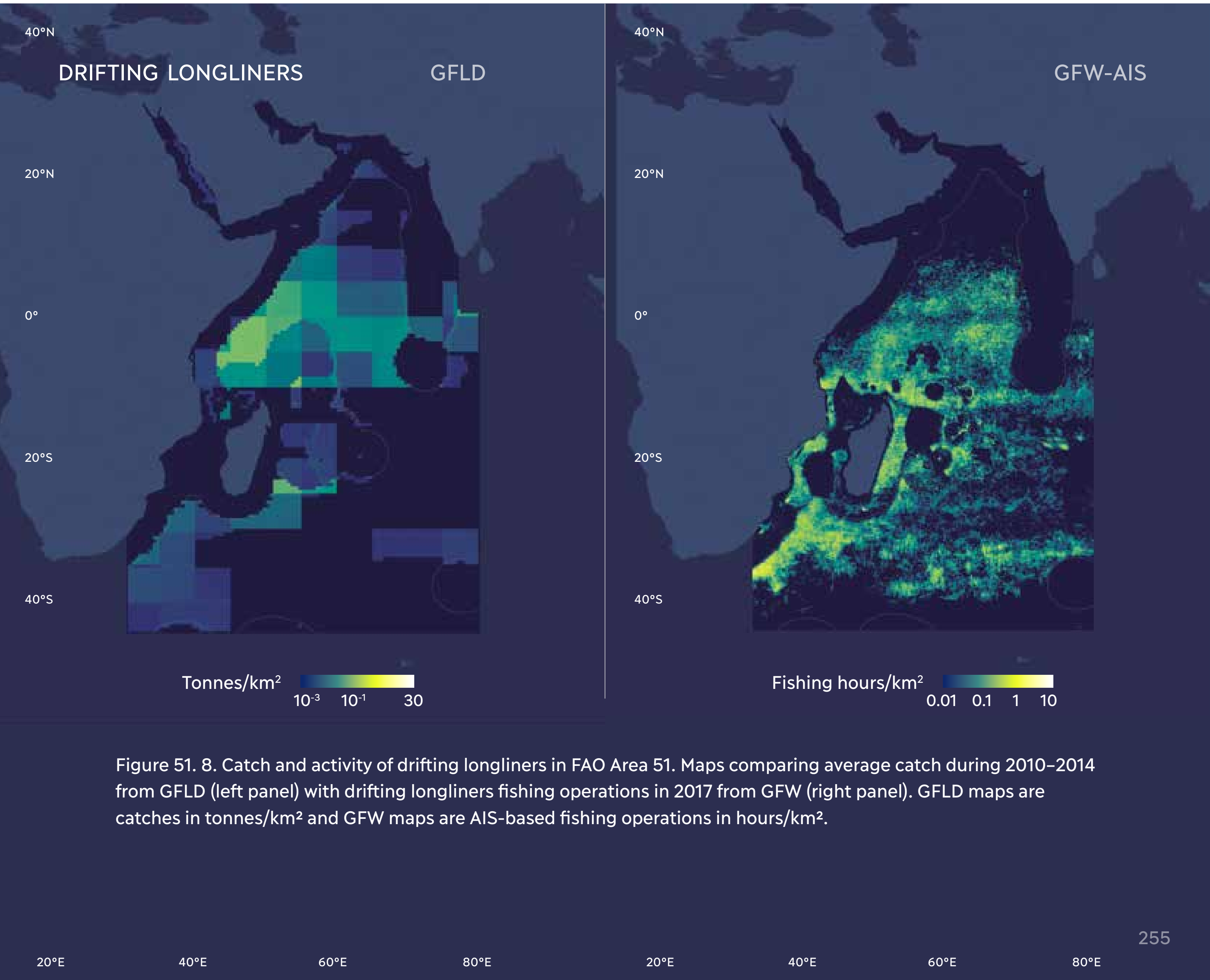


Figure 51. 8. Catch and activity of drifting longliners in FAO Area 51. Maps comparing average catch during 2010–2014 from GFLD (left panel) with drifting longliners fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

For drifting longliners, AIS data identified a small seasonal pattern of fishing activity (Figure 51. 9), which could be related to longliner seasonal spatial movements and spatial differential reception of the AIS system between the northern and southern parts of the area.

Drifting longlines fishing in FAO Area 51

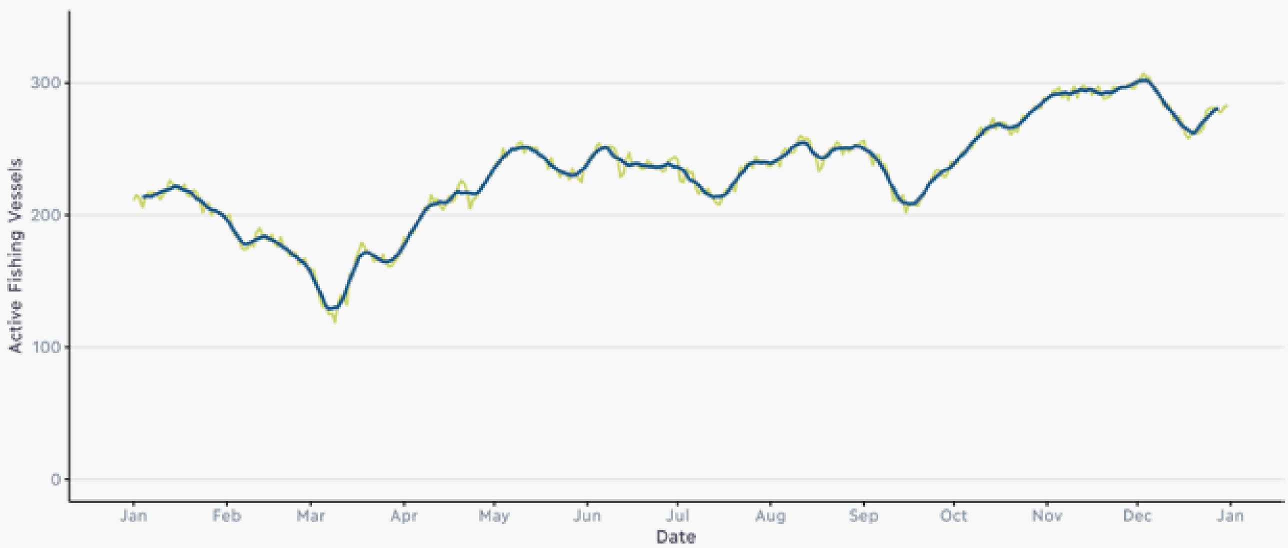


Figure 51. 9. Number of AIS-identified active drifting longliners per day in FAO Area 51 during 2017. Only vessels that fished at least 24 hours in the area over the course of the year are included. Dark blue line shows a 7-day rolling average.

For trawlers, low activity and few vessels were identified by AIS, and the vessels that were identified were restricted to a few coastal regions (Figure 51. 10). A few deep-sea trawlers from the Cook Islands which operated in the region under the management of the Southern Indian Ocean Fisheries Agreement (SIOFA) targeted alfonsino and orange roughy near seamounts. The catch reconstruction (GFLD) found that the most prevalent fishing gear in the region was trawling (Table 51. I), whereas AIS ranked it as being only 7 percent of the fishing activity. The extremely low use of AIS by coastal fleets explains why AIS poorly reflects trawler activity in coastal areas, in contrast to the information from GFLD. On the contrary in the high seas, where the AIS data performs better, GFLD represented trawlers operating across the entire Indian Ocean; this wide characterization is however unlikely, and the AIS data is probably more accurate in depicting a general lack of deep water trawling.

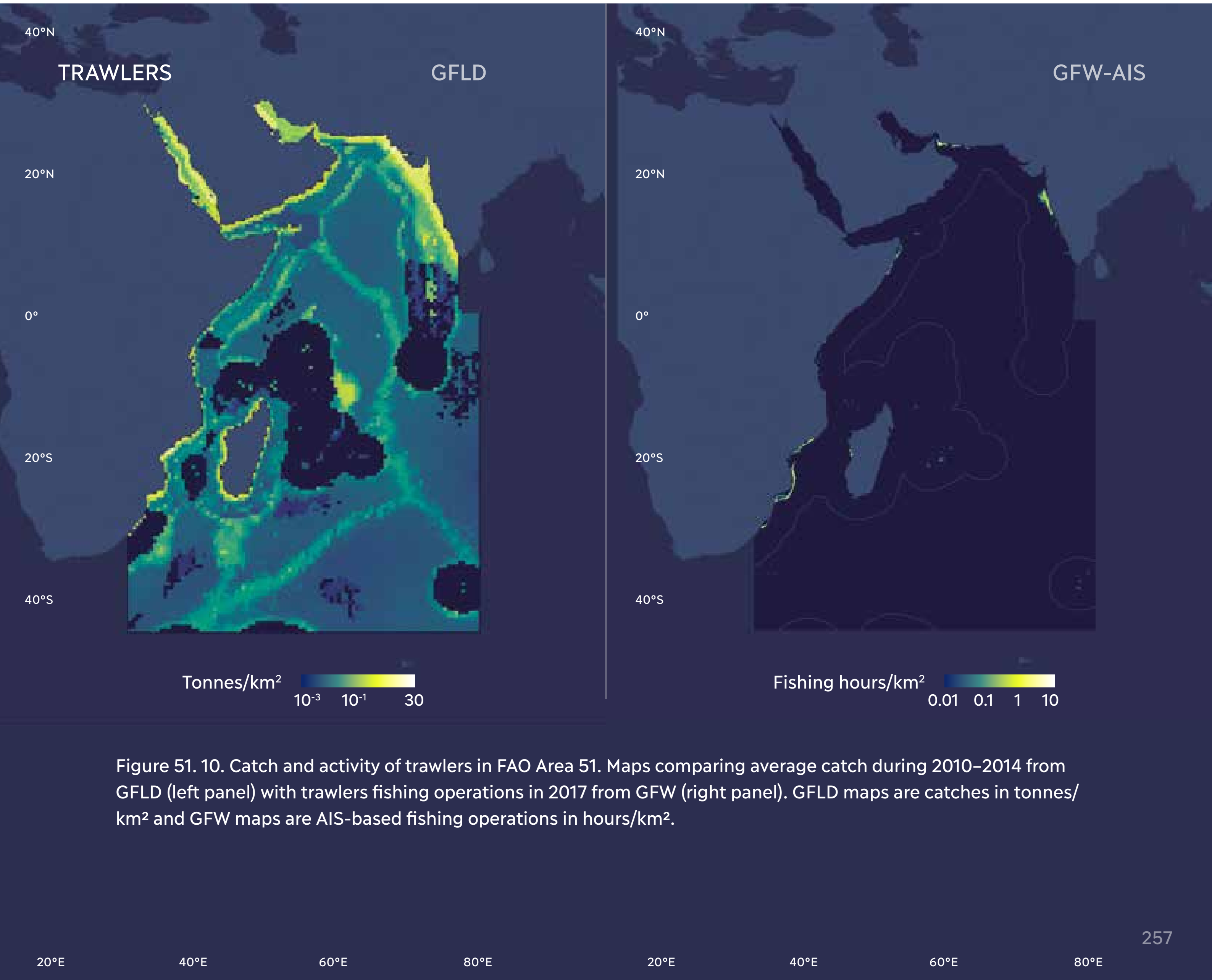


Figure 51. 10. Catch and activity of trawlers in FAO Area 51. Maps comparing average catch during 2010–2014 from GFLD (left panel) with trawlers fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

Regarding purse seiners, AIS did not identify most of the industrial tuna purse seiner fishing activity in the Western Indian Ocean (Figure 51. 11). This underrepresentation is largely because many of these vessels in the region disable their AIS systems during fishing operations for several reasons, including security. Also, for the few purse seiners broadcasting, the AIS algorithm for identifying fishing activity only accounts for setting and hauling time, and does not include searching time, which is the main fishing activity. The Seychelles case study chapter in this report shows that AIS detects properly the number of industrial purse seiners from the Seychelles (13) and European Union (19), but that almost all these vessels turn off their AIS after leaving port. In summary, the AIS system does not capture well the characterization of purse seiners in this region. The comparison with GFLD (2017) confirms this discrepancy by showing that catches from purse seiners occur over much broader geographic areas in FAO Area 51 than currently shown by the AIS characterization (Figure 51. 11). Notice that some vessels from India which were classified as using unknown fishing gears (Figure 51. 4) because the GFW neural net algorithm was not confident of the exact gear type, may be purse seiners.

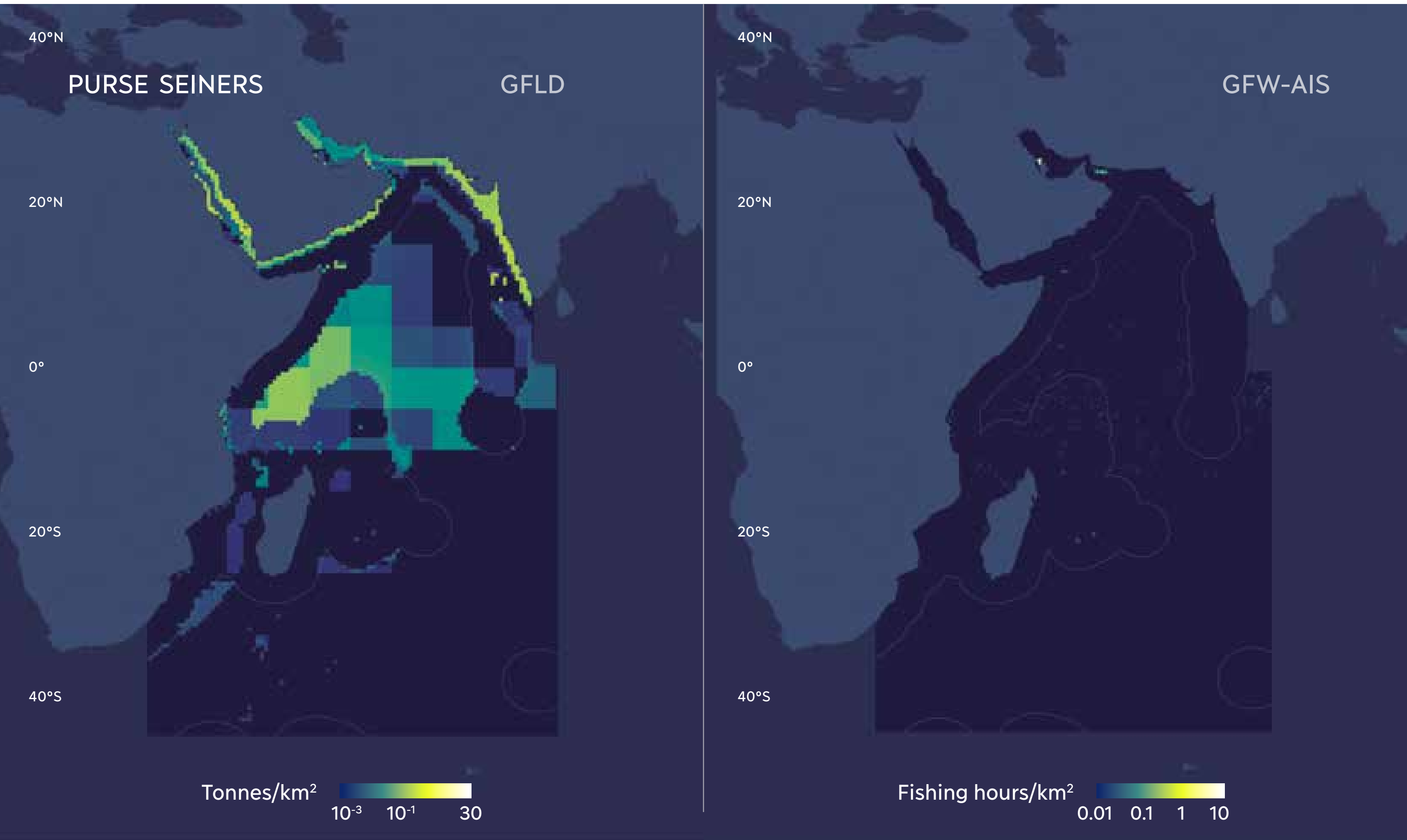


Figure 51. 11. Catch and activity of purse seiners in FAO Area 51. Maps comparing average catch during 2010–2014 from GFLD (left panel) with purse seiners fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

Interestingly, the purse seiner activity best identified by AIS data corresponded to the seasonal fishing activity of the Bahrain fleet, as most of the purse seiners broadcasting AIS all year around in the region are from this nation. The entire Bahraini fleet is covered by AIS and restricted to fishing within national waters. The purse seiners identified, though, were either relatively inactive, or operating with their AIS off or in poor reception regions. Although over 200 purse seines were identified in the region, fewer than 20 were active most days of the year.

Purse seiners fishing in FAO Area 51

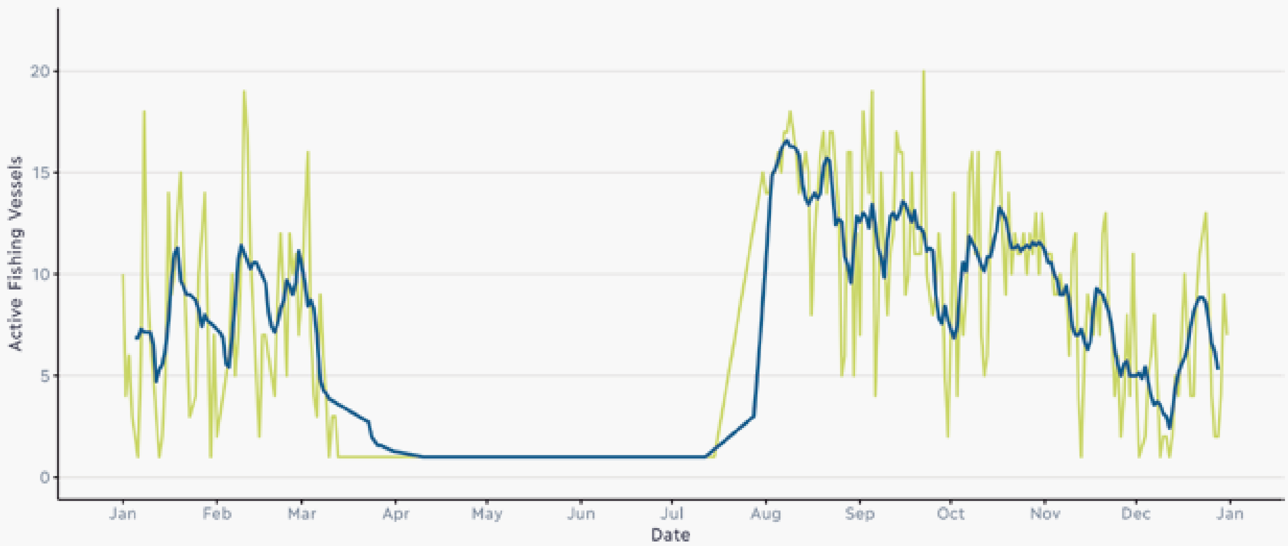


Figure 51. 12. Number of AIS-identified active purse seiners per day in FAO Area 51 during 2017. Only vessels that fished at least 24 hours in the area over the course of the year are included. Dark blue line shows a 7-day rolling average.

ACKNOWLEDGEMENTS

The editors would like to thank Alejandro Anganuzzi, James Geehan and Mark Dimech for excellent comments and feedback during the elaboration of the chapter. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Required citation for this chapter:

Murua, H., Granado, I., Gee, J., Kroodsma, D., Miller, N. A., Taconet, M., Fernandes, J. A. 2019. FAO Area 51 - AIS-based fishing activity in the Western Indian Ocean. *In* Taconet, M., Kroodsma, D., Fernandes, J.A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

Jayaram, C., & Kumar, P. D. 2018. Spatio-temporal variability of upwelling along the southwest coast of India based on satellite observations. *Continental Shelf Research*, 156, 33-42. https://doi.org/10.1016/j.csr.2018.02.003

IOTC–SC20. 2017. *Indian Ocean Tuna Commission Scientific Committee. Report of the 20th Session of the IOTC Scientific Committee. Seychelles, 30 November - 4 December 2017.* Document IOTC–2017–SC20–R[E]. https://www.iotc.org/sites/default/files/documents/2017/12/IOTC-2017-SC20-R_E.pdf

FAO. 2019. *Food and Agriculture Organization of the United Nations. FAO Major Fishing Areas. Western Indian Ocean (Major Fishing Area 51).* http://www.fao.org/fishery/area/Area51/en

FishStatJ, Fisheries and aquaculture software, 2018. Software for fishery statistical time series. *In* FAO Fisheries and Aquaculture Department [online]. Rome. Updated 21 July 2018. [Cited 19 November 2018]. http://www.fao.org/fishery/statistics/software/fishstatj/en

Fernandes, J. A., Cheung, W. W., Jennings, S., Butenschön, M., de Mora, L., Frölicher, T. L.,... & Grant, A. 2013. Modelling the effects of climate change on the distribution and production of marine fishes: accounting for trophic interactions in a dynamic bioclimate envelope model. *Global change biology,* 19(8), 2596-2607. https://doi.org/10.1111/gcb.12231

Fernandes, J.A., 2018. *Chapter 13: Southern Asian fisheries in the Arabian Sea, Bay of Bengal and East Indian Ocean. In* Barange, M., Bahri, T., Beveridge, M., Cochrane, K., Funge-Smith, S., Poulain, F. (Eds.). *Impacts of Climate Change on fisheries and aquaculture: Synthesis of current knowledge, adaptation and mitigation options.* FAO Fisheries Technical Paper 627. Rome, FAO. http://www.fao.org/3/i9705en/i9705en.pdf

Gershanovich, D. Y., & Dubinets, G. A. (1991). Geomorphology of Indian Ocean seamounts. *International Geology Review*, 33(9), 903-913. https://doi.org/10.1080/00206819109465733

Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F.,... & Woods, P. 2018. Tracking the global footprint of fisheries. *Science*, 359(6378), 904-908. https://doi.org/10.1126/science.aao5646

Jennings, S., & Collingridge, K. 2015. Predicting consumer biomass, size-structure, production, catch potential, responses to fishing and associated uncertainties in the world's marine ecosystems. *PloS one*, 10(7), e0133794. https://doi.org/10.1371/journal.pone.0133794

Sala, E., Mayorga, J., Costello, C., Kroodsma, D., Palomares, M. L., Pauly, D.,... & Zeller, D. 2018. The economics of fishing the high seas. *Science advances*, 4(6), eaat2504. https://doi.org/10.1126/sciadv.aat2504

Wafar, M., Venkataraman, K., Ingole, B., Khan, S. A., & LokaBharathi, P. 2011. State of knowledge of coastal and marine biodiversity of Indian Ocean countries. *PLoS one*, 6(1), e14613. https://doi.org/10.1371/journal.pone.0133794

Watson, R. A. 2017. A database of global marine commercial, small-scale, illegal and unreported fisheries catch 1950–2014. *Scientific data*, 4, 170039. https://doi.org/10.1038/sdata.2017.39

Williams, A. J., Georgeson, L., Summerson, R., Hobday, A., Hartog, J., Fuller, M., Swimmer, Y., Wallace, B., & Nicol, S. J. 2018. *Assessment of the vulnerability of sea turtles to IOTC tuna fisheries.* Document IOTC-2018-WPEB14-40. https://www.iotc.org/sites/default/files/documents/2018/08/IOTC-2018-WPEB14-40.pdf

FAO AREA 57

AIS-based fishing activity in the Eastern Indian Ocean

Figure 57. 1. Location of FAO Area 57.

Maitane Grande, Hilario Murua, Igor Granado, Marc Taconet, David Kroodsma, Nathan A. Miller and Jose A. Fernandes

PREAMBLE

This chapter assesses, through a comparison with fleet statistics and public fisheries data, the capacity of Automatic Identification System (AIS) data and Global Fishing Watch (GFW) algorithms (Kroodsma *et al.*, 2018) to identify and quantify fishing vessel activity in the Eastern Indian Ocean. This assessment reviews fleet activity, main gear types, and spatial distribution of fishing vessel activity and fishing operations.

SUMMARY AND CONCLUSIONS FOR THE EASTERN INDIAN

Class A AIS device reception is good throughout the area, except in northern areas around the Bay of Bengal. However, Class B AIS device reception is good only in the southern half of the Indian Ocean, and very poor in the northern half including the Bay of Bengal. Fishing activity in the eastern Indian Ocean is poorly represented by AIS data, even in the high seas, as many of the fleets operating in the area do not use AIS. All artisanal and semi-industrial gears (e.g., pole and line, gill nets, purse seines and longlines) are poorly represented as in other areas. However, these small-vessel gears represent a larger proportion of the region fleets' activity in comparison with most FAO areas.

INTRODUCTION FOR THE EASTERN INDIAN OCEAN

The Eastern Indian Ocean (FAO Area 57; FAO, 2019) encompasses all marine waters of the Eastern Indian Ocean from the southeast coast of India and Bay of Bengal to the west, and the northwest coasts of Australia (Figure 57. 1). Other boundaries include the coast of Java, Sumatra, Malacca and Malay Peninsula. The following coastal countries/territories border FAO Area 57: Australia, Bangladesh, Christmas Island, Cocos (Keeling) Islands, India, Indonesia, Malaysia, Myanmar, Sri Lanka, Thailand and Timor-Leste (Figure 57. 2). Around 29 percent of the total marine area in FAO Area 57 falls under national jurisdiction, compared to 71 percent in the high seas. This proportion of high sea waters is higher than the average across all FAO Areas (54 percent) and close to the areas with the highest proportion of high seas (e.g., around 80 percent in FAO Area 47, Southeast Atlantic; and FAO Area 87, Southeast Pacific).

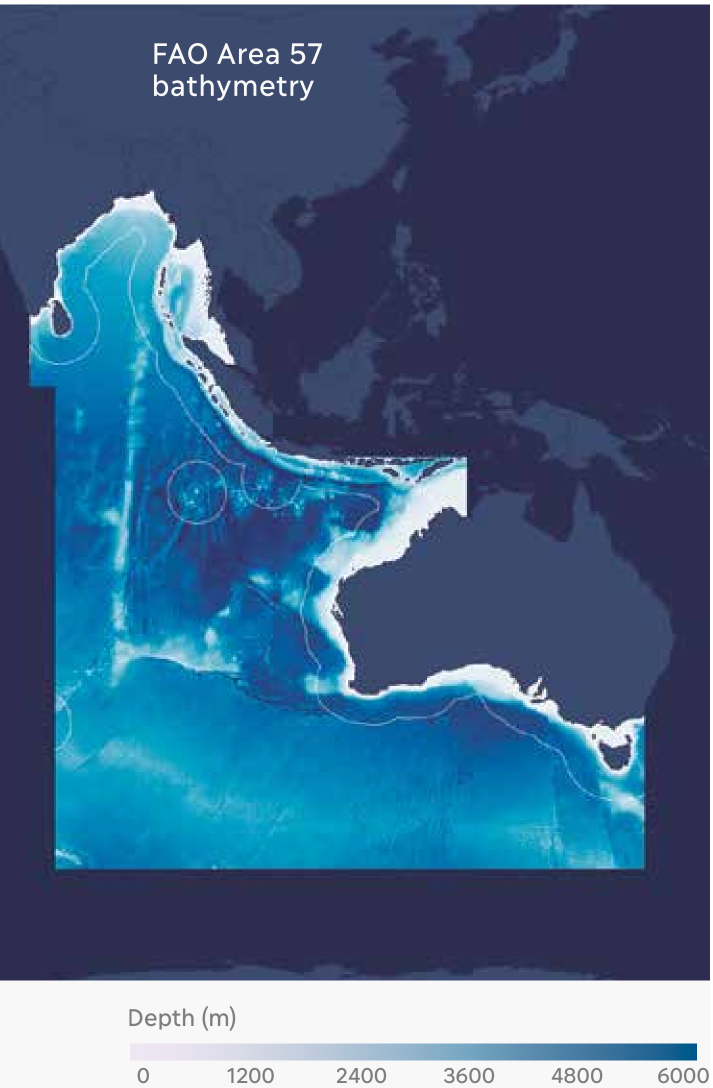


Figure 57. 2. FAO Area 57 bathymetry (depth) and 200 miles coastal arc.

The continental shelves throughout the area are narrow with important seamounts such as the Christmas Island Seamounts and the Muirfield Seamount (Figure 57. 2). This area also has important ridges (e.g. Southeast Indian Ridge and Central Indian Ridge) and the Rodriguez Triple Junction that joins these ridges with the Southwest Indian Ridge (Baines *et al.*, 2007). The northern part of the area falls under the

influence of heavy rainfall in the monsoon belt resulting in many rivers, frequent floods and riverbank erosion in delta regions (Fernandes, 2018). The Eastern Indian Ocean is still showing an increasing trend in landings, with an increase of up to 50 percent of catches in the last decade, reaching a total of 7.7 million tonnes per annum (FAO, 2016). FAO landings statistics (FishStatJ, 2018) show that in the period from 2010 to 2014, catches were dominated by invertebrate and pelagic fish species (e.g. skipjack tuna and yellowfin tuna, hilsa shad, Indian mackerel), but with a large variety of species fished.

REGION FLEETS AND AIS USE IN THE EASTERN INDIAN

Non-motorized vessels make up over 31 percent of the fleets in the region. Vessels over 24 m, which are the vessels most likely to have AIS, account only for 0.4 percent of fishing vessels (Figure 57. 3). Estimating the number of vessels by different size classes in FAO Area 57 is difficult because the two countries with the largest fleets, Indonesia and India, do not report vessel lengths to FAO. Also, both countries border more than one FAO area, so it is not clear how many of their vessels operate only in FAO Area 57.

Fleets of coastal countries/territories in FAO Area 57

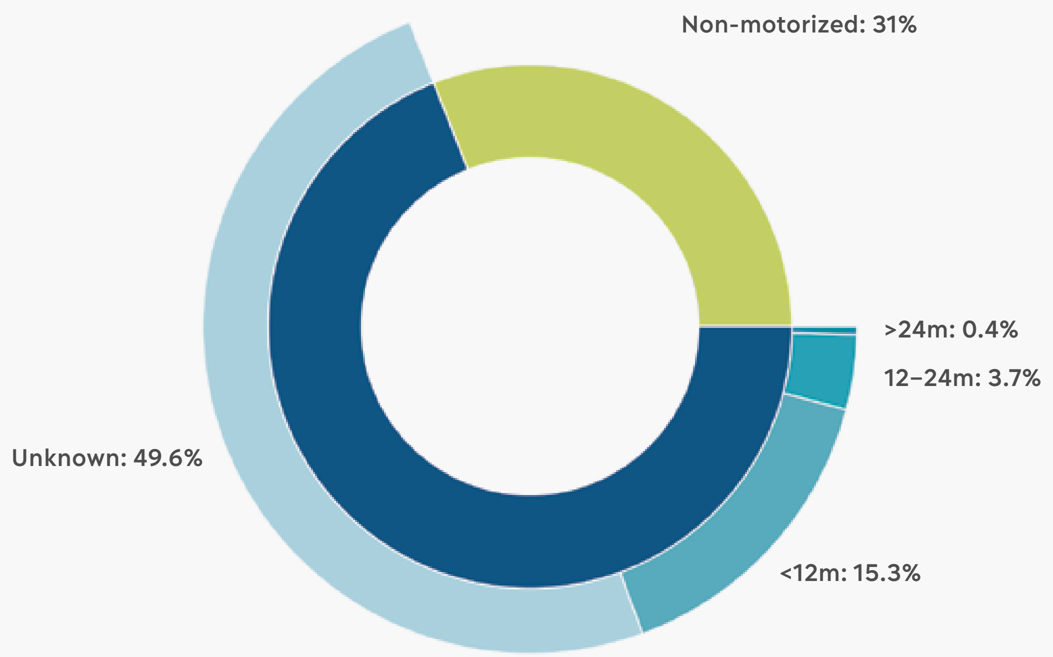


Figure 57. 3. Structural composition of fleets of coastal countries/territories in FAO Area 57. In dark blue motorized fishing vessels and in green non-motorized. Distant water fleets active in FAO Area 57 are not included (see next figure). Notice that although some countries/territories border more than one FAO area, their entire fleet size is included here. Source: FAO statistics for year 2017. Statistics were not available for Christmas Island, Cocos (Keeling) Islands and Timor-Leste.

FAO Area 57 has many countries with large fleets, some with many thousands of fishing vessels (Figure 57. 4). Despite these vast numbers, among countries in the area only Australia has more than 80 vessels using AIS, followed by Malaysia with less than 20 vessels, i.e. likely the majority of Malaysia's vessels over 24 m in length. The distant water fleets of Taiwan Province of China and Japan have more vessels with AIS operating in the region than all coastal nations except for Australia.

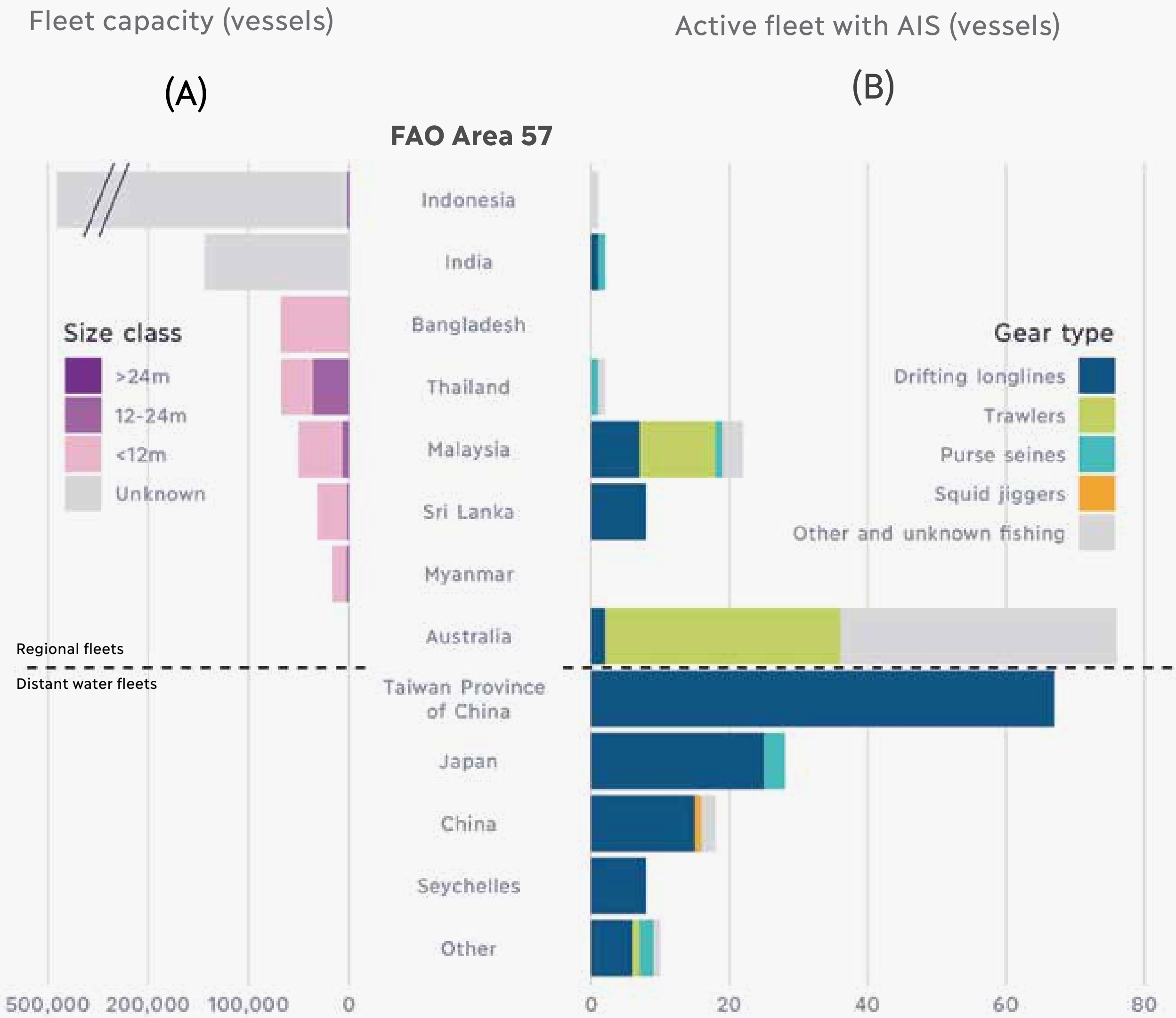
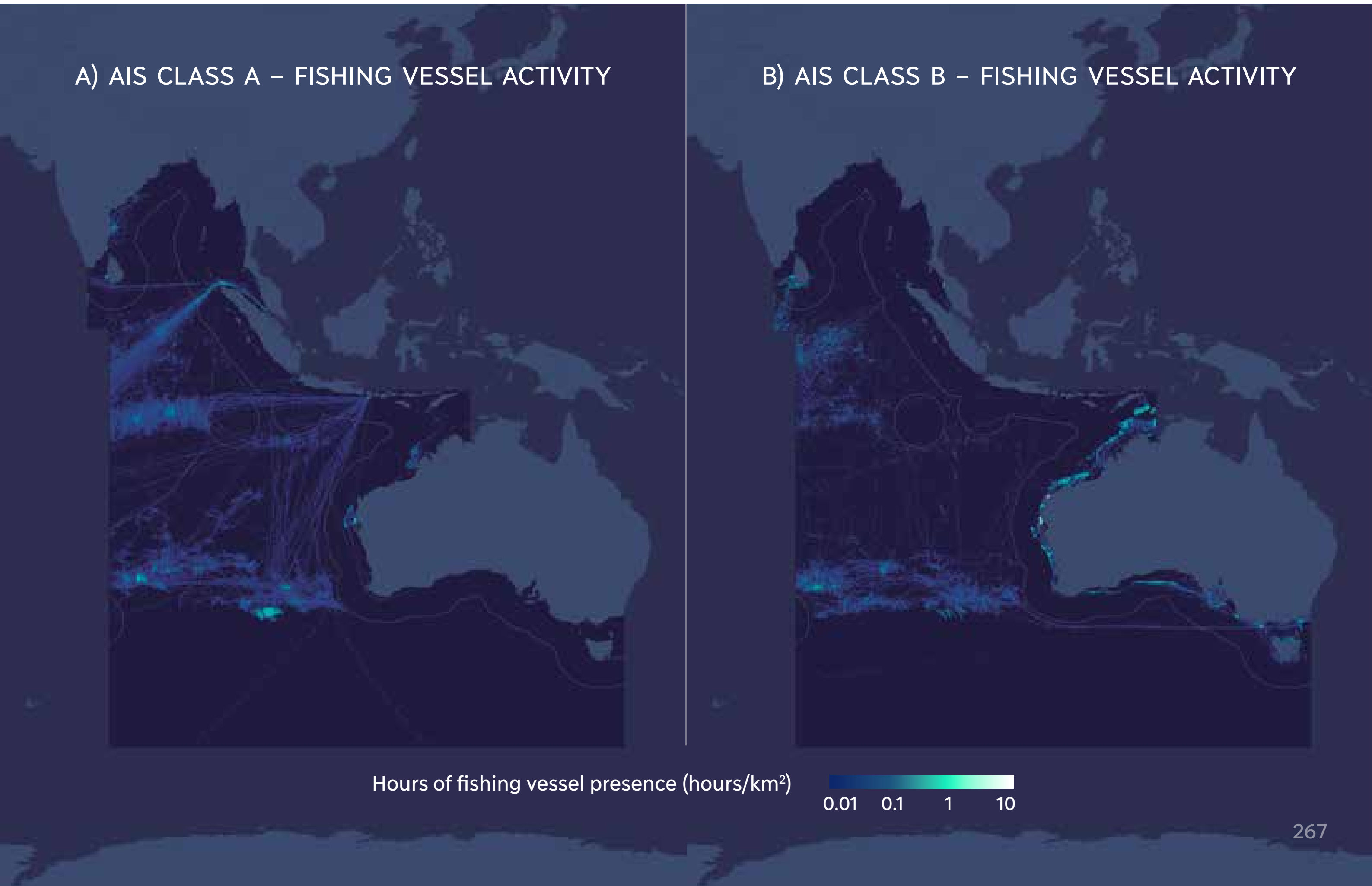


Figure 57.4. Coastal and distant fleets summary based on FAO statistics and AIS data classification by GFW in FAO Area 57 during year 2017. A) Number of motorized vessels as reported to FAO (left panel). The entire fleets of countries/territories are shown, even though these fleets may be active in other FAO areas. Source: FAO statistics. Statistics were not available for the following coastal countries/territories border FAO Area 57: Christmas Island, Cocos (Keeling) Islands and Timor-Leste. B) AIS-identified number of fishing vessels broadcasting AIS during their operations in FAO Area 57 by gear type and flag state (right panel). Dashed lines separate regional fleets (top) from distant fleets (bottom). Only vessels that fished for at least 24 hours in the area are included. Source: GFW.

AIS RECEPTION AND FISHING VESSEL ACTIVITY IN THE EASTERN INDIAN

Figures 57. 5a,b show all the activity of fishing vessels (fishing, searching, in transit) captured by AIS in FAO Area 57 (Class A and Class B AIS devices). Vessels in the high seas are equally likely to use Class A and Class B devices, while almost all the coastal Australian fleet uses Class B. AIS reception is very poor in the northern area of FAO Area 57 (Figure 57. 5c,d), to the extent that Class B devices might not even register with satellite receivers. Class B vessels operating in the middle of the area may not have all their fishing activity recorded (Figure 57. 5d), and those operating in the north may have little or no fishing activity recorded.



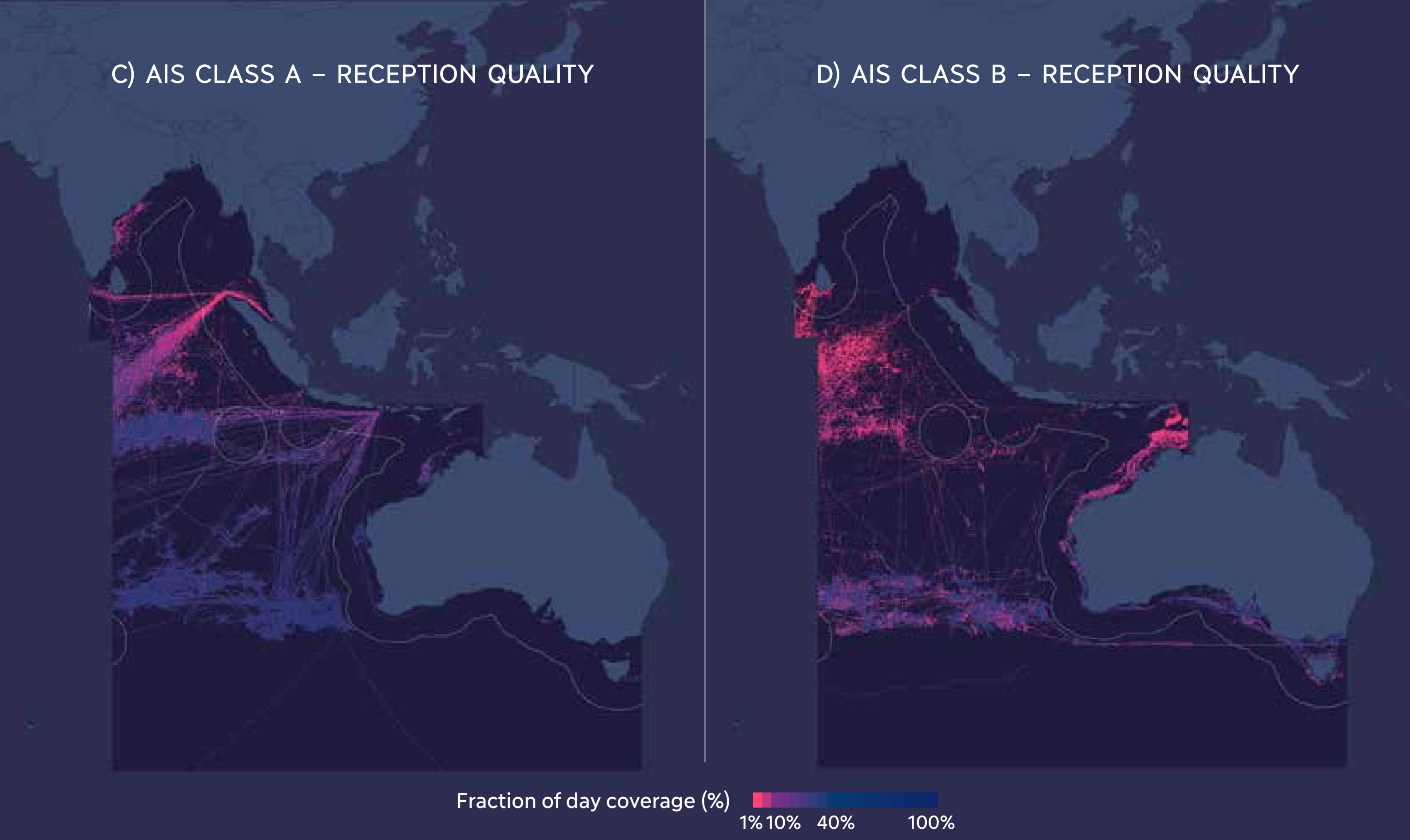
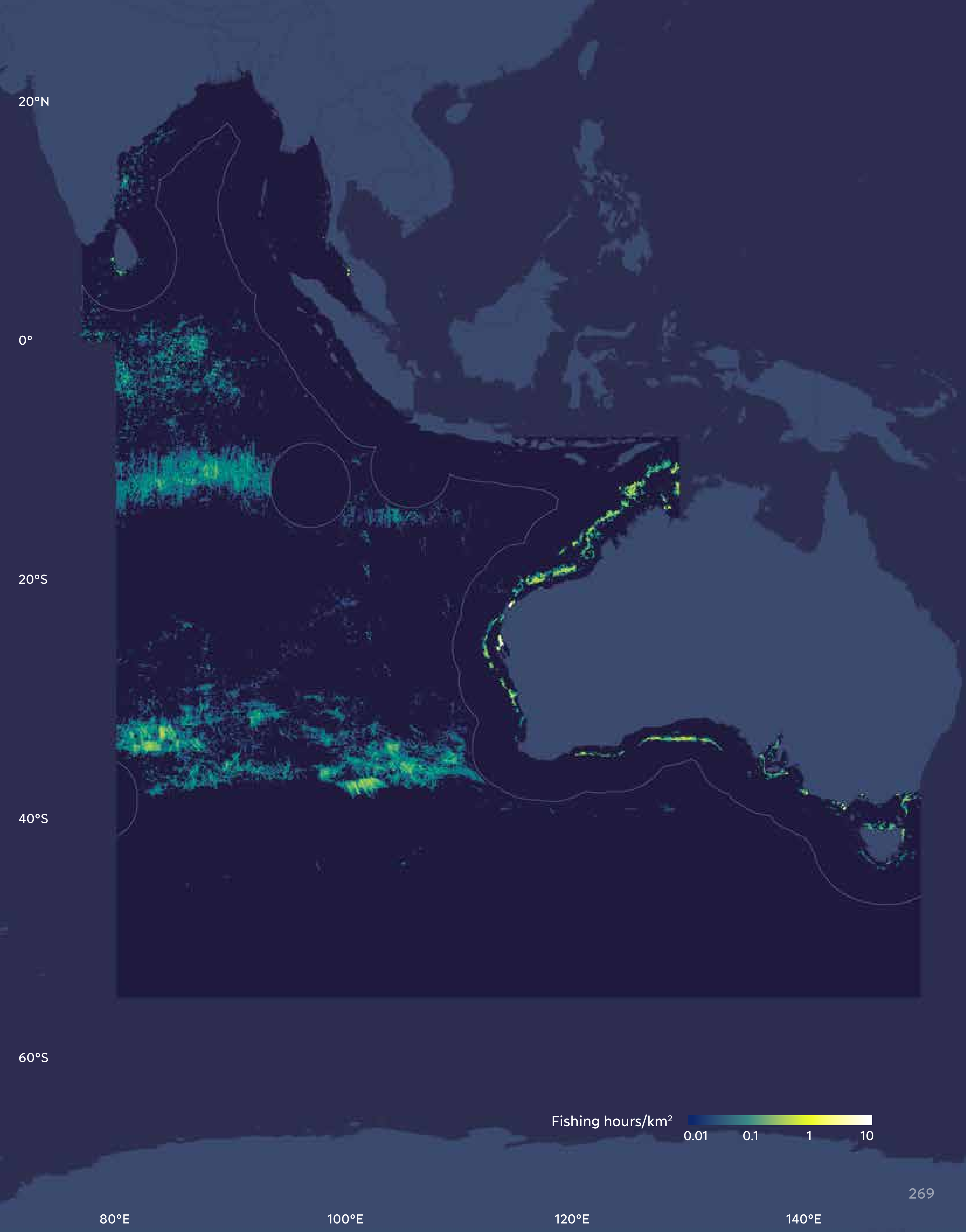


Figure 57. 5. Fishing vessel activity and quality of AIS reception for FAO Area 57 during 2017. Top row shows activity of vessels broadcasting using Class A devices (left panel) and Class B devices (right panel). The bottom row shows reception quality maps for devices Class A (left panel) and B (right panel). Blank spaces on the map (i.e. dark blue ocean background) mean that no signals from fishing vessels in this area were received, which is due to either no vessel activity or poor reception.

The limited AIS information available in the area shows fishing operations along the east Indian coast, off western and southern Australia and in the north and south on high seas (Figure 57. 6). Fishing patterns for most of the important fleets in the area are almost entirely missing, including Indonesia, Malaysia, Thailand, Sri Lanka, India and Bangladesh, whose fleets account for around 95 percent of vessels in FAO Area 57 (Figure 57. 4). While VMS is mandatory for most vessels fishing in the high seas, very limited information is available from AIS in terms of identifying the major activities of industrial vessels, semi-industrial or artisanal vessels (i.e. mainly composed by small vessels under 24 m). In the high seas, there is a large tropical tuna and swordfish/albacore fishery in the north of the area frequented by purse seiners and longliners, while the south is dominated by longline vessels (IOTC, 2017b). The fishing activity on the Australian coastline can also be associated with trawlers fishing various species, as well as drifting longliners for tunas and purse seiners for bluefin tuna and other large pelagic species. Most of the fishing activity identified by AIS along the east coast of India can also be associated with longliners, gillnetters and trawlers. AIS data can detect Australian vessels fishing in the Australian coastal area using several different gear types (Hobsbawn *et al.*, 2017).

Figure 57. 6. The intensity of fishing operations based on AIS data for FAO Area 57 during 2017.



FISHING VESSEL ACTIVITY AND OPERATIONS BY GEARS IN THE EASTERN INDIAN

This section reviews the spatial distribution patterns of the main fishing gears of FAO Area 57 as estimated by Global Fishing Watch (GFW) based on 2017 AIS data. The most recent datasets available at mid-2018 were used to assess GFW capacity to provide an AIS based characterization of fishing activity by fishing gear in terms of presence/absence, intensity and hot spots. The Introduction chapter describes the rationale and challenges for use of contrasting data sources (e.g. Global Fisheries Landings database (GFLD; Watson, 2017)) for benchmarking AIS data classification.

When comparing fishing activity (Table 57. I) based on AIS data with the GFLD catches, fishing activity in this area is poorly represented by AIS. The activity of all fishing gears is underrepresented, whereas the importance of drifting longlines is overrepresented. Despite these limitations, both datasets agree that trawling is an important fishing activity in the area. Pole and line and set gillnets are two important gears in the area that are not captured by the AIS data.

<table>
<tr><th rowspan="2">GEAR TYPES</th><th colspan="2">Catches (GFLD) 2010–2014 average</th><th colspan="2">Total fishing vessel activity (GFW-AIS) 2017</th></tr>
<tr><th>Tonnes of catch in 1000s</th><th>% of catch</th><th>Active days in 1000s</th><th>% of active days</th></tr>
<tr><td>Trawls</td><td>2 382</td><td>33%</td><td>5.0</td><td>24%</td></tr>
<tr><td>Set gillnets</td><td>2 220</td><td>31%</td><td rowspan="3">5.0</td><td rowspan="3">24%</td></tr>
<tr><td>Pole and line</td><td>898</td><td>13%</td></tr>
<tr><td>Other</td><td>1012</td><td>14%</td></tr>
<tr><td>Purse seines</td><td>512</td><td>7%</td><td>0.4</td><td>2%</td></tr>
<tr><td>Drifting longlines</td><td>119</td><td>2%</td><td>10.5</td><td>50%</td></tr>
<tr><td>Total</td><td>7 146</td><td>100%</td><td>20.9</td><td>100%</td></tr>
</table>

Table 57. I. Summary table comparing average catch from GFLD during 2010–2014 with fishing vessel activity from GFW in FAO Area 57. Only vessels that fished for at least 24 hours in FAO Area 57 are included.

Gillnets (including drifting and set gillnets) are one of the main fishing gears in the eastern IOTC area, mainly fishing on neritic tuna and tropical tuna (largely skipjack tuna), but also some marlin species (e.g. black marlin), sharks and sailfish species. In FAO Area 57, countries such as Indonesia, Sri Lanka, Bangladesh and India have significant fleets operating mainly in waters under national jurisdiction but also in the high seas (Premchand *et al.*, 2015; Golden *et al.*, 2017; Hewapathirana and Gunawardane, 2017; IOTC, 2017a; Ruchitmat *et al.*, 2017). Sri Lankan gillnet vessels that operate in the high seas, and which are monitored with VMS (IOTC, 2017a), do not appear to be detected in AIS records. The same situation occurs for other costal countries such as Indonesia, Bangladesh and India where artisanal fishing, mainly dedicated to gillnets, are very poorly represented by AIS data. The AIS-based fishing activity attributed to gillnet is therefore significantly underestimated due to most of these coastal flag state vessels being smaller than 24 m and not using AIS. Therefore, no maps of its distribution are provided here.

Trawler fishing in the high seas is mainly carried out in the upper continental slope and mid-slope depth, which is less than 1 percent of the SIOFA area (SIOFA, 2018). In the Bay of Bengal the marine catch is divided into artisanal and industrial trawler fishing. The industrial fishery is a multi-species fishery dominated by hilsa shad and sardine (Shohidullah Miah, 2015; IOTC 2017a, 2017b). For example, the Bangladesh trawling industry (DoFB, 2017) is divided between fish trawlers (85 percent) and shrimp trawlers (15 percent). Although the number of monitored industrial vessels is increasing, the artisanal fleet is dominant in the area with a significant percentage of non-powered and small powered vessels (Fernandes, 2018). Due to poor AIS coverage and concentration of fishing activities in the northern part, the AIS data (Figure 57. 8) significantly underestimate trawler fishing activity in the area, such as the activities of the Bangladesh fleet (consisting of 201 industrial fishing trawlers and catches of 528 997 tonnes (IOTC, 2017b)). This underestimation could be due partly to the misclassification of multi-purpose vessels able to work with different fishing gears, which are common in the area. It should also be noted, regarding Figure 57.8 and comparisons with the bathymetry maps, that the trawling activity may be overestimated in GFLD as records are registered in deep areas and very far from coastal waters where artisanal trawlers mainly operate.

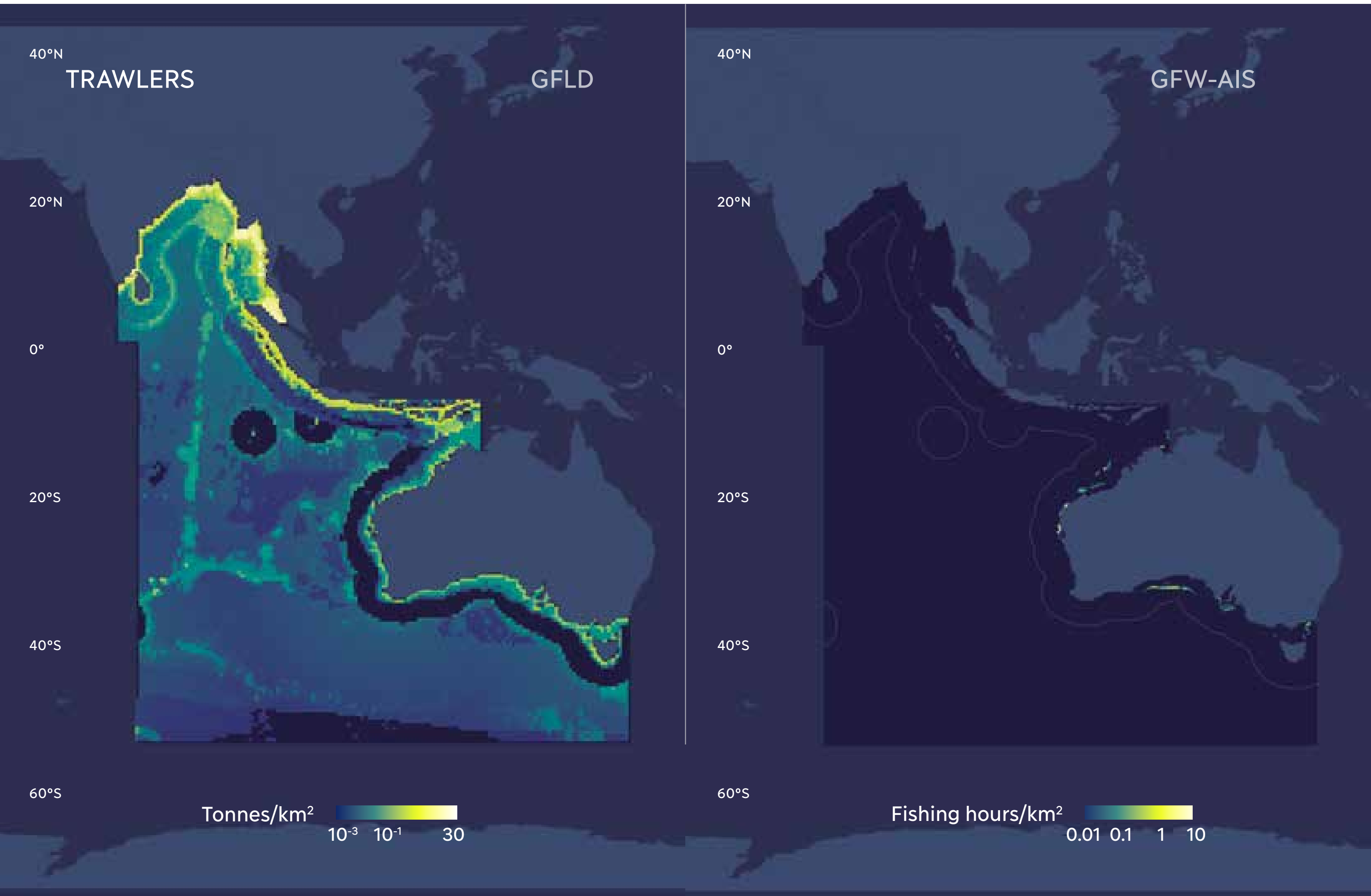


Figure 57. 8. Catch and activity of trawlers in FAO Area 57. Maps comparing average catch during 2010–2014 from GFLD (left panel) with trawler fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

AIS data seem to capture well areas of high intensity activity by longliners including the southern area high intensity patches (better than GFLD), but it fails to detect activity in most of the area as shown in GFLD and in RFMO data (Taconet *et al.*, 2018). According to the IOTC, 45 Japanese longliners were active in the south-eastern IOTC area in 2016 (between 0° S and 20° S) (IOTC 2017a, 2017b), though just under 30 Japanese longliners were detected by AIS in the area during 2017. China and Taiwan Province of China also maintain some fishing activity in the area with longline driftnets on the eastern side, mainly for the ice fresh-longliners (Xu *et al.*, 2017). In the northern-most high seas, fishing activity detected by AIS are likely to be mainly Chinese longliners, which tend to operate in the western part of Indian Ocean (Xu *et al.*, 2017). The fishing activity in mid-latitudes of the Cocos (Keeling) Islands and the Christmas Island are mainly longliners targeting bigeye tuna (IOTC, 2017b). The most southern activity is also dominated by longliners targeting bigeye and southern bluefin tuna (IOTC, 2017b). Longliner activity in Bangladesh is dominated by small-scale fisheries targeting coastal species (Rabbani *et al.*, 2014; Adnan *et al.*, 2016), but also sharks and rays (Krajangdara *et al.*, 2008).

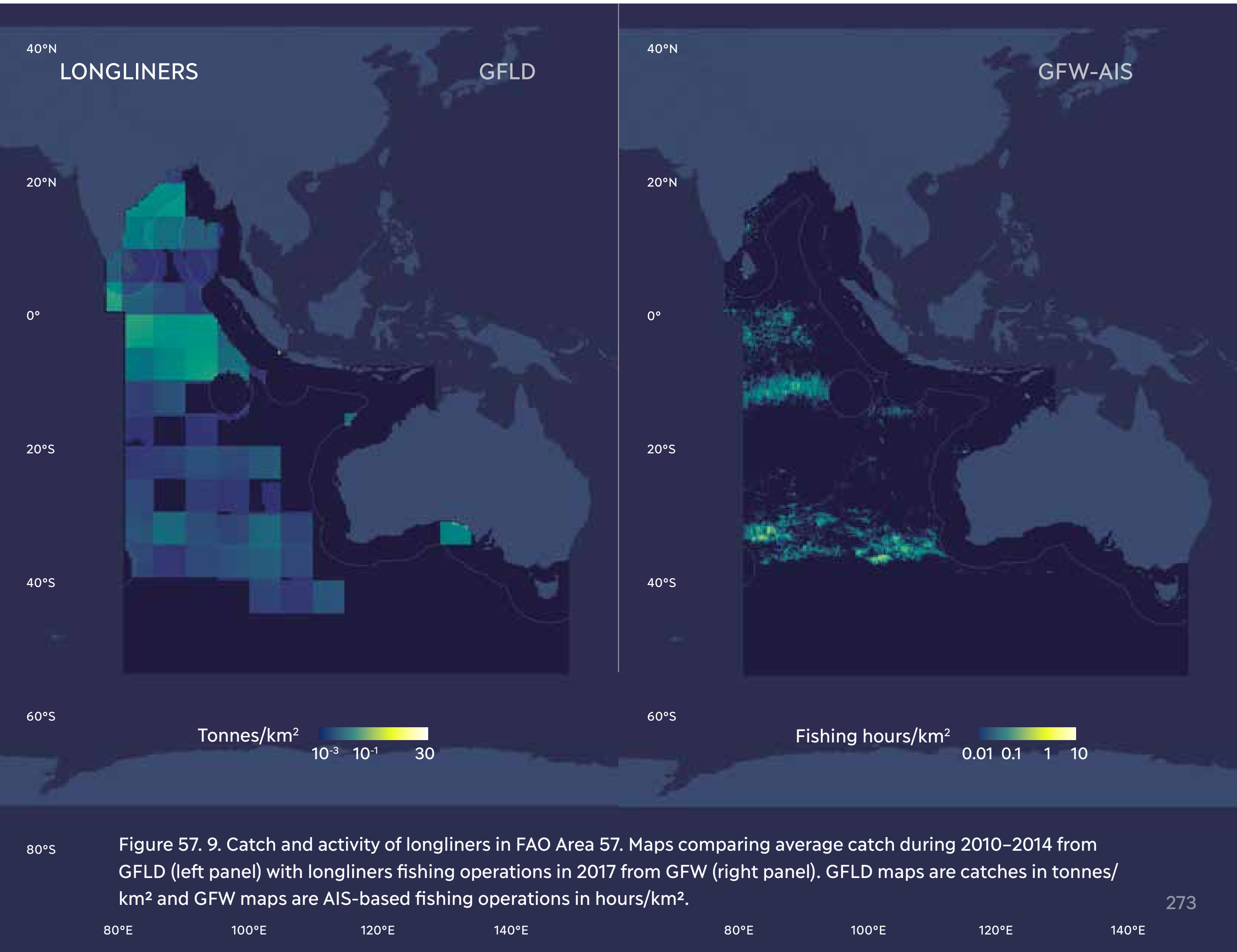


Figure 57. 9. Catch and activity of longliners in FAO Area 57. Maps comparing average catch during 2010–2014 from GFLD (left panel) with longliners fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

ACKNOWLEDGEMENTS

The editors would like to thank James Geehan and Rishi Sharma for excellent comments and feedback during the elaboration of the chapter. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Required citation for this chapter:

Grande, M., Murua, H., Granado, I., Taconet, M., Kroodsma, D., Miller, N. A., Fernandes, J. A. 2019. FAO Area 57 - AIS-based fishing activity in the Eastern Indian Ocean. *In* Taconet, M., Kroodsma, D., Fernandes, J.A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

Adnan, K. M. M., Ahamed, J. U., Sarker, & S. A. 2016. An Economic Analysis of Marine Fish Production in Cox's Bazar District of Bangladesh. *Amity Journal of Agribusiness*, 1(1), 22-33. https://amity.edu/UserFiles/admaa/205Paper%202.pdf

Baines, A. G., Cheadle, M. J., Dick, H. J., Scheirer, A. H., John, B. E., Kusznir, N. J., & Matsumoto, T. 2007. Evolution of the Southwest Indian Ridge from 55 45′ E to 62 E: Changes in plate-boundary geometry since 26 Ma. *Geochemistry, Geophysics, Geosystems*, 8(6), 1-31. https://doi.org/10.1029/2006GC001559

DoFB, 2017. *Yearbook of Fisheries Statistics of Bangladesh 2016-2017.* Department of Fisheries of Bangladesh, 34, 1-124. http://fisheries.portal.gov.bd/sites/default/files/files/fisheries.portal.gov.bd/page/4cfbb3cc_c0c4_4f25_be21_b91f84bdc45c/Fisheries%20Statistical%20Yearboook%202016-17_Final.pdf

FAO. 2016. *Food and Agriculture Organization of the United Nations. The State of World Fisheries and Aquaculture 2016 (SOFIA). Contributing to food security and nutrition for all.* Rome. http://www.fao.org/3/a-i5555e.pdf

FAO. 2019. *Food and Agriculture Organization of the United Nations. FAO Major Fishing Areas. Eastern Indian Ocean (Major Fishing Area 57).* http://www.fao.org/fishery/area/Area57/en

Fernandes, J.A., 2018. Chapter 13: Climate change impacts, vulnerabilities and adaptations: Southern Asian fisheries in the Arabian Sea, Bay of Bengal and East Indian Ocean. *In* Barange, M., Bahri, T., Beveridge, M., Cochrane, K., Funge-Smith, S., Poulain, F. (Eds.). *Impacts of Climate Change on fisheries and aquaculture: Synthesis of current knowledge, adaptation and mitigation options.* FAO Fisheries Technical Paper 627. http://www.fao.org/3/i9705en/i9705en.pdf

FishStatJ. 2018. Fisheries and aquaculture software. FishStatJ - software for fishery statistical time series. *In* FAO Fisheries and Aquaculture Department [online]. Rome. Updated 21 July 2018. [Cited 19 November 2018]. http://www.fao.org/fishery/statistics/software/fishstatj/en

Golder M.I., Barua, S., Rashida Akter, M., & Roy, B. 2017. *Bangladesh National Report to the Scientific Committee of the Indian Ocean Tuna Commission. Marine Fisheries Survey Management Unit Agrabad, Chittagong Under Department of Fisheries (DoF) Bangladesh.* Document IOTC–2017–SC20–NR32. https://www.iotc.org/sites/default/files/documents/2017/11/IOTC-2017-SC20-NR32_-_Bangladesh.pdf

Hewapathirana, H.P.K., & Gunawardane, N.D.P. 2017. *Sri Lanka National Report to the Scientific Committee of the Indian Ocean Tuna Commission, 2017.* Department of Fisheries and Aquatic Resources (DFAR) Sri Lanka. Document IOTC-2017-SC20-NR25. https://www.iotc.org/sites/default/files/documents/2017/11/IOTC-2017-SC20-NR25_-_Sri_Lanka.pdf

Hobsbawn, P., Patterson, H.M., & Williams, A.J. 2017. *Australian National Report to the Scientific Committee of the Indian Ocean Tuna Commission for 2017.* Research by the Australian Bureau of Agricultural and Resource Economics and Sciences. Document IOTC-2017-SC20-NR01. https://www.iotc.org/sites/default/files/documents/2017/11/IOTC-2017-SC20-NR01_-_Australia_0.pdf

IOTC. 2017a. *Report of the 20th Session of the IOTC Scientific Committee. Seychelles, 30 November – 4 December 2017.* Document IOTC–2017–SC20–R. Seychelles, 30 November - 4 December 2017. https://www.iotc.org/sites/default/files/documents/2017/12/IOTC-2017-SC20-R_E.pdf

IOTC. 2017b. *Japan National Report to the Scientific Committee of the Indian Ocean Tuna Commission, 2017.* National Research Institute of Far Seas Fisheries, Japan Fisheries Research and Education Agency and Fisheries Agency, Government of Japan. Document IOTC-2017-SC20_NR11. https://www.iotc.org/sites/default/files/documents/2017/11/IOTC-2017-SC20-NR11_-_Japan.pdf

Krajangdara, T., Sujittosakul, R., & Rahman, M. J. 2008. *Elasmobranches found in the Bay of Bengal from pelagic longline and drift gill net fishing. The ecosystem based fishery management in the Bay of Bengal.* BIMSTEC, Department of Fisheries and SEAFDEC, Thailand, 190-194. http://map.seafdec.org/downloads/BIMSTEC/017-Elasmobranches-Reangchai.pdf

Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F.,... & Woods, P. 2018. Tracking the global footprint of fisheries. *Science*, 359(6378), 904-908. https://doi.org/10.1126/science.aao5646

Miah, M. S. 2015. Climatic and anthropogenic factors changing spawning pattern and production zone of Hilsa fishery in the Bay of Bengal. *Weather and Climate Extremes*, 7, 109-115. https://doi.org/10.1016/j.wace.2015.01.001

Premchand, L. Ramalingam, A., Tiburtius, A., Siva, A.D., Rajashree, B. S., & Rahul, K.B.T. 2015. *India's National Report to the Scientific Committee of the Indian Ocean Tuna Commission'2015. Fishery Survey of India, Government of India, Botawala Chambers, Sir. P. M. Road, Mumbai.* Document IOTC–2015–SC18–NR09. https://www.iotc.org/sites/default/files/documents/2015/11/IOTC-2015-SC18-NR09_-_India.pdf

Rabbani, M. G., Khan, M. A., Islam, M. S., & Lucky, R. Y. 2014. Technical Efficiency of the Setbag Net Fishery in Bangladesh: An Application of a Stochastic Production Frontier Model. *The Agriculturists*, 15(2), 59-65. https://doi.org/10.3329/agric.v15i2.35465

Ruchimat T., Wudianto, Fahmi, Z., Setyadji, B., & Sadiyah, L. 2017. *Indonesia National Report to the Scientific Committee of the Indian Ocean Tuna Commission, 2017.* Centre for Fisheries Research, Jakarta, and Research Institute for Tuna Fisheries, Benoa Bali. Document IOTC-2017-SC20-NR09. https://www.iotc.org/sites/default/files/documents/2017/11/IOTC-2017-SC20-NR09_Indonesia_0.pdf

SIOFA. 2018. *Scientific Committee of the Southern Indian Ocean Fisheries Agreement. Report of the Third Meeting of the Scientific Committee of the Southern Indian Ocean Fisheries Agreement. La Réunion, 20-24 March.* http://www.apsoi.org/sites/default/files/documents/meetings/Report%20of%20the%20Third%20Meeting%20of%20the%20SIOFA%20Scientific%20Committee_0.pdf

Taconet, P., Chassot, E., Barde, J. 2018. *Global monthly catch of tuna, tuna-like and shark species (1950-2015) aggregated by 1° or 5° squares (IRD level 2) (Version 1) [Data set].* Zenodo. http://doi.org/10.5281/zenodo.1164128

Watson, R. A. 2017. A database of global marine commercial, small-scale, illegal and unreported fisheries catch 1950–2014. *Scientific data*, 4, 170039. https://doi.org/10.1038/sdata.2017.39

Xu L., Wang X., Chen Y., Wu F., Zhu, J., Yang, X., 2017. *[China] National Report to the Scientific Committee of the Indian Ocean Tuna Commission, 2017.* Document IOTC-2017-SC20-NR02. https://www.iotc.org/sites/default/files/documents/2017/11/IOTC-2017-SC20-NR02_-_China.pdf

FAO AREA 61

AIS-based fishing in the Northwest Pacific

Figure 61. 1. Location of FAO Area 61.

Maitane Grande, Josu Santiago, Hilario Murua, Igor Granado, David Kroodsma, Nathan A. Miller, Marc Taconet and Jose A. Fernandes

PREAMBLE

This chapter assesses, through a comparison with fleet statistics and public fisheries data, the capacity of Automatic Identification System (AIS) data and Global Fishing Watch (GFW) algorithms (Kroodsma *et al.*, 2018) to identify and quantify fishing vessel activity in the Northwest Pacific Ocean. This assessment reviews fleet activity, main gear types, and spatial distribution of fishing vessel activity and fishing operations.

SUMMARY AND CONCLUSIONS FOR THE NORTHWEST PACIFIC

AIS use in FAO Area 61 is dominated by the Chinese fleet. Because of poor AIS reception in the western part of this region and the difficulties accessing regional fleet registries to verify GFW vessel classification, the usefulness of AIS data to identify the fishing level activity by gear type is very limited in this area. AIS identifies fishing activity better in the high seas in the eastern half of the region and in the far north, especially in the Sea of Okhotsk, where both reception and use of AIS are higher. Intense fishing activity is also observed in Japanese and Republic of Korea waters, but poor satellite reception limits AIS reception beyond the range of terrestrial receivers.

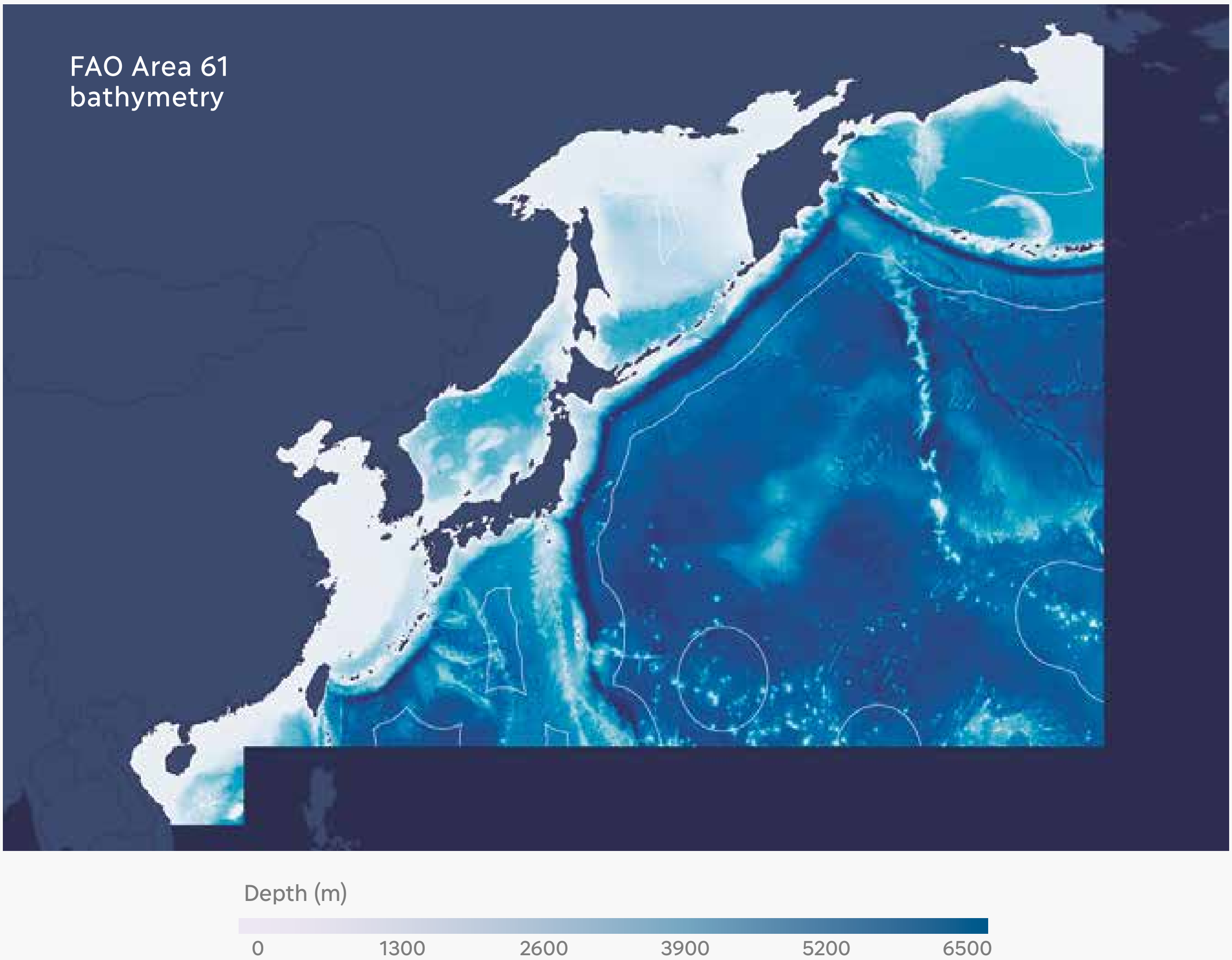


Figure 61. 2. FAO Area 61 bathymetry (depth) and 200 nautical mile arc.

INTRODUCTION FOR THE NORTHWEST PACIFIC

Waters of the Northwest Pacific (FAO Area 61) are bounded by longitude 175° W, latitude 20° N and the Asian continent (Figure 61. 1). The following coastal countries/territories are bounded by FAO Area 61: China, China Macao SAR, Ghina Hong Kong SAR, Taiwan Province of China,

Japan, Democratic People's Republic of Korea, Republic of Korea and the Russian Federation (Figure 61. 2). In this region, 52 percent of the waters are under national jurisdiction and the remaining 48 percent in the high seas. This proportion of high seas is lower than total regions' average (54 percent). The north Pacific is managed by bilateral agreements among countries, the Western and Central Pacific Fisheries Commission (WCPFC), the North Pacific Anadromous Fisheries Commission (NPAFC) and North Pacific Fisheries Commission (NPFC).

The continental shelf is wide in the continental coasts in the Sea of Okhotsk, Sea of Japan, Yellow Sea and East China Sea. Oceanographic features of the western North Pacific are largely characterized by two western boundary currents (WBCs): Kuroshio (subtropical WBC), which transports warm and oligotrophic water, and the Oyashio (subarctic WBC) which transports cold and nutrient-rich subarctic water (Holsman *et al.*, 2018). Where these currents meet, mixing promotes biological production and sustains high fishery production in the Northwest Pacific. In addition, strong temperature gradients between the Oyashio and Kuroshio delineate a variety of species habitats (Holsman *et al.*, 2018). The Northwest Pacific provides 25 percent of worldwide capture fisheries annually with an annual catch of over 21 million tonnes (FAO, 2016). Major species captured in the region are anchovies, large-head hairtails, chub mackerels and Alaska pollock (FAO, 2016). FAO landing statistics (FishStatJ, 2018) show that in the period from 2010 to 2014, catches were dominated by invertebrate and pelagic fish species. The largest catches were made of Alaska pollock, Japanese anchovy, largehead hairtail, Pacific chub mackerel, scads, marine molluscs, Akiami paste shrimp, squid species, seerfishes, gazami crab, Pacific saury, yellow croaker, croaker species, Pacific herring, daggertooth pike conger, threadfin breams, Japanese flying squid, silver pomfrets and yesso scallop. These 20 species and groups made up 70 percent of the reported catch from 2010 to 2014.

The so-called Donut Hole high seas area has a special fishing regime that is regulated by the agreement on the Conservation and Management of the Living Marine Resources of the Central Bering Sea (Dunlop, 1994), a multilateral convention agreed in February 1994 by representatives of the two coastal states (the Russian Federation and the United States of America) and four fishing nations (Japan, China, Republic of Korea and Poland) to protect the Bering Sea pollock fishery from over-exploitation. A similar area, the Peanut Hole, enclosed within the Russian EEZ exists in the central Sea of Okhotsk.

The largest fishing fleet operating within Northwest Pacific is China, with over 60 percent of its total reported catch taken from this Area in the period 2010–2014. However, China's historical reported catches in the NPFC area reached 90 percent of its total catch, which could be an overestimation due to (i) a fraction of distant-catches may have been spatially misreported (Blomeyer *et al.*, 2012) and (ii) an over-reporting triggered by the government reward policy that favored those that meet or surpass planed catch targets (Pauly *et al.*, 2014).

REGION FLEETS AND AIS USE IN THE NORTHWEST PACIFIC

Region fleets of coastal states and territories in FAO Area 61 have a high proportion of non-motorized vessels. Almost 40 percent of fishing vessels in the countries and territories of this region do not have engines (Figure 61. 3). The proportion of motorized vessels over 24 m in this area (4.3 percent) is higher than in other areas. Most of these larger vessels are Chinese (Figure 61. 4).

Fleets of coastal countries/territories in FAO Area 61

Figure 61. 3. Structural composition of fleets of coastal countries/territories in FAO Area 61. In dark blue motorized fishing vessels and in green non-motorized. Distant water fleets active in FAO Area 61 are not included (see next figure). Notice that although some countries/territories border more than one FAO Area, their entire fleet size is included here. Source: FAO statistics for 2017. Statistics were not available for the following coastal countries/territories within FAO Area 61: China Hong Kong SAR, China Macao SAR, and Democratic People's Republic of Korea.

AIS use in FAO Area 61 is generally high for vessels over 24 m, and relatively low for vessels below this size. China has the region's largest fleet, with almost 250 000 total motorized fishing vessels and just over 35 000 vessels over 24 m. At least half of these large vessels appear to regularly use AIS. However, AIS use among the remaining motorized fishing vessels is low. Japan reports almost the same total number of motorized fishing vessels as China, but far fewer vessels over 24 m, with only about 650 at that size operating globally. Of these, almost all appear to be broadcasting AIS. Very few of the vessels under 24 m, however, appear to broadcast AIS. Taiwan Province of China and the Republic of Korea also appear to have almost all their vessels over 24 m broadcasting AIS, while very few under this size do. In contrast to the other fleets, the

Russian fleet, according to FAO statistics and other registers, has over 1 150 vessels over 24 m and very few smaller than this size. Of the large vessels, about half appear to regularly use AIS.

Because of the difficulty in obtaining vessel registries in this region with information on the gear types of vessels (e.g. not available, online location difficult to find or not available in English), it is challenging to assess the accuracy of GFW's vessel classification algorithms, which predict the gear type of vessels. Nonetheless, for China, the algorithm predicts trawlers to be the most common gear type, followed by set gillnets (reported here as "other and unknown" gear), which is similar to what is reported by the China Fishery Statistical Yearbook for 2018. For vessels operating in the high seas, there is a higher confidence for their gear types, as many of these vessels appear in RFMO registries and can be verified by matching the AIS vessels to the registries. These vessels, though, are a small minority of the vessels operating in the region. In FAO Area 61, of over 40 000 active estimated fishing vessels broadcasting AIS in 2017, only 2 358 were matched to registries, and the gear types were identified for only 865 vessels.

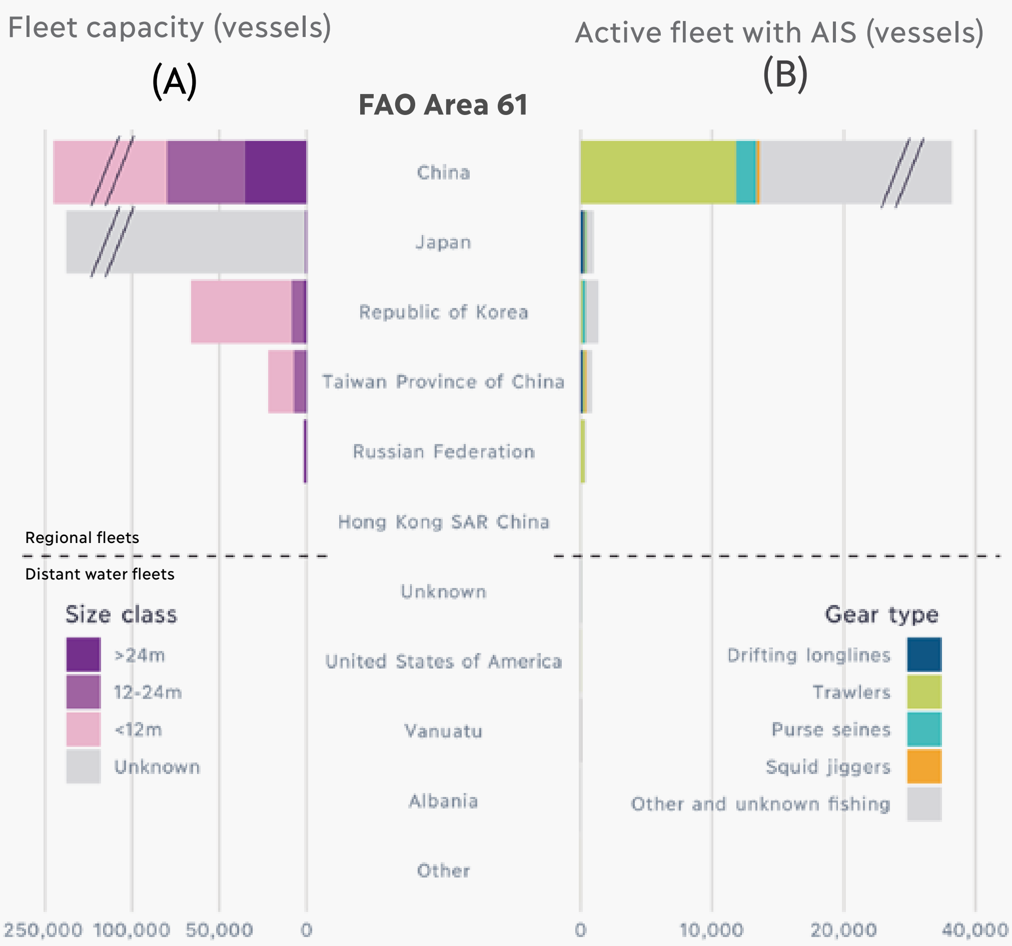


Figure 61.4. Summary of coastal and distant fleets based on FAO statistics and AIS data classification by GFW in FAO Area 61 during 2017. A) Fleet capacity: Number of motorized vessels as reported to FAO. The entire fleet of the Russian Feredation is shown, even though this fleet may be active in other regions. Sources: FAO statistics. B) Active Fleet: AIS-identified number of fishing vessels broadcasting AIS during their operations in FAO Area 61 by gear type and flag state. Dashed lines separate regional fleets (top) from distant fleets (bottom). Only vessels that fished for at least 24 hours in the area are included. Source: GFW.

To test whether the GFW's vessel classifier algorithm was accurately classifying fishing and non-fishing vessels, the GFW team manually revised a sample of Korean and Japanese vessels by Googling the MMSI numbers. GFW obtained very little information when reviewing Chinese vessels. For Japan, GFW's model identified 1 250 fishing vessels, of which 927 consistently broadcasted AIS as fishing and 323 broadcasted as non-fishing vessels. A similar review of South Korean vessels suggested that almost all vessels were fishing vessels, except for a few whose MMSI number was used by multiple vessels. Although China´s fishing capacity in domestic waters could be over-reported (Pauly *et al.*, 2014), the estimates given by AIS data in this study underestimate China's fishing capacity and activity, mostly due to the low fraction of fishing vessels using AIS (about 14 percent of all its fleet) (Figure 61. 4; FAO, 2017).

AIS RECEPTION AND FISHING VESSEL ACTIVITY IN THE NORTHWEST PACIFIC

Figure 61. 5 shows the presence of vessels using high quality Class A and lower-quality Class B AIS devices. About 35 000 of the region's roughly 40 000 vessels use Class B devices. A notable exception is the Russian fleet, which uses almost entirely Class A. Satellite AIS reception is extremely poor in the western half of this region, and this affects both Class A and Class B reception. Poor reception affects mainly the northeast region of FAO Area 61 for Class A, while Class B has poor coverage in the entire western half of the region and, except near terrestrial receivers along the coastline, is almost useless. Class A performs reasonably well east of 140° E, but west of 140° E the fishing activity by vessels with AIS is likely to be significantly undercounted except when activity occurs close to coastal terrestrial receivers. Because the Chinese fleet uses almost exclusively Class B AIS devices, the AIS dataset is limited to identifying fishing activity only close to the Chinese shore, where AIS coastal reception is good. As a result, the AIS data miss a good quantity of fishing activity in this region by vessels that have AIS.

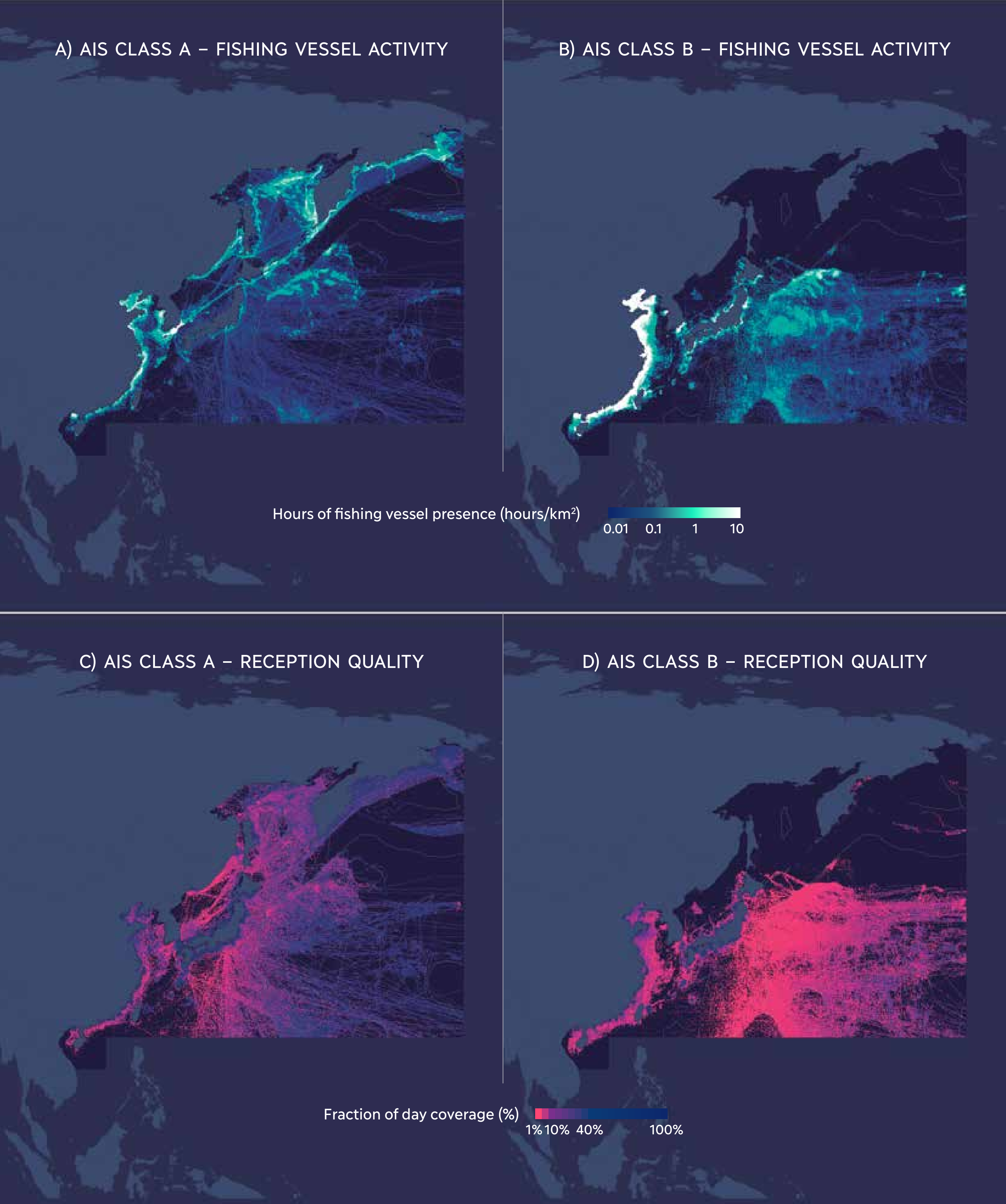


Figure 61. 5. Fishing vessel activity and quality of AIS reception for FAO Area 61 during 2017. Top row shows the intensity of fishing vessel activity for vessels broadcasting Class A devices (left panel) and Class B devices (right panel). The bottom row shows reception quality maps for Class A (left panel) and B (right panel) devices. Blank spaces on the map (i.e. dark ocean background) mean that no signals from fishing vessels in that region were received, which is due to either no vessel activity or poor reception.

The spatial patterns of the intensity of fishing operations detected by AIS (Figure 61. 6) are driven by two key determinants: the extent of continental shelf and associated bathymetry, and the lack of good reception in western regions in places far from terrestrial receivers. Along the continental coastline, fishing activity is highly affected by AIS reception as is shown in Figure 61. 5b, where the absence of operations is related with a low AIS coverage, except for the Western Sea of Okhotsk which has good AIS reception providing more reliable information on fishing operations.

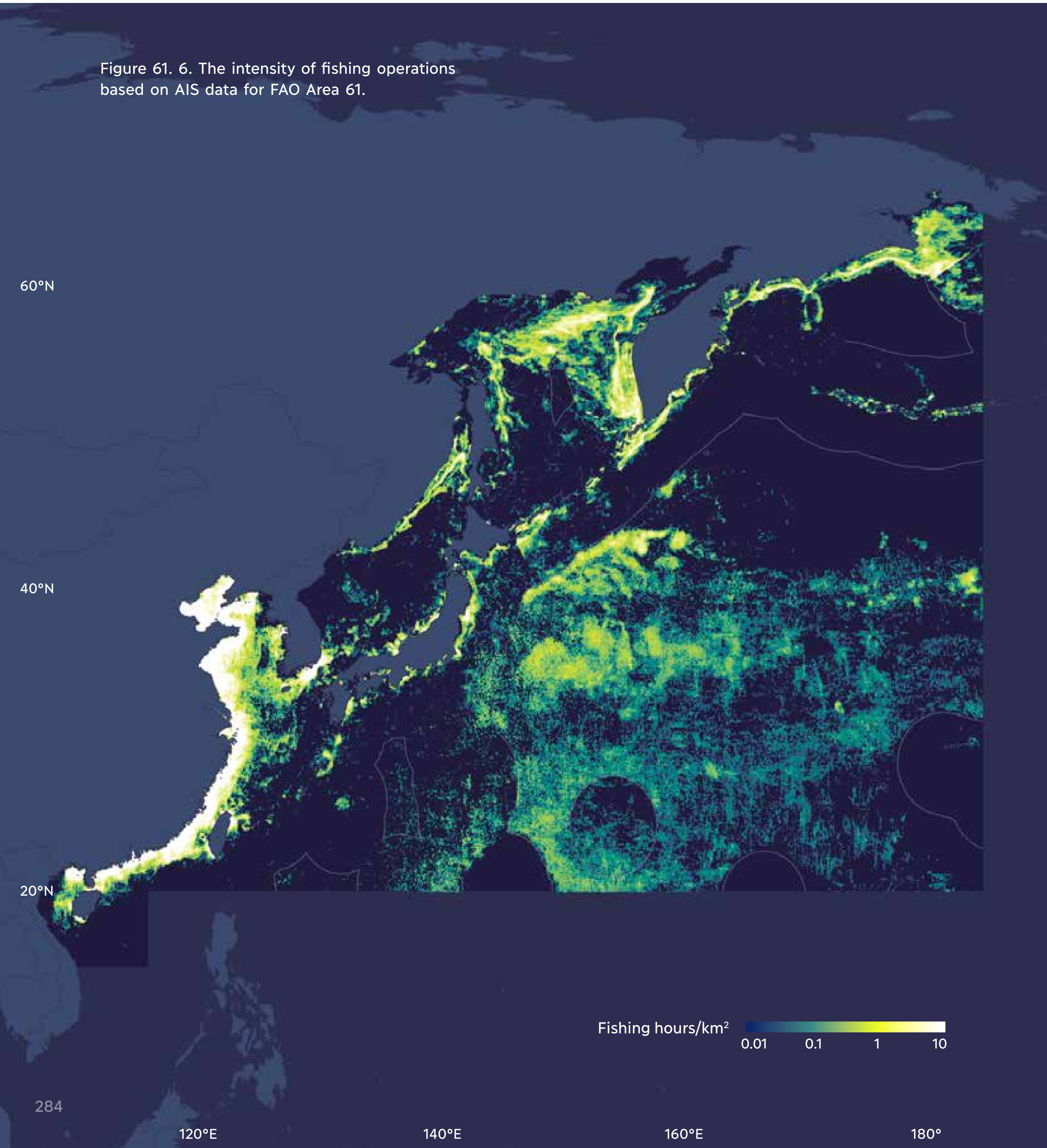


Figure 61. 6. The intensity of fishing operations based on AIS data for FAO Area 61.

FISHING VESSEL ACTIVITY AND OPERATIONS BY GEAR IN THE NORTHWEST PACIFIC

This section reviews the spatial distribution patterns of the main fishing gears in FAO Area 61 as estimated by Global Fishing Watch (GFW) based on 2017 AIS data. The most recent datasets available at mid-2018 were used to assess GFW capacity to provide an AIS based footprint of fishing activity and operations by fishing gear in terms of presence/absence, intensity and hotspots. The Introduction chapter describes the rationale and challenges for use of contrasting data sources (e.g. Global Fisheries Landings database (GFLD; Watson, 2017)) for benchmarking AIS data classification.

Comparing catch by gear type in FAO Area 61 is difficult because of the low reliability of gear classification in the EEZs using AIS and fleet registers. As a result, most fishing vessels were classified as "others" without information on gear type. The GFLD of catch reconstruction for 2010–2014 shows that trawling is the most important gear in the area with a high variety of gears, such as purse seines, set gill nets, pole and line, being also significant. GFW's AIS-based classification appears to represent longliner operations reasonably well, even though it is likely missing some activity in the western part of the region due to poor reception. Some vessels could be incorrectly labeled as squid vessels by GFW because they fish with lights at night and have similar movement patterns to some squid jiggers but target Pacific saury off the northeast of Japan instead.

GEAR TYPES	Catches (GFLD) 2010–2014 average		Total fishing vessel activity (GFW-AIS) 2017	
	Tonnes of catch in 1000s	% of catch	Active days in 1000s	% of active days
Trawls	10 413	49%	886.9	32%
Other	2 840	13%	1 642.6	60%
Set gillnets	1 934	9%		
Pole and line	1 483	7%		
Driftnets	1 141	5%		
Pots and traps	617	3%		
Trollers	478	2%		
Purse seines	2 129	10%	113.8	4%
Drifting longlines	153	1%	51.9	2%
Squid jiggers	82	0%	35.2	1%
Total	21 276	100%	2 730.4	100%

Table 61. I. Summary table comparing average catch from GFLD during 2010–2014 with fishing vessel activity from GFW in FAO Area 61. Only vessels that fished for at least 24 hours in FAO Area 61 are included.

The dominance of trawling operations in the area (Figure 61. 7) can be explained by a wide, productive continental shelf (Bensch *et al.*, 2008), and the productive Alaskan pollock stock which supports an important trawl fishery (Van van Eynde, 2017). The spatial distribution of trawler operations captured by AIS data occurs mainly in the Chinese EEZ, the Sea of Okhotsk, Bering Sea, and around the Kuril Islands, which waters are mainly inside of the Russian EEZ and where trawlers target Alaska pollock (FAO, 2017) and cod (Frank Van Eynde, 2017). This, together with Figure 61. 4 indicates that the largest non-Chinese fleet trawlers identified by AIS data are Russian. Therefore, the spatial distribution based on AIS data appears to be missing most of the trawling operations of Japan, China, and Republic of Korea fleets targeting alfonsino and armorhead in the high seas (FAO, 2009; NPFC, 2018).

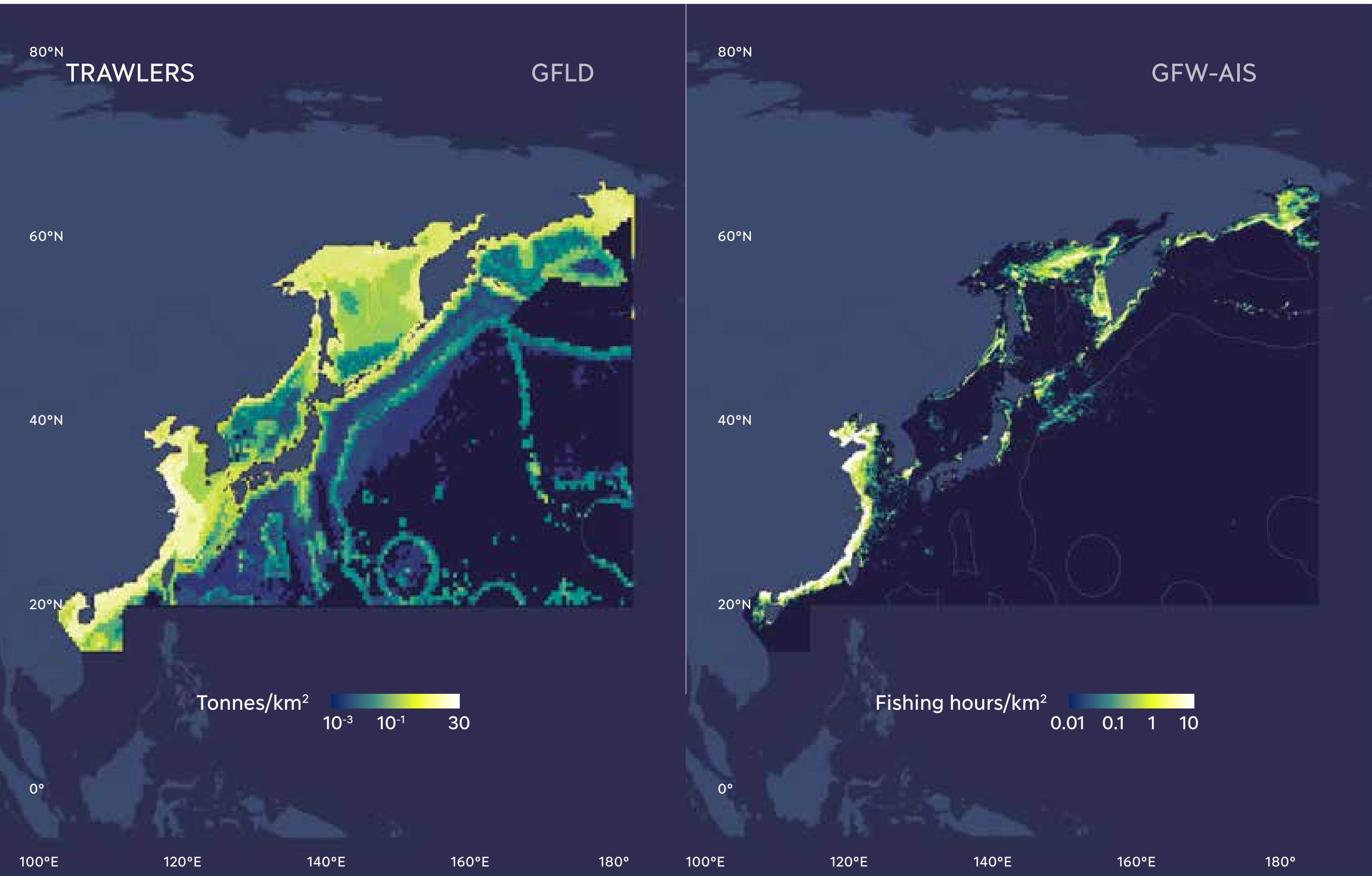


Figure 61. 7. Catch and activity of trawlers in FAO Area 61. Maps comparing average catch during 2010–2014 from GFLD (left panel) with trawlers fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours per km².

Purse seiner fishing operations in the GFLD database are concentrated along the coastline (Figure 61. 8). Purse seiner fishing operations detected by AIS shows much lower activity, mainly concentrated in coastal areas of China and the Republic of Korea and in the high seas just along the national jurisdiction border. GFLD also suggests that some purse seining catch is spread out evenly across much of the region's pelagic domain, which is unlikely. Purse seiners target mainly small pelagics, such as Japanese anchovy and chub mackerel, which are caught mainly by Japanese and Chinese vessels (NPFC, 2018; FAO, 2017) off northern Japan, but these fishing operations are poorly detected by AIS likely due to the use of Class B devices with poor reception in the area.

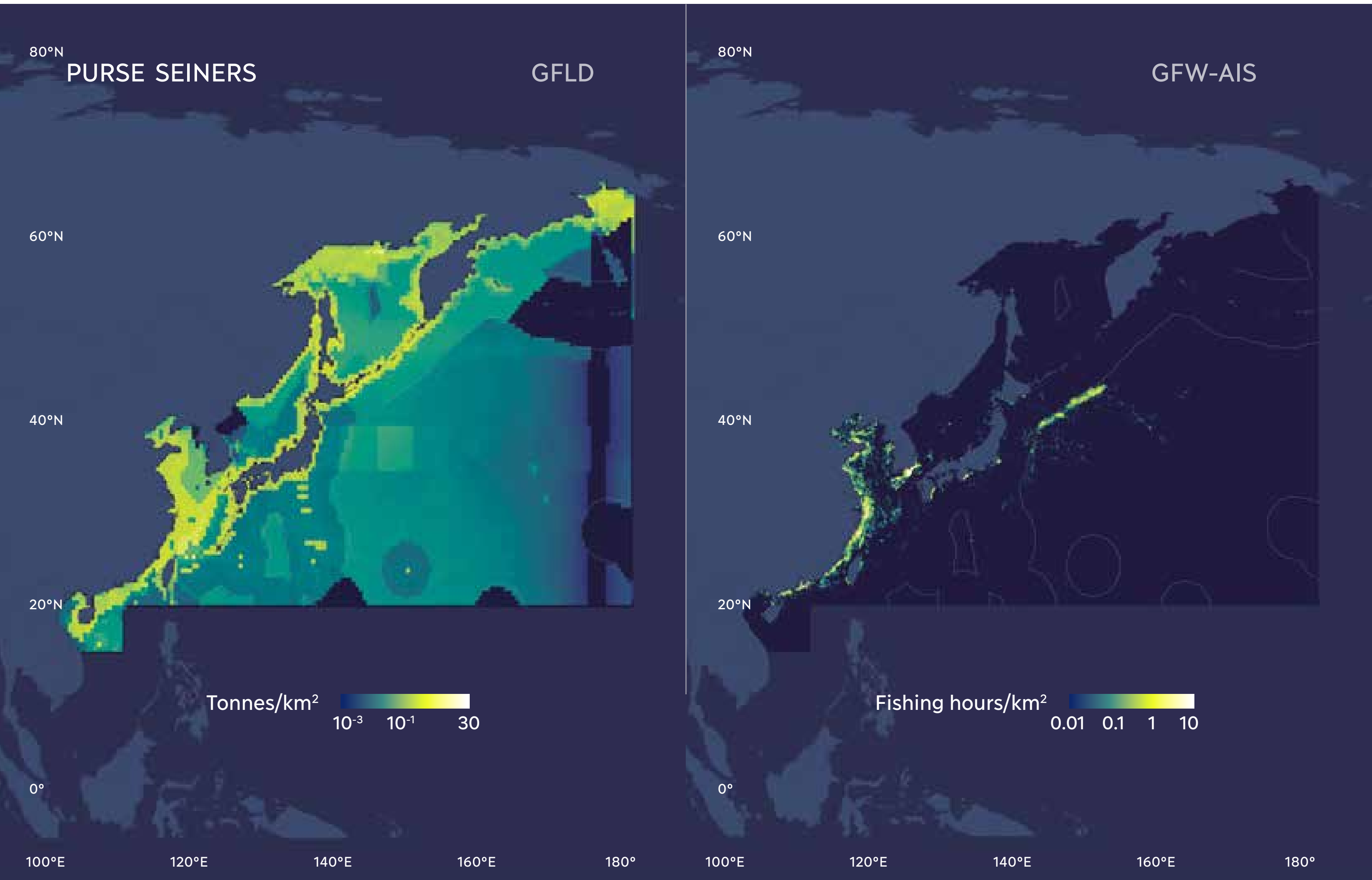


Figure 61. 8. Catch and activity of purse seiners in FAO Area 61. Maps comparing average catch during 2010–2014 from GFLD (left panel) with purse seiners fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours per km².

Drifting longliner fishing operations identified by AIS correspond mainly to both distant water and domestic fleets. Effort by the distant water fleet's large vessels is widespread on high seas of the southeastern part of the region. Part of this fleet targets bigeye and yellowfin for the frozen sashimi market in central and eastern tropical waters, and another targets albacore for canning in the more temperate waters (Williams and Reid, 2018) (Figure 61. 9). However, if GFLD maps are correct, some fishing operations should be detected by AIS off the Kuril Islands, around Sakhalin Island and northern Sea of Japan, Yellow Sea and East China Sea. The absence of AIS fishing operations in these areas could be due to poor reception as many of the longline vessels in the region, especially from China, use Class B AIS devices and the reception in this area is poor. Moreover, some of these longliners are likely small vessels that may not broadcast AIS.

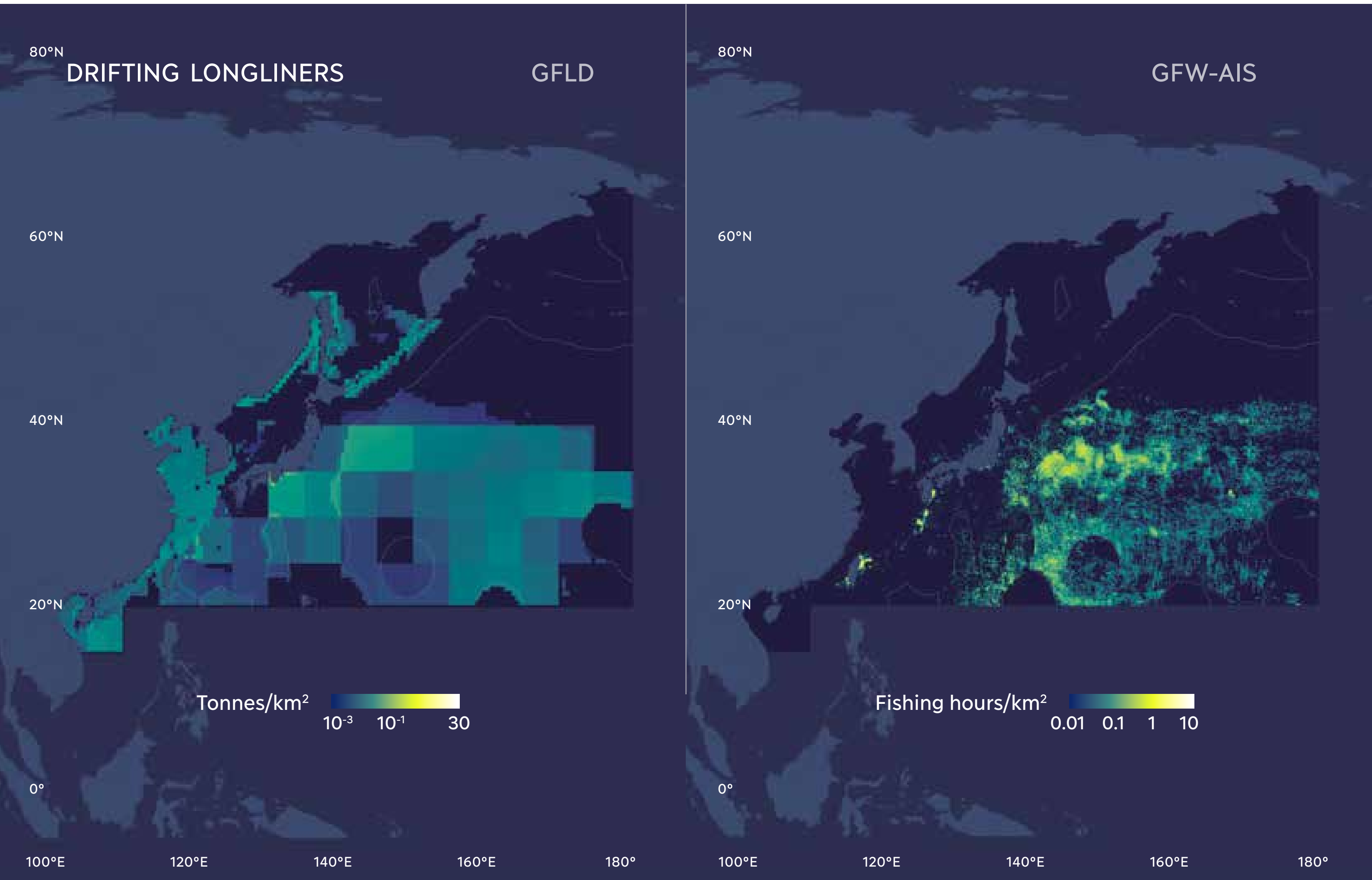


Figure 61. 9. Catch and activity of drifting longliners in FAO Area 61. Maps comparing average catch during 2010–2014 from GFLD (left panel) with drifting longliners fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours per km².

Figure 61. 10 shows the annual trend in number of active vessels (dominated by trawlers) broadcasting AIS per day in FAO Area 61. As Chinese vessels make up the vast majority of vessels in the region, the graph largely reflects the activity of these vessels. During the summer months, a moratorium on fishing in the Chinese EEZ is in place. Another minimum in fishing occurs during the Chinese New Year, which took place at the end of January in 2017. Fishing activity peaked in September, when more than 10 000 vessels broadcasted AIS on the same day.

Vessels fishing in FAO Area 61

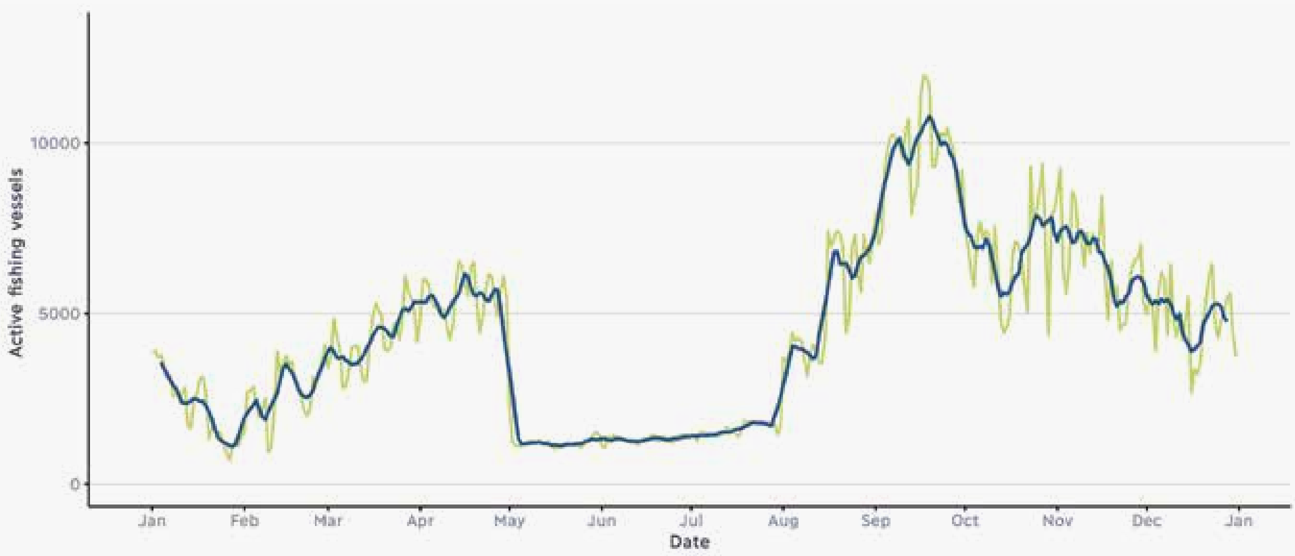


Figure 61. 10. Number of AIS-identified active fishing vessels per day in FAO Area 61 identified with AIS in 2017. Only vessels that fished at least 24 hours in the region over the course of the year are included. Dark blue line shows a 7-day rolling average.

ACKNOWLEDGEMENTS

The editors would like to thank Yimin Ye, Vladimir Radchenko and Peter Flewwelling for excellent comments and feedback during the elaboration of the chapter. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Required citation for this chapter:

Grande, M., Santiago, J., Murua, H., Granado, I., Kroodsma, D., Miller, N. A., Taconet, M., Fernandes, J. A. 2019. FAO Area 61 - AIS-based fishing activity in the Northwest Pacific. *In* Taconet, M., Kroodsma, D., Fernandes, J.A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

Bensch, A., Gianni, M., Gréboval, D., Sanders, J.S., Hjort, A. 2009. *Worldwide review of bottom fisheries in the high seas.* FAO Fisheries and Aquaculture Technical Paper. No. 522, Rev.1. Rome, FAO. http://www.fao.org/tempref/docrep/fao/012/i1116e/i1116e01.pdf

Blomeyer, R., Goulding, I., Pauly, D., Sanz, A., & Stobberup, K. 2012. *The role of China in world fisheries. Directorate General for Internal Policies.* Policy Department B: Structural and Cohesion Policies. European Parliament. http://www.europarl.europa.eu/meetdocs/2009_2014/documents/pech/dv/chi/china.pdf

Dunlap, W. V. 1994. A Pollock-Fishing Agreement for the Central Bering Sea. *Boundary and Security Bulletin*, 2, 49-57. https://www.dur.ac.uk/ibru/publications/download/?id=40

FAO. 2016. *Food and Agriculture Organization of the United Nations. The State of World Fisheries and Aquaculture 2016 (SOFIA). Contributing to food security and nutrition for all.* Rome. http://www.fao.org/3/a-i5555e.pdf

FAO. 2017. *Food and Agriculture Organization of the United Nations. FAO yearbook. Fishery and Aquaculture Statistics. 2015/FAO annuaire. Statistiques des pêches et de l'aquaculture. 2015/FAO anuario. Estadísticas de pesca y acuicultura. 2015.* Rome/Roma, Italy/Italie/Italia. http://www.fao.org/3/a-i7989t.pdf

FAO. 2019. *Food and Agriculture Organization of the United Nations. FAO Major Fishing Areas. Northwest Pacific Ocean (Major Fishing Area 61).* http://www.fao.org/fishery/area/Area61/en

FishStatJ. 2018. Fisheries and aquaculture software. FishStatJ - software for fishery statistical time series. *In* FAO Fisheries and Aquaculture Department [online]. Rome. Updated 21 July 2018. [Cited 19 November 2018]. http://www.fao.org/fishery/statistics/software/fishstatj/en

Holsman, K., Hollowed, A., Ito, S., Bograd, S., Hazen, E., King, J., Mueter, F., Perry, R. I., 2018. Chapter 6. Climate change impacts, vulnerabilities and adaptations: North Pacific and Pacific Arctic marine fisheries. *In* Barange, M., Bahri, T., Beveridge, M., Cochrane, K., Funge-Smith, S., Poulain, F. (Eds.). *Impacts of Climate Change on fisheries and aquaculture: Synthesis of current knowledge, adaptation and mitigation options.* FAO Fisheries Technical Paper 627. www.fao.org/3/I9705EN/i9705en.pdf

Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F.,... & Woods, P. 2018. Tracking the global footprint of fisheries. *Science*, 359(6378), 904-908. https://doi.org/10.1126/science.aao5646

McKinnell, S.M. and Dagg, M.J. [Eds.] 2010. *Marine Ecosystems of the North Pacific Ocean, 2003-2008.* PICES Special Publication 4. https://meetings.pices.int/publications/special-publications/NPESR/2010/PICES_PUB4_Chp1_Synthesis.pdf

NPFC. 2018. *The North Pacific Fisheries Commission. Scientific Committee. 2018. 3rd Meeting Report. NPFC-2018-SC03-Final Report. Tokyo, Japan, 17-20 April.* https://www.npfc.int/sites/default/files/2018-08/NPFC-2018-SC03-Final%20Report_0.pdf

Pauly, D., Belhabib, D., Blomeyer, R., Cheung, W. W., Cisneros-Montemayor, A. M., Copeland, D.,... & Österblom, H. 2014. China's distant-water fisheries in the 21st century. *Fish and Fisheries*, 15(3), 474-488. https://doi.org/10.1111/faf.12032

Van Eynde, F. 2017. *Fishery sector Overview 2017. Russian and North West Region. Flanders Investment & Trade Market Survey. Saint Petersburg, Russia.* https://www.flandersinvestmentandtrade.com/export/sites/trade/files/market_studies/2017-Russia-Fish-sector-Overview.pdf

Watson, R. A. 2017. A database of global marine commercial, small-scale, illegal and unreported fisheries catch 1950–2014. *Scientific data*, 4, 170039. https://doi.org/10.1038/sdata.2017.39

Williams, P., & Reid, C. 2018. *Overview of Tuna Fisheries in the Western and Central Pacific Ocean, including Economic Conditions - 2017. Document WCPFC-SC14-2018/GN-WP-01. Scientific committee Fourteenth Regular Session. Busan, Republic of Korea 8-16 August 2018.* https://www.wcpfc.int/file/217925/download?token=TrYmhwbE

FAO AREA 67

AIS-based fishing activity in the Northeast Pacific

Figure 67. 1. Location of FAO Area 67.

Ane Iriondo, Josu Santiago, Hilario Murua, Igor Granado, Marc Taconet, David Kroodsma, Nathan A. Miller and Jose A. Fernandes

PREAMBLE

This chapter assesses, through a comparison with fleet statistics and public fisheries data, the capacity of Automatic Identification System (AIS) data and Global Fishing Watch (GFW) algorithms (Kroodsma *et al.*, 2018) to identify and quantify fishing vessel activity in the Northeast Pacific. This assessment reviews fleet activity, main gear types, and spatial distribution of fishing vessel activity and fishing operations.

SUMMARY AND CONCLUSIONS FOR THE NORTHEAST PACIFIC

Fishing in the Northeast Pacific is dominated by the fleets of the United States of America and Canada, both of which have a high adoption of AIS by larger vessels. AIS Class A reception is excellent, but Class B device reception is medium to poor in most of the area. Trawlers are the most important gear in FAO Area 67, where AIS data highlight well the spatial distribution and intensity of their activity. In addition, AIS data show high seas activity that corresponds to longline fishing activity, mainly from Asian countries targeting temperate tunas, swordfish and sharks. Other fishing gears (e.g. set gillnets) are not well represented in the AIS data. Gill netting and salmon purse seining off Alaska occur within territorial waters with boats averaging 10 m in length. Another shortcoming is that some Alaskan vessels switch gears during the year, but current GFW algorithms only assign one gear to each vessel, leading to misclassification cases of fishing activity.

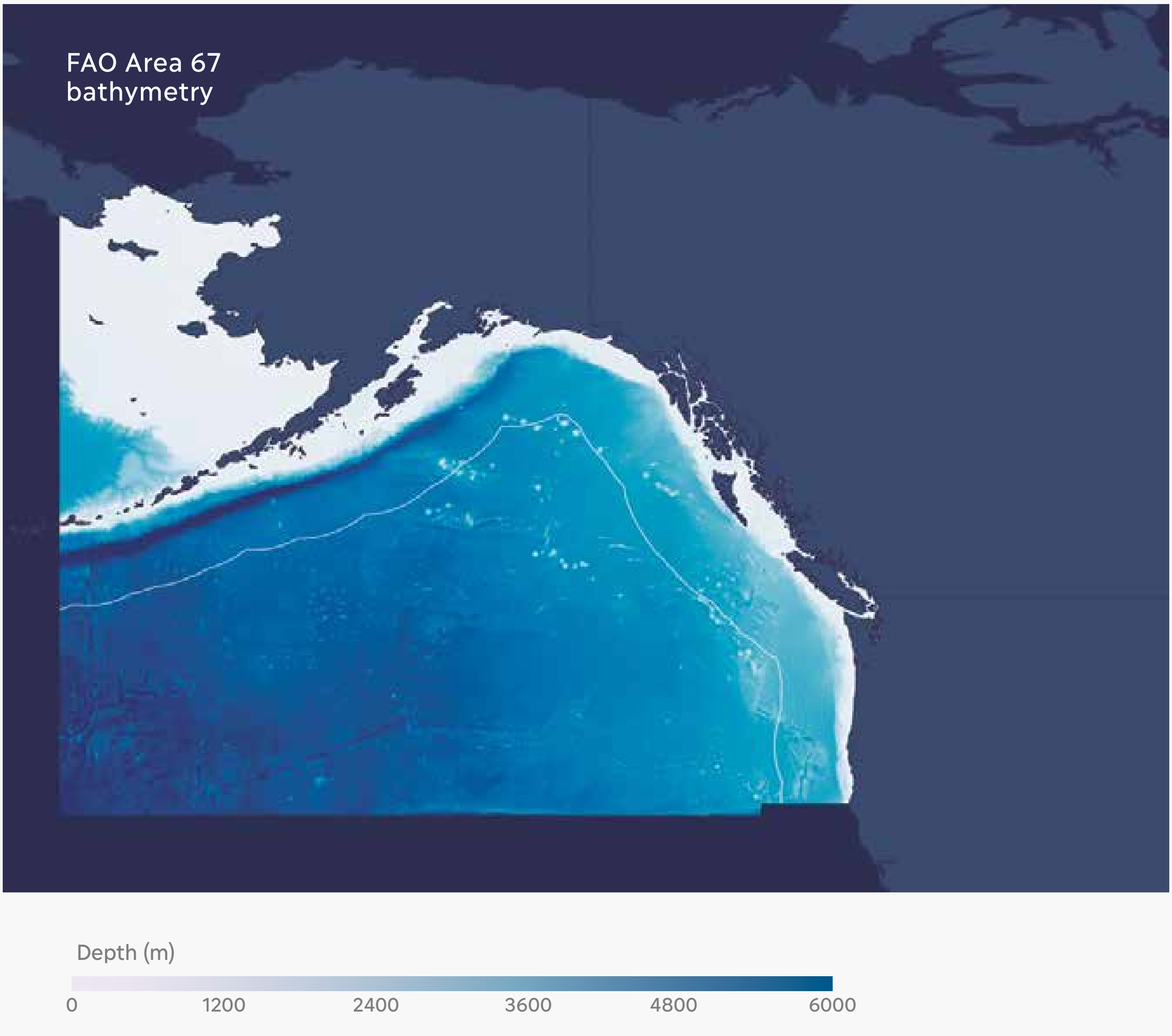


Figure 67. 2. FAO Area 67 bathymetry (depth) and 200 miles coastal arc.

INTRODUCTION FOR THE NORTHEAST PACIFIC

The Northeast Pacific (FAO Area 67; FAO, 2019) comprises the marine waters bounded (Figure 67. 1) in the north by Alaska (state of United States of America), in the southeast by Canada and the United States of America, and in the northwest by the Russian Federation (eastern Gulf of Anadyr), which are all coastal countries/territories bordering this FAO area (Figure 67. 2). In this area, about 40 percent of marine waters are under national jurisdiction, leaving 60 percent in the high seas. This proportion of high seas is higher than the FAO average for all areas (54 percent) (the proportion of high seas in all FAO areas ranges between 20 percent and 80 percent).

In this region, fisheries are managed by at least seven Regional Fishery Bodies (RFBs). Five are non-tuna RFBs: The North Pacific Fisheries Commission (NPFC), the North Pacific Anadromous Fish Commission (NPAFC), the Convention on the Conservation and Management of Pollock Resources in the Central Bering Sea (CCBSP), the International Pacific Halibut Commission (IPHC) and the Pacific Salmon Commission (PSC). Two are tuna RFBs: The Western and Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC). The Pacific Salmon Treaty, signed by Canada and the United States of America in 1985, provides the framework for conservation and management of Pacific salmon stocks, affecting fishing activity distribution in coastal waters.

The continental shelf of the Canadian area is very narrow; whereas that of Alaska is wide and covers more than half of the FAO area in the Bering Sea (Mathis *et al.*, 2015). FAO Area 67 encompasses several distinct "large marine ecosystems" including the California Current, the Gulf of Alaska and East Bering Sea. Structural habitats include boulders, corals, anemones, kelp and other living organisms attached to the ocean bottom. Because fishing gear has the potential to disturb structural habitat, regulations have been implemented to protect areas where these important habitat types are known to occur. Vast areas of the North Pacific have been permanently closed to groundfish trawling and scallop dredging to reduce potential adverse impacts on sensitive habitats and to protect benthic invertebrates. The Northeast Pacific produced 3.2 million tonnes of fish in 2013, which is roughly the average catch level maintained since the early 1970s. Alaska pollock represents about 40 percent of the total landings with 1.3 million tonnes in 2018 (FAO, 2016). Groundfish such as cod, rockfish, and sablefish, pelagic herring and salmon are also large contributors to the regional catch (FAO, 2016).

REGION FLEETS AND AIS USE IN THE NORTHEAST PACIFIC

The coastal countries and territories bordering FAO Area 67 do not report non-motorized vessels (Figure 67. 3). However, they report a higher fraction of vessels over 24 m, vessels more likely to use AIS, than the global average (2.8 percent in this region, compared to 1.2 percent globally).

Fleets of coastal countries/territories in FAO Area 67

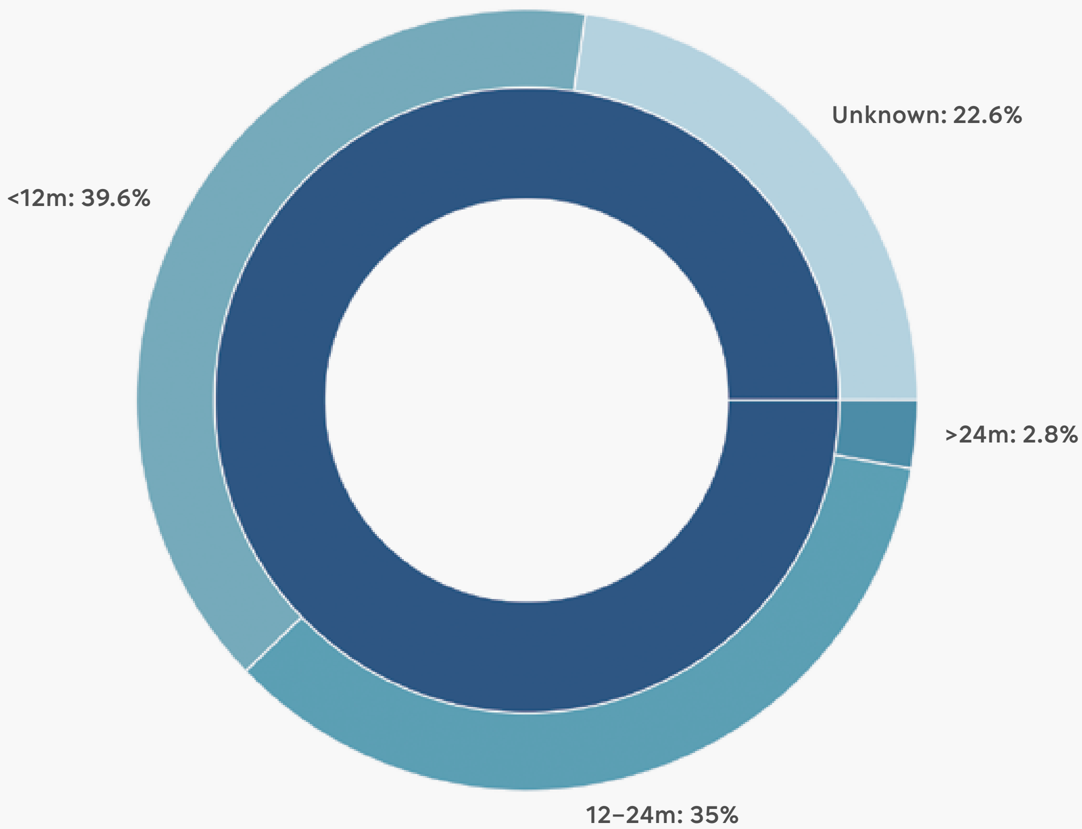


Figure 67. 3. Structural composition of fleets for coastal countries/territories within FAO Area 67. In dark blue motorized fishing vessels and in green non-motorized. Distant water fleets active in FAO Area 67 are not included (see next figure). Note that all the countries/territories border more than one FAO area, yet their entire fleet size is included here. Sources: FAO statistics for 2017.

AIS use in FAO Area 67 by United States of America and Canada is significant (Figure 67. 4). According to a review of registries, almost 100 percent of the United States of America vessels over 24 m have AIS with 615 vessels broadcasting AIS. The United States of America mandates AIS on vessels larger than 19 m (65 feet), and according to the government of Alaska, there were just over 620 fishing vessels of this size authorized to fish in Alaska in 2018. Note that this FAO area also includes Washington and Oregon states, and some vessels are authorized to fish in

states and not Alaska. Therefore, it is likely that the total number of United States of America vessels over 19 m in this area is greater than the number observed in the AIS data. Some vessels could be missing because they are inactive or because they operate with their AIS turned off. It also appeared that most Canadian large vessels also broadcast AIS. Canada reported to FAO they only had 52 fishing vessels over 24 m, but this number was likely underreported; GFW AIS identified over 100 vessels of this size in the global Canadian fleet. According to FAO statistics, United States of America vessels account for nearly 90 percent of the total landings for the area. The federally managed Alaskan fisheries include a wide variety of fishing vessels. Commercial fishing vessels range from small skiffs using longlines to catch halibut, to the largest catcher-processor boats, which catch and process pollock in the Bering Sea. FAO Area 67 is at the margins of the Russian territory and out of the total Russian fleet (1 534 reported to FAO, most of which above 24 m), a small portion would be active in this area as evidenced by AIS trawler data. The largest distant water fleet in the area is Taiwan Province of China, operating with a few vessels in the high seas in the southwestern part. Of the 822 likely fishing vessels broadcasting AIS in FAO Area 67, 760 were matched to registries, and 532 had gear types assigned.

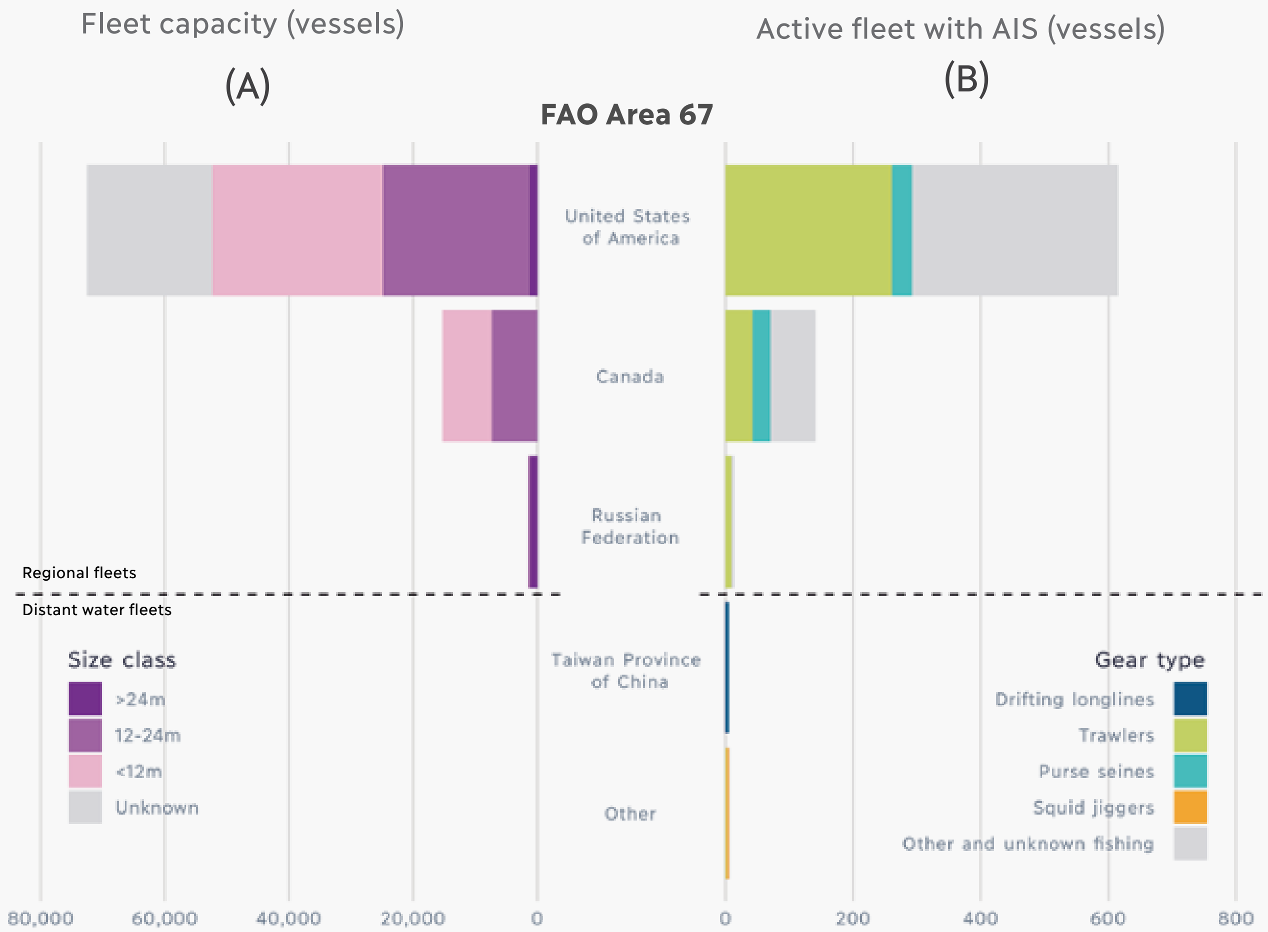


Figure 67. 4. Summary of coastal and distant fleets based on FAO statistics and AIS data classification by GFW in FAO Area 67 for 2017. A) Number of motorized vessels as reported to FAO. The entire national fleets of the United States of America, Canada and the Russian Federation are displayed, even though these countries border multiple FAO areas. Sources: FAO statistics. B) AIS-identified number of fishing vessels broadcasting AIS during their operations in FAO Area 67 by gear type and flag state. Dashed lines separate regional fleets (top) from distant water fleets (bottom). Only vessels that fished for at least 24 hours in the area are included. Source GFW.

AIS RECEPTION AND FISHING VESSEL ACTIVITY IN THE NORTHEAST PACIFIC

Figures 67. 5a,b show all fishing vessel activity captured by AIS in FAO Area 67 (Class A and Class B AIS devices). AIS Class A reception is excellent across all FAO Area 67 (Figure 67. 5c). On the other hand, AIS Class B device reception is poor for most of the area (Figure 67. 5d), partially because there are few coastal AIS receivers in Alaska to record these weaker devices. About half the Canadian vessels and about one third of United States of America vessels use weaker Class B AIS devices. Notably, almost no Class B vessels operate in Bristol Bay or the Bering Sea.

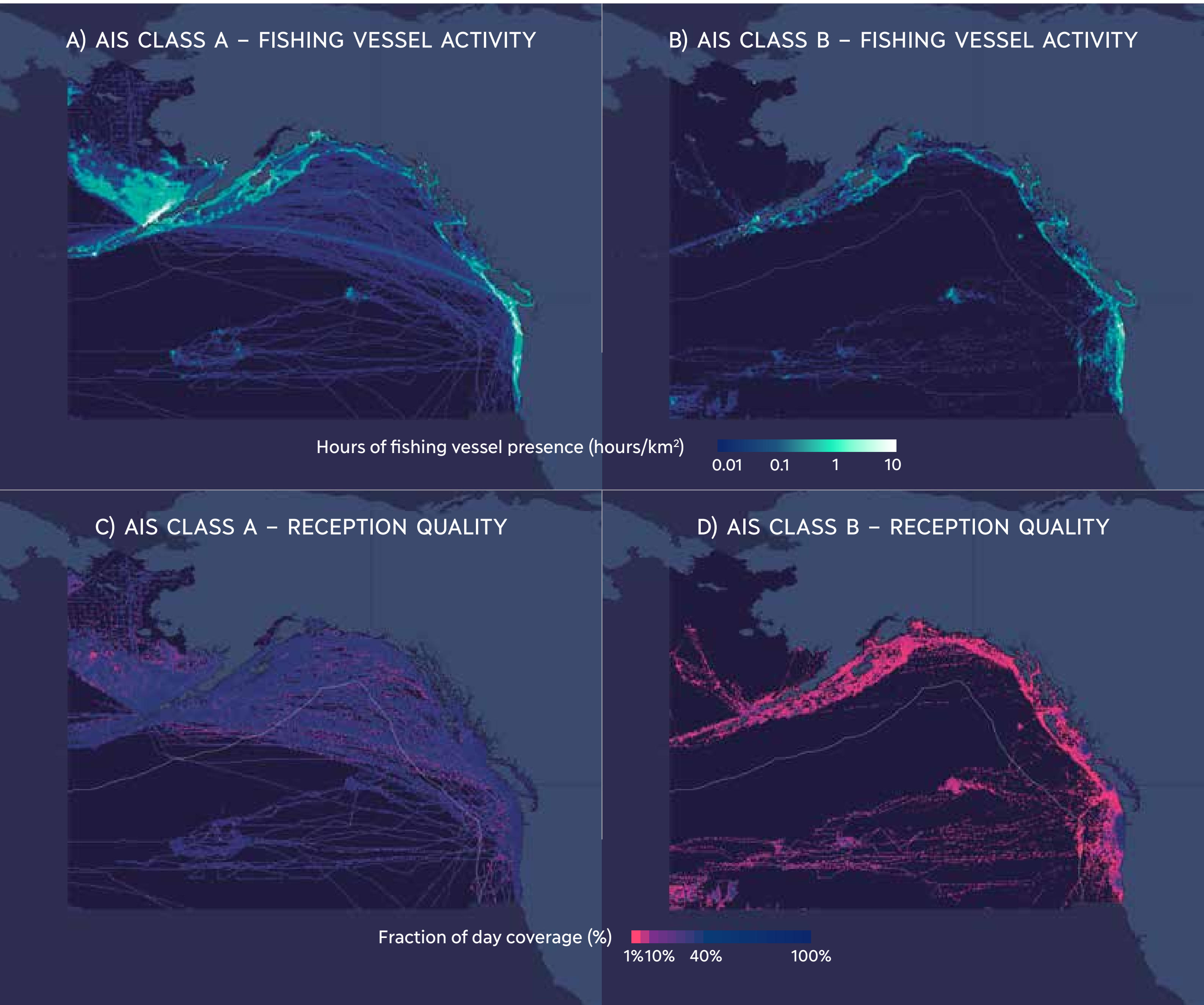


Figure 67. 5. Fishing vessel activity and quality of AIS reception for FAO Area 67 during 2017. Top row shows activity of vessels broadcasting AIS Class A (left panel) and Class B (right panel). The bottom row shows reception maps for devices Class A (left panel) and B (right panel). Blank spaces on the map (i.e. dark blue ocean background) mean that no signals from fishing vessels in the area were received, which is due to either no vessel activity or poor reception.

AIS fishing operations (Figure 67. 6) showed high fishing activity within EEZs in the northwest part of FAO Area 67 (Bering Sea), in the central north portion (Gulf of Alaska) and in the southeast portion. In the Bering Sea there is an important pollock fishery of pelagic trawlers from Alaska and a cod fishery conducted by longliners. While the trawl fishery harvests most of the groundfish caught in the area, these fish can also be caught with troll, longline, hook and line, pots, gillnets and other gear. For instance, in the Gulf of Alaska there are halibut and groundfish longline fisheries. Fishing activity in the high seas far from the continent was identified by AIS-GFW as mainly from United States of America pole and line as well as drifting longlines and squid jiggers from Asian countries. This activity also corresponded to the northern margins of the distribution of longline fishing activity, mainly from Asian countries, targeting temperate tunas, swordfish and sharks (FACATT, 2017; IATTC, 2017; Holmes and Zhang, 2017; NOAA, 2017).

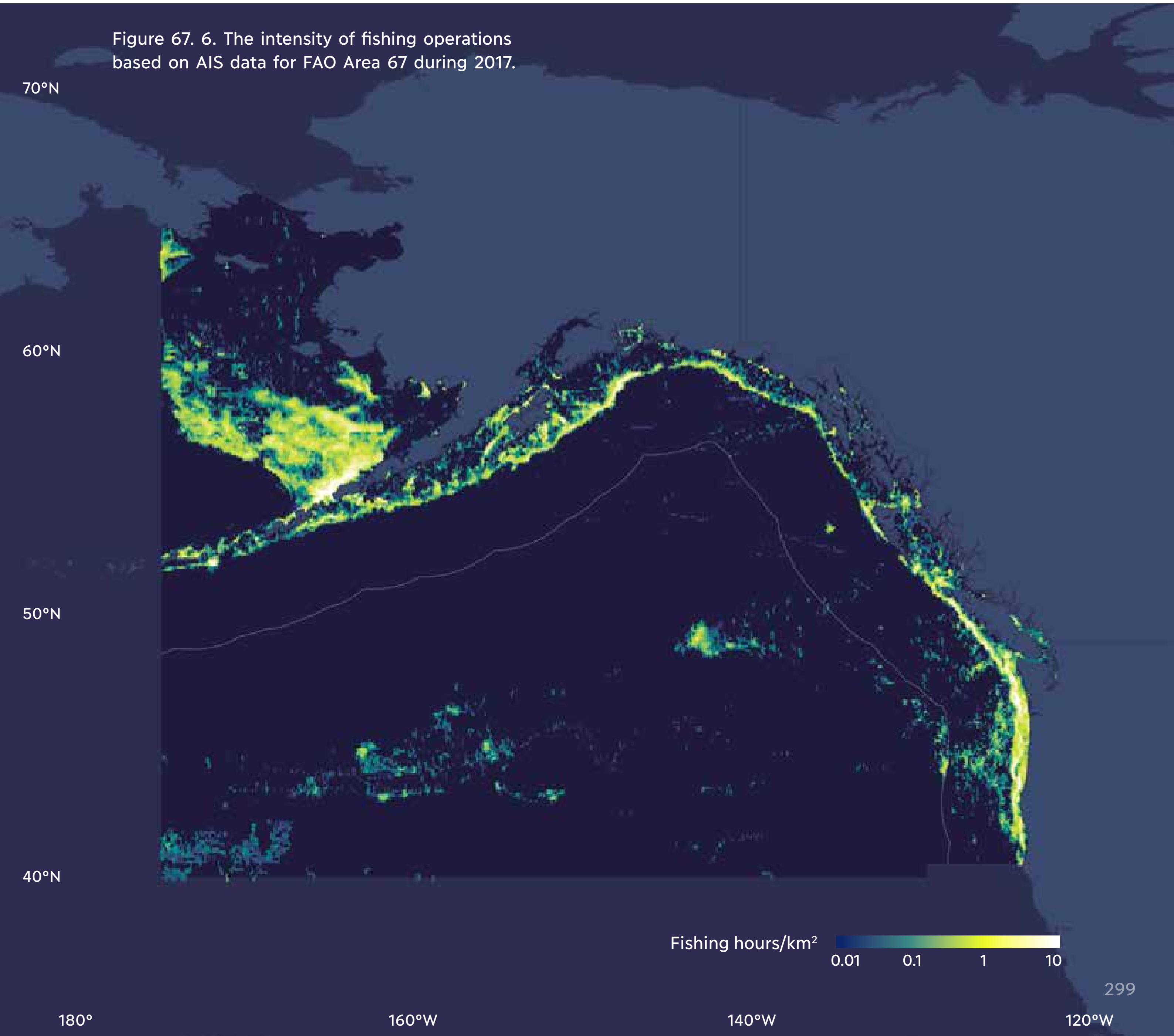


Figure 67. 6. The intensity of fishing operations based on AIS data for FAO Area 67 during 2017.

FISHING VESSEL ACTIVITY AND OPERATIONS BY GEARS IN THE NORTHEAST PACIFIC

This section reviews the spatial distribution patterns of the main fishing gears in FAO Area 67 as estimated by Global Fishing Watch (GFW) based on 2017 AIS data. The most recent datasets available as of mid-2018 have been used to assess GFW capacity to provide an AIS based characterization of fishing activity by fishing gear in terms of presence/absence, intensity and hotspots. The Introduction chapter describes the rationale and challenges for use of contrasting data sources (e.g. Global Fisheries Landings database (GFLD; Watson, 2017)) for benchmarking AIS data classification.

Table 67. I compares average catch in FAO Area 67 according to GFLD for 2010–2014 with the days of activity by fishing vessels with AIS in 2017. Both databases highlighted trawlers as the main fishing gear. GFW, though, could not identify set gillnets, one of the most important gear types, potentially because many gillnets are small vessels under 12 m (Witherell *et al.*, 2012) that usually do not have AIS and mostly target salmon. A review by external experts showed that both GFLD and GFW had misclassified some purse seiner activity, and the actual purse seiner activity was likely lower than displayed. This issue might stem from multi-gear use leading to gear type assignation errors. As a result of this review, some of GFW purse seiner activity has been reclassified into the other gears category and the map displayed for purse seiners (Figure 67. 9) resulted from this post-external review correction.

GEAR TYPES	Catches (GFLD) 2010–2014 average		Total fishing vessel activity (GFW-AIS) 2017	
	Tonnes of catch in 1000s	% of catch	Active days in 1000s	% of active days
Trawls	2 132	77%	40.8	51%
Set gillnets	156	6%		
Pots and traps	54	2%	35.1	44%
Other	244	9%		
Purse seines	184	7%	4.4	5%
Drifting longlines	13	0.5%	0.1	0.1%
Total	2 785	100%	80.4	100%

Table FAO 67. I. Summary table comparing average catch from GFLD during 2010–2014 with fishing vessel activity from GFW in FAO Area 67. Only vessels that fished for at least 24 hours in FAO Area 67 are included.

There is good agreement for trawler fishing activity distribution and intensity between AIS-GFW and GFLD information (Figure 67. 7), but GFLD likely spreads out trawling activity across a wider spatial area than it really covers. AIS delineated very well trawling fishing intensity in relation to the continental shelf edge, as well as marking activity hotspots on a few high seas seamounts off Canadian waters. An external review suggested that trawling activity in southeast Alaska was misclassified, and this activity was most likely conducted by "other gears". Trawler fishing activity in the area showed activity concentrated in the narrow Canadian continental shelf and the wider continental shelf of Alaska. These vessels target mainly pollock. GFW highlighted the area with the highest intensity in the Bering Sea, and the pattern of trawling here was roughly in spatial agreement with other assessments (Witherell *et al.*, 2012). However, there is the possibility that some of this trawler activity may not have been as intense as shown here and instead resulted from a misclassification of longliner and pot vessel activity. These two gears concentrate close to Alaska and Unimak Islands and target Pacific cod and sablefish (Witherell *et al.*, 2012). Pot vessel activity seems to be important in these islands. The GFW classifications in this area were drawn from a combination of vessel registries and the neural net vessel classification. As some of these vessels are multi-gear vessels, that may have led to misclassification of their activity.

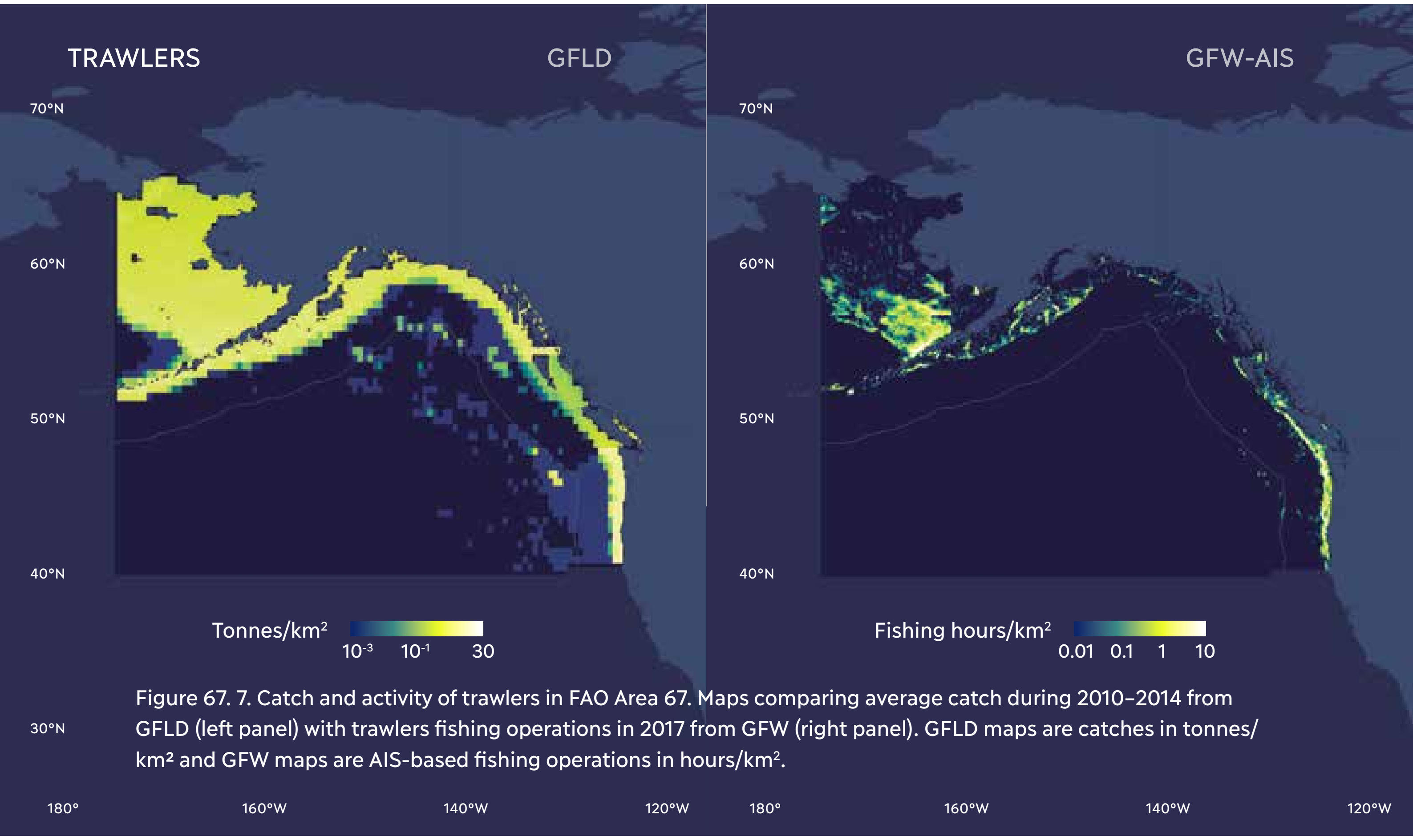


Figure 67. 7. Catch and activity of trawlers in FAO Area 67. Maps comparing average catch during 2010–2014 from GFLD (left panel) with trawlers fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

The Central and the Western Gulf of Alaska trawl fleet targets a variety of groundfish species throughout the year, starting with pollock or Pacific cod, then flatfish, rockfish and Pacific halibut as those fisheries' seasons are opened. Trawl fisheries are generally regulated by target species Total Allowable Catch (TAC) and seasons. There are two seasons for pollock, the first one starting in mid-January and the second one in mid-June. For each season a proportion of the total TAC allocation for each species is set. Therefore, the two peaks in the seasonal pattern could be explained by the opening of each fishing season. This is clearly observed in the temporal characterization of fishing activity in FAO Area 67 (Figure 67. 8). This temporal characterization, including all gear types, showed that active vessels ranged from less than 50 vessels in January to more than 250 vessels in July and August with seasonal patterns showing two peaks in February-March and in July-September.

Vessels fishing in FAO Area 67

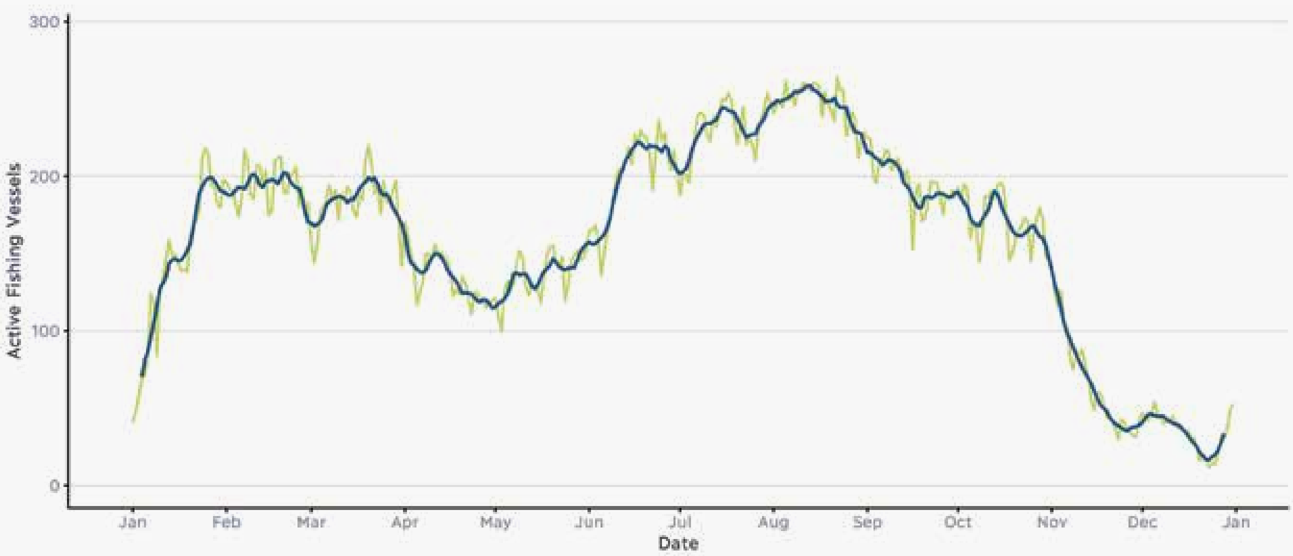


Figure 67. 8. Number of AIS-identified active fishing vessels per day in FAO Area 67 during 2017. Only vessels that fished at least 24 hours in the area over the course of the year are included. Dark blue line shows a 7-day rolling average.

Purse seiner fishing activity could not be correctly mapped by either AIS-GFW or GFLD (Figure 67. 9) since seiners in FAO Area 67 are small vessels up to 58 feet (limit) or 19.3 m that stay fishing very close to shore. The AIS map is likely showing longliners or AIS on flagpole marking sets (Witherell *et al.*, 2012). The GFLD map thus likely represents a gross overestimation of purse seiner activity in the area. AIS maps initially showed a more realistic fishing pattern than GFLD. However, before careful review during writing of this chapter, GFW data also included a significant amount of purse seiner activity along the continental shelf far from shore, where it was very unlikely to have occurred. A reexamination of these vessels showed that many were registered as purse seiners on an Alaskan registry (and thus were displayed as purse seiners by GFW), although they were likely multi-gear vessels and may not have been purse seining that far from shore. After review, many of these vessels, about twenty in number, were reclassified to "other."

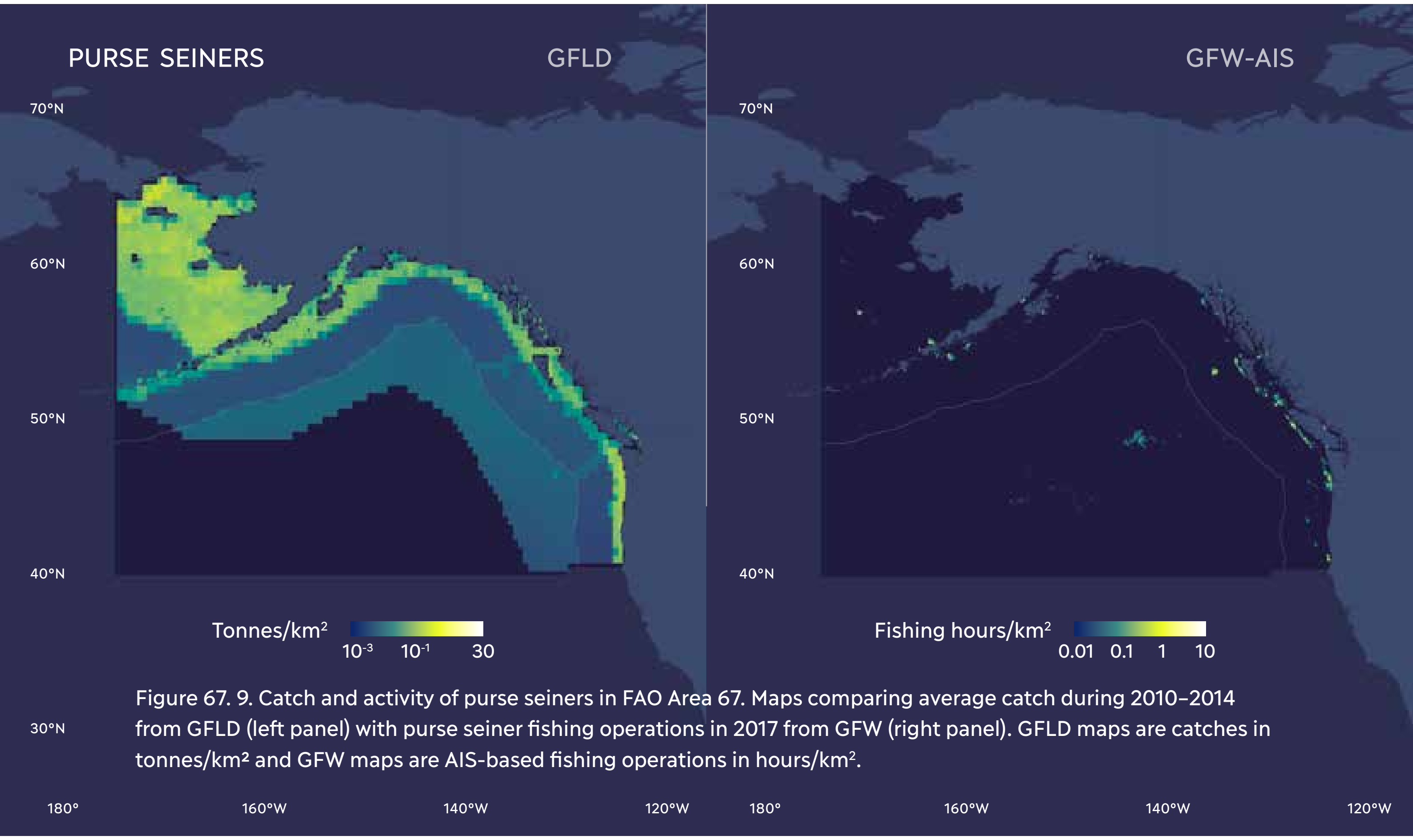


Figure 67. 9. Catch and activity of purse seiners in FAO Area 67. Maps comparing average catch during 2010–2014 from GFLD (left panel) with purse seiner fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

ACKNOWLEDGEMENTS

The editors would like to thank Jennifer Gee, Alexander Kotlarov and Vladimir Radchenko for excellent comments and feedback during the elaboration of the chapter. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Required citation for this chapter:

Iriondo, A., Santiago, J., Murua, H., Granado, I., Taconet, M., Kroodsma, D., Miller, N. A., Fernandes, J. A. 2019. FAO Area 67 - AIS-based fishing activity in the Northeast Pacific. *In* Taconet, M., Kroodsma, D., Fernandes, J.A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

FAO. 2016. *Food and Agriculture Organization of the United Nations. The State of World Fisheries and Aquaculture 2016 (SOFIA). Contributing to food security and nutrition for all.* Rome. http://www.fao.org/3/a-i5555e.pdf

FAO. 2019. *Food and Agriculture Organization of the United Nations. FAO Major Fishing Areas. Northeast Pacific (Major Fishing Area 67).* http://www.fao.org/fishery/area/Area67/en

FACATT. 2017. *Fisheries Agency, Council of Agriculture, Taipei, Taiwan. National Report of Chinese-Taipei (Taiwanese Tuna and Tuna-like Fisheries in the North Pacific Ocean). Document ISC/17/PLENARY/05. 17th Meeting of the International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific Ocean. Vancouver, BC, Canada, 12-17 July.* http://isc.fra.go.jp/pdf/ISC17/ISC17plenary05-National_Report_of_Chinese-Taipei(Taiwanese_Tuna_and_Tuna-Like_Fisheries_in_the_North_Pacific_Ocean).pdf

Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F.,... & Woods, P. 2018. Tracking the global footprint of fisheries. *Science*, 359(6378), 904-908. https://doi.org/10.1126/science.aao5646

NOAA. 2017. *National Marine Fisheries Service. National Report of UNITED STATES OF AMERICAA. (UNITED STATES OF AMERICAA. Fisheries and Research on Tuna and Tuna-like Fisheries in the North Pacific Ocean). Document ISC/17/PLENARY/09. 17th Meeting of the International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific Ocean. Vancouver, BC, Canada, 12-17 July.* http://isc.fra.go.jp/pdf/ISC17/ISC17plenary09-US_National_report.pdf

IATTC. 2017. Inter- American Tropical Tuna Commission. Fishery report 2016. EPO Tunas and billfishes fishery. FIRMS Reports. *In* Fisheries and Resources Monitoring System (FIRMS) [online]. Rome. Updated 10 April 2017. http://firms.fao.org/firms/fishery/346/en

Mathis, J. T., Cooley, S. R., Lucey, N., Colt, S., Ekstrom, J., Hurst, T.,... & Feely, R. A. 2015. Ocean acidification risk assessment for Alaska's fishery sector. *Progress in Oceanography*, 136, 71-91. https://doi.org/10.1016/j.pocean.2014.07.001

Holmes, J., Zhang, Z., 2017. *National report of canada (Canadian Tuna and Tuna-like Fisheries in the North Pacific Ocean in 2016). Document ISC/17/PLENARY/04. 17th Meeting of the International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific Ocean Vancouver, Canada 12-17 July.* http://isc.fra.go.jp/pdf/ISC17/ISC17plenary04-National_Report_of_Canada(Canadian_Tuna_and_Tuna-Like_fisheries_in_the_North_Pacific_Ocean_in_2016).pdf

Watson, R. A. 2017. A database of global marine commercial, small-scale, illegal and unreported fisheries catch 1950–2014. *Scientific data*, 4, 170039. https://doi.org/10.1038/sdata.2017.39

Wilson, M. T., Mier, K. L., & Cooper, D. W. 2016. Assessment of resource selection models to predict occurrence of five juvenile flatfish species (Pleuronectidae) over the continental shelf in the western Gulf of Alaska. *Journal of Sea Research*, 111, 54-64. https://doi.org/10.1016/j.seares.2015.12.005

Witherell, S., Fey, M., Fina, M. 2012. *Fishing Fleet Profiles.* North Pacific Fishery Management Council. https://www.npfmc.org/wp-content/PDFdocuments/resources/FleetProfiles412.pdf

FAO AREA 71

AIS-based fishing activity in the Western Central Pacific

Figure 71. 1. Location of FAO Area 71.

Josu Santiago, Igor Granado, Jennifer Gee, Marc Taconet, David Kroodsma, Nathan A. Miller and Jose A. Fernandes

PREAMBLE

This chapter assesses, through a comparison with fleet statistics and public fisheries data, the capacity of Automatic Identification System (AIS) data and Global Fishing Watch (GFW) algorithms (Kroodsma *et al.*, 2018) to identify and quantify fishing vessel activity in the Western Central Pacific during 2017. This assessment reviews fleet activity, main gear types, and spatial distribution of vessel activity and fishing operations.

SUMMARY AND CONCLUSIONS FOR THE WESTERN CENTRAL PACIFIC

AIS use and reception are extremely poor at the western end of this area, but relatively high and good on the eastern edge. As a result, AIS captures almost none of the important fishing activity in southeast Asia – particularly regarding the domestic fleets. Overall, all gear types are poorly represented except for pelagic longliners and purse seiners from distant water fleets operating to the east of Papua New Guinea.

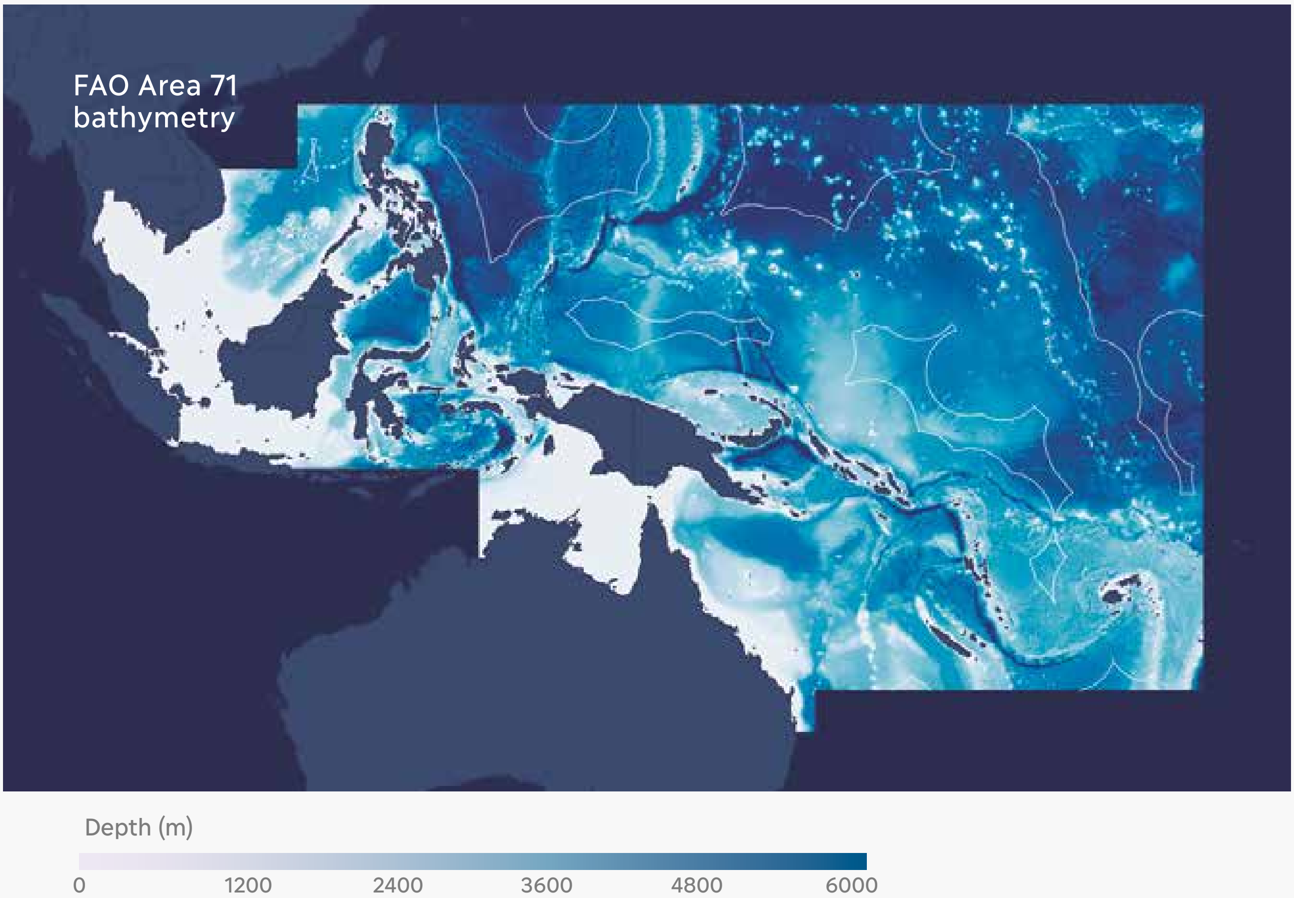


Figure 71. 2. FAO Area 71 bathymetry (depth) and 200 miles coastal arc.

INTRODUCTION FOR THE WESTERN CENTRAL PACIFIC

Waters of the Western Central Pacific (FAO Area 71; FAO, 2019) are bounded by latitudes 20° N and 25° S, longitude 175° W in the east and in the west the Oceania continent land area and Asian countries and territories (Figure 71. 1). The following coastal countries/territories are within FAO Area 71: Australia, Brunei Darussalam, Cambodia, Fiji, Guam, Indonesia, Kiribati, Malaysia, Marshall Islands, Micronesia, Northern Mariana Islands, Nauru, New Caledonia, Palau, Papua New Guinea, Philippines, Singapore, Solomon Islands, Thailand, Tuvalu, Vanuatu, Vietnam and Wallis and Futuna Islands (Figure 71. 2). In FAO Area 71, over 80 percent of marine waters are in national jurisdictions, leaving less than 20 percent in the high seas. This proportion of high seas is the lowest across all FAO areas (the average is 54 percent).

The Western and Central Pacific Ocean is dominated by a large continental shelf area (6.6 million km^2) which is bordered in the north by Southeast Asian countries and in the south-east by Indonesia and Australia (FAO, 2005). FAO Area 71 supports major industrial tuna fisheries and a variety of small-scale coastal fisheries (Bell *et al.*, 2018). Industrial tuna surface fisheries target skipjack tuna (and yellowfin tuna using purse seine and pole and line fishing methods (Bell *et al.*, 2018). Fishing activity by the large-vessel, distant-water longline fleets of Japan, Republic of Korea and Taiwan Province of China accounts for most of the activity. Activity is widespread as sectors of these fleets target bigeye and yellowfin for the frozen sashimi market in central and eastern tropical waters, and albacore for canning in the more temperate waters (Williams and Reid, 2018). However, most of the catches concentrate in latitudes 10-20° S within coastal waters (Brouwer *et al.*, 2018). Small fisheries target mainly demersal fish and invertebrates associated with coral reefs, mangroves and seagrasses, and increasingly yellowfin tuna and other large pelagic fish in nearshore waters (Bell *et al.*, 2018).

The Western Central Pacific is the second most productive FAO area after the Northwest Pacific and catches have increased in recent years to 12.4 million tonnes and a 15 percent share of world captures (FAO, 2016). Major species captured in the region are tuna and tuna like species and small pelagics such as sardinellas and anchovies (FAO, 2016). FAO landings statistics (FishStatJ, 2018) show that in the period from 2010 to 2014, catches were dominated by invertebrate and pelagic fish species. The largest catches were of marine fishes such as skipjack tuna, scads, yellowfin tuna, sardinellas, cephalopods, natantian decapods, short mackerel, common squids, Stolephorus anchovies, kawakawa, bigeye scad, Indian mackerel, goldstripe sardinella, threadfin breams, Indian mackerels, trigate tuna, bullet tuna and narrow-barred Spanish mackerel. These 18 species items made up 70 percent of the reported catch in that period.

REGION FLEETS AND AIS USE IN THE WESTERN CENTRAL PACIFIC

Coastal states and territories in FAO Area 71 reported having about one third of their vessels as non-powered under 12 m (Figure 51. 3). Vessels over 24 m, which are the vessels most likely to use AIS, accounted for 0.3 percent of the region fleet and almost all these large vessels were from Indonesia, Thailand and Malaysia. The Philippines may also have some vessels of this size, but these numbers were not reported to FAO. Non-motorized vessels under 12 m normally lack AIS and it is unlikely that vessels between 12 and 24 m use AIS devices in the region with the exception of some distant water fleets.

Fleets of coastal countries/territories in FAO Area 71

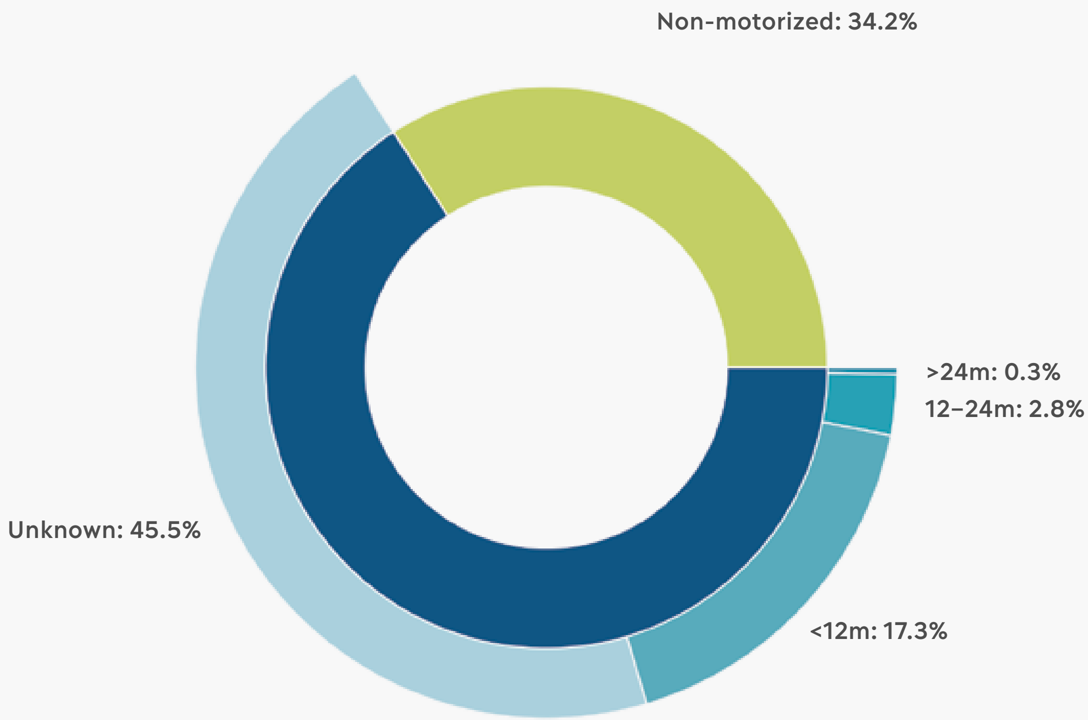


Figure 71. 3. Structural composition of coastal countries'/territories' fleets in FAO Area 71. In dark blue motorized fishing vessels and in green non-motorized. Distant water fleets active in FAO Area 71 are not included (see next figure). Notice that although some countries/territories border more than one FAO area, their entire fleet size is included here. Sources: FAO statistics. Statistics were not available for the following coastal countries/territories border FAO Area 71: Marshall Islands, Micronesia, Palau, Solomon Islands and Wallis and Futuna Islands.

Few regional fleet vessels use AIS (Figure 71. 4). While countries of Southeast Asia, including Thailand, the Philippines, and Indonesia have some of the largest fleets in the world with many vessels over 12 m, almost none of them had AIS. The top three fishing nations in FAO Area 71 according to AIS, namely China, Taiwan Province of China and Japan, are all from other regions (e.g. FAO Area 61). The use of AIS by these distant water fleets is very high.

According to Sala *et al.* (2018), in the WCPFC area of which FAO Area 71 is a subregion, 100 percent of Taiwanese longliners over 250 GRT and 40 percent under 250 GRT have AIS. Similarly, almost 100 percent of Vanuatu longliners over 100 GRT (usually over 24 m) have AIS, and 100 percent of all Korean, Japanese, Chinese and U.S. longliners and purse seiners in the WCPFC broadcast AIS. These numbers can differ from other reports and publications because of spatial coverage and the type of longliners covered in each publication. For example, in Sala *et al.* (2018) over 400 active Chinese longliners were reported in the WCPFC area,. However, these represented pelagic longliners in all of the WCPFC convention area which includes FAO areas 61, 71 and 81. In addition, the FAO Area 81 chapter indicates that not only pelagic longliners are reported to FAO statistics, but also bottom longliners operating within China's EEZ. Similarly, Williams and Reid (2018) estimated around 120 domestic purse seiners in 2017 in the wider WCPFC convention area. Of the 1 371 likely fishing vessels broadcasting AIS in FAO Area 71, 1 068 were matched to registries, and 952 had gear types identified. Taiwanese and Chinese fleets had the most vessels with AIS, followed by Japan and Australia.

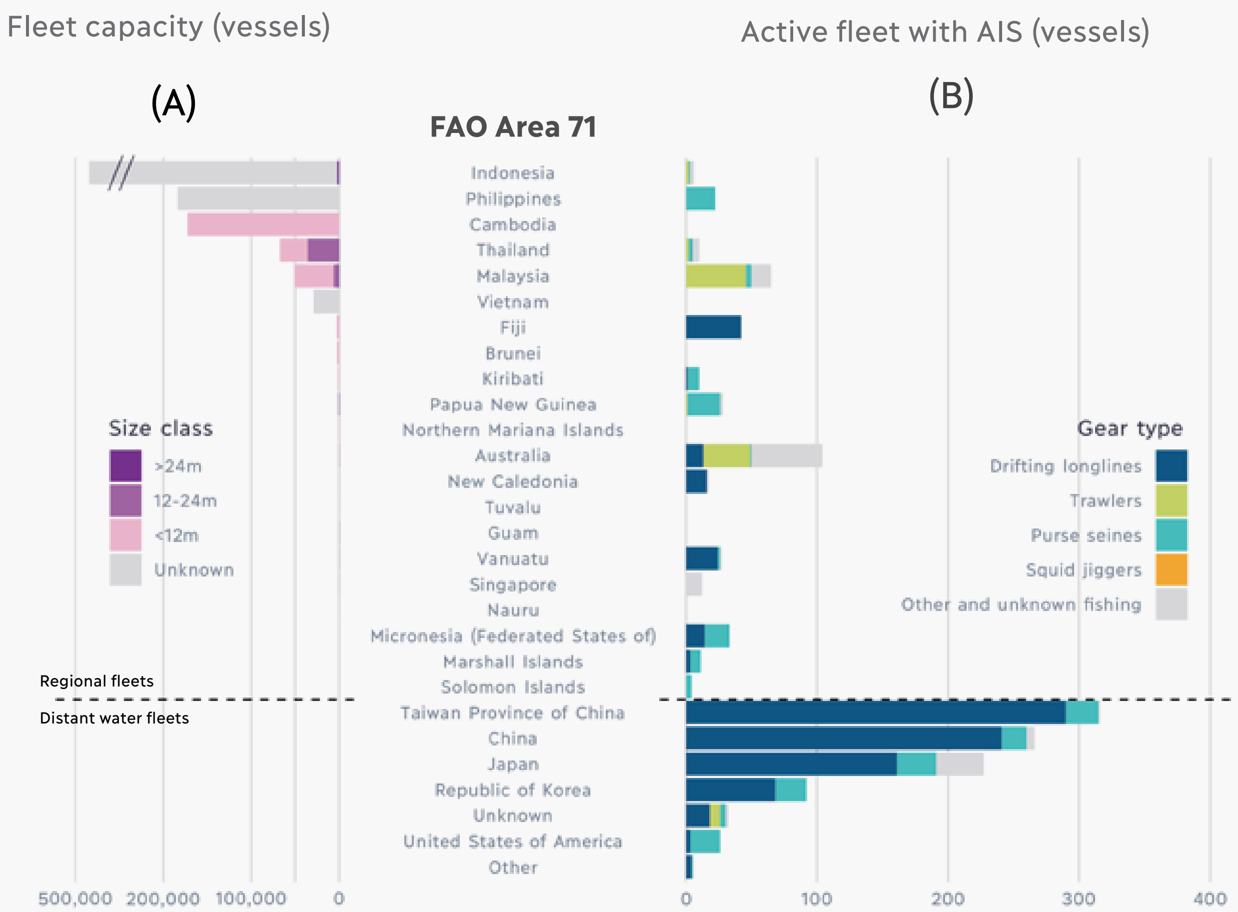
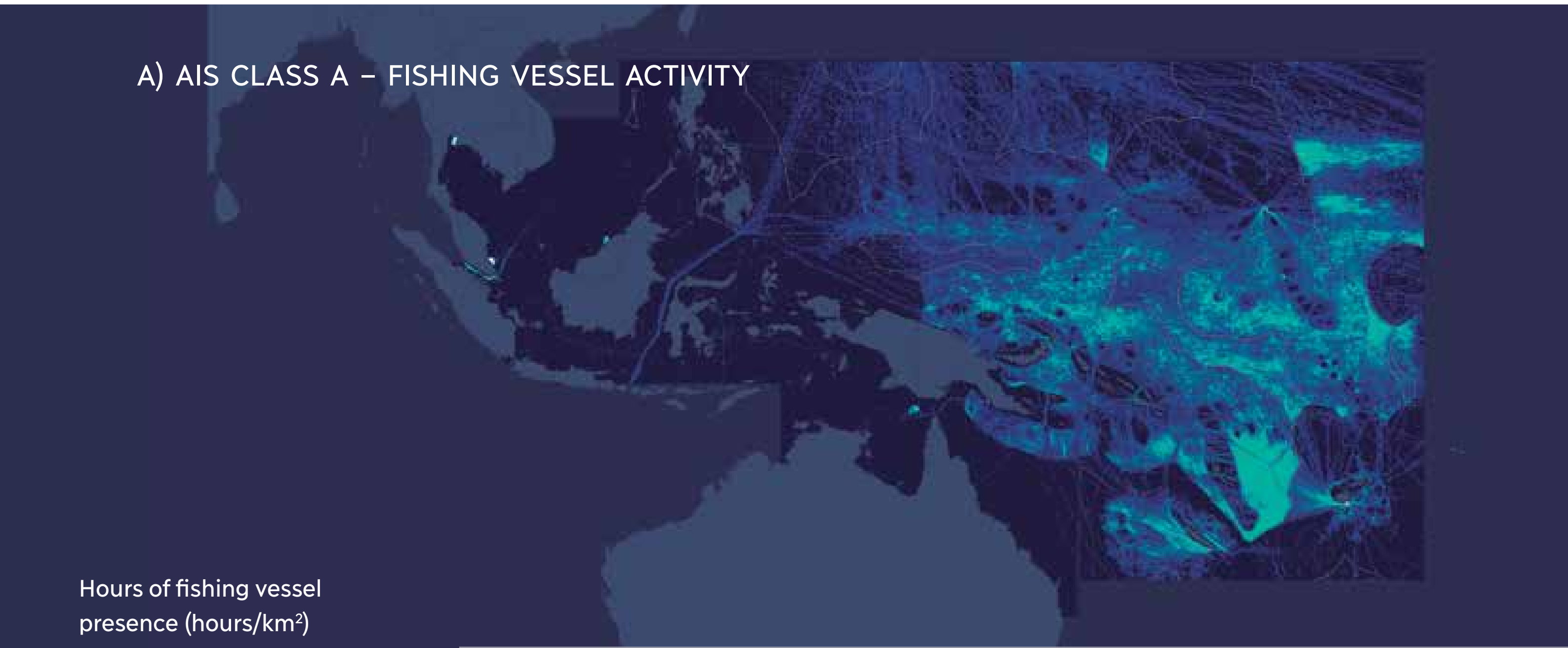


Figure 71.4. Summary of coastal and distant fleets based on FAO statistics and AIS data classification by GFW in FAO Area 71. A) Number of motorized vessels as reported to FAO. The entire fleets of coastal countries/territories border, even though these fleets may be active in other FAO areas. Source: FAO statistics for 2017. Statistics were not available for the following coastal countries/territories within FAO Area 71: Marshall Islands, Micronesia, Palau, Solomon Islands and Wallis and Futuna Islands. B) AIS-identified number of fishing vessels broadcasting AIS during their operations in FAO Area 71 by gear type and flag state. Dashed lines separate regional fleets (top) from distant fleets (bottom). Only vessels that fished for at least 24 hours in the area are included. Source: GFW.

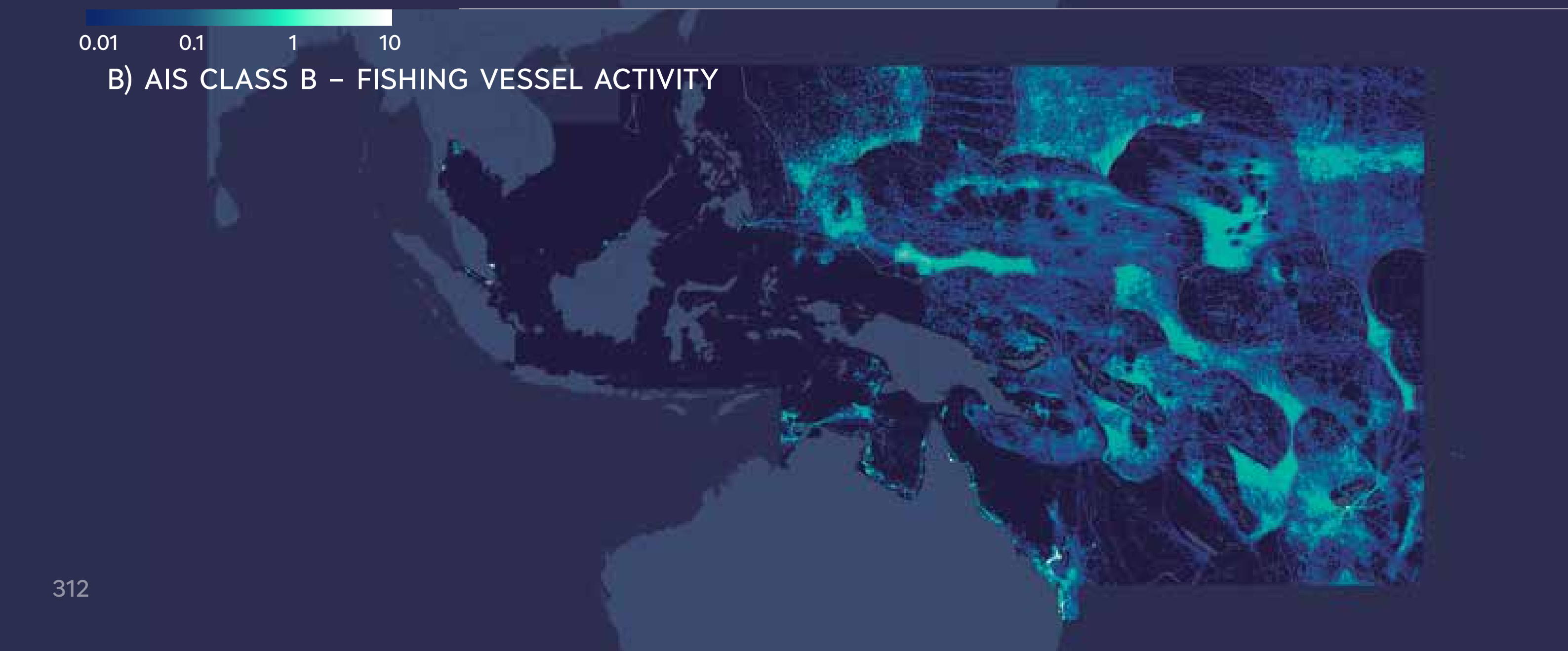
AIS RECEPTION AND FISHING VESSEL ACTIVITY IN THE WESTERN CENTRAL PACIFIC

Figures 71. 5a,b show all fishing vessel activity captured by AIS in FAO Area 71 (Class A and Class B AIS devices). Just under two thirds of the vessels in FAO Area 71 use Class B devices, including almost all Australian and Taiwanese vessels, with other fleets having a mix of Class A and Class B devices. AIS reception was extremely poor in the western edge of the area and relatively good in the eastern edge, similar to AIS use. Class A reception was good across most of the area except for the far west, where high vessel numbers broadcasting AIS caused interferences (Figure 71. 5c). In general, Class B reception was relatively good in the eastern half of the area (Figure 71. 5d). However, because signals are weaker than for Class A devices, to the west near Asia, coverage was poorer due to interference caused by high vessel traffic. Vessels broadcasting Class B messages in the western third of this area are probably not even registered by the satellites, contributing to the massive blank region in the western third of the map (Figure 71. 5d).

A) AIS CLASS A – FISHING VESSEL ACTIVITY



B) AIS CLASS B – FISHING VESSEL ACTIVITY



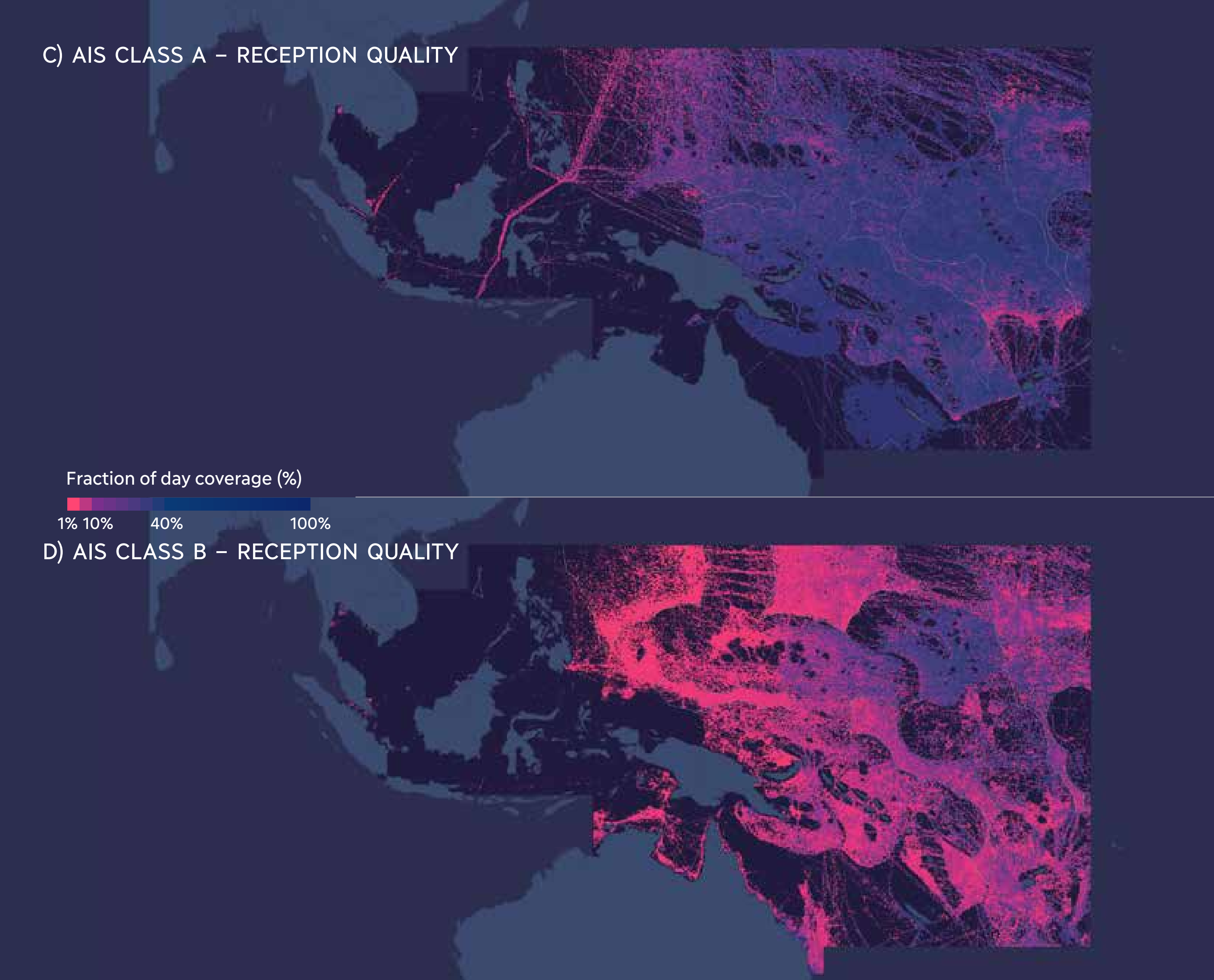
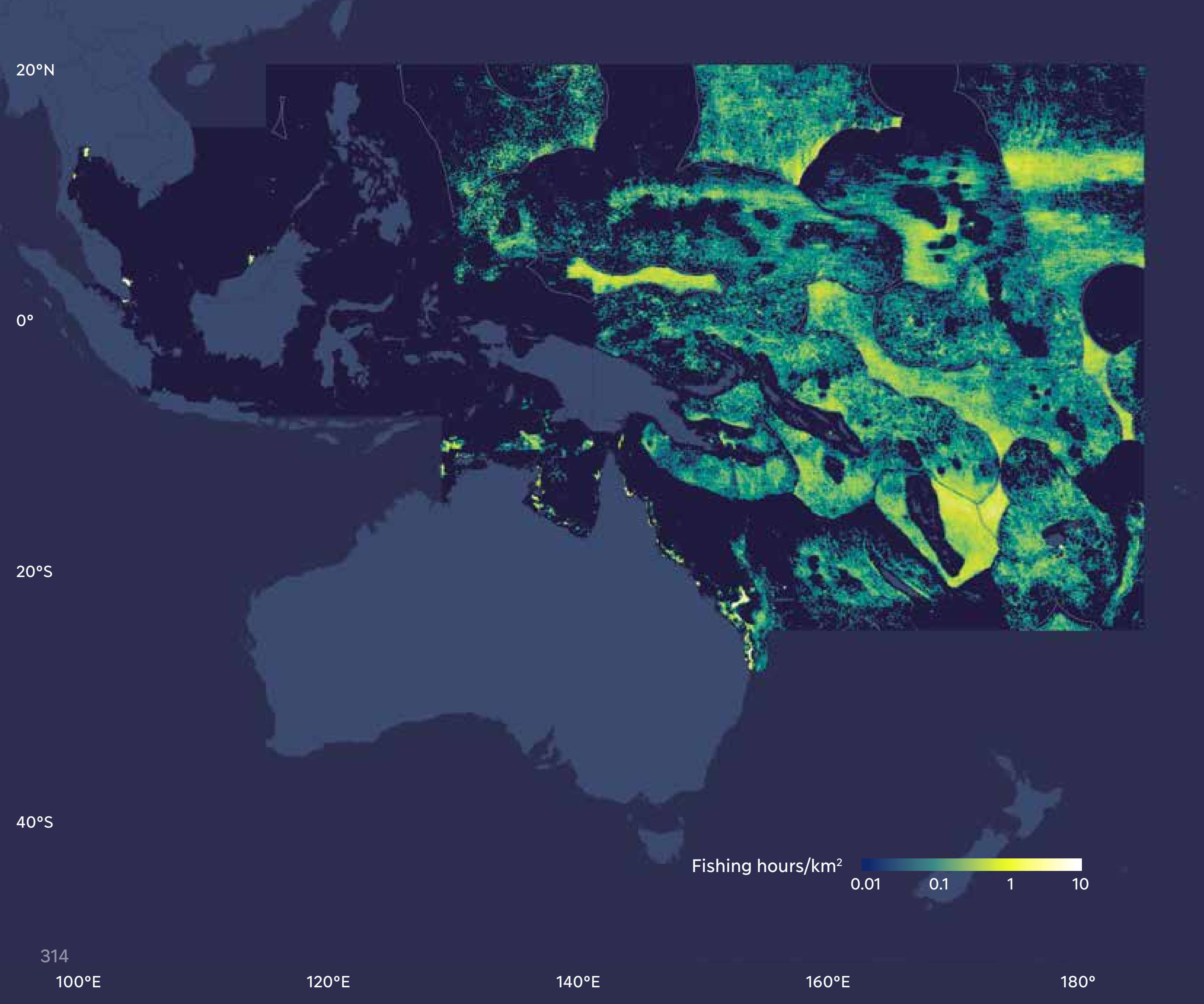


Figure 71. 5. Fishing vessel activity and quality of AIS reception for FAO Area 71 during 2017. The top rows show activity of vessels broadcasting using Class A devices and Class B devices. (A) shows activity of vessels broadcasting using Class A devices and (B) shows the same for Class B devices. (C) and (D) show reception quality maps for devices Class A and B. Blank spaces on the map (i.e. dark blue ocean background) mean that no signals from fishing vessels in that region were received, which is due to either no vessel activity or poor reception.

Fishing operations during 2017, based on AIS reception and use, concentrated in the high seas at the eastern portion of the area and clearly showed activity intensification in the high seas' pockets (Figure 71. 6). This fishing activity detected by AIS, mainly from distant water fleets targeting tuna species, strongly showed in the high seas pockets surrounded by EEZs, which clearly indicated the existence of different management regimes in the area. Almost entirely absent in the AIS data is the intense fishing activity known to occur in Southeast Asia and Indonesia. Malaysian trawlers below 24 m constituted a notable exception, with activity concentrated in three coastal water spots close to terrestrial receivers. Note that Malaysian trawling likely extends across a much greater area, but satellite reception is so poor that the vessels would go undetected. Meanwhile, activity by Australian vessels was clearly visible in coastal areas of the northeastern Australian coast.

Figure 71. 6. The intensity of fishing operations based on AIS data for FAO Area 71 during 2017.



FISHING VESSEL ACTIVITY BY GEAR IN THE WESTERN CENTRAL PACIFIC

This section reviews the spatial distribution patterns of the main fishing gears in FAO Area 71 as estimated by Global Fishing Watch (GFW) based on 2017 AIS data. The most recent datasets available at mid-2018 were used to assess GFW capacity to provide an AIS based footprint of fishing activity by fishing gear in terms of presence/absence, intensity and hotspots. The Introduction chapter describes the rationale and challenges for use of contrasting data sources (e.g. Global Fisheries Landings database (GFLD; Watson, 2017)) for benchmarking AIS data classification.

When comparing fishing activity based on AIS data with average annual catches during the period 2010–2014 from GFLD (Table 71. I), it is observed that the AIS data was missing a high fraction of all gear types, although it was slightly better for purse seiners and drifting longliners. This discrepancy was likely due to the extremely low use of AIS by fleets in the western half of the area and high traffic in some areas. Drifting longliner fishing activity percentage based on AIS data by GFW was much higher than catch percentage by these vessels in FAO Area 71, whereas trawler activity was lower than their catch percent (Table 71. I). There seemed to be agreement on the importance of purse seiner activity in both AIS-GFW and GFLD. Set gillnets, that accounted for 14 percent of the catch, were not detected by AIS-GFW. During 2014, the purse seiner fishery accounted for 65 percent of the total tuna catch in the WCPFC area which comprises FAO Area 71, west of FAO Area 81 and most of FAO Area 61 (Williams and Terawasi, 2015). GFLD troller activity reported in this area is likely to be incorrect since the South Pacific troll fishery is based in the coastal waters of New Zealand, and along the Sub-Tropical Convergence Zone below 30° S waters (Williams and Reid, 2018).

GEAR TYPES	Catches (GFLD) 2010–2014 average		Total fishing vessel activity (GFW-AIS) 2017	
	Tonnes of catch in 1000s	% of catch	Active days	% of active days
Trawls	5 032	45%	7.8	4%
Purse seines	1 497	13%	40.4	21%
Set gillnets	1 493	13%	10.0	5%
Other	1 158	10%		
Trollers	852	8%		
Pole and line	341	3%		
Drifting longlines	899	8%	132.5	69%
Total	11 275	100%	190.8	100%

Table 71. I. Summary table comparing average catch from GFLD during 2010–2014 with fishing vessel activity from GFW in FAO Area 71. Only vessels that fished for at least 24 hours in FAO Area 71 are included.

Trawling activity in FAO Area 71 (Figure 71. 7), as depicted by the GFLD database, was intense along the coastlines of Indonesia and Southeast Asia. Almost all of this activity was absent from the AIS data because few of these vessels carry AIS, and because satellite AIS reception is extremely poor in Southeast Asia. Only a few trawlers operating close to terrestrial receivers in Malaysia were detected in this heavily trawled area. A few Australian trawlers were also present in the AIS data along the northeastern Australian coast.

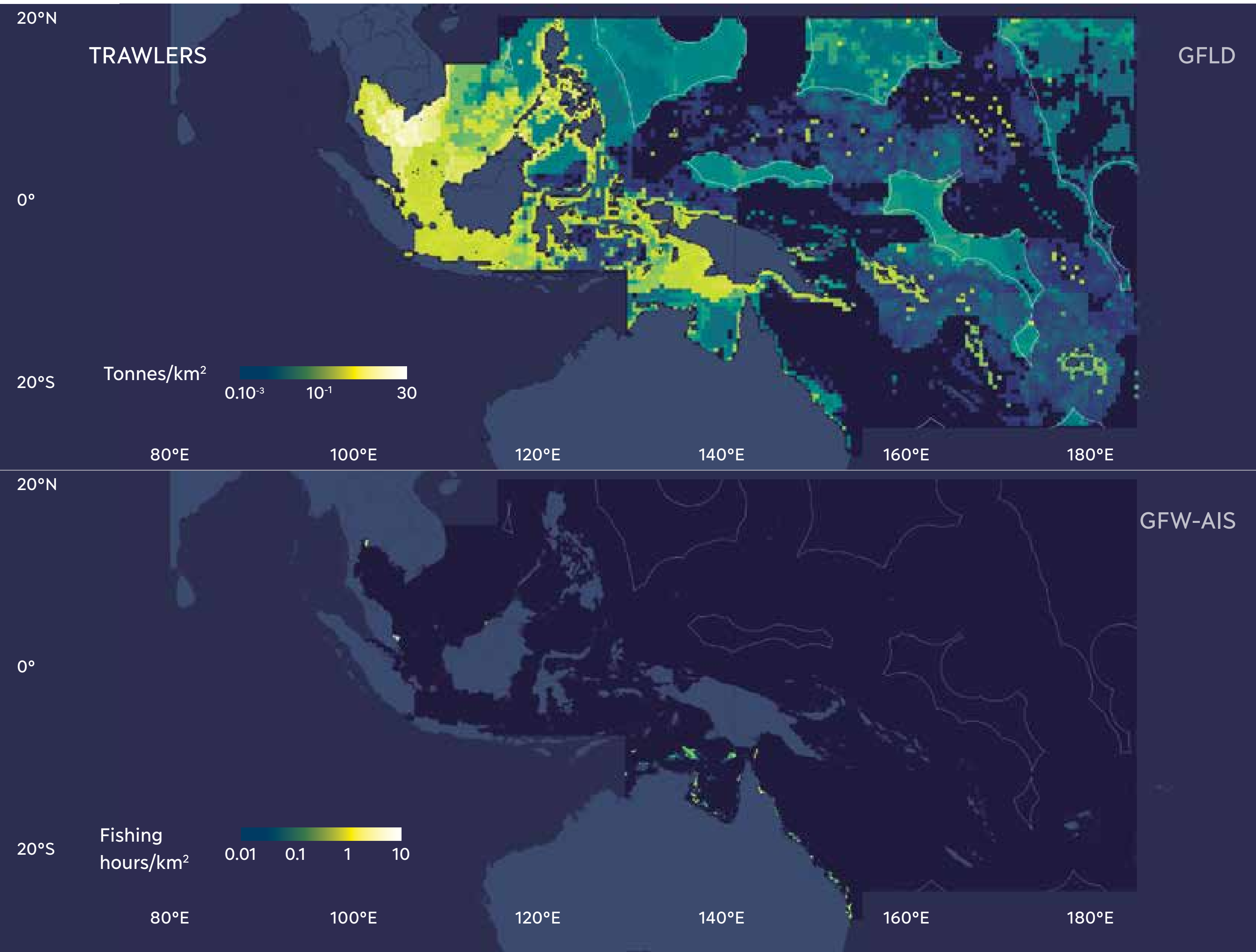


Figure 71. 7. Catch and activity of trawlers in FAO Area 71. Maps comparing average catch during 2010–2014 from GFLD (top panel) with trawlers fishing operations in 2017 from GFW (bottom panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

AIS based fishing activity for purse seiners (Figure 71. 8) was missing the intense activity in the western portion (Williams and Terawasi, 2015; Williams and Reid, 2018) of the region due to low AIS use and reception. In the eastern region, GFLD showed intense fishing activity in the high seas. This was likely an error, as around 80 percent of the WCPO purse seine catch between 2010-2016 was within PNA EEZs, the remaining percentage being taken in waters of other Commission Members, especially Indonesia and the Philippines, and the high seas (Clark, 2017; Murua *et al.*, 2018).

WCPFC regulations limit the number of fishing days and partially restrict purse seining in these high seas pockets. These regulations may explain why GFW-AIS data showed almost no fishing by purse seiners (broadcasting AIS) in these high seas pockets. GFLD also suggested that purse seiner fishing was much more widespread than implied by the AIS data. The purse-seiner fishery in FAO Area 71 is essentially a skipjack fishery, unlike those of other ocean areas. Skipjack generally accounts for 65–77 percent of the purse seiner catch, with yellowfin accounting for 20–30 percent and bigeye for only a small proportion of 2-5 percent. Small amounts of albacore tuna are also taken in temperate water purse seine fisheries in the North Pacific (Williams and Reid, 2018).

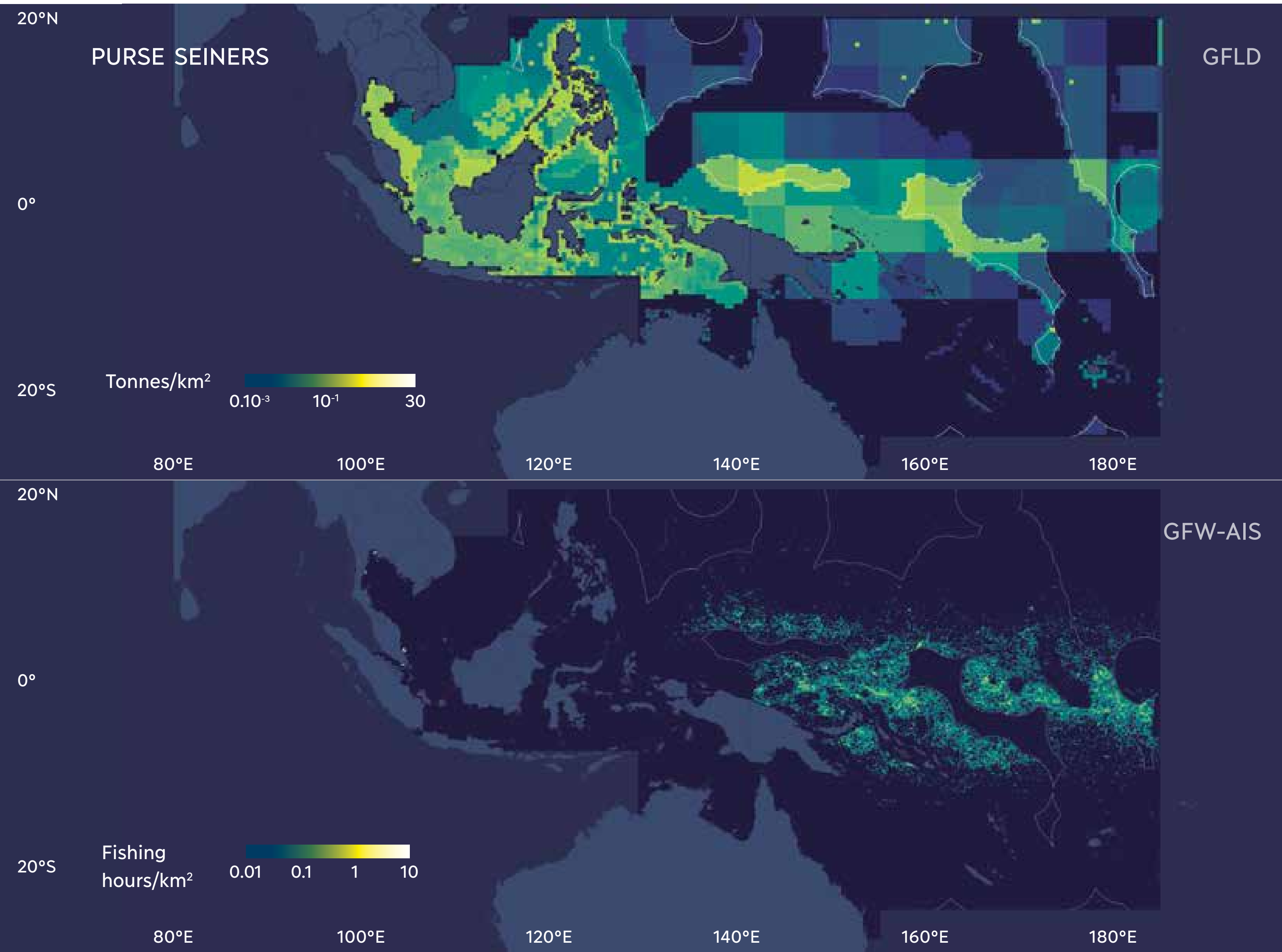


Figure 71. 8. Catch and activity of purse seiners in FAO Area 71. Maps comparing average catch during 2010–2014 from GFLD (top panel) with purse seiners fishing operations in 2017 from GFW (bottom panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

Drifting longliner activity (Figure 71. 9) in both GFLD and AIS was more intense in the high seas. However, this was likely an artifact from the higher use of AIS mostly by distant water fleets. It did not reflect that the highest fishing intensity is concentrated in the western areas, often within national waters (Williams and Terawasi, 2015; Williams and Reid, 2018), where AIS only detected sparse activity. AIS data detected temperate longline activity in the southeast of the area, although activity in the high seas appeared to be overestimated. GFLD may have underestimated fishing intensity in the eastern parts of the area. The tuna fishery accounts for around 10–13 percent of the total catch and has two main components: 1) large distant water freezer vessels (typically above 250 GRT) operating over large portions of the FAO area, targeting either tropical (yellowfin, bigeye tuna) or subtropical (albacore tuna) species; and 2) smaller offshore vessels (typically bellow 100 GRT) which are usually domestically-based, with ice or chill capacity, and serving fresh or air-freight sashimi markets, or canneries (Williams and Reid, 2018).

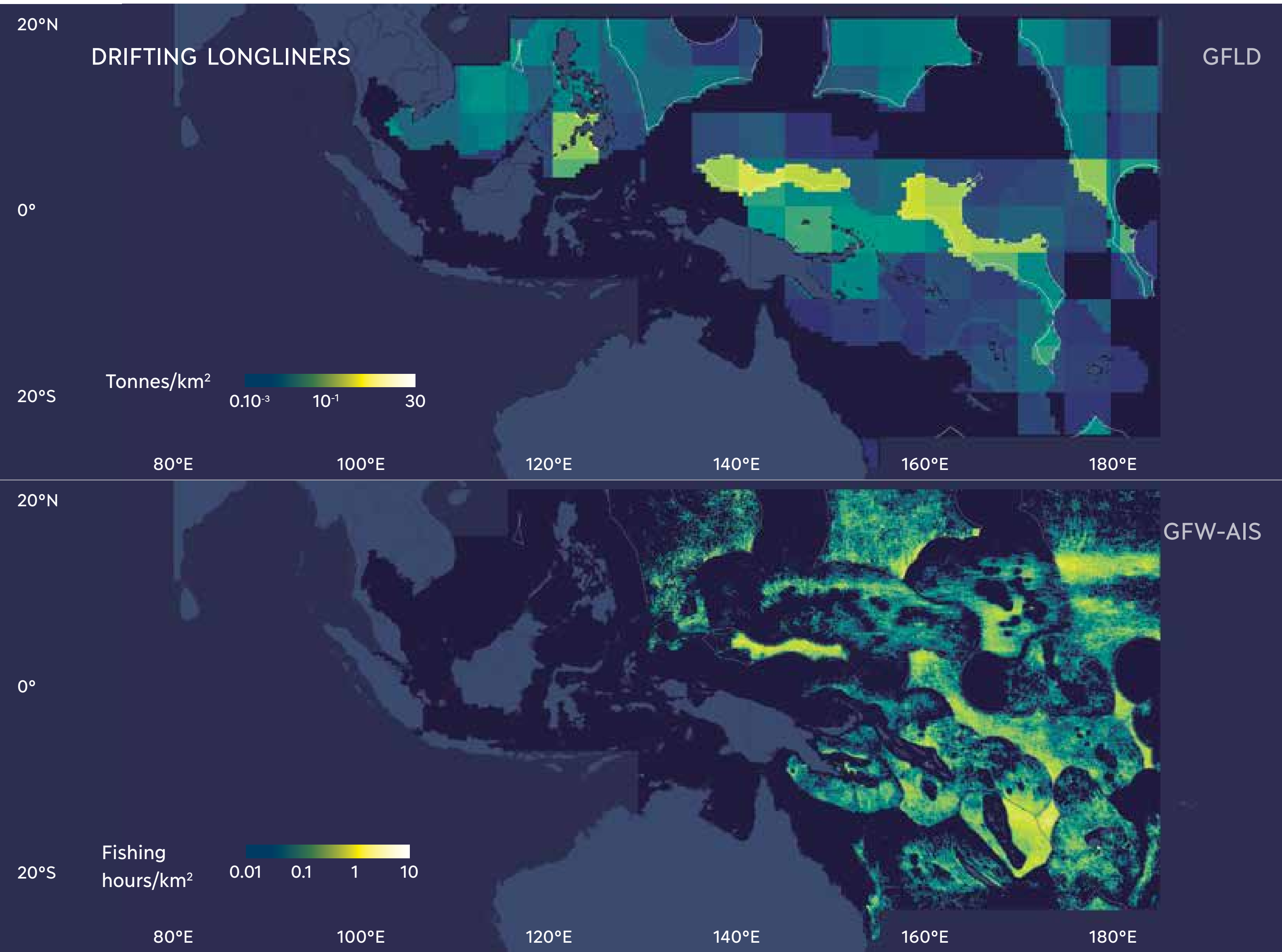


Figure 71. 9. Catch and activity of longliners in FAO Area 71. Maps comparing average catch during 2010–2014 from GFLD (top panel) with longliners fishing operations in 2017 from GFW (bottom panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

ACKNOWLEDGEMENTS

The editors would like to thank Graham Pilling, Rishi Sharma and Manuel Feliz Pérez Moreno for excellent comments and feedback during the elaboration of the chapter. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Required citation for this chapter:

Santiago, J., Granado, I., Gee, J., Taconet, M., Kroodsma, D., Miller, N. A., Fernandes, J. A. 2019. FAO Area 71 - AIS-based fishing activity in the Western Central Pacific. *In* Taconet, M., Kroodsma, D., Fernandes, J.A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

Bell, J.D., Allain, V., Gupta, A. S., Johnson, J. E., Hampton, J., Hobday, A., Lehodey, P., Lenton, A., Moore, B.R., Pratchett, M. S., Senina, I., Smith, N., Williams, P. 2018. Chapter 14. Climate change impacts, vulnerabilities and adaptations: Western and Central Pacific Ocean marine fisheries. *In* Barange, M., Bahri, T., Beveridge, M., Cochrane, K., Funge-Smith, S., Poulain, F. (Eds.). *Impacts of Climate Change on fisheries and aquaculture: Synthesis of current knowledge, adaptation and mitigation options.* FAO Fisheries Technical Paper 627. http://www.fao.org/3/i9705en/i9705en.pdf

Brouwer S., Pilling, G., Williams, P., WCPFC Secretariat. 2018. *Trends in the South Pacific Albacore Longline and Troll Fisheries.* Document WCPFC-SC14-2018/ SA-IP-08 Rev. 2. Scientific committee fourteenth regular session. Busan, Republic of Korea, 8-16 August. https://www.wcpfc.int/file/217890/download?token=DTjw3Rnl

Clark, S. 2017. *Purse Seine Fishing Activity in PNA Waters.* Document WCPFC-SC13-2017/ ST-IP-12. Scientific committee Thirteenth Regular Session. Rarotonga, Cook Islands 9 – 17 August 2017. https://www.wcpfc.int/file/215189/download?token=oZvrUnhb

FAO. 2005. *Food and Agriculture Organization of the United Nations. Review of the state of world marine fishery resources.* FAO Fisheries Technical Paper No. 457. Rome, FAO. http://www.fao.org/3/y5852e/y5852e00.htm

FAO. 2019. *Food and Agriculture Organization of the United Nations. FAO Major Fishing Areas. Wester Central Pacific (Major Fishing Area 71).* http://www.fao.org/fishery/area/Area71/en

FishStatJ. 2018. Fisheries and aquaculture software. FishStatJ - software for fishery statistical time series. *In* FAO Fisheries and Aquaculture Department *[online].* Rome. Updated 21 July 2018. [Cited 19 November 2018]. http://www.fao.org/fishery/statistics/software/fishstatj/en

Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F.,... & Woods, P. 2018. Tracking the global footprint of fisheries. *Science*, 359(6378), 904-908. https://doi.org/10.1126/science.aao5646

Murua, J., Itano, D., Widodo, A. 2018. *Characterizing small and medium scale tuna purse seine and ring net vessels in Indonesia.* ISSF Technical Report 2018-06. International Seafood Sustainability Foundation, Washington, D.C., USA. https://iss-foundation.org/downloads/16557/

Watson, R. A. 2017. A database of global marine commercial, small-scale, illegal and unreported fisheries catch 1950–2014. *Scientific data*, 4, 170039. https://doi.org/10.1038/sdata.2017.39

Williams and Terawasi, 2015. *Overview of tuna fisheries in the western and central Pacific Ocean, including economic conditions - 2014.* Document WCPFC-SC11–2014/GN WP-1. Scientific committee eleventh regular session. Pohnpei, Federated States of Micronesia, 5-13 August. https://www.wcpfc.int/file/31812/download?token=xXKUyD-e

Williams, P. and Reid, C. 2018. *Overview of Tuna Fisheries in the Western and Central Pacific Ocean, including Economic Conditions - 2017.* Document WCPFC-SC14-2018/GN-WP-01. Scientific committee Fourteenth Regular Session. Busan, Republic of Korea 8-16 August 2018. https://www.wcpfc.int/node/30231/zip

FAO AREA 77

AIS-based fishing activity in the Eastern Central Pacific

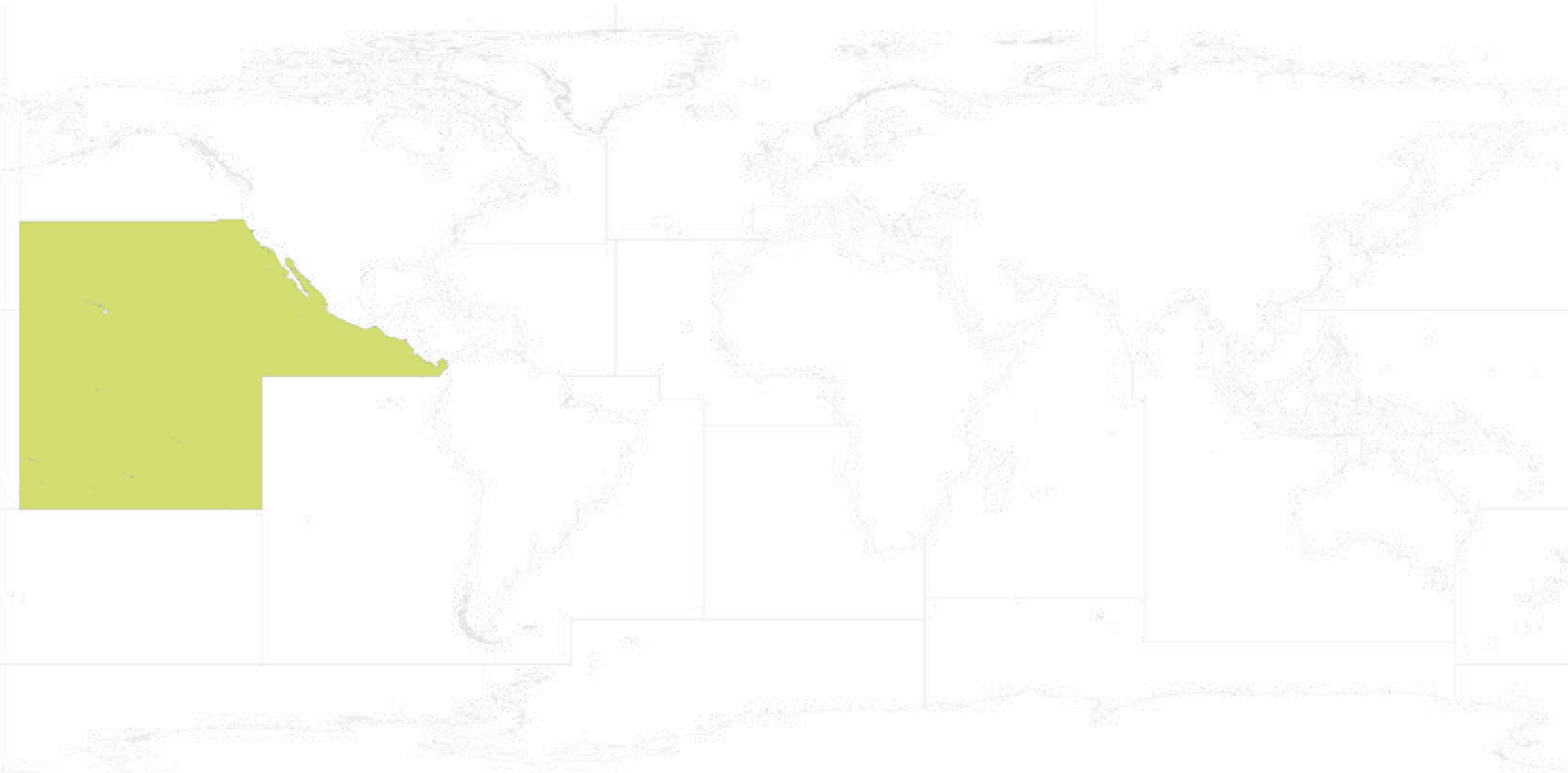


Figure 77. 1. Location of FAO Area 77.

Josu Santiago, Igor Granado, David Kroodsma, Nathan A. Miller, Marc Taconet and Jose A. Fernandes

PREAMBLE

This chapter assesses, through a comparison with fleet statistics and public fisheries data, the capacity of Automatic Identification System (AIS) data and Global Fishing Watch (GFW) algorithms (Kroodsma *et al.*, 2018) to identify and quantify fishing vessel activity in the Eastern Central Pacific. This assesment reviews fleet activity, main gear types, and spatial distribution of vessel activity and fishing operations.

SUMMARY AND CONCLUSIONS FOR THE EASTERN CENTRAL PACIFIC

AIS use in the area was relatively low for Mexico and Central America due to the high proportion of domestic near-shore small scale fishing fleets, but high for the United States of America and the distant water fleets. AIS reception was excellent for Class A AIS devices across the entire area. Class B AIS device reception performed poorly in the southern half of the area near coastal areas. The spatial distribution patterns of fishing activity by longliners and purse seiners was well captured by AIS data. However, fishing intensity was overrepresented for longliners in relation to other gears activity and underrepresented for purse seiners. This was partly because almost no coastal purse seiner vessels broadcast AIS signal. Fishing activity by squid jiggers and set gillnets was also underrepresented by GFW algorithms based on AIS data. AIS-based fishing activity mapped by GFW seemed to be realistic for the high seas, whereas in waters under national jurisdiction both activity and intensity were poorly reflected due to the low use of AIS.

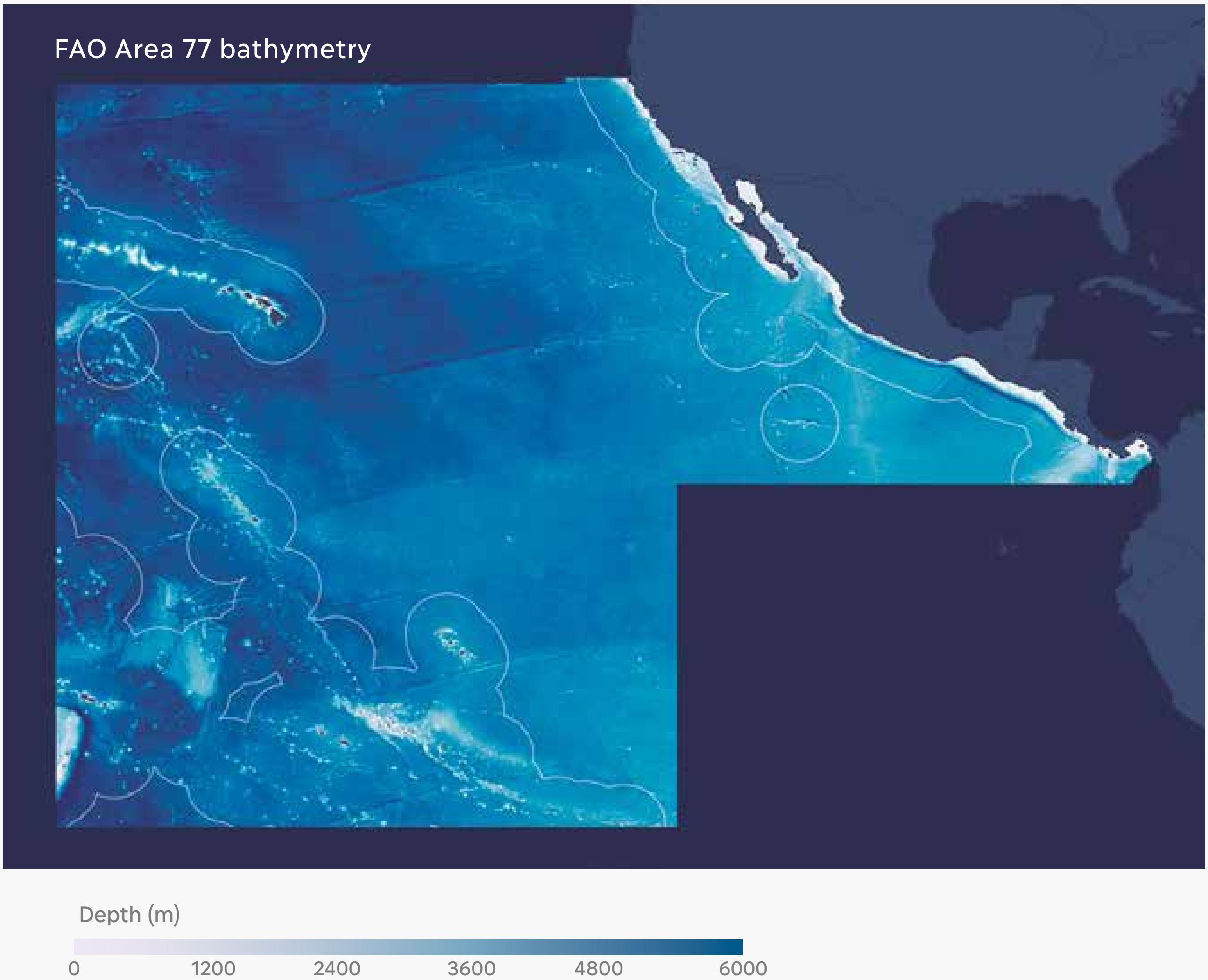


Figure 77. 2. FAO Area 77 bathymetry (depth) and 200 miles coastal arc.

INTRODUCTION FOR THE EASTERN CENTRAL PACIFIC

Eastern Central Pacific (FAO Area 77) compromises marine waters bounded by longitude 130° W in the west, 40°30'N latitude in the north, and 25° S and 5° N latitude in the south (Figure 77. 1). The following coastal countries/territories border FAO Area 77: American Samoa, Cook Islands, Costa Rica, El Salvador, French Polynesia, Guatemala, Honduras, Kiribati, Mexico, Nicaragua, Niue, Panama, Samoa, Tokelau, Tonga, United States of America Minor Outlying Islands and United States Minor Outlying Islands (Figure 77. 2). In this area, about 37 percent of the marine waters are under national jurisdiction while 63 percent are in the high seas. This proportion of high seas is higher than the average for FAO areas (54.2 percent). FAO Area 77 falls into the convention areas of at least four different regional fisheries management organizations (RFMOs): the North Pacific Fisheries Commission (NPFC), the Western and Central Pacific Fisheries Commission (WCPFC), the Inter-American Tropical Tuna Commission (IATTC), and the South Pacific Regional Fisheries Management Organisation (SPRFMO).

Most of the continental shelf is narrow and fairly steep (Figure 77. 2), with the bottom reaching extreme ocean depths very near the coast (FAO, 2005). The area is strongly affected by the El Niño-Southern Oscillation (ENSO). The Humboldt Current System and the California Current System are important for upwelling and therefore also important for the fisheries in the area (Lluch-Cota *et al.*, 2018). The Eastern Central Pacific has shown a typical oscillating pattern in its catches since the 1980s and produced about 2.1 million tonnes in 2013. The most abundant species in this area are California pilchard (*Sardinops caeruleus*), Pacific anchoveta (*Cetengraulis mysticetus*), and yellowfin tuna (*Thunnus albacares*) (FAO, 2016).

REGION FLEETS AND AIS USE IN THE EASTERN CENTRAL PACIFIC

Regional fleets in FAO Area 77 showed that vessels over 24 m, the most likely to use AIS, were a small fraction (0.8 percent) of the vessels in this area (Figure 77. 3). Instead, vessels between 12 and 24 m were a significant proportion (16.7 percent), but not all of them are required to use AIS. The small motorized vessels <12 m constituted the largest proportion (58.6 percent) but this segment was not using AIS. Note that non-motorized vessels (10.5 percent) were only a third of the global average of 34 percent (based on SOFIA, 2016).

Fleets of coastal countries/territories in FAO Area 77

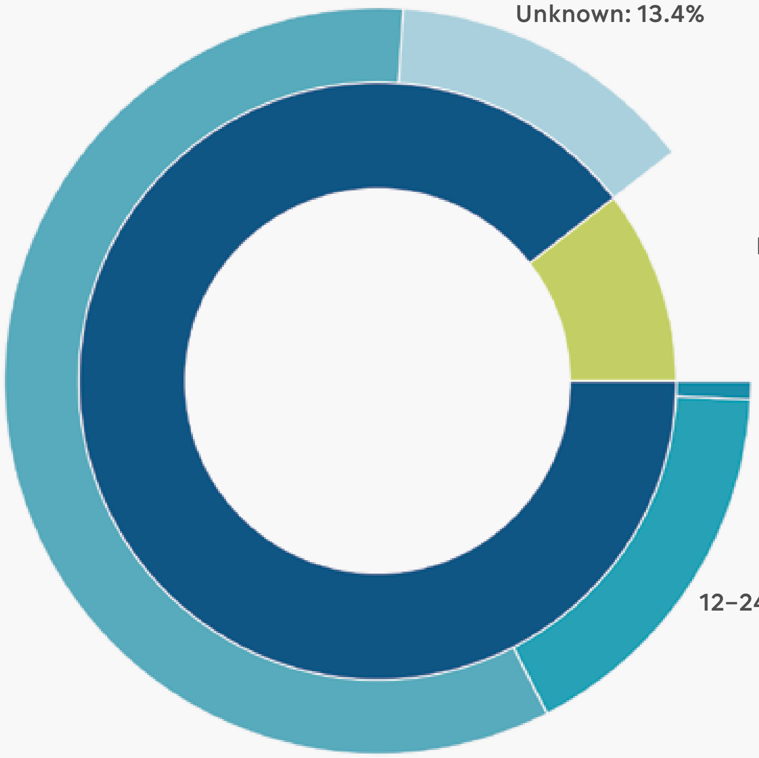


Figure 77. 3. Structural composition of fleets of coastal countries/territories in FAO Area 77. In dark blue motorized fishing vessels and in green non-motorized. Distant water fleets active in FAO Area 77 are not included (see next figure). Notice that Mexico, United States of America, Honduras, Nicaragua, Panama, Guatemala and Costa Rica are coastal states bordering more than one FAO area, yet their entire fleet size is included here. Source: FAO statistics for 2017. Statistics were not available for the following territories and states: Niue, Samoa, Tokelau and United States of America Minor Outlying Islands.

AIS use in the region's coastal fleets is relatively low. Almost all vessels from the United States of America larger than 24 m are equipped with an AIS device. However, only a few vessels from Mexico broadcasted AIS data and almost no vessels from other countries/territories do (Figure 77. 4). As a result, AIS was not very informative in assessments of the demersal fisheries in this area, except for some limited use in coastal Mexico. In oceanic areas in the eastern part of the area, AIS use was much higher. For instance, although Mexico has less than 20 percent of its vessels over 24 m with AIS, Sala *et al.* (2018) estimated that about 75 percent of Mexico's high seas purse seiner fleet broadcasts AIS. Sala *et al.* (2018) also estimated that more than 80 percent of the active high seas fleet was broadcasting AIS. Because the area has a significant proportion of waters in the high seas, and the high seas use of AIS is quite good, high seas fleets from outside the area dominated the AIS data. Apart from the United States of America, most vessels operating in the area that broadcasted AIS were not coastal states (Figure 77.4b). Many of these vessels appeared on RFMO vessel registries and could be identified. Out of 1 060 fishing vessels operating in the area and broadcasting AIS, 912 were matched to registries, and 812 had gear types identified on these registries.

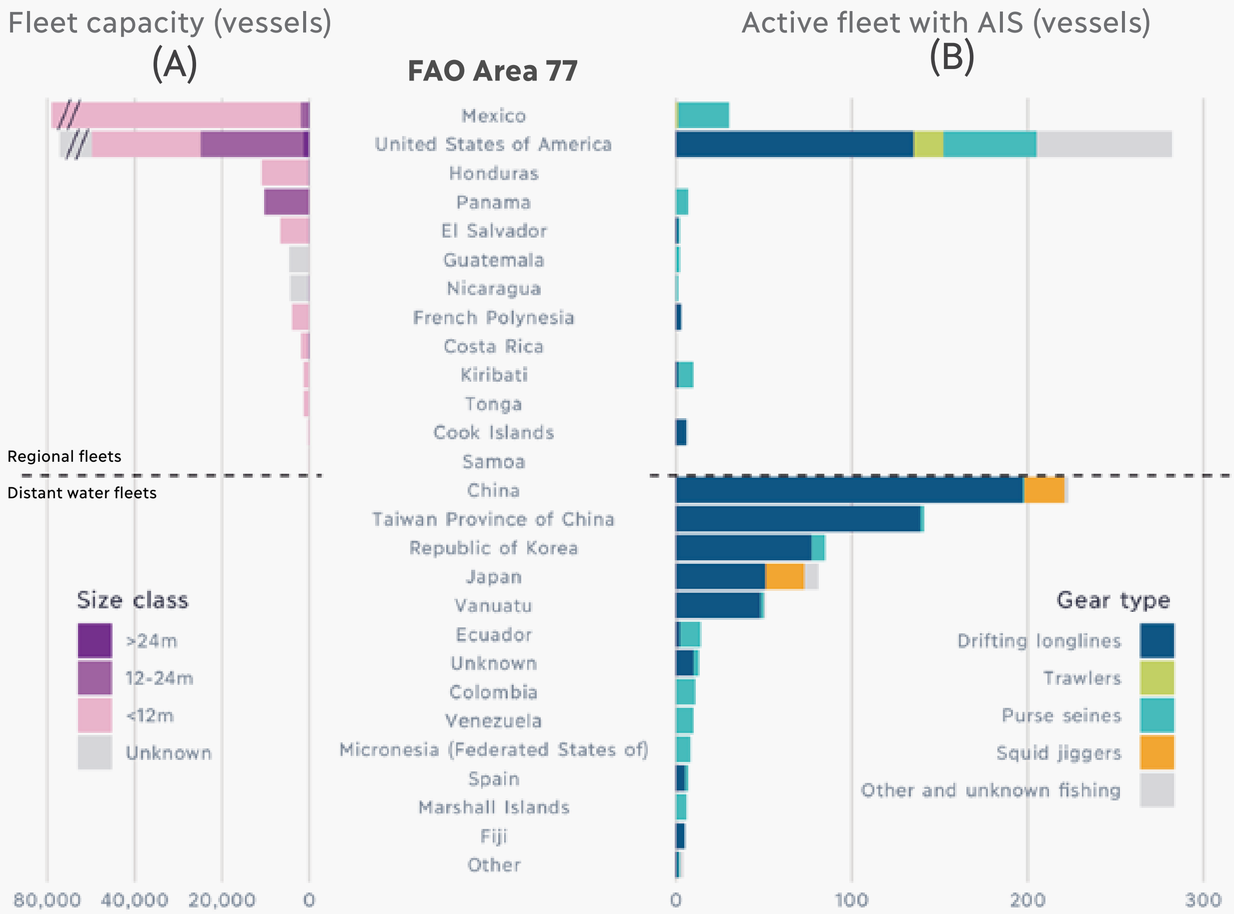


Figure 77. 4. Summary of coastal and distant fleets based on FAO statistics and AIS data classification by GFW in FAO Area 77 during 2017. A) Number of motorized vessels as reported to FAO (left panel). The entire coastal fleets are displayed, even though several countries and territories border more than one FAO area (Mexico, United States of America, Honduras, Nicaragua, Panama, Guatemala and Costa Rica). Source: FAO statistics. B) AIS-identified number of fishing vessels broadcasting AIS during their operations in FAO Area 77 by gear type and flag state (right panel). Dashed lines separate regional fleets (top) from distant fleets (bottom). Only vessels that fished for at least 24 hours in the area are included. "Unknown" means that the vessel was broadcasting an invalid MMSI number that could not be matched to a flag state.

AIS RECEPTION AND FISHING VESSEL ACTIVITY IN THE EASTERN CENTRAL PACIFIC

Figures 77. 5a,b show presence of all fishing vessel activity captured by AIS in FAO Area 77 (Class A and Class B AIS devices). AIS reception was excellent for Class A AIS devices across the entire area (Figure 77. 5c), whereas reception of Class B AIS devices was poorer (Figure 77. 5d). The use of Class B devices was far more common, with about two thirds of the vessels in the area broadcasting Class B messages, although the fraction varied by fleet. Unlike elsewhere in the United States of America, the Hawaiian longline fleet (most of the detections near Hawaii) used exclusively Class B AIS devices. Instead, the coastal fleets of Central America use only Class A AIS devices. The fleets in the southern parts of the area use a mix of both types of AIS devices.

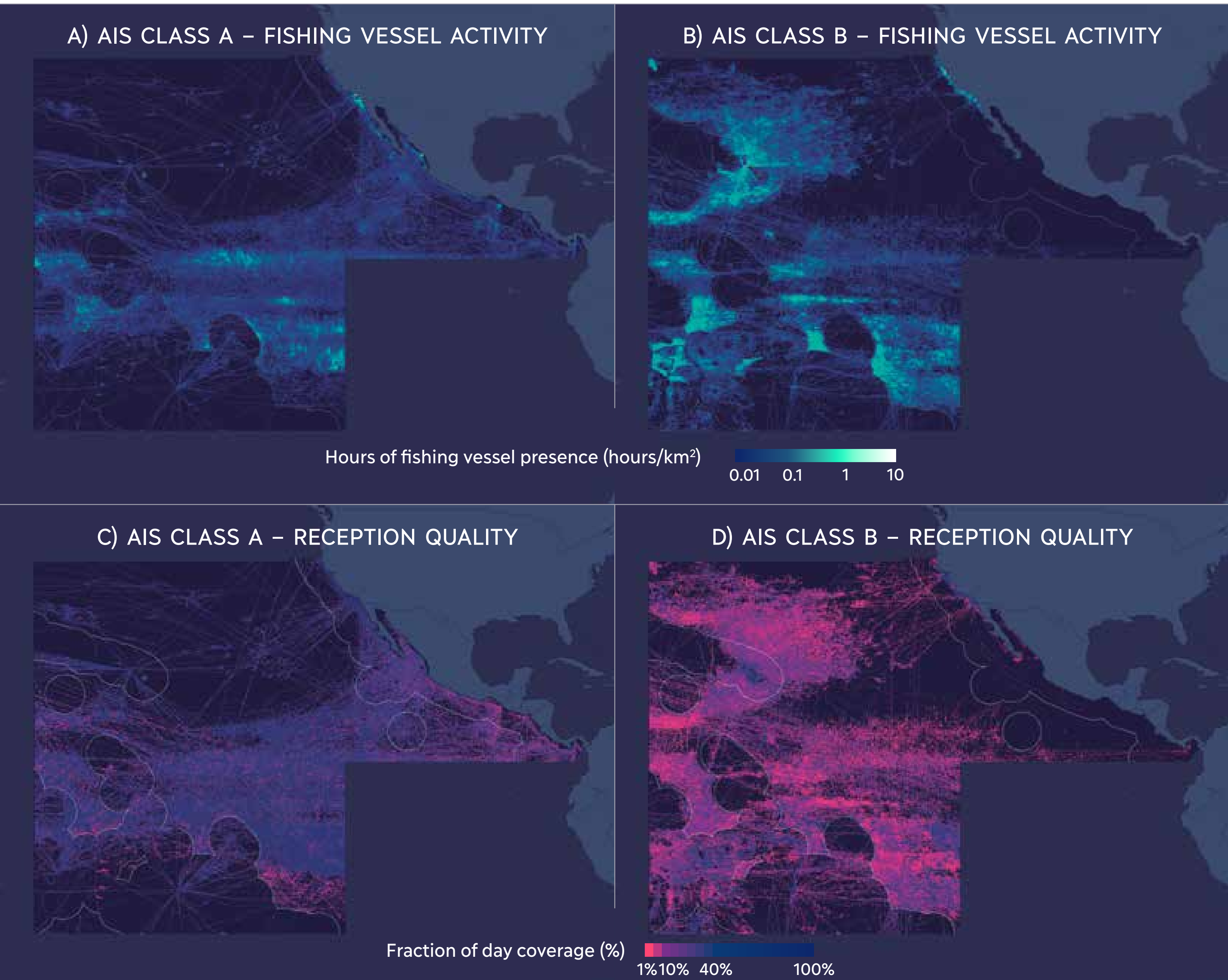
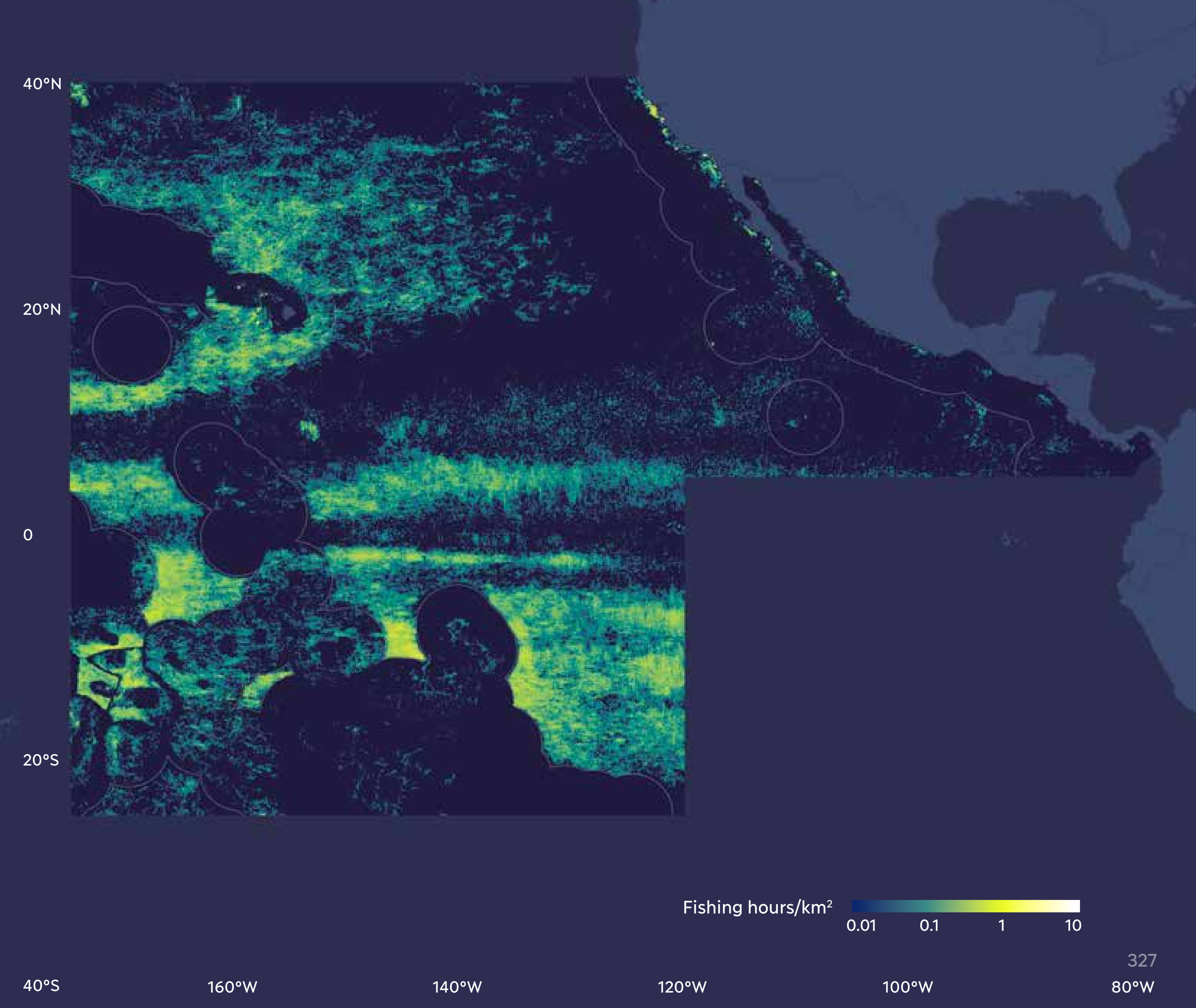


Figure 77. 5. Fishing vessel activity and quality of AIS reception for FAO Area 77 during 2017 without discriminating between different activities (e.g. fishing, searching, in transit). Top row shows activity of vessels broadcasting using Class A devices (left panel) and Class B devices (right panel). The bottom row shows reception quality maps for devices Class A (left panel) and B (right panel). Blank spaces on the map (i.e. dark blue ocean background) mean that no signals from fishing vessels in this area were received, which is due to either no vessel activity or poor reception.

Fishing operations mapped by Global Fishing Watch based on AIS (Figure 77. 6) seemed to be realistic for the high seas except in the center of the FAO area, where much of the purse seiners' activity was missing. However, the activity and intensity of fishing in waters under national jurisdiction along the American continent were poorly reflected by AIS due to the smaller vessel size, associated with lower use of AIS. In general, coastal activity was very poorly represented by AIS data in the area, while the high seas had relatively good coverage. Use of AIS in the national waters of the island countries/territories was variable. For example, in Hawaii, most fishing activity detected by AIS was longliner activity undertaken within the EEZ but clearly outside of an inner perimeter around the island whereas other gear fishing activity was poorly detected by AIS. In Kiribati and the Cook Islands, non-significant activity was recorded by AIS satellites. In French Polynesia, detected activity was very scattered.

Figure 77. 6. The intensity of fishing operations based on AIS data for FAO Area 77 during 2017.



FISHING VESSEL ACTIVITY AND OPERATIONS BY GEARS IN THE EASTERN CENTRAL PACIFIC

This section reviews the spatial distribution patterns in FAO Area 77 of the main fishing gears as estimated by Global Fishing Watch (GFW) based on 2017 AIS data. The most recent datasets available as of mid-2018 were used to assess GFW capacity to provide an AIS based footprint of fishing activity by fishing gear in terms of presence/absence, intensity and hotspots. The Introduction chapter describes the rationale and challenges for use of contrasting data sources (e.g. Global Fisheries Landings database (GFLD; Watson, 2017)) for benchmarking AIS data classification.

Trawler activity, which is one of the most important gears in the area (Victorero *et al.*, 2018), was poorly captured in the AIS data (Table 77. I). Similarly, purse seiners along the coastlines catching important small pelagic species quantities such as California pilchard and Pacific anchoveta were also poorly represented in AIS data. Moreover, WCPFC (2018) reported that bigeye, yellowfin and albacore tuna catches accounted for 214 348 tonnes during 2017, over double the catches reported by GFLD for drifting longliners during 2014. Catches of tuna and tuna-like species in the Eastern Pacific for 2014-2017 were dominated by purse seiners, which were responsible for 88 percent of catches. Longliners only accounted for 9 percent, and all other gears were 3 percent (IATTC, 2018). Skipjack and yellowfin were the top captured species in the area, which are the principal targets of tuna purse seiners. These facts confirm that purse seiner activity was underrepresented in relation to longliners which were overrepresented in AIS data.

GEAR TYPES	Catches (GFLD) 2010–2014 average		Total fishing vessel activity (GFW-AIS) 2017	
	Tonnes of catch in 1000s	% of catch	Active days in 1000s	% of active days
Purse seines	1 057	56%	15.6	12%
Trawls	290	15%	1.6	1%
Squid jigger	126	7%	0.7	1%
Set gillnets	106	6%	5.4	4%
Other	218	11%		
Drifting longlines	100	5%	110.4	83%
Total	1 899	100%	133.7	100%

Table 77. I. Summary table comparing average catch from GFLD during 2010–2014 with fishing vessel activity from GFW in FAO Area 77. Only vessels that fished for at least 24 hours in FAO Area 77 are included.

The spatial pattern of longliner fishing activity and areas of highest intensity targeting tuna and swordfish in the high seas were well captured by AIS (Figure 77. 7). There was good agreement between GFLD distribution and AIS distribution except in national jurisdictions where AIS use was low, likely associated with the higher concentration of smaller vessels without AIS. The United States of America fleet concentrated in the north. Chinese activity has been increasing in the last five years (IATTC, 2018). The main species targeted by longliners were albacore, bigeye, yellowfin, swordfish and billfishes. There were two types of tuna longline vessels: ice fresh tuna longliners, including those targeting albacore, and deep-frozen tuna longliners targeting bigeye as the main species. They operate mainly in the high seas and to a lesser extent in the EEZs of Pacific Island Countries. In the case of the French Polynesian EEZ, there has been no fishing agreement inside the EEZ for foreign fleets since 2001 (WCPFC, 2018b). The limited AIS activity shown in French Polynesian waters corresponded to the local longliner fleet. Long distance foreign fleets also do not operate in the United States of America Pacific Islands EEZs.

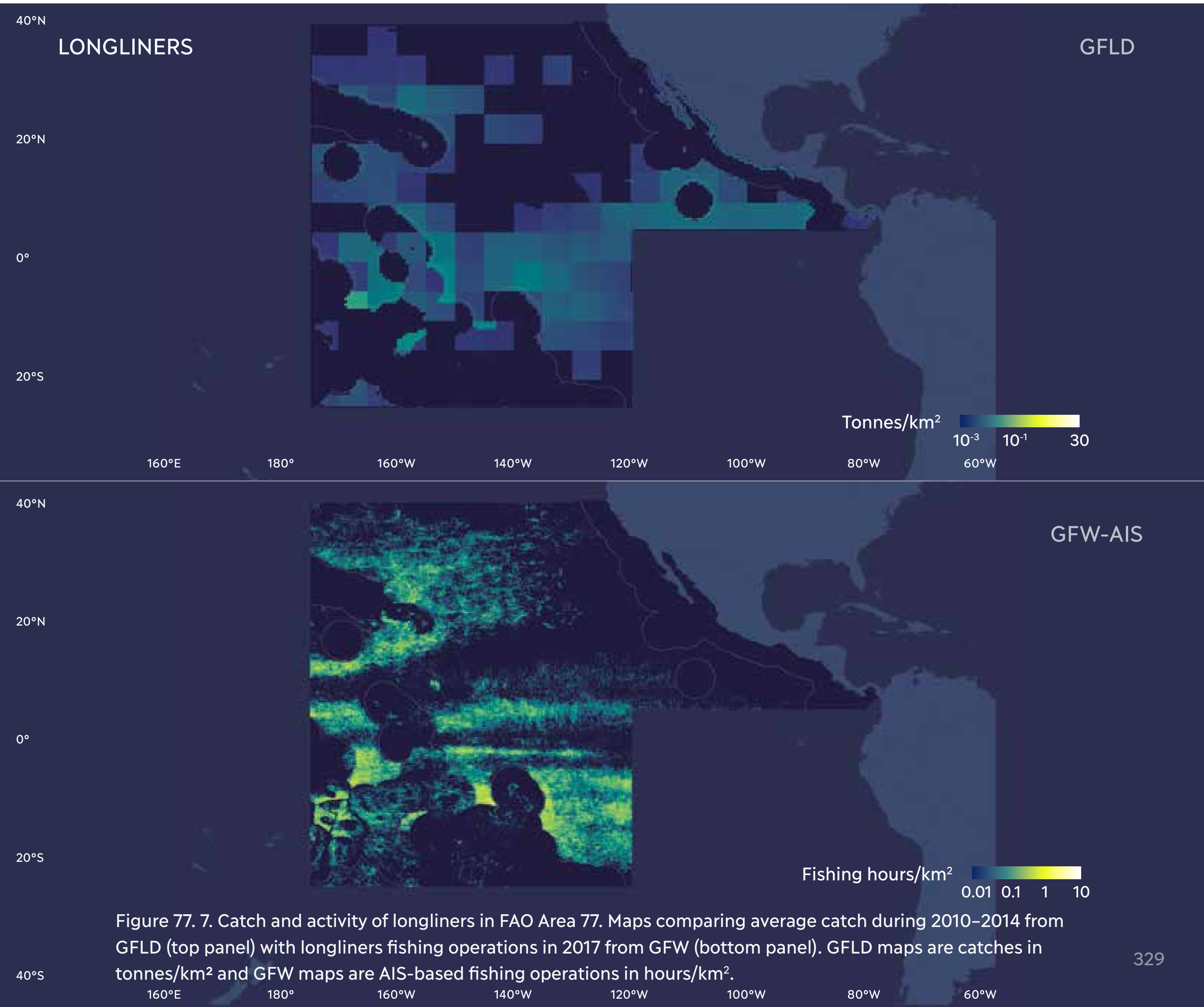


Figure 77. 7. Catch and activity of longliners in FAO Area 77. Maps comparing average catch during 2010–2014 from GFLD (top panel) with longliners fishing operations in 2017 from GFW (bottom panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

The GFW-AIS distribution of purse seiner activity was well captured (Figure 77. 8) but underrepresented in relation to longliner activity. Compared with IATTC 2018 data, purse seiner fishing activity derived from AIS was quite coherent. Most purse seiner activity north of 10º N likely corresponded to dolphin-tuna sets, whereas patterns shown south of the Equator were mainly related to fish aggregating device (FAD) sets. The IATTC established a total annual catch limit for yellowfin and bigeye (combined) caught by capacity class 4, 5, and 6 purse-seiners of 97 711 t for the fishery on floating objects, and 162 182 tonnes on dolphin sets by class-6 vessels (Resolution C-17-01).

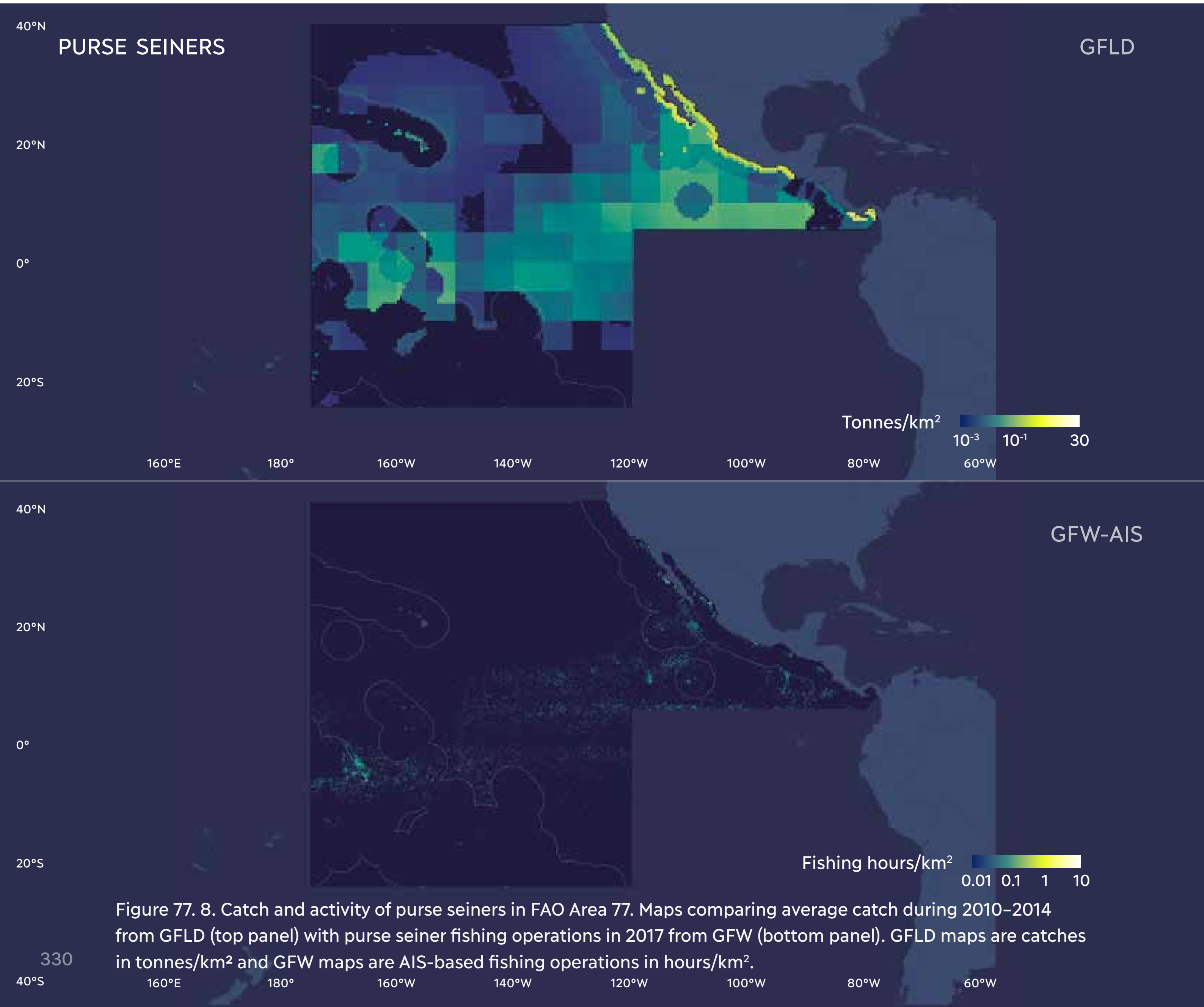


Figure 77. 8. Catch and activity of purse seiners in FAO Area 77. Maps comparing average catch during 2010–2014 from GFLD (top panel) with purse seiner fishing operations in 2017 from GFW (bottom panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

Purse seiner fishing activity showed a marked seasonal pattern associated with the closure periods for purse seiners over 182 ton carrying capacity established by IATTC conservation and management measures (Figure 77. 9).

Purse seiner fishing activity in FAO Area 77

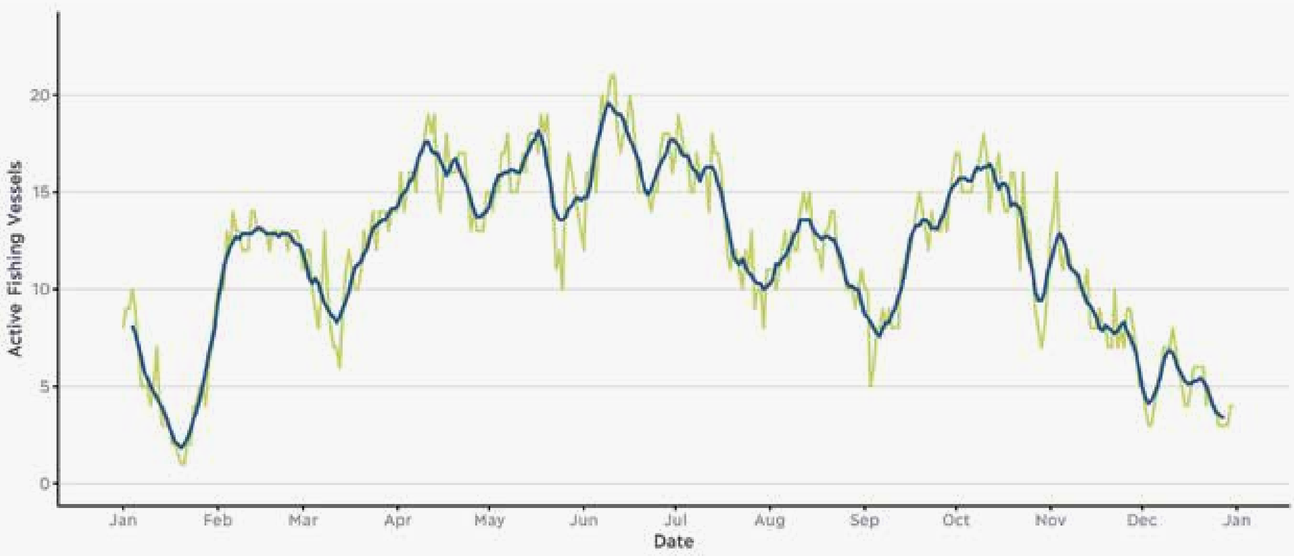


Figure 77. 9. Number of AIS-identified active purse seiner fishing vessels per day in FAO Area 77 during 2017. Only vessels that fished at least 24 hours in the area over the course of the year are included. Dark blue line shows a 7-day rolling average.

ACKNOWLEDGEMENTS

The editors would like to thank Jennifer Gee, Manuel Feliz Pérez Moreno and Carolina Minte-Vera for excellent comments and feedback during the elaboration of the chapter. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Required citation for this chapter:

Santiago, J., Granado, I., Kroodsma, D., Miller, N. A., Taconet, M., Fernandes, J. A. 2019. FAO Area 77 - AIS-based fishing activity in the Eastern Central Pacific. *In* Taconet, M., Kroodsma, D., Fernandes, J.A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

FAO. 2005. *Food and Agriculture Organization of the United Nations. Review of The State of World Marine Fishery Resources.* FAO Fisheries and Aquaculture Technical Paper No. 457. Rome, FAO. http://www.fao.org/3/y5852e/y5852e00.htm

FAO. 2016. *Food and Agriculture Organization of the United Nations. The State of World Fisheries and Aquaculture 2016 (SOFIA). Contributing to food security and nutrition for all.* Rome. http://www.fao.org/3/a-i5555e.pdf

FAO. 2019. *Food and Agriculture Organization of the United Nations. FAO Major Fishing Areas. Eastern Central Pacific (Major Fishing Area 77).* http://www.fao.org/fishery/area/Area77/en

IATTC. 2018. *Inter-American Tropical Tuna Commission. Tunas, billfishes and other pelagic species in the Eastern Pacific Ocean in 2017. 93rd meeting Inter-American Tropical Tuna Commission.* Document IATTC-93-0. San Diego, California (United States of America), 24, 27-30 August 2018. (also available at https://www.iattc.org/Meetings/Meetings2018/IATTC-93/PDFs/Docs/_English/IATTC-93-01_The-fishery-in-2017-and-status-of-the-tuna-and-billfish-stocks.pdf

Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F.,... & Woods, P. 2018. Tracking the global footprint of fisheries. *Science*, 359(6378), 904-908. https://doi.org/10.1126/science.aao5646

Lluch-Cota, S. E., Arreguín-Sánchez, F., Salvadeo, C. J., Luna, P. M. M. 2018. Chapter 10: Climate change impacts, vulnerabilities and adaptations: Northeast Tropical Pacific marine fisheries. *In* Barange, M., Bahri, T., Beveridge, M., Cochrane, K., Funge-Smith, S., Poulain, F. (Eds.). *Impacts of Climate Change on fisheries and aquaculture: Synthesis of current knowledge, adaptation and mitigation options.* FAO Fisheries Technical Paper No. 627. Rome, FAO. http://www.fao.org/3/i9705en/i9705en.pdf

Sala, E., Mayorga, J., Costello, C., Kroodsma, D., Palomares, M. L., Pauly, D., Sumaila, R., & Zeller, D. 2018. The economics of fishing the high seas. *Science advances,* 4(6), eaat2504. http://doi.org/10.1126/sciadv.aat2504

Victorero, L., Watling, L., Deng Palomares, M. L., & Nouvian, C. 2018. Out of sight, but within reach: A Global History of Bottom-Trawled Deep-Sea Fisheries from> 400 m depth. *Frontiers in Marine Science*, 5, 98. https://doi.org/10.3389/fmars.2018.00098

Watson, R. A. 2017. A database of global marine commercial, small-scale, illegal and unreported fisheries catch 1950–2014. *Scientific data*, 4, 170039. https://doi.org/10.1038/sdata.2017.39

WCPFC. 2018a. *Western and Central Pacific Fisheries Commission. Annual report to the Commission. Part 1: information on fisheries, research, and statistics. Fourteenth Regular Session of the Scientific Committee. The Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean.* Document WCPFC-SC14-AR/CCM-07. BUnited States of American, South Korea, 8–16 August 2018. https://www.wcpfc.int/file/216143/download?token=eHxWQ-gA

WCPFC. 2018b. *Western and Central Pacific Fisheries Commission. Annual report to the Commission. Part 1: information on fisheries, research, and statistics. French Polynesia.* Document WCPFC-SC14-AR/CCM-08. BUnited States of American, South Korea, 8–16 August 2018. https://spccfpstore1.blob.core.windows.net/digitallibrary-docs/files/f3/f370bdba09cb41e0e8e89f0eaafd0123.pdf?sv=2015-12-11&sr=b&sig=SYSJoHo8nT7W7mKBQ%2BCPEgySNKakIA%2FA3BdYNqwhZSU%3D&se=2019-11-16T13%3A50%3A09Z&sp=r&rscc=public%2C%20max-age%3D864000%2C%20max-stale%3D86400&rsct=application%2Fpdf&rscd=inline%3B%20filename%3D%22AR_CCM_08_French_Polynesia_Part_1.pdf%22

FAO AREA 81

AIS-based fishing activity in the Southwest Pacific

Figure 81. 1. Location of FAO Area 81.

Iker Zudaire, Josu Santiago, Igor Granado, Marc Taconet, David Kroodsma, Nathan A. Miller and Jose A. Fernandes

PREAMBLE

This chapter assesses, through a comparison with fleet statistics and public fisheries data, the capacity of Automatic Identification System (AIS) data and Global Fishing Watch (GFW) algorithms (Kroodsma *et al.*, 2018) to identify and quantify fishing vessel activity in the Southwest Pacific. This assessment reviews fleet activity, main gear types, and spatial distribution of vessel activity and fishing operations.

SUMMARY AND CONCLUSIONS FOR THE SOUTHWEST PACIFIC

AIS use and reception in this area was relatively high. The exception was reception of Class B devices in the northwestern part of the area. Trawlers and drifting longliners were the most important gears in the area. The trawler industry operating in New Zealand waters appeared well represented in AIS data, but not the demersal activity off Tasmania. Distribution of drifting longliner activity was well represented in AIS in the northern area but missing activity in the central area.

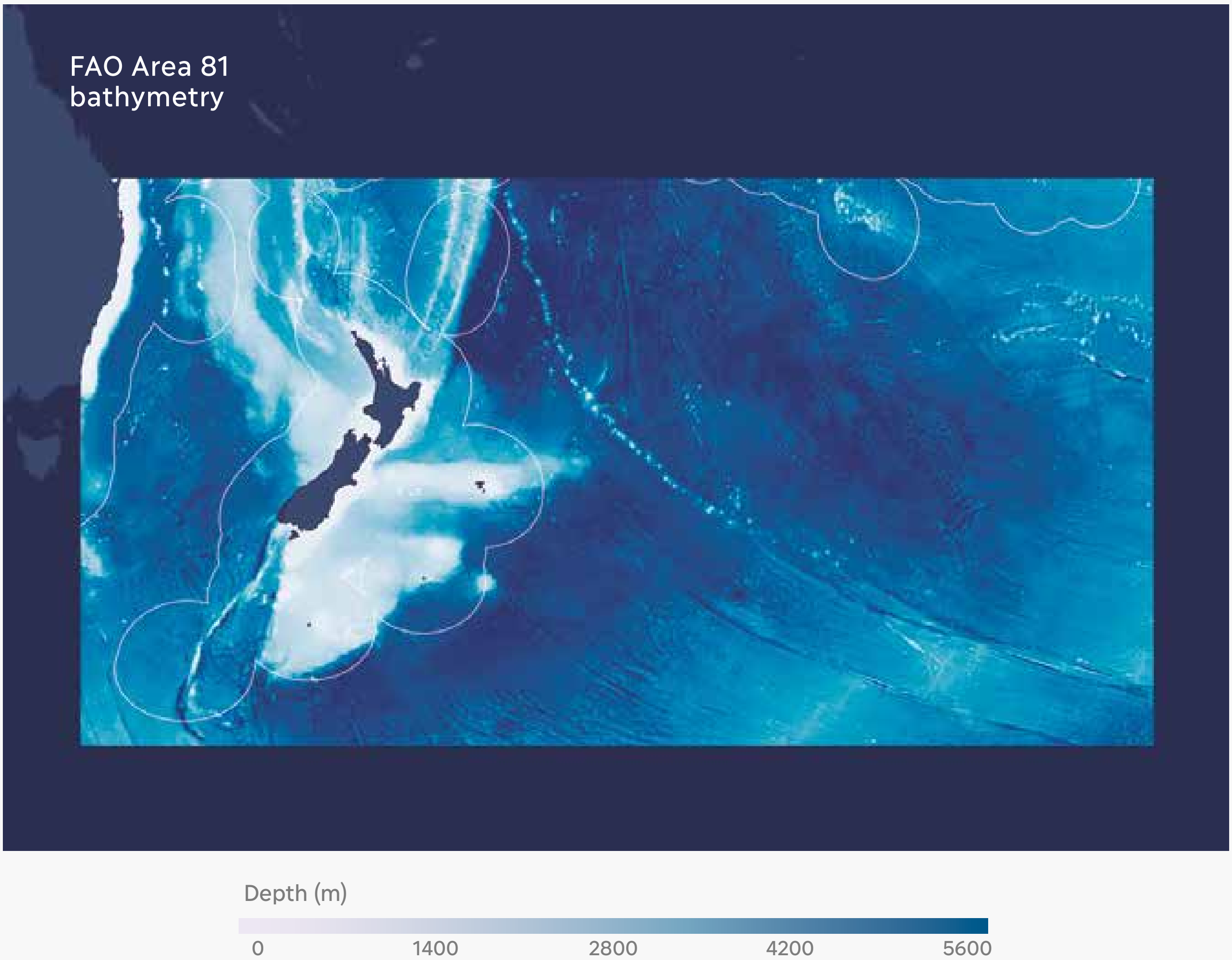


Figure 81. 2. FAO Area 81 bathymetry (depth) and 200 nautical mile arc.

INTRODUCTION FOR THE SOUTHWEST PACIFIC

The Southwest Pacific (FAO Area 81; FAO, 2019) covers all marine waters of the Southwest Pacific bounded by latitudes 25° S to 60° S, and longitudes 150° E to 120° W, and Australia in the northwest (Figure 81. 2). The following coastal countries/territories are within FAO Area 81: Australia, New Zealand, Norfolk Island and Pitcairn. All together, they determine an area under national jurisdiction of 27 percent, while the high seas cover 73 percent, mostly in eastern part, of the total marine waters. This proportion is higher than the FAO areas' average (54 percent) and close to the areas with the highest proportion (FAO areas 47 and 87, with over 80 percent). FAO Area 81 falls into the convention areas of at least two different regional fisheries organizations (RFMOs): the Western and Central Pacific Fisheries Commission (WCPFC) and the South Pacific Regional Fisheries Management Organization (SPRFMO).

The Australian continental shelf is very narrow, whereas New Zealand has a wide continental shelf with large areas of relatively shallow seas extending southeast to the scattered sub Antarctic islands, and northwest as far as tropical New Caledonia; this shelf also extends in the high seas towards Australia. The total surface of the Southwest Pacific, FAO Area 81, is 27.7 million km^2 with only 0.4 million km^2 of continental shelf. The region is mostly deep oceanic water, with many shallower waters close to New Zealand and Australia which include seamounts where bathypelagic fish resources are exploited (FAO, 2011). This area has usually produced the lowest catch volume among all FAO areas (FAO, 2011) and is included among the group of regions showing overall fishing decline following historical peaks (FAO, 2016). Nominal catches increased from less than 50 000 tonnes in 1950 to 917 000 tonnes in 1992 and then gradually declined to 600 000 tonnes in 2009 (FAO, 2011). This decreasing pattern has continued afterwards, in 2014 catches were 543 000 tonnes (FAO, 2016). FAO landings statistics (FishStatJ, 2018) show that in the period from 2010 to 2014, catches were dominated by invertebrate and pelagic fish species. The largest catches were of blue grenadier, jack and horse mackerels, Southern blue whiting, Wellington flying squid, snoek, pink cusk-eel, skipjack tuna, albacore, blue mackerel and southern hake.

REGION FLEETS AND AIS USE IN THE SOUTHWEST PACIFIC

Regional fleets (essentially Australia and New Zealand) in FAO Area 81 showed non-motorized fishing vessels reported to be only 0.3 percent, while motorized under 12 m, which are likely not to have AIS, were close to 50 percent (Figure 81. 3). Motorized vessels over 24 m represented 7.5 percent of the total regional vessels, mostly from New Zealand and Australia (Figure 81. 3). These are data for the coastal states and territories not considering distant water fleets, discussed below (Figure 81. 4). Note that Australia had likely underreported motorized fishing vessel numbers under 12m, many of which may have been classified as recreational. This would mean that the actual fraction of smaller vessels in this region is likely larger than displayed on the chart below.

Fleets of coastal countries/territories in FAO Area 81

Figure 81. 3. Structural composition of fleets of coastal countries/territories in FAO Area 81. In dark blue motorized fishing vessels and in green non-motorized. Distant water fleets active in FAO Area 81 are not included (see Figure 81.4). Notice that Australia is a coastal state bordering three FAO areas (57, 71 and 81). Sources: FAO statistics. Statistics were not available for the following areas: Norfolk Island and Pitcairn.

Based on comparisons with national registries, AIS use by New Zealand and Australia in the region was good for large vessels. Although only a fraction of vessels under 24 m in the region used AIS, it appeared that most vessels larger than this size did broadcast AIS (Figure 81. 4). Similarly, in the high seas, it was estimated that most fishing vessel activity was by vessels using AIS devices (Sala *et al.*, 2018). In this Area, New Zealand had the highest number of vessels

broadcasting AIS, followed by the distant water pelagic fleets of China and Taiwan Province of China, which were mostly drifting longliners. The identity of most vessels with AIS in the region was verified with official vessel registries. Out of 312 presumed fishing vessels, 271 were matched to registries, and the gear type identified in registries for 224 of them. In the past, 20 countries/territories have been involved in fishing in the Southwest Pacific Ocean (FAO, 2011). These include Australia, Canada, China, the Cook Islands, Estonia, Georgia, Japan, the Republic of Korea, Latvia, Lithuania, New Zealand, Norway, Pitcairn Islands, Poland, the Russian Federation, Spain, Taiwan Province of China, Ukraine, the Union of Soviet Socialist Republics and the United States of America. Very few of these are now seen in the AIS data.

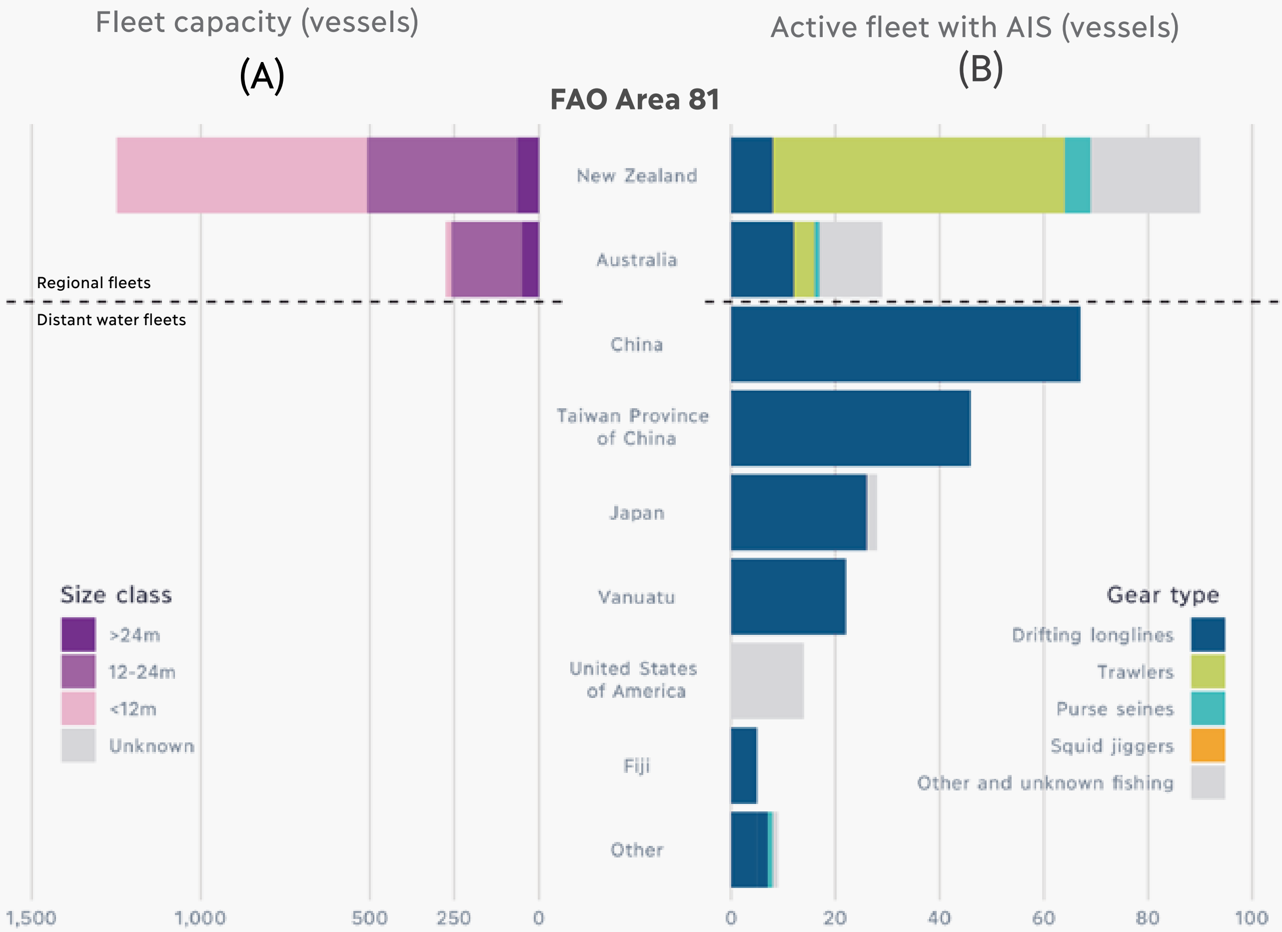


Figure 81. 4 Summary of coastal and distant water fleet based on FAO statistics and AIS data classification by GFW in FAO Area 81 during 2017. A) Number of motorized vessels as reported to FAO (left panel). The entire national fleets for each country/territory are shown, despite some of them not operating in Area 81. For example, Australia includes the fleets operating in FAO areas 57, 71 and 81 since FAO statistics are reported at country/territory level. FAO statistics were not available for Norfolk Island and Pitcairn. B) AIS-identified number of fishing vessels broadcasting AIS during their operations in FAO Area 81 by gear type and flag state (right panel). Dashed lines separate regional fleets (top) from distant fleets (bottom). Only vessels that fished for at least 24 hours in the area are included. Source: GFW.

AIS RECEPTION AND FISHING VESSEL ACTIVITY IN THE SOUTHWEST PACIFIC

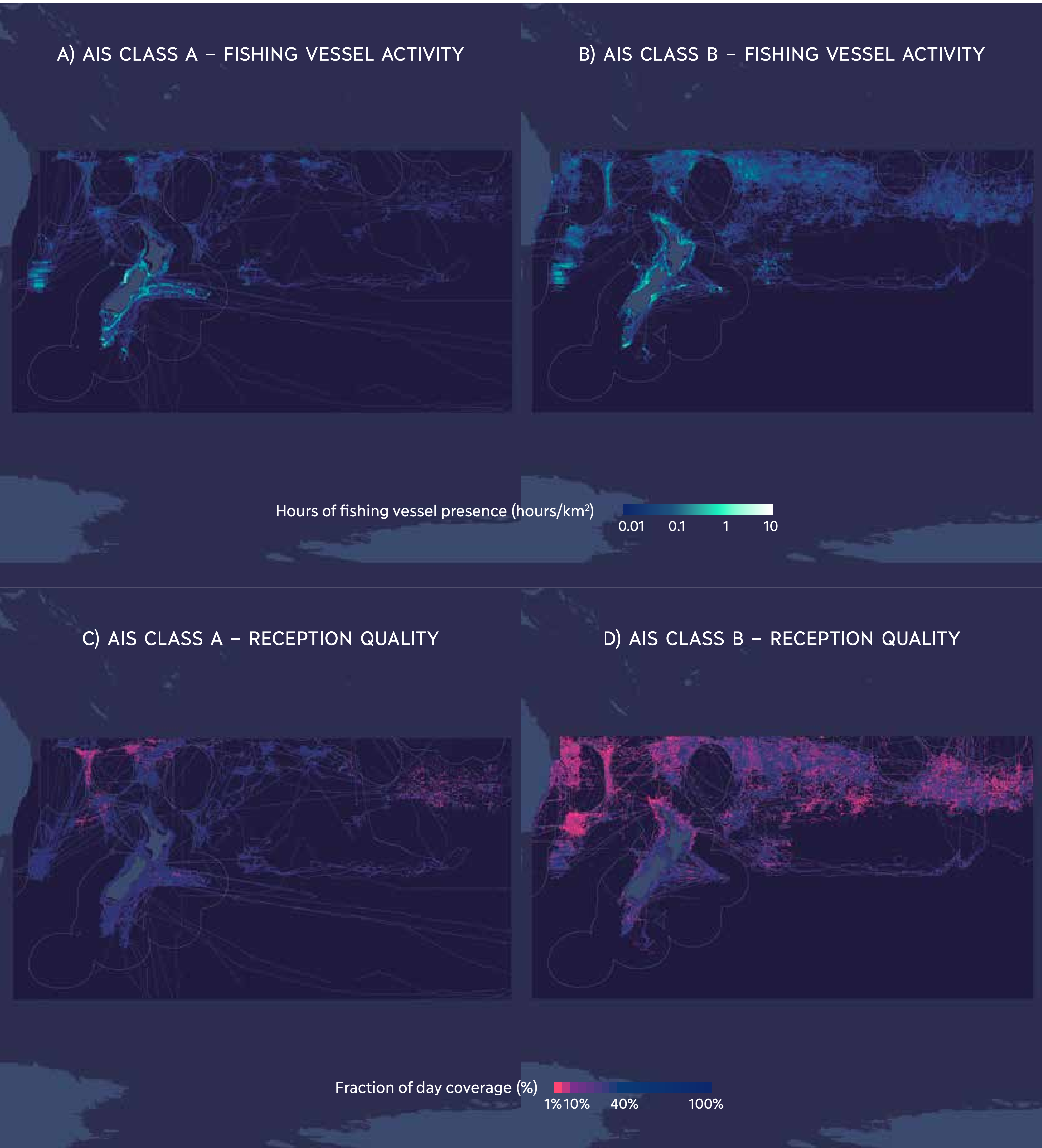
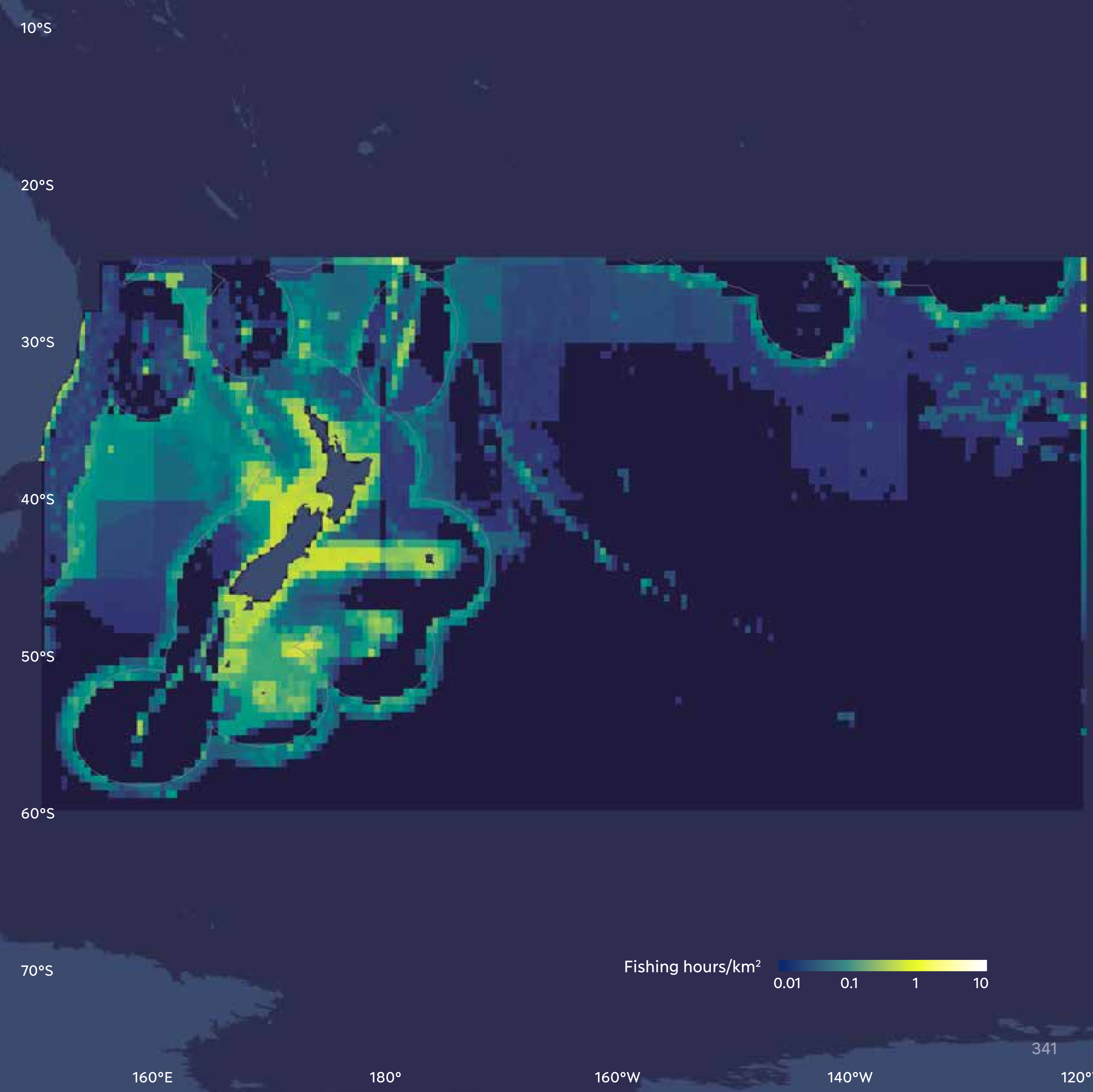


Figure 81. 5. Fishing vessel activity and quality of AIS reception for FAO Area 81 during 2017. Top row shows activity of vessels broadcasting using Class A devices (left panel) and Class B devices (right panel). The bottom row shows reception quality maps for devices Class A (left panel) and B (right panel). Blank spaces on the map (i.e. dark blue ocean background) mean that no signals from fishing vessels in this area were received, which is due to either no vessel activity or poor reception.

Fishing operations seemed to be concentrated in the northern area except in small island territory EEZs likely fished by small vessels without AIS devices. AIS revealed coastal fishing concentrations along the New Zealand coast, while fishing activity was nearly absent off-shore of the New Zealand waters. There was concentration of AIS on the high seas continental shelf between Australia and Norfolk Island and in high seas/open waters in deep seas.

Figure 81. 6. The intensity of fishing operations based on AIS data for FAO Area 81 during 2017.



FISHING VESSEL ACTIVITY AND OPERATIONS BY GEARS IN THE SOUTHWEST PACIFIC

This section reviews the spatial distribution patterns of the main fishing gears in FAO Area 81 as estimated by Global Fishing Watch (GFW) based on 2017 AIS data. The most recent datasets available at mid-2018 were used to assess GFW capacity to provide an AIS based characterization of fishing activity by fishing gear in terms of presence/absence, intensity and hotspots. The Introduction chapter describes the rationale and challenges for use of contrasting data sources (e.g. Global Fisheries Landings database (GFLD; Watson, 2017)) for benchmarking AIS data classification.

When comparing fishing activity (Table 81. I) based on AIS data with the GFLD catches, GFLD identified trawlers as the main activity in FAO Area 81, while AIS had them as the second most important (although some of the "unknown" vessels in AIS may have been trawlers). It appeared that the GFLD was missing significant longliner activity (based on published data by the WCPFC, it would be around 10 percent instead of 4 percent of the catch; WCPFC, 2016). In addition, large-scale pelagic driftnetters and all deep-water gillnetters which usually operate in the high seas were forbidden in the SPRFMO Convention Area since 2013 (SPRFMO CMM 08-2013). This explains discrepancies between GFLD and AIS data in relation to set gillnets, since the fishery after 2013 would tend to use non-AIS required smaller vessels within EEZs. Purse seiners, which appeared to mainly operate in coastal waters, were considered by both sources as marginal gears in this area. The majority were small coastal pelagic seiners. During 2017, New Zealand had 6 offshore pelagic purse seiners registered that operated in the Western Pacific when fishing (WCPFC, 2019).

GEAR TYPES	Catches (GFLD) 2010–2014 average		Total fishing vessel activity (GFW-AIS) 2017	
	Tonnes of catch in 1000s	% of catch	Active days in 1000s	% of active days
Trawls	301	58%	11.8	37%
Other	63	12%		
Set gillnets	57	11%	4.03	13%
Pole and line	39	7%		
Purse seines	31	6%	0.6	2%
Drifting longlines	23	4%	15.6	48%
Total	513	100%	32.4	100%

Table 81. I. Summary table comparing average catch from GFLD during 2010–2014 with fishing vessel activity in 2017 from GFW in FAO Area 81. Only vessels that fished for at least 24 hours in FAO Area 81 are included.

The international water zones were primarily exploited by deep-sea bottom trawl fisheries targeting orange roughy (*Hoplostethus atlanticus*) and alfosino (*Beryx splendens*) (Bensch *et al.*, 2019), with most of the catch reported by New Zealand and Australian vessels (Figure 81. 7). Both GFLD and AIS characterization seemed to represent well the trawler fleet operating on the continental shelf of New Zealand's EEZ targeting blue grenadier (*Macruronus novaezelandiae*), however, they differed when identifying deep water trawling in the high seas. The GFLD suggested that there was trawling activity in the high seas associated with seamounts, most likely targeting orange roughy and alfonsino. However, this activity was minimal, representing less than 1 percent of the area's catch. SPRFMO prohibited bottom fishing activities in the Convention area except for bottom fishing by Members or Cooperating Non-Contracting Parties (CNCP) (SPRFMO CMM 03-2018). It is possible that these vessels were being missed by AIS or that the fishery had less spatial extent than suggested by GFLD, which is likely assigning catches based on depth. By assigning fishing based on depth, GFLD could be showing a higher extent of the activity. AIS seemed to also show sparse trawling activity off the Australian coast.

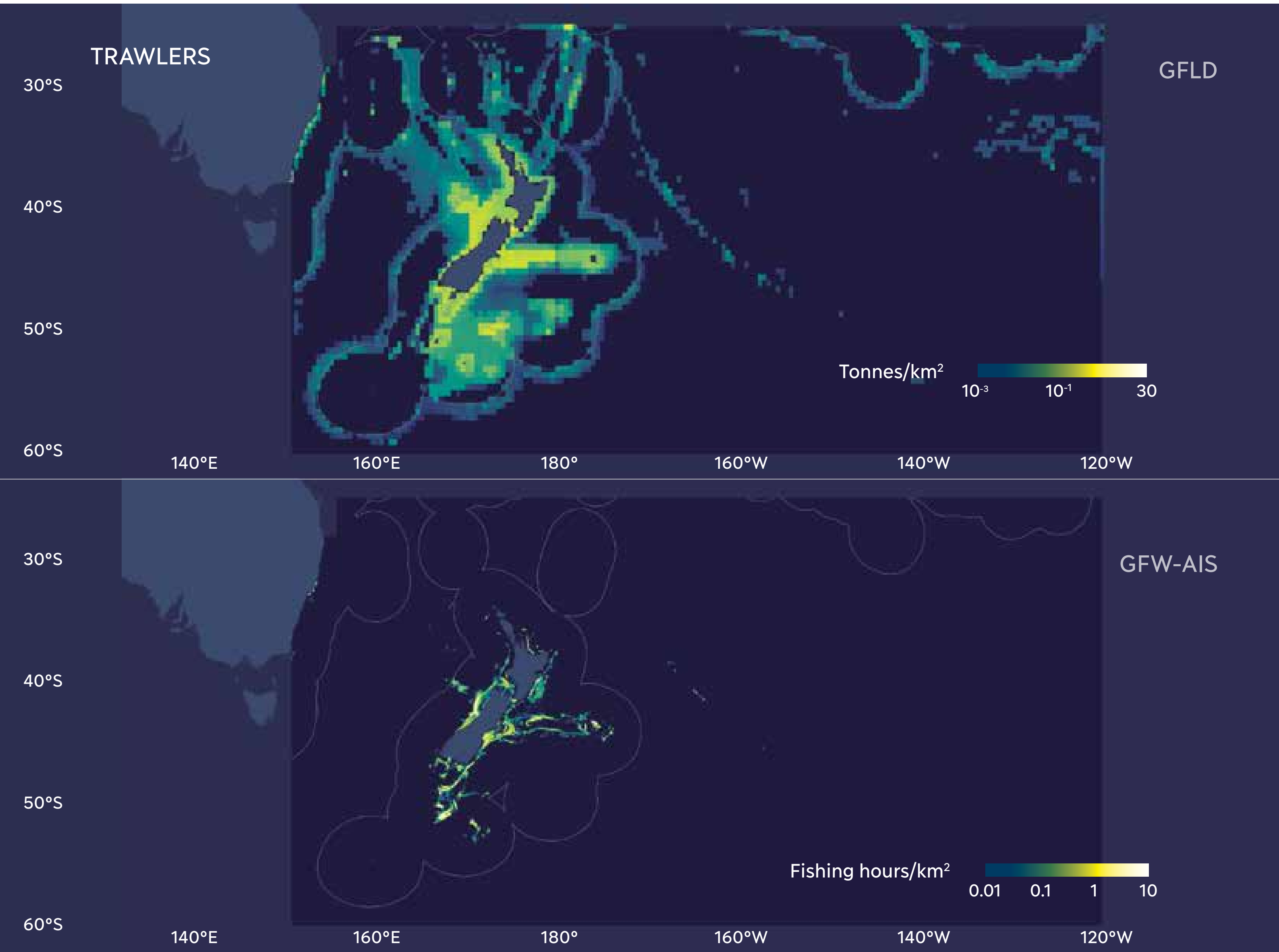


Figure 81. 7. Catch and activity of trawlers in FAO Area 81. Maps comparing average catch during 2010–2014 from GFLD (top panel) with trawlers fishing operations in 2017 from GFW (bottom panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km2.

AIS data shows an extended fishing activity of drifting longliners, essentially in the high seas of the northern part zone. In addition, RFMO catches in the high seas amount to an average of 43 000 tonnes of tuna (mainly albacore tuna - *Thunnus alalunga*), billfish (mainly striped marlin - *Kajikia audax*), and swordfish (*Xiphias gladius*) for the 2010-2016 period (WCPFC, 2016). Therefore, it is very likely that GFLD estimates were too low for this region. In particular, while AIS and GFLD shared similar spatial patterns in the western part of the area, AIS showed that the activity developed much more eastward than suggested by GFLD. However, a recent reconstruction of catch data showed activity in the center of the area, which was missed by GFLD and AIS data (Taconet *et al.*, 2018). Longliner fleets targeting tuna and tuna-like species include the Australian and New Zealand offshore albacore fishery, the distant-water albacore fishery (vessels from Taiwan Province of China, China and Vanuatu), and the relatively new distant-water swordfish fishery that comprises mainly European Union distant water vessels (Williams and Reid, 2018).

Figure 81. 8. Catch and activity of drifting longliners in FAO Area 81. Maps comparing average catch during 2010–2014 from GFLD (top panel) with drifting longliner fishing operations in 2017 from GFW (bottom panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

ACKNOWLEDGEMENTS

The editors would like to thank Sebastian Rodriguez and Andrew Wright for excellent comments and feedback during the elaboration of the chapter. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Required citation for this chapter:

Zudaire, I., Santiago, J., Granado, I., Taconet, M., Kroodsma, D., Miller, N. A., Fernandes, J. A. 2019. FAO Area 81 - AIS-based fishing activity in the Southwest Pacific *In* Taconet, M., Kroodsma, D., Fernandes, J.A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

Bensch, A., Gianni, M., Gréboval, D., Sanders, J., and Hjort, A. 2009. *Worldwide review of bottom fisheries in the high seas.* FAO Fisheries and Aquaculture Technical Paper. No. 522. Rome, FAO. https://www.cbd.int/doc/meetings/mar/soiom-2016-01/other/soiom-2016-01-fao-06-en.pdf

FAO. 2011. *Food and Agriculture Organization of the United Nations. Review of The State of World Marine Fishery Resources.* FAO Fisheries and Aquaculture Technical Paper. No. 569. Rome, FAO. http://www.fao.org/3/i2389e/i2389e.pdf

FAO. 2016. *Food and Agriculture Organization of the United Nations. The State of World Fisheries and Aquaculture 2016 (SOFIA). Contributing to food security and nutrition for all.* Rome. http://www.fao.org/3/a-i5555e.pdf

FAO. 2019. *Food and Agriculture Organization of the United Nations. FAO Major Fishing Areas. Southwest Pacific (Major Fishing Area 81).* http://www.fao.org/fishery/area/Area81/en

FishStatJ. 2018. Fisheries and aquaculture software. FishStatJ - software for fishery statistical time series. *In FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 21 July 2018. [Cited 19 November 2018]. http://www.fao.org/fishery/statistics/software/fishstatj/en

Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F.,... & Woods, P. 2018. Tracking the global footprint of fisheries. *Science*, 359(6378), 904-908. https://doi.org/10.1126/science.aao5646

Sala, E., Mayorga, J., Costello, C., Kroodsma, D., Palomares, M. L., Pauly, D.,... & Zeller, D. 2018. The economics of fishing the high seas. *Science advances*, 4(6), eaat2504. http://doi.org/10.1126/sciadv.aat2504

SPRFMO (CMM 08-2013). *South Pacific Regional Fisheries Management Organisation. Conservation and Management Measure for Gillnets in the SPRFMO Convention Area.* Document CMM 08-2013. The Commission of the South Pacific Regional Fisheries Management Organisation. http://www.sprfmo.int/assets/Fisheries/Conservation-and-Management-Measures/CMM-08-2013-Gillnetting-27Feb17.pdf

SPRFMO (CMM 03-2018). *Conservation and Management Measure for the Management of Bottom Fishing in the SPRFMO Convention Area.* Document CMM 03-2018.The Commission of the South Pacific Regional Fisheries Management Organisation. https://www.sprfmo.int/assets/Fisheries/Conservation-and-Management-Measures/2018-CMMs/CMM-03-2018-Bottom-Fishing-8March2018.pdf

Taconet, P., Chassot, E., Barde, J. 2018. *Global monthly catch of tuna, tuna-like and shark species (1950-2015) aggregated by 1° or 5° squares (IRD level 2) (Version 1) [Data set]. Zenodo.* http://doi.org/10.5281/zenodo.1164128

Watson, R. A. 2017. A database of global marine commercial, small-scale, illegal and unreported fisheries catch 1950–2014. *Scientific data*, 4, 170039. https://doi.org/10.1038/sdata.2017.39

Williams, P., & Reid, C. 2018. *Overview of Tuna Fisheries in the Western and Central Pacific Ocean, including Economic Conditions - 2017.* Document WCPFC-SC14-2018/GN-WP-01. Scientific committee Fourteenth Regular Session. Busan, Republic of Korea 8-16 August 2018. https://www.wcpfc.int/file/217925/download?token=TrYmhwbE

WCPFC (2016. *Western & Central Pacific Fisheries Commission. Tuna Fishery Yearbook 2016.* Oceanic Fisheries Programme, Pacific Community, Noumea, New Caledonia. https://www.wcpfc.int/file/157898/download?token=XjEe_8pa

WCPFC. 2018. *Western & Central Pacific Fisheries Commission. Summary Report. Fourteenth Regular Session of the Scientific Committee.* Document WCPFC-SC14. The Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean. Busan, South Korea, 8-16 August 2018. https://www.wcpfc.int/system/files/WCPFC-SC14-Summary%20Report%20-%2017Nov2018_Rev01-17Feb-19Feb2019%20%28Para183%2C184%20numbering%20fixed%29.docx

WCPFC. 2019. *Western & Central Pacific Fisheries Commission. Tuna Fishery Yearbook 2017.* Oceanic Fisheries Programme, Pacific Community, Noumea, New Caledonia. https://www.wcpfc.int/doc/wcpfc-tuna-fisheries-yearbook-2017

FAO AREA 87

AIS-based fishing activity in the Southeast Pacific

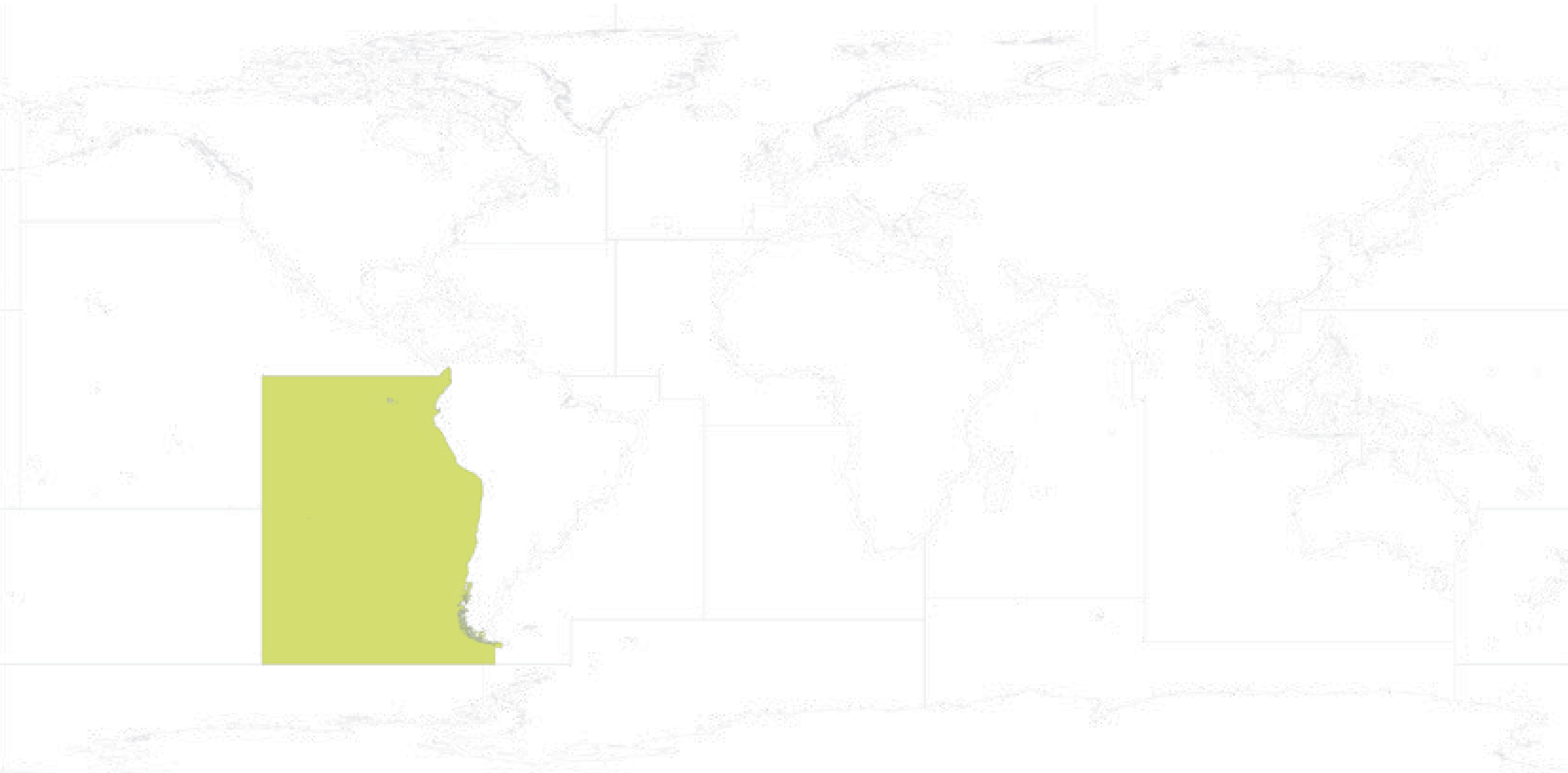


Figure 87. 1. Location of FAO Area 87.

Maitane Grande, Hilario Murua, Igor Granado, David Kroodsma, Nathan A. Miller and Jose A. Fernandes

PREAMBLE

This chapter assesses, through a comparison with fleet statistics and public fisheries data, the capacity of Automatic Identification System (AIS) data and Global Fishing Watch (GFW) algorithms (Kroodsma *et al.*, 2018) to identify and quantify fishing vessel activity in the Southeast Pacific. This assessment reviews fleet activity, main gear types, and spatial distribution of vessel activity and fishing operations.

SUMMARY AND CONCLUSIONS FOR THE SOUTHEAST PACIFIC

AIS use is good in the high seas, especially for distant water fleets, but low in the coastal regions. Class A reception is good across the region, while Class B performs well except for vessels operating just outside the South American EEZs. Coastal AIS data, including the highly productive Peruvian fleet fishing anchoveta, is poorly represented in the AIS data. In contrast, high seas fishing, especially by squid jiggers, is well represented. Drifting longliners are also better captured than other gears, while purse seiners for tropical tunas are underestimated by AIS. The most important fishing activity in the area, purse seiners for anchoveta and other small pelagic species, are mainly distributed in Peruvian and Chilean EEZs, while purse seiner and drifting longliner activity for tunas and squid jiggers are distributed both in EEZs and on the high seas.

Figure 87.2 FAO Area 87 bathymetry (depth) and 200 miles coastal arc.

INTRODUCTION FOR THE SOUTHEAST PACIFIC

The Southeast Pacific (FAO Area 87; FAO, 2019) encompasses all marine waters bounded by the western coast of South America, ranging from the north of Colombia to south of Chile (Figure 87. 1). The following coastal countries/territories are within FAO Area 87: Chile, Colombia, Ecuador and Peru (Figure 87. 2). In this region, 20 percent of the marine waters are within national jurisdiction, leaving 80 percent in the high seas. This proportion of high seas is the highest of all the FAO areas (average is 54 percent). FAO Area 87 falls into the convention areas of at least four different regional fisheries management organizations (RFMOs): the North Pacific Fisheries Commission (NPFC), the Western and Central Pacific Fisheries Commission (WCPFC), the Inter-American Tropical Tuna Commission (IATTC), and the South Pacific Regional Fisheries Management Organisation (SPRFMO).

Throughout most of FAO Area 87, the continental shelf is narrow and with a steep slope, with most areas suitable for pelagic fisheries. Areas suitable for bottom trawling are off northern Colombia, Ecuador, northern Peru, and central and southern Chile where the continental shelf is broader (FAO, 2011). The coastal area is dominated by the Humboldt–Peru eastern boundary current system with a seasonal upwelling impacting the productivity, with Peru and northern Chile being among the world's most productive areas. Large environmental fluctuation brought by ENSO affects the fish stock productivity in the region (FAO, 2011). As a result, species volume and composition, as well as fishing effort, experience large seasonal and interannual variations (FAO, 2011). The main fisheries are coastal small pelagics dominated by anchoveta (*Engraulis ringens*), which is responsible for the largest catches in the world (3.6 million tonnes in 2015) (FAO, 2016). This resource comprises three stocks (north-central Peru stock, southern Peru stock, central-southern Chile stock) and catches come mostly from the north-central stock, with fisheries managed through a maximum catch limit per vessel system in Peru (Yonashiro and Baldín, 2016; IMARPE, 2017). Jack mackerel (*Trachurus murphyi*) is another heavily harvested species with catches around 400 000 tonnes in 2017 (SPRFMO, 2018). The Chilean jack mackerel is widespread throughout the South Pacific, along the shelf and oceanic waters adjacent to Ecuador, Peru, and Chile, and across the South Pacific along the Subtropical Convergence Zone. This has been described as the “jack mackerel belt” that goes from the coast of Chile to New Zealand within a 35° to 50° S latitude band across the South Pacific (SPRFMO, 2018b).

REGION FLEETS AND AIS USE IN THE SOUTHEAST PACIFIC

Over 75 percent of regional coastal state and territory fleets in FAO Area 87 were motorized vessels under 12 m in length, almost none of which broadcast AIS. Non-motorized vessels made up another 14 percent. Vessels larger than 24 m, which were the only vessels having a significant proportion with AIS devices, constituted only about 1.6 percent of the fishing vessels in these coastal fleets.

Fleets of coastal countries/territories in FAO Area 87

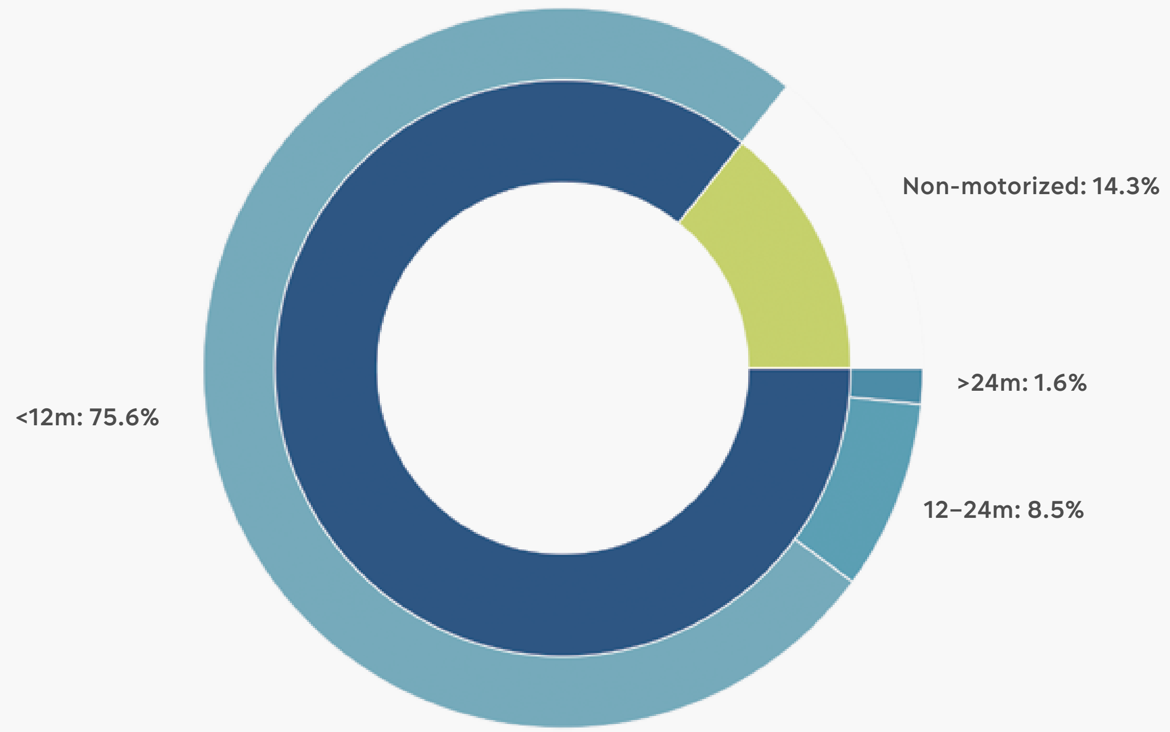


Figure 87. 3. Structural composition of fleets of coastal countries/territories in FAO Area 87. In dark blue motorized fishing vessels and in green non-motorized. Distant water fleets active in FAO Area 87 are not included (see next figure). Notice that Colombia borders more than one FAO area, yet its entire fleet size is included here. Source: FAO statistics for year 2017.

AIS use was medium to low in the fishing vessels of countries and territories of South America. According to a GFW review of vessel registries and AIS use, less than one fifth of Ecuadorian vessels over 24 m had AIS, while about a third of Peruvian vessels had AIS, and just over a third of Chilean vessels of this size broadcasted AIS. According to GFW data, no Peruvian vessels under 24 m broadcasted AIS, and only a handful of Ecuadorian, Chilean, and Colombian vessels under 24 m had AIS (Figure 87. 4). Peruvian and Chilean purse seiners were the most frequent broadcasting vessels in coastal areas. Of the 839 vessels that fished in the region for at least 24 hours, 704 were matched by AIS to registries, and the gear type was

identified for 615 vessels. The fraction of vessels from distant water fleets using AIS was much higher, and the fleet with the most vessels broadcasting AIS in this region was China's high seas fleet, most of which are squid jiggers. SPRFMO (2018) reported 356 Chinese squid jiggers fishing 296 000 tonnes of jumbo flying squid during 2017, but the actual number of active vessels varied from 180 (April) to 327 (November). Drifting longliners from China, Republic of Korea and Japan targeting large pelagics also played a significant role in the region, and estimates from Sala *et al.* (2018) suggest that the majority of these longliner fleets broadcast AIS. Overall, AIS use was roughly split evenly between Class A and the lower quality Class B.

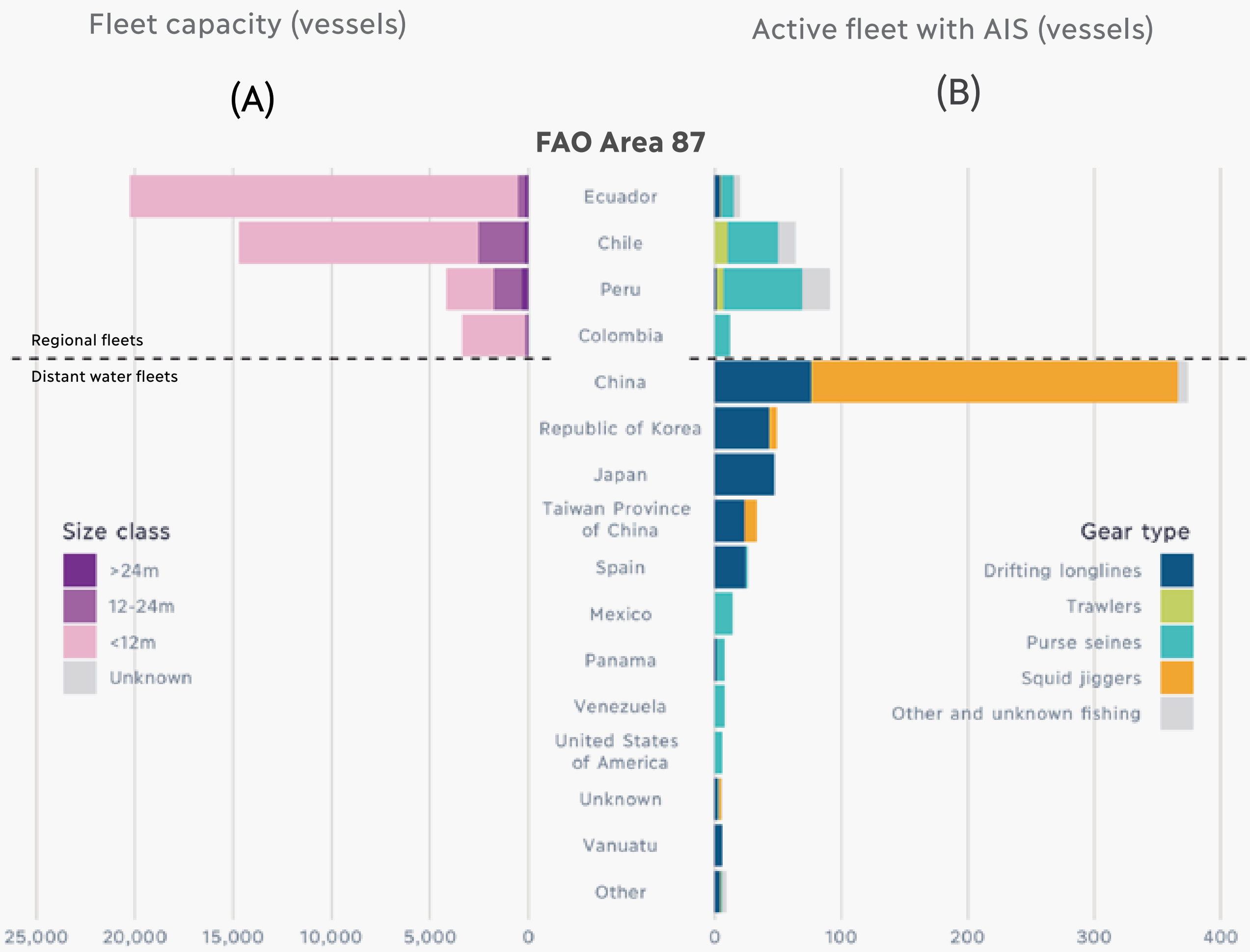


Figure 87. 4. Summary of Coastal and distant water fleets based on FAO statistics and AIS data classification by GFW in FAO Area 87 during 2017. A) Number of motorized vessels as reported to FAO (left panel). The entire national Colombian fleet is shown even though it borders multiple FAO areas. Source: FAO statistics. B) AIS-identified number of fishing vessels broadcasting AIS during their operations in FAO Area 87 by gear type and flag state (right panel). Dashed lines separate regional fleets (top) from distant fleets (bottom). Only vessels that fished for at least 24 hours in the area are included. Source: GFW.

AIS RECEPTION AND FISHING VESSEL ACTIVITY IN THE SOUTHEAST PACIFIC

Figure 87. 5 shows the presence of Class A and Class B fishing vessels in the region and the reception quality of messages received from these devices. Although Peru, Chile, Ecuador and Colombia had few vessels with AIS, those that broadcasted AIS mostly used high quality Class A devices. The distant water pelagic fleets used similarly Class A and Class B, although there is a high use of Class B by squid fleets. Reception was generally good across the region, except for Class B for the squid fleets. This lower reception may have been because Class B broadcasts at a lower rate when the vessels move slower than 2 knots, and most squid vessels fish by drifting with the currents at lower velocity than 2 knots. The fishing vessel presence map showed well the routes of foreign vessels to/from and among high seas fishing concentration zones (mostly squid jigging).

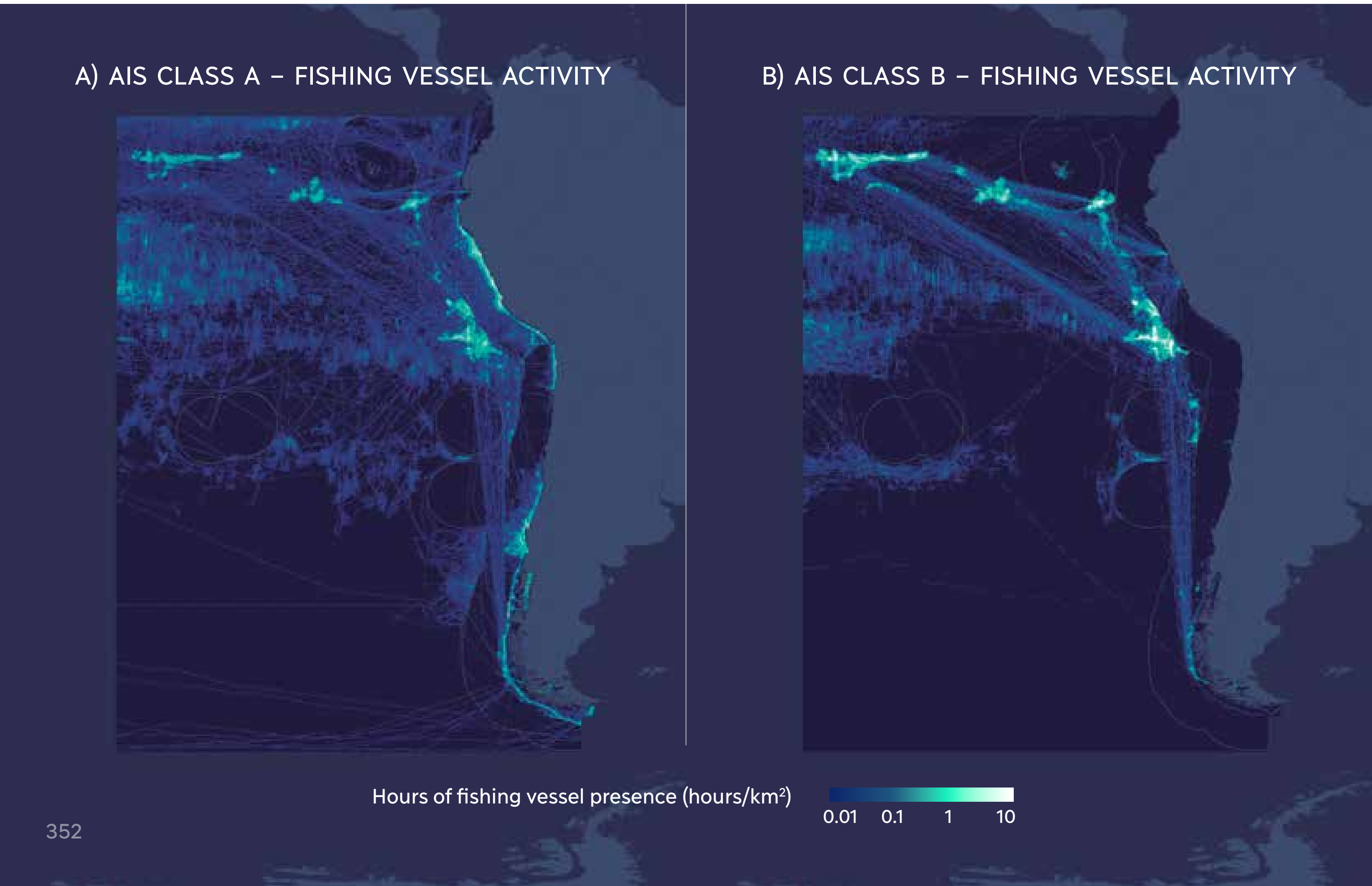
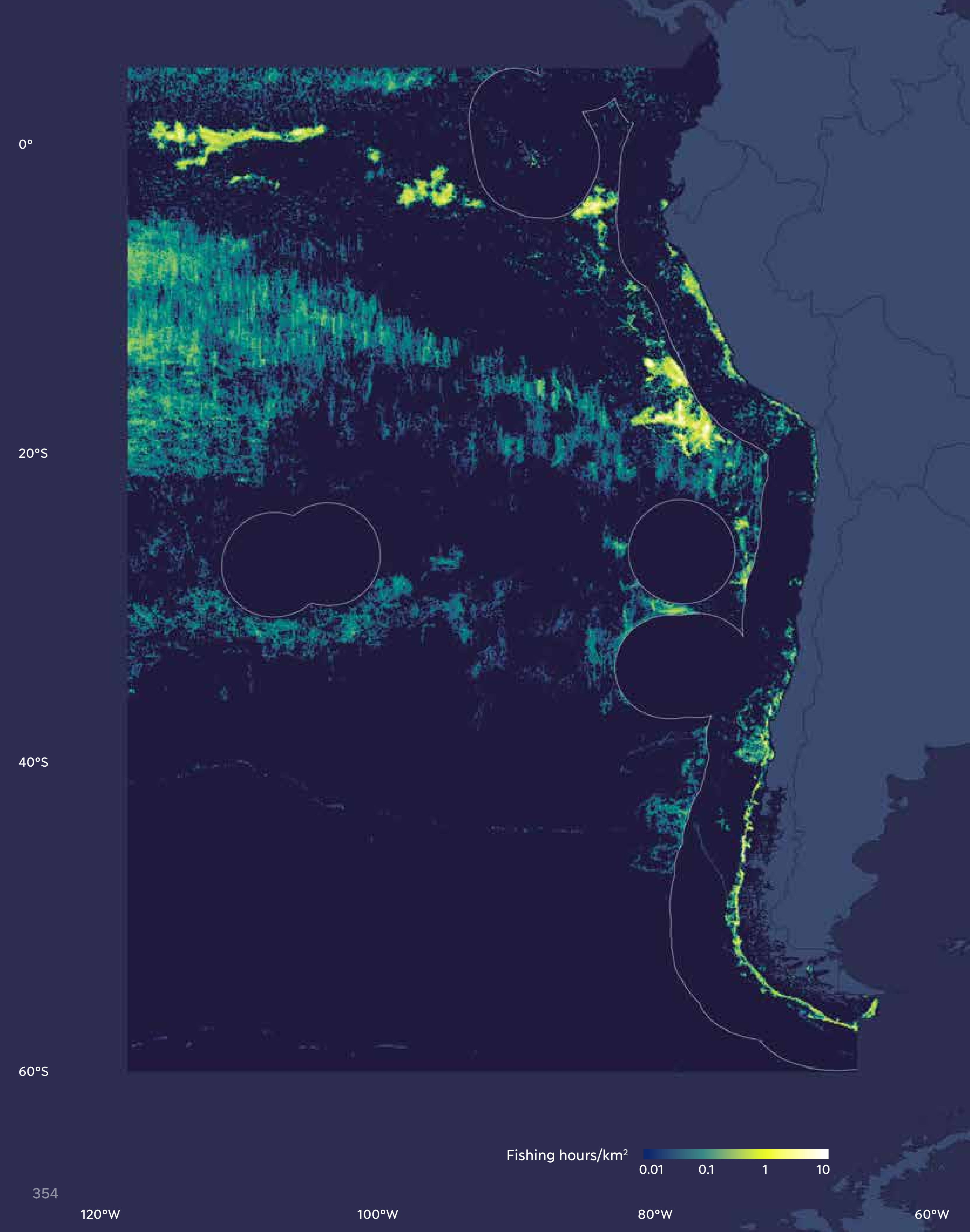


Figure 87. 5. Fishing vessel activity and quality of AIS reception for FAO Area 87 during 2017. Top row shows activity of vessels broadcasting using Class A devices (left panel) and Class B devices (right panel). The bottom row shows reception quality maps for devices Class A (left panel) and B (right panel). Blank spaces on the map (i.e. dark blue ocean background) mean that no signals from fishing vessels in this area were received, which is due to either no vessel activity or poor reception.

Fishing operations detected by GFW based on AIS data were concentrated in the northern areas and some coastal areas (Figure 87. 6). However, often in waters under national jurisdiction, few vessels had AIS, resulting in low fishing activity detected by AIS even in areas known to have high amounts of fishing. Peru and Chile fish mainly in their EEZs while other fishing countries (dominated by China) work in the high seas/open areas (Xu *et al.*, 2017). Peru is responsible for 50 percent of the catches in the region (SPRFMO, 2017a). The spatial pattern of fishing in the Peruvian EEZ roughly reflects the spatial extent of the Peruvian anchoveta fleet, but not its intensity: a review of Peruvian vessels by GFW and Oceana suggested that about 10 percent of the anchoveta fleet had AIS. The sudden interruption of AIS detection when passing from Peruvian to northern Chilean waters reflected a change in fleet characteristics and AIS use. The Chilean fleet squid catch is shared between artisanal fisheries mainly with jiggers (80 percent) and industrial mid water-trawlers (20 percent) (SPRFMO, 2016, 2017c). According to a Chilean report for the SPRFMO (SPRFMO, 2017c), 16 industrial vessels and 1 408 small scale vessels of Chile fish giant squid. This fleet, operating within the Chilean EEZ, appears not to be captured by AIS.

Figure 87. 6. The intensity of fishing operations based on AIS data for FAO Area 87 during 2017.



FISHING VESSEL ACTIVITY AND OPERATIONS BY GEAR IN THE SOUTHEAST PACIFIC

This section reviews the spatial distribution patterns of the main fishing gears in FAO Area 87 as estimated by Global Fishing Watch (GFW) based on 2017 AIS data. The most recent datasets available at mid-2018 were used to assess GFW capacity to provide an AIS based footprint of fishing activity by fishing gear in terms of presence/absence, intensity and hotspots. The Introduction to the FAO area chapter describes the rationale and challenges for use of contrasting data sources (e.g. Global Fisheries Landings database (GFLD; Watson, 2017)) for benchmarking AIS data classification.

The most important gear type in the region was purse seiners, as these were responsible for taking the majority of the region's highly productive anchoveta catch. The average annual catches over the period 2010–2014 from GFLD suggested that purse seiners were responsible for almost four fifths of the catch (Table 87. I). As only about 10 percent of Peruvian industrial anchovy vessels broadcasted AIS, and none of the artisanal ones did, the AIS only captured a small portion of this activity, and purse seiners were highly underrepresented. In contrast, the high seas squid fleet was well represented in the AIS data. Other important gear types in the region, such as trawlers and set gillnets were poorly represented as these were mostly coastal vessels that did not have AIS. The importance of drifting longliner activity seemed to be overstated in AIS data. This could have been because most of the drifting longliners were using and broadcasting AIS but their relative contribution to the catch was low because most of the catch in the region is due to purse seiners and jiggers fishing for small pelagics and squid.

GEAR TYPES	Catches (GFLD) 2010–2014 average		Total fishing vessel activity (GFW-AIS) 2017	
	Tonnes of catch in 1000s	% of catch	Active days in 1000s	% of active days
Purse seines	6 658	78%	17.8	16%
Squid jigger	908	11%	61.6	57%
Trawls	435	5%	3.1	3%
Other	366	4%	5.4	5%
Set gillnets	155	2%		
Drifting longlines	34	0%	20.4	19%
Total	8 557	100%	108.4	100%

Table 87. I. Summary table comparing average catch from GFLD during 2010–2014 with fishing vessel activity from GFW in FAO Area 87. Only vessels that fished for at least 24 hours in FAO Area 87 are included.

Squid jigger fishing activity from AIS showed very dense concentrations in the northern areas at the latitude of Galapagos Island and in the high seas along the EEZs of Peru and northern Chile. The same spatial distribution pattern could also be seen by the Visible Infrared Imaging Radiometer Suite (VIIRS), a sensor on a U.S. government satellite that can detect bright lights at night, during 2017. Because this fleet of squid jiggers uses bright lights to attract squid to the surface, they could be seen, and the distribution of these lights was almost identical to AIS squid jigger fishing activity in the region, providing supporting evidence of the location of the squid fleet during the night (Figure 87. 7). GFLD placed squid jigger activity during 2010–2014 in coastal areas, corresponding only with the Peruvian artisanal fleet (SPRFMO, 2018), which was not detected by AIS, probably because small vessels do not use AIS. GFLD also placed much squid jigger activity near seamounts, in particular on the latitudinal ridge 22°-26° S and longitudinal ridge 110°-115° W along all the region and on the high seas, not observed in VIIRS patterns. However, monthly catch distributions based on Chinese logbooks of squid jigging vessels showed that their vessels operated in the high seas next to the Peruvian and Ecuadorean EEZs in 2017, replacing the fishing areas of high seas off Chile (Li *et al.*, 2016). It should not be excluded that these differences between GFLD and VIIRS-AIS sources could have been due to temporal changes in squid distribution between 2010-14 and 2017.

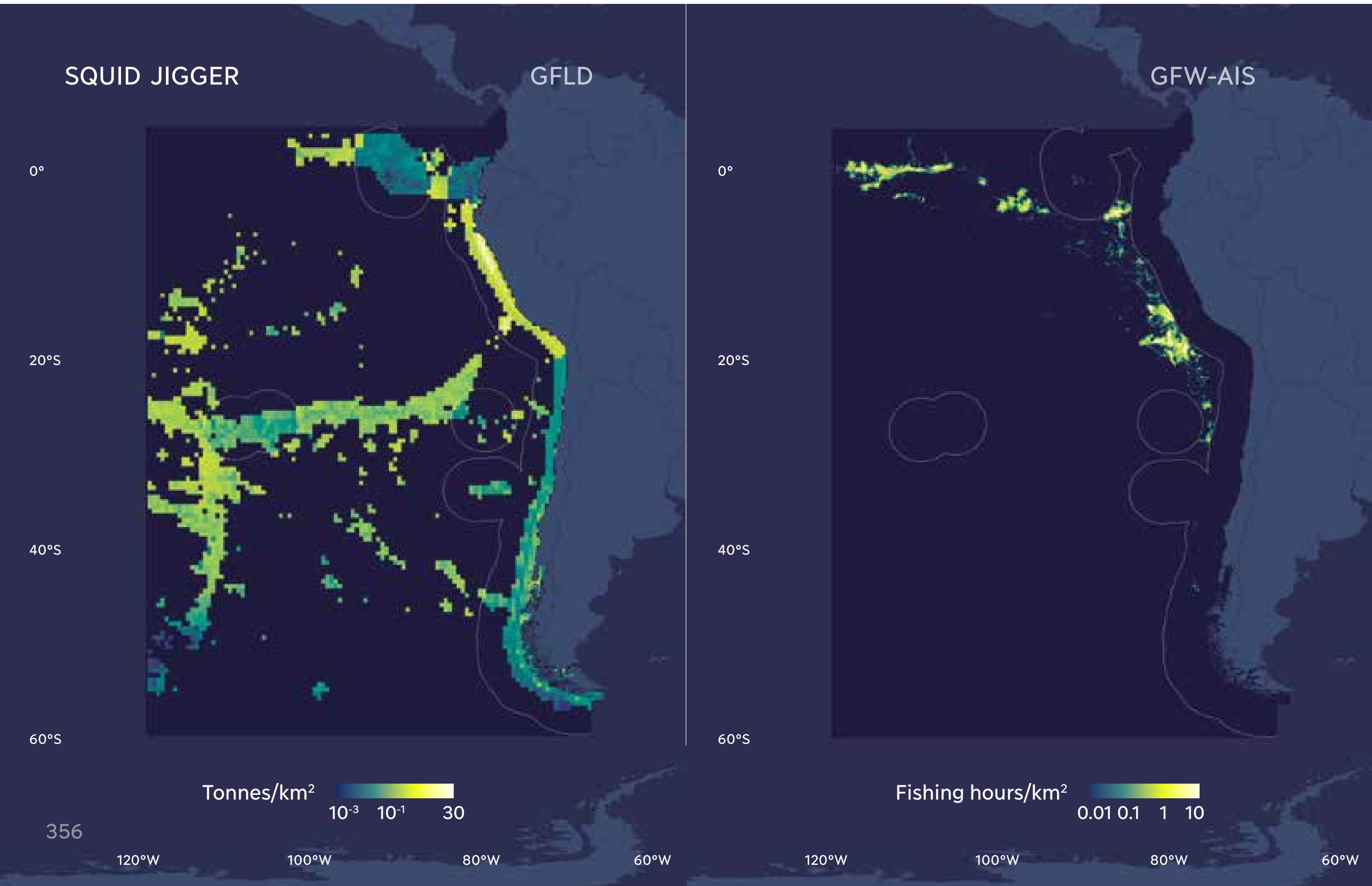


Figure 87. 7. Catch and activity of squid jiggers in FAO Area 87. Maps comparing average catch during 2010–2014 from GFLD (left panel) with squid jiggers fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km². Comparative VIIRS night image during 2017 (bottom panel).

The anchoveta is fished by purse seiners mainly in the Peruvian and Chilean EEZs and caught principally from March to July, peaking in May. The AIS distribution of the fishing activity and intensity seemed to be realistic for Peru, where it was mostly concentrated over the narrow continental shelf, whereas GLFD also suggested fishing activity far offshore (Figure 87. 8). In Chile the fishing activity was also coastal but more diffuse and mostly located in the central part of Chile. During 2014, 912 vessels were registered in Peru (Yonashiro and Baldín, 2016) and although positioning systems are mandatory for effort management in this country, this effort was underestimated in AIS records as reflected by the number of vessels by flag state (Figure 87. 4). In Peru, artisanal and small-scale fisheries have until recently not been managed under a catch limit program (Hoare, 2017) and in the case of Chile such fisheries contribute nearly 50 percent of the catches (SUBPESCA, 2017). Purse seiners are also responsible for catches of other seasonal small pelagic species such as jack mackerel, with Chile responsible for the bulk of the catches (SPRFMO, 2017a, 2017b). Overall these small pelagic fisheries occur mainly in the EEZs of Peru and Chile (FAO, 2011), indicating that the significant contribution of artisanal and small-scale fisheries was underrepresented in the AIS data.

Regarding purse seiners fishing for tropical tunas, both AIS and GFLD identified purse seiner activity in the high seas north of 5° N by Mexico, Panama and Colombia, although the AIS data included a very weak contribution of these vessels. GFLD also suggested that there was purse seiner activity across the southern Pacific and off the far south of Chile, both of which are unlikely, and the latter probably corresponding to other coastal artisanal fisheries (e.g. traps targeting king crabs *Lithodes* and *Paralomis*). The fishing vessel activity associated with fisheries for tropical tunas and tuna-like species which takes place under the IATTC mandate and is responsible for around 10 percent of catches in FAO Area 87 (FAO, 2011; IATTC, 2017), seemed to be underestimated by AIS. Those tuna catches, primarily from purse seiners (i.e. 281 registered in the IATTC area) working mainly north of the 10° S and seasonally down to 20° S near Peru (IATTC, 2017), seemed poorly identified by AIS.

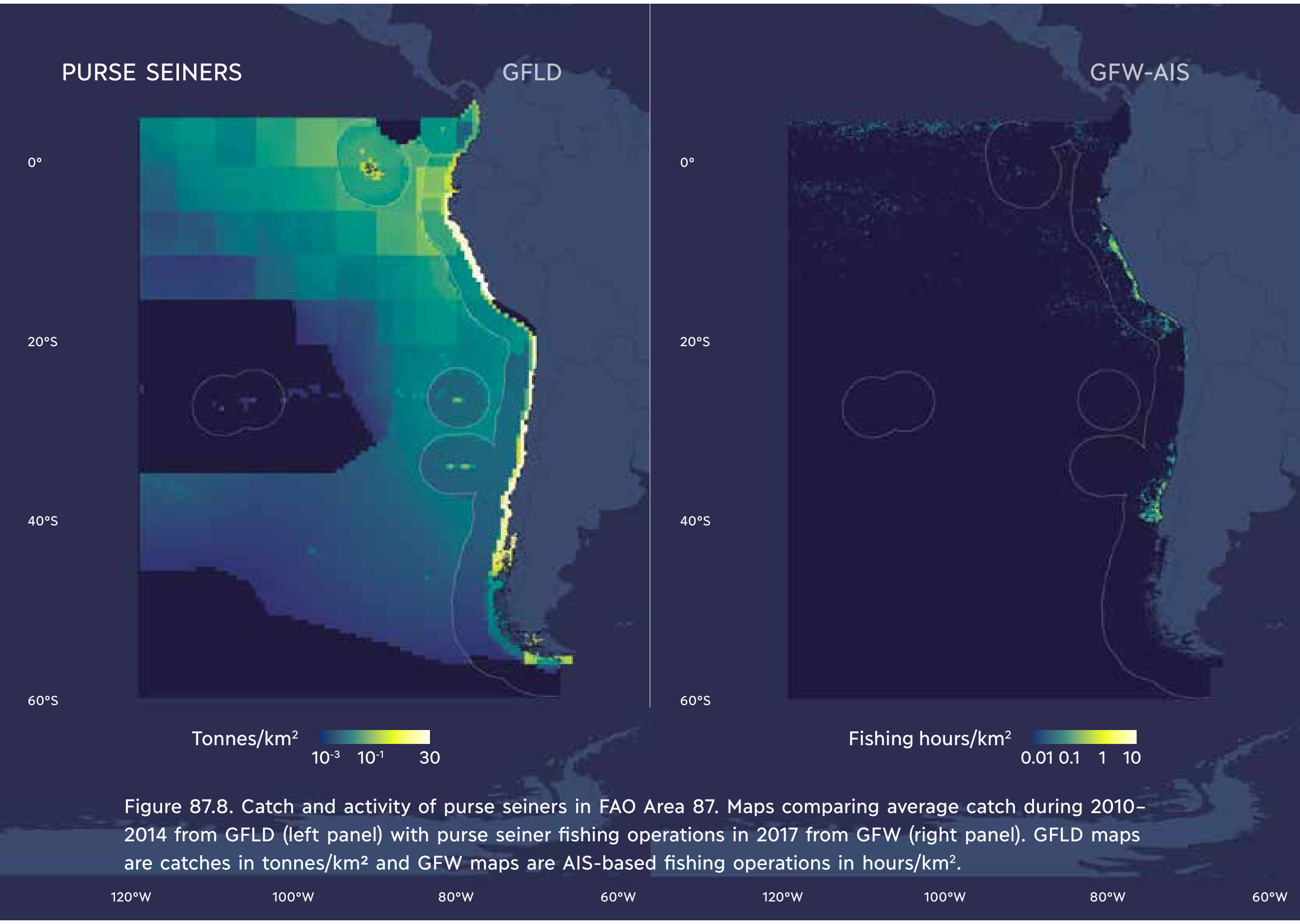


Figure 87.8. Catch and activity of purse seiners in FAO Area 87. Maps comparing average catch during 2010–2014 from GFLD (left panel) with purse seiner fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

Longline fleets target bigeye, yellowfin and albacore tunas, with 1 229 large longliner vessels registered in the IATTC area and dominated by Chinese, Japanese and Korean flags operating between 100°-120° W and 0°-20° S (IATTC, 2017). According to AIS, longliners seemed to have a more extended activity than GFLD, extending eastward to 80° W and southward to 33° S, but avoiding the island EEZs (Figure 87. 9), which is confirmed by RFMO data (Taconet *et al.*, 2018). Both GFLD and AIS data underrepresented the extent of this fishery. However, GFDL and AIS data together provided a more realistic distribution of the activity (Taconet *et al.*, 2018). Catches were also understimated in GFLD despite longliner catches (Taconet *et al.*, 2018) being much less than the purse seiner catches of tropical tunas and small pelagics.

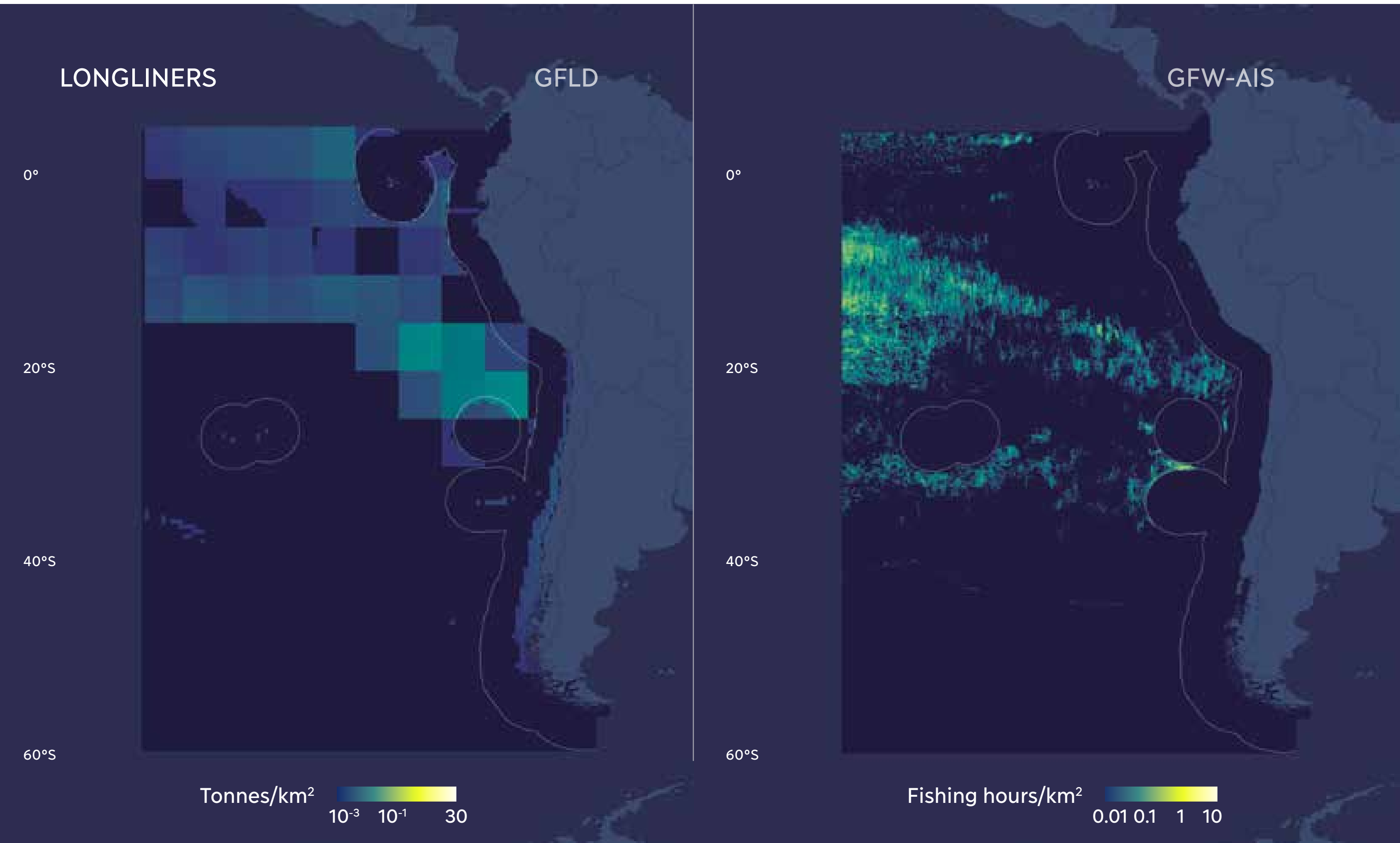


Figure 87.9. Catch and activity of longliners in FAO Area 87. Maps comparing average catch during 2010–2014 from GFLD (left panel) with longliner fishing operations in 2017 from GFW (right panel). GFLD maps are catches in tonnes/km² and GFW maps are AIS-based fishing operations in hours/km².

ACKNOWLEDGEMENTS

The editors would like to thank Sebastian Rodriguez, Carolina Minte-Vera, Fernando Jara and Enzo Acuñafor for excellent comments and feedback during the elaboration of the chapter. This publication represents the research and experience of authors and reviewers, but does not represent their employers' and collaborators' views or opinions.

Required citation for this chapter:

Grande, M., Murua, H., Granado, I., Kroodsma, D., Miller, N. A., Fernandes, J. A. 2019. FAO Area 87 – AIS-based fishing activity in the Southeast Pacific. *In* Taconet, M., Kroodsma, D., Fernandes, J.A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)

REFERENCES

FAO. 2011. *Food and Agriculture Organization of the United Nations. Review of The State of World Marine Fishery Resources.* FAO Fisheries and Aquaculture Technical Paper. No. 569. Rome, FAO. http://www.fao.org/3/i2389e/i2389e.pdf

FAO. 2016. *Food and Agriculture Organization of the United Nations. The State of World Fisheries and Aquaculture 2016 (SOFIA). Contributing to food security and nutrition for all.* Rome. http://www.fao.org/3/a-i5555e.pdf

FAO. 2019. *Food and Agriculture Organization of the United Nations. FAO Major Fishing Areas. Pacific, Southeast (Major Fishing Area 87).* http://www.fao.org/fishery/area/Area87/en

FishStatJ. 2018. Fisheries and aquaculture software. FishStatJ - software for fishery statistical time series. *In* FAO Fisheries and Aquaculture Department [online]. Rome. Updated 21 July 2018. [Cited 19 November 2018]. http://www.fao.org/fishery/statistics/software/fishstatj/en

IATTC. 2017. *Inter-American Tropical Tuna Commission. Tunas, billfishes and other pelagic species in the eastern Pacific Ocean in 2016.* Document WCPFC-SC13-2017/ GN-WP-02. Scientific committee thirteenth regular session. WCPFC. Rarotonga, Cook Islands 9 – 17 August 2017. Document IATTC-92-04a. 92nd meeting Mexico City, Mexico 24 July-28 July 2017. https://www.wcpfc.int/file/140776/download?token=SHyZTBr9

IMARPE. 2017. *Instituto del Mar del Perú. Desarrollo de la pesquería de anchoveta en la región sur de Perú desde Julio hasta Diciembre 2017 y perspectivas de explotación para el periodo Enero-Junio 2018.* Ministerio de la Producción, Perú. http://www.imarpe.gob.pe/imarpe/archivos/informes/informe_desarrollo_pesca_anchoveta_sur_2018.pdf

Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F.,... & Woods, P. 2018. Tracking the global footprint of fisheries. *Science*, 359(6378), 904-908. https://doi.org/10.1126/science.aao5646

Li, G., Chen, X., Zou, X., & Liu, B. (2016, October). National Report of China to the 2016 SPRFMO Science Committee Part II: the Squid Jigging Fishery. SC-04-11 rev1. *In SPRFMO 4th Meeting of the Scientific Committee. The Hague, 10-15 October 2015.* https://www.sprfmo.int/assets/Meetings/Meetings-2013-plus/SC-Meetings/4th-SC-Meeting-2016/SC04-papers/SC-04-11-rev1-Chinas-Annual-Report-Part-II-Revised-Squid-jigging-fishery.pdf

SPRFMO. 2016. *South Pacific Regional Fisheries Management Organisation. Report of the 4th Scientific Committee Meeting. The Hague, Kingdom of the Netherlands, 10-14 October 2016.* https://www.sprfmo.int/assets/Meetings/Meetings-2013-plus/SC-Meetings/4th-SC-Meeting-2016/SC04-report/SC-04-FinalReport-Rev1-25Oct2016.pdf

SPRFMO. 2017a. *South Pacific Regional Fisheries Management Organisation. SC5 Annex 09 – 2017 Jack mackerel Assessment Input and Results.* https://www.sprfmo.int/assets/SC5-2017/Annex-9-2017-Assessment-input-and-results.pdf

SPRFMO. 2017b. *South Pacific Regional Fisheries Management Organisation. Chile's Annual Report to the 2017 SPRFMO Scientific Committee Part II: Jumbo Squid Fishery.* Document SC5-Doc22. 5th Meeting of the Scientific Committee. Shanghai, China, 23 - 28 September 2017. https://www.sprfmo.int/assets/SC5-2017/SC5-Doc22-Chiles-Annual-report-Part-II-Squid-jigging-fishery.pdf

SPRFMO. 2018a. *South Pacific Regional Fisheries Management Organisation. Catch data submitted to the SPRFMO Secretariat (as at 28 December 2017).* COMM 6 - INF 03. 6th Meeting of the Commission Lima, Peru, 30 January to 3 February 2018. https://www.sprfmo.int/assets/2018-COMM6/COMM6-INF03-Data-Submitted-to-the-Secretariat.pdf

SPRFMO. 2018b. *South Pacific Regional Fisheries Management Organisation. Report of Jack mackerel stock assessment workshop.* Document SPRFMO–2018–SCW6. Valparaiso, Chile, May 28-30. http://www.sprfmo.int/assets/SCW6-CJM-assessment/Report-of-Jack-mackerel-stock-assessment-workshop-SCW6.pdf

Subpesca. 2017. *Subsecretaría de Pesca y Acuicultura, Gobierno de Chile. Informe Sectorial de Pesca y Acuicultura.* Departamento de Análisis Sectorial. http://www.subpesca.cl/portal/618/articles-99515_documento.pdf

Taconet, P., Chassot, E., Barde, J. 2018. *Global monthly catch of tuna, tuna-like and shark species (1950-2015) aggregated by 1° or 5° squares (IRD level 2) (Version 1) [Data set]. Zenodo.* http://doi.org/10.5281/zenodo.1164128

Watson, R. A. 2017. A database of global marine commercial, small-scale, illegal and unreported fisheries catch 1950–2014. *Scientific data*, 4, 170039. https://doi.org/10.1038/sdata.2017.39

Conclusions and overview of Global Atlas of AIS-based fishing activity

Marc Taconet, Jose A. Fernandes, Nathan A. Miller and David Kroodsma

CONCLUSIONS OF AIS TECHNOLOGY AND GFW ALGORITHMS

This Atlas reveals both promising findings and key limitations of inferring fishing effort from AIS data. Key findings include:

In 2017, AIS was broadcast by approximately 60 000 fishing vessels. These vessels were identified through a combination of vessel registries and GFW algorithms. Just over 22 000 of these vessels were identified by matching AIS to vessel registries, while the rest were identified by GFW algorithms that identify fishing vessels based on their behavior. The number of vessels broadcasting AIS is consistently increasing every year as more vessels, voluntarily or due to national legislation, install devices: between 2014 and 2017, the number of vessels broadcasting increased by between 10 percent and 30 percent each year. These estimates only account for vessels that had more than 24 hours of fishing operations in a given year.

The active fleet determined from AIS data is biased towards 1) large vessels; 2) upper- and middle-income countries/territories; 3) distant water fleets, in particular in the high seas. Although globally the majority (between 52 percent and 85 percent) of fishing vessels larger than 24 m use AIS, relatively few (14 percent to 19 percent) fishing vessels between 12 and 24 m in length broadcast AIS, and only a minor fraction (<0.4 percent) of vessels under 12 m do so. Also, the vessels broadcasting AIS predominantly belong to upper- and upper middle-income countries because 1) the majority of vessels over 24 m are from these richer countries/territories and 2) these countries/territories generally have stronger regulations that require AIS. Finally, AIS use is relatively high in distant water fleets (fleets of vessels fishing in the EEZs of foreign nations or in the high seas), which often belong to, or are owned by, upper-income countries. In the high seas, over 80 percent of fishing effort is exerted by vessels with AIS.

Poor AIS reception limits the ability to monitor fleets in some parts of the world. AIS reception varies significantly as a result of numerous factors, and this influences the ability to detect a vessel and monitor various fleets around the world. These factors include: the density of vessels broadcasting AIS in an area; the type of AIS device used by the vessels (high quality Class A/ lower

quality Class B); and the type of receiver (satellite/terrestrial). Note that a coastline well covered with a network of terrestrial antennas provides good reception even in areas of high vessels density. The area with the worst overall AIS reception is Southeast Asia. Other areas of especially poor satellite reception include the northern Indian Ocean, the Gulf of Mexico, east Asia and Europe. In most European waters and parts of east Asia, a large network of terrestrial antennae receivers provides reception close to shore, making up for poorer AIS satellite coverage in these regions.

GFW's vessel classification algorithms are better for some gears than others, as revealed by comparing AIS fishing vessel activity and operations with other data sources. For this Atlas, the gears of vessels have been identified by combining data from registries with algorithms that infer the gear type based on the vessel behavior. The models described by GFW (see Vessel Classification Model in the section AIS-Based Methods for Estimating Fishing Vessel Activity and Operations) performed well when compared with registry data. Errors can occur, however, when incorrect or outdated registry information is used to train models, or when training data are lacking for some types of vessels. The current algorithms perform well in classifying the most common gear types among larger vessels: trawlers, tuna purse seiners and drifting longliners. The classification algorithms were less robust when differentiating gears that are usually associated with small-scale vessels, such as set gillnets, set longlines, trawls and pots and traps, among others. The current algorithms also do not differentiate between subtle variants of fishing practices such as small pelagic versus large pelagic purse seining, or bottom trawl versus pelagic trawl. Also, currently, the GFW's AIS algorithms can only assign one gear type to a vessel, limiting the ability to differentiate multi-gear vessels.

Use of AIS varies among regions of the oceans, as revealed by comparing AIS fishing vessel activity with catch reconstructions. A comparison of fishing vessel activity inferred from AIS with estimated catch estimates reveals how AIS use varies among oceans. Both AIS and catch reconstructions suggest that fishing vessel activity is highest in FAO Major Fishing Areas 61 and 27. Some of the largest disagreements between datasets are for Areas 57 and 71, likely because few fishing vessels in Southeast Asia broadcast AIS and AIS reception is poor in this region. Within FAO Areas, the comparisons highlight where AIS most accurately documents fishing effort.

Converting AIS activity to fishing effort is not straightforward and depends on the gear type. GFW's current fishing algorithms (see Fishing Operations Model in the section AIS-Based Methods for Estimating Fishing Vessel Activity and Operations) determine if a vessel has its gear in the water at a given time, and estimate fishing operations measured in fishing hours. This activity can be mapped out in high-resolution, as shown throughout the various maps of this Atlas. However, because there are substantial differences among fishing gears in the amount of time for which fishing gears are deployed in the water (e.g. longliners vs. purse seiners), fishing

hours do not compare well across gear types. Therefore, for catch and effort comparisons, fishing effort - measured in days at sea - is used instead. These model comparisons also do not take into consideration the fact that vessels of different sizes and gears catch different amounts of fish per day of activity. Note that the current definition of "fishing hours" by gear is not the same as the definition used by some regional bodies, making some comparisons challenging. For instance, the time searching for fish by purse seines is often included in estimates of "fishing hours," but the GFW algorithms do not include this searching time, instead treating it as "transiting" time, and only consider fishing time when the purse seiner is surrounding the fish school and hauling it onboard (i.e. during the set which only lasts 2-3 hours). Nonetheless, using fishing operations, measured in "fishing hours", allows identification of where fish may have been taken from the ocean instead of simply mapping the tracks of a vessel for an entire day.

CONCLUSIONS BY FISHING GEARS

The following global maps show the extent of fishing operations mapped by AIS data. Maps are presented in fishing hours per square kilometer, as this unit can provide activity maps of higher resolution and allow better comparisons with catches. The global fishing map (Figure Conc. 1) shows the most intense level of fishing in the Chinese EEZ and EEZs of European nations. Fishing operations in the pelagic regions, though at a lower intensity, are widespread. An apparent lack of operations is observed in Southeast Asia and the northern Indian Ocean, where few vessels broadcast AIS. Also visible are the effects of oceanic international boundaries, with fishing operations often concentrating around the edges of EEZs.

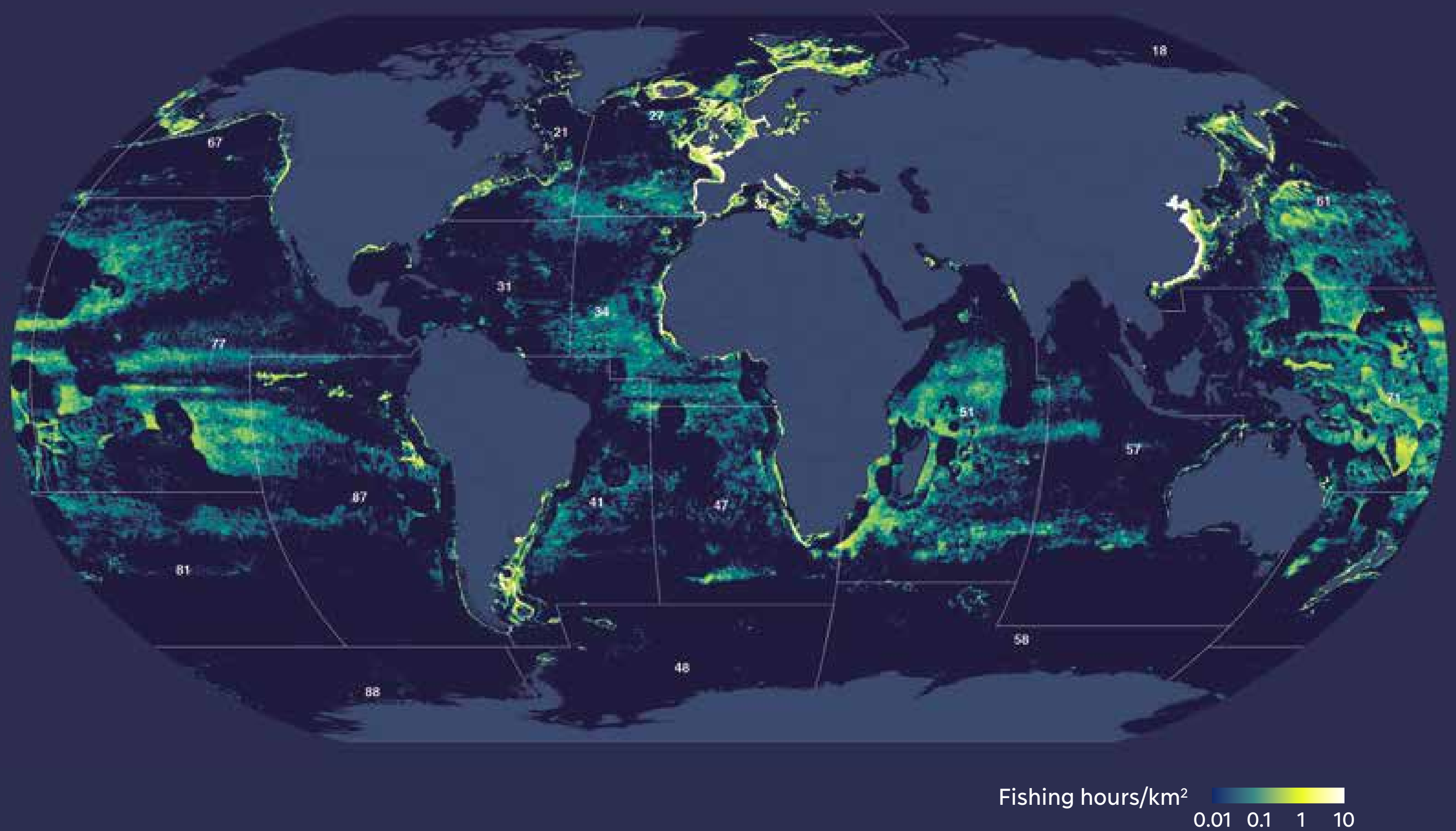


Figure Conc. 1. Global fishing operations in 2017.

When mapping operations by gear (Figures Conc.2-4) highly varied spatial patterns are found.

Trawls (Figure Conc. II) are a major fishing gear worldwide. Their operations are mostly confined to continental shelves up to 200 m depth or seamounts. This can be observed in the AIS detected activity which is concentrated in coastal areas. Trawls are the main fishing gear in Europe (FAO Areas 27, 34 and 37), South Atlantic Ocean (FAO Areas 41 and 47), Indian Ocean (FAO Areas 51 and 57), North Pacific Ocean (FAO Areas 61 and 67) and Central Pacific Ocean (FAO Areas 71 and 77).

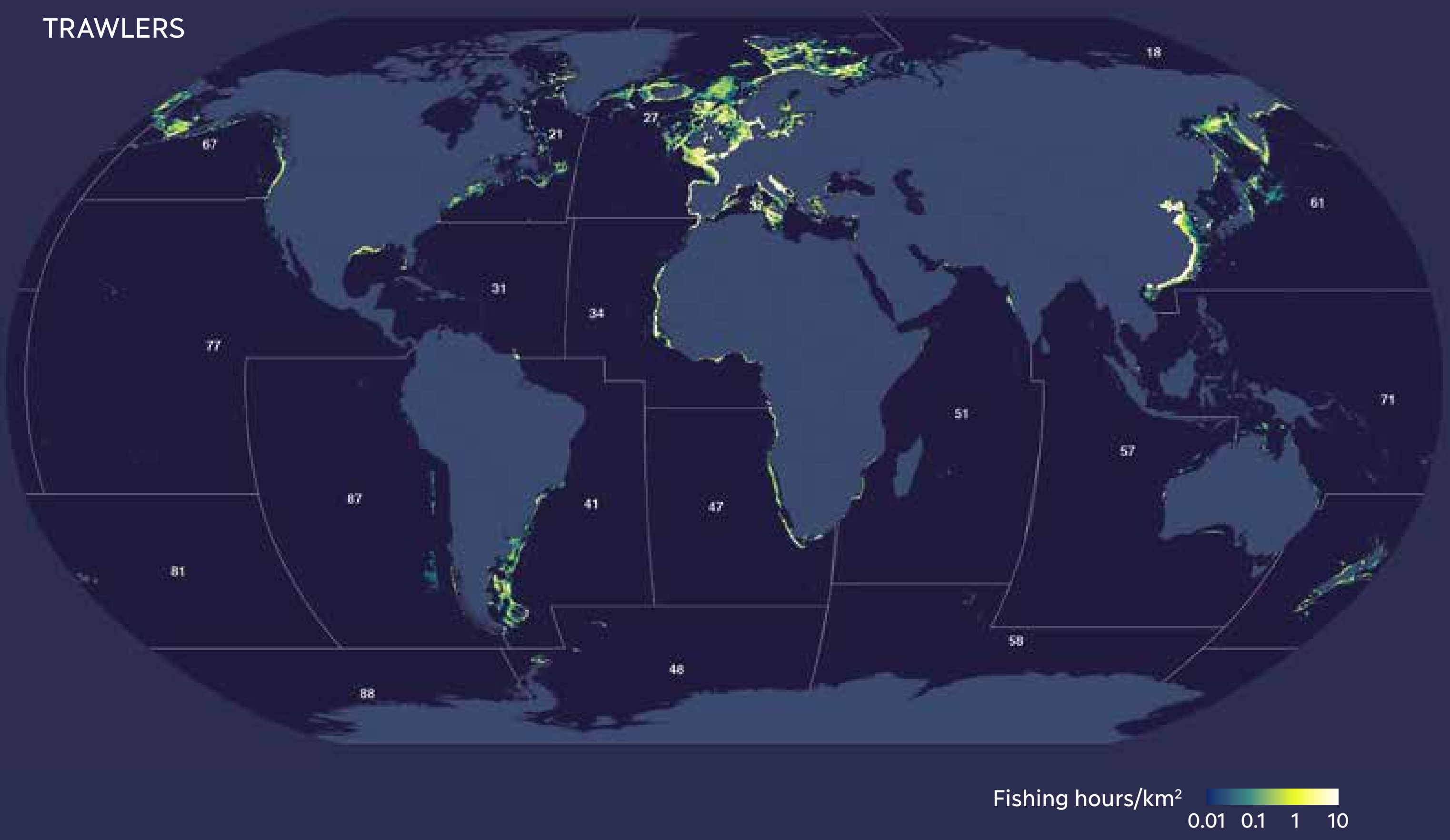


Figure Conc. 2. Global fishing operations by trawlers in 2017

Trawls are also the main fishing gear in the Western Central Atlantic (FAO Area 31). The high level of trawling in this area reflects both wide, productive continental shelves and the fact that a high proportion of trawlers have AIS. In contrast, little trawling is detected by AIS off Indonesia and Southeast Asia (Areas 57 and 71), and along the entire coastlines of the Indian Ocean (Areas 51 and 57). This low representation of trawling is largely due to very low use of AIS in this region, rather than a real lack of trawling activity. Similarly, except for Chile and Argentina, trawling off Latin America and in the Caribbean is light according to AIS data (Areas 87, 41, 31 and southern 77) but this is likely due to a lack of AIS use and not a lack of trawling. Trawling is seen along most of North America (Areas 67 and 21). Notably, there is little trawling along the Antarctic shelf (Areas 48, 58 and 88) or in the Arctic other than north of Europe (almost none in Area 18, but a considerable amount in northern Area 27).

Purse Seiners (Figure Conc. 3) include both large tuna purse seiners which are active in pelagic regions in lower latitudes, and smaller coastal purse seiners which operate along the world's continental shelves. Purse seines are another main fishing gear worldwide, however its AIS-based activity appears to be lower than longliners. This is likely as result of smaller purse seine vessels that may not use AIS, and larger tuna purse seiner vessels which may turn off their AIS particularly in the Indian Ocean region.

Figure Conc. 3. Global fishing operations by purse seiners in 2017

The North Atlantic Ocean (FAO Areas 21, 27 and 37) is a region where AIS use by all fishing gears is high and AIS data show purse seiner activity more concentrated within national jurisdictions. The Central and South Atlantic Ocean (FAO Areas 31, 34, 41 and 47) are regions where vessels targeting small pelagics are common and AIS use is relatively low, resulting in an underestimation of fishing operations by purse seiners. The Northwest and Western Central Pacific Ocean (FAO Area 61, 71) exhibit relatively good coverage of pelagic purse seiners to the east of Papua New Guinea. To the west of Papua New Guinea, however, AIS satellite reception is poor and few vessels use AIS, restricting the utility of AIS for identifying purse seiner operations

in the western portions of these FAO areas, closer to Asia. In the rest of the Pacific Ocean (FAO Areas 67, 77, 81 and 87) the spatial distribution of purse seiner operations is relatively well characterized, though the intensity is often underrepresented. Nearshore purse seiner operations are often missing as these vessels are less likely to use AIS and may switch gears between seasons, resulting in misclassification. In the Indian Ocean (FAO Areas 51 and 57) purse seiner operations are poorly represented even in the high seas as few purse seine vessels within these areas consistently use AIS. Purse seine fishing operations are not identified in the Southern Ocean around Antarctic (FAO Areas 48, 58 and 88) or in the Arctic Sea (FAO Area 18).

Longliners (Figure Conc. 4) have by far the largest AIS footprint and are prevalent in all basins except for the Arctic and Southern Ocean. These vessels operate mainly in the high seas within RFMO waters. Because many of these vessels are over 24 m in length, a high proportion use AIS. For this reason, the distribution of fishing operations and spots of higher intensity are well captured in general by AIS data. Due to the higher proportion of AIS devices on longliners relative to other gears, their importance in relation to other gears can be overrepresented. For instance, although their catch usually represents less than 2 percent of the global catch (Watson 2017), they represent 10 percent of the vessel days in the AIS data.

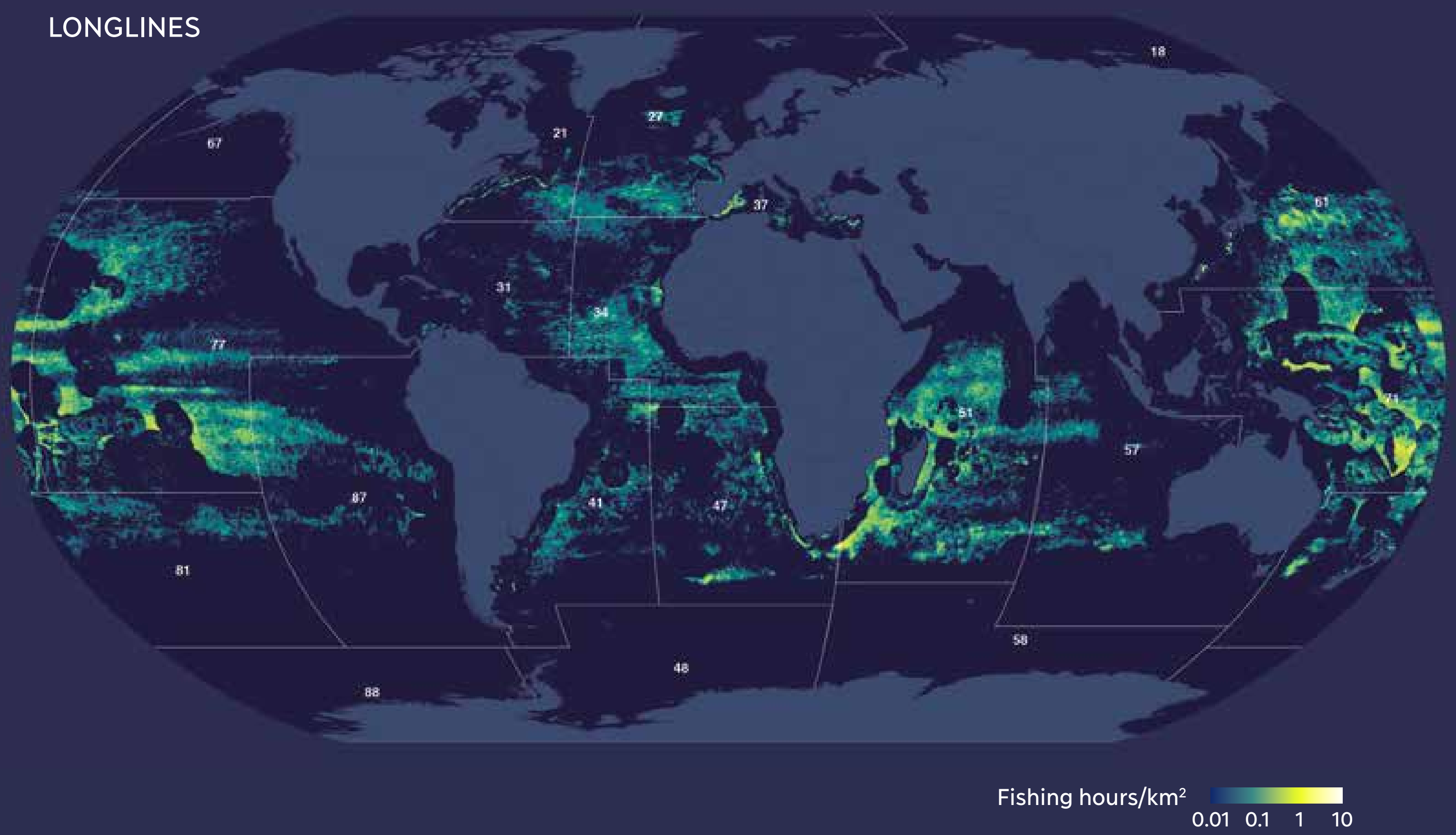


Figure Conc. 4. Global fishing operations by longliners in 2017

The North Atlantic Ocean (FAO Areas 21, 27 and 37) is a region where AIS use by all fishing gears is very high and where AIS and VMS data show longliner activity more concentrated within EEZs. The Central and South Atlantic Ocean (FAO Areas 31, 34, 41 and 47) is a region where fishing vessel activity by longliners seems to be lower than in other areas and mainly concentrated in the high seas. The highest fishing vessel activity and catch in the Northwest and Western Central Pacific (FAO Areas 61, 71) is by longliners, whereas their importance is minor in the rest of the Pacific Ocean (FAO areas 67, 77, 81 and 87). The Indian Ocean (FAO

areas 51 and 57) is the second-most important region in terms of longliner activity and catches (after the Western Central). AIS data show an accurate distribution of fishing vessel activity and areas of higher intensity in this ocean, however, the data represent longliners activity better in the Western Indian Ocean compared to the Eastern Indian Ocean.

Squid jiggers (Figure Conc. 5) activity has been increasing in the past 5-10 years, mostly in the high seas near South America and in the Northwest Pacific, as revealed by the comparison between the catch reconstruction and AIS data. This recent activity detected by AIS would have been missed if using traditional data sources generally updated with several years lag, and this may explain some of the differences between the AIS data on squid jiggers and the GFLD dataset. There are fleets operating in the Pacific to the west of equatorial South America (FAO Area 87) and in the high seas near Argentina (FAO Area 41), the Arabian Peninsula (FAO Area 51), and east of Japan (FAO Area 61). With the exception of China, almost no squid jigging occurs close to shore according to AIS data. This distribution results from the fact that only large, pelagic squid jiggers appear to use AIS. For instance, the small scale coastal squid fleets such as in the Gulf of Thailand, or the Peruvian artisanal squid fleet that operates within its EEZ, are not represented here (see Figure Conc. 5 which for example shows only fishing in the high seas by Asian fleets just outside the Peruvian EEZ).

Figure CFG. 5. Global fishing operations by squid jiggers in 2017

Also, it should be noted that the category of squid jiggers likely includes other types of vessels that fish using similar methods. For instance, it is known that some of the vessels operating in Area 61 to the east of Japan are fishing for Pacific saury. Because these vessels move similarly to squid jiggers while fishing (i.e. generally drift with the currents at night), the GFW vessel classification algorithm identifies them as squid jiggers.

GLOBAL COMPARISONS WITH CATCH RECONSTRUCTIONS

Throughout this Atlas, fishing vessel activity from AIS has been compared with catch reconstruction data, drawing on the Global Fisheries Landing Data (GFLD) version 2, compiled by Reg Watson. This catch reconstruction database estimates, at 0.5° x 0.5° degree resolution, the catch by species and gear type across the entire globe from 1950 to 2014 (Figure Conc. 6). The mapping to fishing gears depends on the fished taxon, the fishing country, and the year.

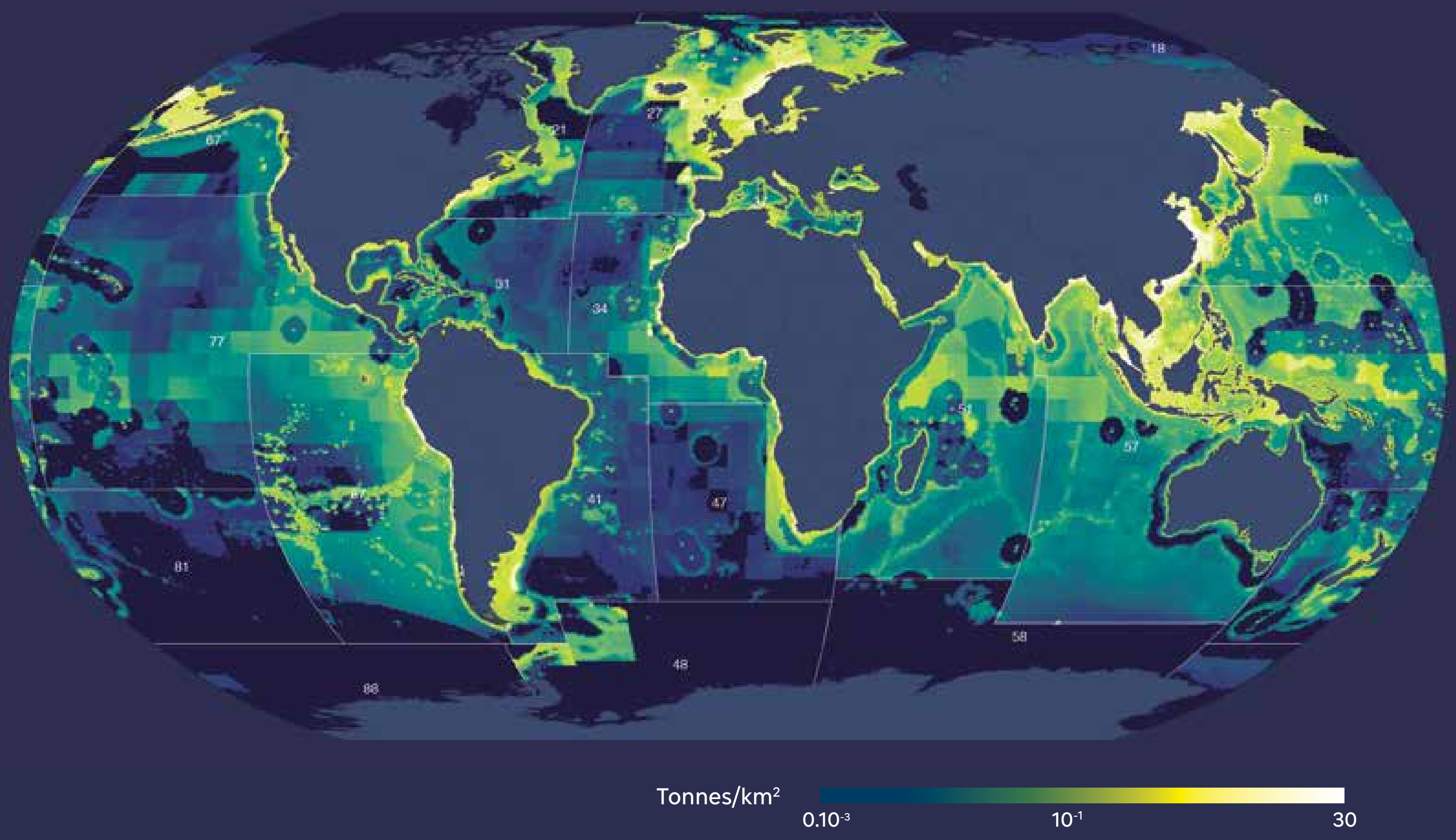


Figure Conc.6. GFLD average catch in the period 2010 to 2014.

For each FAO region, in this Atlas, AIS estimated fishing effort and operations have been compared with catch estimates reported by the GFLD. Such comparisons should be taken with caution as the data are aggregated at different scales and in different units. The AIS data measure effort by vessel, for example, whereas GFLD measures aggregated catch by spatial strata. Direct comparisons are complicated by the fact that catch per unit effort varies dramatically by gear type and target species across the world. Also, the unit of fishing effort used in this Atlas – days at sea by vessels – does not account for differences in vessel size. One would expect, for the same number of fishing hours, a factory trawler 100 m in length to catch an order of magnitude more fish, by weight, than a 15-meter coastal trawler. Consequently, while both datasets provide global estimates of fishing and their comparison can

illustrate methodological strengths and weaknesses, direct comparisons should keep in mind inherent differences in the underlying data.

Despite these challenges, comparing catch with AIS effort can help understand where the AIS data is insufficient, and where it is more or less representative of the total fishing activity. It is useful for highlighting broad spatial patterns, and showing, within regions, where fishing activity is concentrated.

Comparing the catch reconstruction data from GFLD for 2010–2014 with AIS fishing effort by region by gear type for 2017 can help identify which regions have better and worse AIS use (Figure Conc. 7). Although catch varies substantially by FAO region, there is somewhat broad agreement between the AIS data and catch data from the regions with the highest catch according to GFLD. Both the AIS data and the catch data identify Area 61 as the most heavily fished regions, and region 27 as the second most important. The largest difference is seen in Area 57, which includes Indonesia and southeast Asia, where GFLD shows as the fourth most important region by catch, while the few AIS data for this region leads GFW to identify it as the 15th most important region by activity.

The comparison also shows that the trawlers are the most important fleets followed by purse seiners, other gears and longliners (Figure Conc. 7). Squid jiggers are also significant in FAO Area 41, 61 and 67. Squid jiggers activity importance is less well captured in GFLD. However, both datasets show similar patterns of importance of fishing gears by FAO areas.

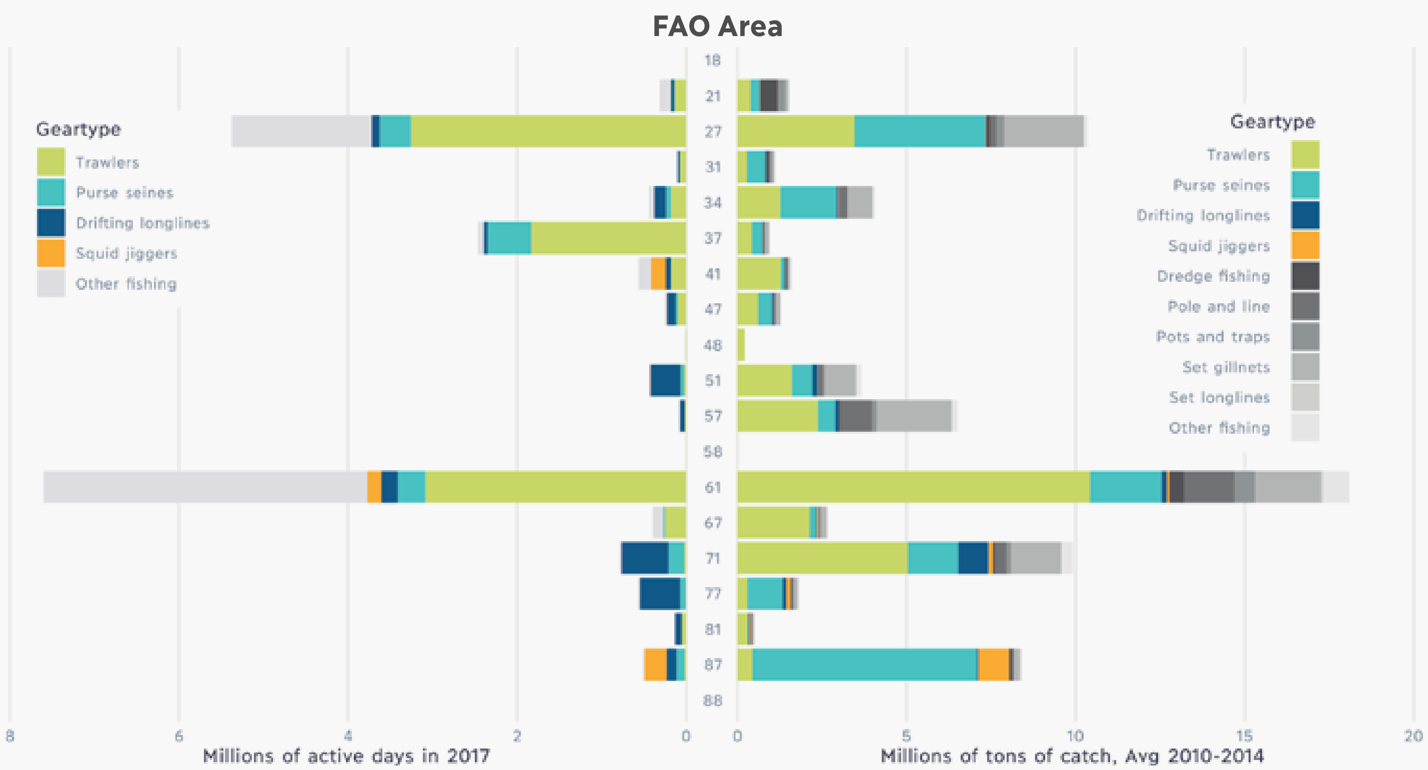


Figure Conc. 7. AIS Active Days and Catch by FAO Area code (middle)

REFERENCES

Kroodsma, D.A., Mayorga, J., Hochberg, T., Miller, N.A., Boerder, K., Ferretti, F., Wilson, A., Bergman, B., White, T.D., Block, B.A., Woods, P., Sullivan, B., Costello, C. & Worm, B. 2018a. Tracking the global footprint of fisheries. *Science*, 359(6378): 904–908. https://doi.org/10.1126/science.aao5646

Watson, R.A. 2017. A database of global marine commercial, small-scale, illegal and unreported fisheries catch 1950–2014. *Scientific Data*, 4: 170039. https://doi.org/10.1038/sdata.2017.39

Watson, R.A. & Tidd, A. 2018. Mapping nearly a century and a half of global marine fishing: 1869–2015. *Marine Policy*, 93: 171–177. https://doi.org/10.1016/j.marpol.2018.04.023

Western and Central Pacific Fisheries Commission. 2*018. Tuna Fishery Yearbook 2017.* https://www.wcpfc.int/doc/wcpfc-tuna-fisheries-yearbook-2017

CONCLUSIONS BY FAO MAJOR FISHING AREA

The capacity to estimate fishing vessel activity and operations from AIS varies among the FAO Major Fishing Areas - and by the fleets operating within them - primarily due to different levels of AIS use and reception. Within national jurisdictions, AIS use is lower due to artisanal fleets having more exemptions to regulations (e.g. small vessels not requiring AIS devices). Reception quality varies greatly within national waters. In some regions, because of a high number of vessels, satellite reception is poor due to AIS signal interference. Along many coastlines, however, this poor satellite reception can be compensated for by terrestrial receivers. In the high seas outside of national jurisdictions, AIS reception and use is in general much better and AIS can be a useful source for RFBs having mandate in the high seas. Indeed this activity in the high seas represents only a relatively small proportion of the global catch.

Overall, in areas with good AIS use and reception, AIS data can facilitate the characterization of fishing vessel activity, improve transparency, and be useful for fisheries analyses supporting management needs. While the potential of AIS data for use in fisheries management is large, it must be carefully considered with respect to which vessels and fishing activities are recorded or observed and those that are not, which in some regions can be a significantly large proportion (e.g. artisanal and coastal fleets). These considerations are summarized for each FAO Major Fishing Area below.

The Arctic Sea (**FAO area 18**) shows very low amounts of industrial fishing and the fishing vessel activity is dominated by small scale purse seiners and gillnets with low AIS use, which limits its capacity to show fishing activity patterns and intensity.

The Indian Ocean (**FAO areas 51 and 57**) is another region where industrial fishing is proportionally lower than artisanal fishing when comparing to the rest of the world. Low levels of AIS use by artisanal and semi-industrial fleets in coastal countries, as well as by industrial pelagic purse seiners, limits the usefulness of AIS in this region for mapping activity and operations. Even for industrial vessels, AIS use is lower than in the rest of the world and almost all gears seem to be poorly represented in the AIS data. Only the fishing activity of the distant-water longline fleet, which has relatively high use of AIS, seems to be well mapped and only for the southern part of the region.

The North Atlantic Ocean (**FAO areas 21, 27 and 37**) is a region where AIS has good potential to estimate the fishing activity due to high industrialization of fleets. The United States of America, Canada and European countries, which are responsible for most of the fishing activity in the region, have good AIS use for vessels larger than 24m, and some countries have significant AIS use for vessels below this size (in Europe, almost all vessels over 15m broadcast AIS, and in the U.S., almost all vessels over 19m). AIS reception is good across the region for

larger vessels broadcasting with high-quality Class A devices. Reception, however, is poorer for lower quality Class B devices. The southern Mediterranean, African and Middle East countries have extremely low AIS use in the southern and eastern areas of this ocean. Trawling seems to be well represented in terms of spatial distribution and intensity hotspots in the North Atlantic and the northern Mediterranean Sea. However, in the Mediterranean Sea, AIS appears to overrepresent the importance of the trawlers and longliners, and misses important gears such as dredges, purse seines and set gillnets. Activity is poorly captured in the southern Mediterranean, along the northern coast of Africa, where few vessels use AIS.

The Central Atlantic Ocean (**FAO areas 31 and 34**) is a region where AIS use is poor except for vessels from the United States of America, Morocco, Europe and distant water fleets from Asia. There are also many areas with poor AIS reception in the region. The primary fishing gears detected by AIS are trawls, drifting longlines and, to a lesser extent, purse seines. The international longline fleets are relatively well represented in the AIS data, especially in the high seas, while estimates of fishing activity based on AIS data underrepresent the importance of purse seiners in this region. Other important gears in the region which are also not identified in the AIS data include various artisanal fleets (pots and traps, trolling lines, dredges and set gillnets).

The South Atlantic Ocean (**FAO areas 41 and 47**) is a region where AIS use is poor with the exception of fleets from Argentina, Uruguay, South Africa and distant water fleets. AIS data identify well the high importance and spatial distribution of fishing activity by trawlers but overrepresents the relative importance of squid jiggers and longliners. The third most important fishing gear in the area are set gillnets, which AIS appears to be unable to distinguish correctly.

The North Pacific Ocean (**FAO areas 61 and 67**) shows that AIS use and fishing activity is dominated by the Chinese fleet in the west, and by the United States of America and Canada in the east, both of which have a relatively high adoption of AIS by larger vessels. Trawlers are the most important gear in FAO Area 67, and AIS data highlight well the spatial distribution of trawling activity but partially underrepresent its importance. In contrast, AIS data show high seas activity that might be overrepresenting the longline fishing activity, mainly from Asian countries, targeting temperate tunas, swordfish and sharks.

The Central Pacific Ocean (**FAO Areas 71 and 77**) shows, in general, poor use of AIS except by the United States of America and by distant water fishing fleets. Overall, very few of the most important fishing gears and their activity in the region are properly represented by AIS data. However, the spatial pattern of pelagic longline and purse seine distant water fleets is well captured in many areas, but overrepresented in relation to other important fishing gears.

The South Pacific Ocean (**FAO areas 81 and 87**) shows good use of AIS in the high seas by Australia, New Zealand and distant water fleets, but poor in most coastal regions. AIS reception is in general good. Trawlers, set longliners and squid jiggers are the most important gears in the region and well represented by AIS data.

The Southern Ocean around Antarctica (**FAO areas 48, 58 and 88**) shows fishing activity mostly conducted by distant water fleets using Class A devices and with good AIS reception quality across the region. Official fisheries data report that the activity is entirely from bottom-set longliners and mid-water trawlers and the AIS data identify well the activity of these gears.

GENERAL CONCLUSIONS AND FUTURE WORK

This publication is an effort to put into context a new form of fisheries monitoring based on metrics and indicators derived from Automatic Identification System (AIS) technology. This approach has been enabled by innovative developments in transmitters, sensors, satellites, big data and artificial intelligence, as well as legislation that has mandated the use of AIS devices. This Atlas provides new measures of fishing vessel activity using these data, and aligns these measures with existing standard fishery concepts and definitions. It also compares the AIS-based information with existing knowledge of fisheries worldwide and in each of the 19 FAO Major Fishing Areas. The conclusions drawn from this Atlas show that, in 2017, AIS can start to be considered a valid technology for estimating certain fishery indicators. However, the technology is largely limited to the largest vessels above 24 m operating in most of the world (except in some northern areas where the limit is 15 m) and these large vessels are a very small proportion of the world's fishing fleet, especially in central and southern areas. It is of high interest to understand how much of the fishing activity and related effort/catches could be monitored in near real time based on the AIS technology, and how such accounting will evolve over time with improvements in AIS use, AIS reception and algorithm performance. This Atlas does not provide a detailed quantitative estimate of AIS-based accounting in terms of catches, although this conclusion suggests possible ways to reach such objective.

A first step towards achieving the goals stated above would be to link the AIS database with the Global Record of Stocks and Fisheries, and to compare the fishing activity with the existing databases of stocks and fisheries inventories which contain status and catch information. A second step would similarly connect AIS with existing databases of fisheries catch and effort statistics, such as the FAO global capture production statistics, or the FIRMS Tuna Atlas. These connections could be done semi automatically and eased by the adoption of common data standards among the different databases. The application and usefulness of such integration will be much enhanced if additional knowledge can be included, such as FAO gear type or vessel type descriptions, FAO species fact sheets and related species distribution maps, OBIS' Aquamaps, bathymetric and seafloor morphology GIS maps, or regional and national jurisdiction boundaries. Bringing these data feeds together in a big data multidisciplinary project involving artificial intelligence could provide reliable, near real-time monitoring of fishing vessel activity and fishing effort, and could even potentially allow for rapid estimation of catches. This service could also provide quantitative metrics on the evolving proportion of fisheries and corresponding catches and effort being monitored by AIS. However, as highlighted in this Atlas, human control and verification will be needed in all analyses, comparisons and reviews.

Substantial progress that improves the performance of AIS-based fishing algorithms can be expected. Today's Global Fishing Watch AIS algorithm demonstrates good performance in identifying the main industrial fishing gears, such as longline, trawls, and purse seines. However, it still lacks the capacity to distinguish between certain gears, such as between trawls and dredges, purse seines and Danish seines, and pelagic trawls from bottom trawls, and support for differentiating fishing activities by multi-gear fishing vessels is needed. As a result, some fishing operations are assigned to the wrong gear. Additionally, the uneven performance by gear, as well as the uneven use of AIS across gears, leads to overestimation and underestimation of the importance of gears in different areas. This over/under estimation can affect certain applications, such as spatial planning or quantifying different types of environmental, economic, and social impact. The algorithm also fails to provide the right metric of fishing effort for gears such as purse seines -- although this publication's Seychelles case study pinpoints possible directions for rapid progress. With research efforts and integration of more data sources as suggested above, these issues will be progressively resolved.

The production of this Atlas has already demonstrated the potential for gains in data quality and knowledge. By comparing different sources of data and working with a multidisciplinary team of fisheries and computer science experts, the work for this Atlas has helped improve the quality of FAO Fleet statistics, revealed mistakes in classifications of gear types in the European Union (EU) registry, and, in a few cases, resulted in improved performance of the AIS algorithm for categorizing fishing gear operations. This work, notably the case studies, also demonstrates the benefits of bringing together vessel registries, VMS, logbooks, and AIS data. In the Northwestern Pacific, the cross referencing of vessel name, IMO, and MMSI with the Regional Fishery Management Organizations (RFMOs) vessel lists facilitated identification of which vessels were authorized to fish and with what gear. Also, differences found between GFW-AIS and existing registries enabled identification of vessels that are not registered. These comparisons provide hints at the possible scales of Illegal, Unreported, and Unregulated (IUU) fishing in certain RFMO areas, however these cannot be confirmed from this analysis alone.

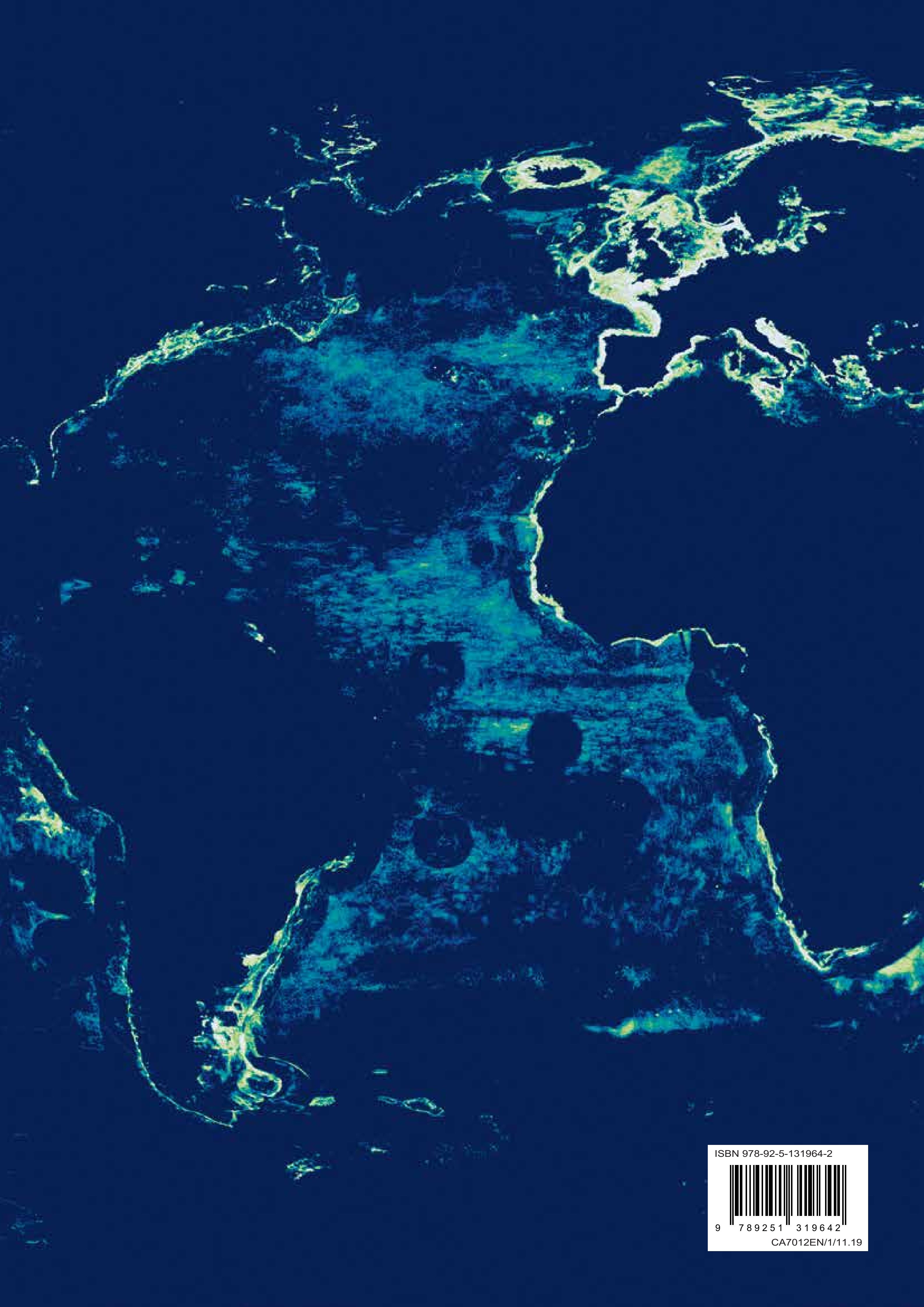
Several reviewers also expressed their belief that assembling AIS, vessel registries, VMS, and logbook data could noticeably improve the estimates of effort and CPUEs in fish stock assessment studies. For example, in the Northwest Atlantic, AIS can help provide fishing hours for trawls and improve estimates that are currently approximated using VMS data, which often has a lower polling frequency. In areas like the Western Central Pacific, where AIS use and reception is not as strong, AIS merely supplements – not supersedes – other specific sources of information for fisheries management. In this region, VMS is well established and remains a key data source which has vastly greater monitoring coverage and systems in place to manage

fisheries on this basis. Vessels covered by VMS are, however, only the ones willing to comply with regulations, and the other vessels that do not wish to be tracked are missed. In this region, AIS acts as a useful (and more widely available) source of information which can provide a broader picture of vessel activity in the area, including for cross-jurisdictions assessments because VMS generally remains confidential within jurisdictional limits. Considering this potential, there are suggestions that RFMOs work with IMO towards making AIS mandatory for all fishing vessels for both safety as well as monitoring under similar rules (e.g. no tampering, alternate power supply and interrupted transmission resulting in mandatory position reporting or return to a port for repairs). Such a cooperative and committed effort could result in the cheapest and most efficient vessel and safety monitoring available globally.

Finally, it must be emphasized that, at present, it is difficult to use AIS to evaluate the fishing vessel activity in areas where the most important fisheries are either conducted by small vessels lacking AIS or by IUU fleets with limited or no use of AIS. This underlines that AIS outputs should be taken with caution and that AIS should be analyzed in concert with local knowledge of an area. Future progress using new technology could be quite useful for filling in the missing gaps of current undetectable fleet segments. In the near future, a series of newer satellites will be capable of detecting smaller Class B AIS transponders, others will be able to combine Synthetic-Aperture Radar (SAR) and AIS to identify dark targets, and low orbit satellites will detect vessels using radio frequency. Additionally, technological developments for monitoring small-scale vessels using AIS-like technologies will be highly informative. In developing countries, some leading-edge companies already run pilots of vessel tracking technology either with private (e.g. fish buyers) or government counterparts/customers, where low cost devices designed to be uniquely installed on small vessels transmit AIS-like vessel positions during daily trips. The adoption of these devices might be accelerated considering that maritime law enforcement authorities around the world all share the problems of not being able to detect smaller crafts including fishing vessels.

Required citation for this chapter:

Taconet, M., Fernandes, J. A., Miller, N. A., Kroodsma, D. 2019. Conclusions and overview of Global Atlas of AIS-based fishing activity. *In* Taconet, M., Kroodsma, D., Fernandes, J.A. (eds.) *Global Atlas of AIS-based fishing activity - Challenges and opportunities.* Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf)



ISBN 978-92-5-131964-2

9 789251 319642

CA7012EN/1/11.19