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RESEARCH

Seeing like an algorithm: the limits of using remote sensing to link vessel movements with worker abuse at sea

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Abstract
The ship tracking and mapping capabilities that geospatial technology provides create an opportunity to observe fishing vessels as they move through established maritime boundaries. This paper connects data availability to ground-truthing research and explores the limits of vessel movement mapping in representing worker abuse at sea through three related themes. First, a conceptual background links the advancements in maritime remote sensing to critical GIS scholarship and provides a background on worker abuse aboard Taiwanese fishing vessels. Second, the paper examines the potential of machine learning algorithms to represent worker abuse at sea, arguing that more extensive ground-truthing research with workers could help address variations in the data and limited data sets. Third, I use remote sensing data to identify and unpack Taiwanese fishing across the three EEZs with the most concentrated Taiwanese fishing activity: starting with Taiwan, followed by the Falkland Islands, and Seychelles. I argue that fishing activity and the digital representation of vessel movements are governed by terrestrial geopolitics and subject to manipulation by ship captains. Finally, the conclusion offers recommendations for how future research can capitalize on the capabilities of AIS, particularly with respect to addressing problems of working conditions and abuse at sea.

Keywords Automatic identification system · AIS · Work at sea · Taiwan · Exclusive economic zones (EEZs) · Fishing · Forced labour at sea · Global fishing watch · Google · Satellite vessel tracking

Introduction

There is a growing interest in the application of geospatial technologies to examine working conditions at sea. The qualitative and human basis of these digital productions is often downplayed as researchers, humanitarian organizations, and governments work to do more with the data. This paper connects data availability to ground-truthing research and explores the limits of vessel movement mapping. The critical approach to the study of map-making in this analysis is anchored to an extensive body of work that connects cartography to dominant political structures (Sack 1986; Vandergeest & Peluso 1995; Scott, 1998) and examines the relationships between GIS, local sources of knowledge, and the production of territory (Pickles, 1995; O'Sullivan 2006; Sheppard 2005; Blomley 2019). I argue that mapping technology not only observes but also influences the representation and movement of fishing vessels.

First, a conceptual background links the advancements in maritime remote sensing to critical GIS scholarship and provides a background on worker abuse aboard Taiwanese fishing vessels. Second, I critically examine how the spatial imagery of fishing trips represents the behaviour of people working aboard fishing vessels (Joo et al. 2015). Recent research that uses algorithms to estimate the scope of forced labour at sea has received considerable attention (McDonald et al. 2021). Despite the stunning capacity of machine learning algorithms that use the big data produced by the Automatic Identification System (AIS) to model vessel movements, they still depend on validating data (Swartz et al. 2021). I argue that more extensive ground-truthing research with workers could help address variations in the data and limited data sets.

Third, I employ remote sensing data to unpack Taiwanese fishing across the three EEZs with the most concentrated Taiwanese fishing activity: starting with Taiwan, followed by the Falkland/Malvinas Islands, and Seychelles. By

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examining the case of the Taiwanese fishing fleet within the geopolitical boundaries of EEZs, this paper connects the production and distribution of maritime vessel movement data to terrestrial geopolitics. I argue that fishing activity and the digital representation of vessel movements are governed by terrestrial geopolitics and subject to manipulation by ship captains. Finally, the conclusion offers recommendations for how future research can capitalize on the capabilities of AIS, particularly with respect to addressing problems of working conditions and abuse at sea.

Background and conceptual framework

The political economy and use of geospatial technology have changed radically over the last two decades. It was initially employed by corporations and state interests through military, marketing, land planning, census, and industry applications, including fishing. Researchers have documented how these uses of geographic information systems initially required a considerable degree of technical expertise, and how the technology has started to become available to civil society (Lake 1993; Elwood, 2008; Haklay 2013; Pavlovskaya, 2018). The history of the automatic identification system (AIS) follows the same trajectory as other geospatial technologies that make up geographic information systems (GIS). Critical geographers have long maintained that "maps do more than represent reality; they are instruments by which state agencies draw boundaries, create territories, and make claims enforced by their courts of law" (Vandergeest & Peluso 1995, p. 389). In the same way, as GIS applications have decentralized and spread through web-based computing, mobile, and visual technologies, so too have AIS capabilities.

A critical history of mapping provides a conceptual background for my analyses. The aim is to situate what is represented within geopolitical and economic contexts. According to O'Sullivan (2006), a growing trend in research that takes a critical approach to the "methods and techniques reliant on geographic information systems (GIS)" began in the 1990s (p. 785). *Ground Truth: The Social Implications of Geographic Information Systems* by Pickles (1995) is considered by many to be the ground-breaking edited collection of work that helped foster a critical approach that describes how maps are the manifestations of efforts to exert geopolitical control. My analyses of the challenges and limitations of using AIS technology to map the movements of fishing vessels are grounded in this critical literature. The focus on a critical history of AIS and tracing the origins of the technology and its uses to state-based and global market actors is an extension of critical geography analyses. For example, in Scott's (1998) *Seeing Like a State* he describes how "Legibility is a condition of manipulation. Any substantial intervention in society…requires the invention of units that are visible" (p. 183). AIS maps represent fishing vessels using the national flags under which they are registered and display their movements on maps transcribed with geopolitical and geoeconomic borders.

The digital rendering of previously unseen fishing vessels and the ability to map their movements through geopolitical boundaries at sea are made possible by modern geopolitical and geoeconomic forces that organize to publish and share geospatial data. Scott's (1998) work helps focus a critical approach on an examination of how these geopolitical and economic interests shape "whatever units are being manipulated" and to appreciate how the aim will be to organize their presentation in a manner that allows "them to be identified, observed, recorded, counted, aggregated, and monitored" (p. 183). This is precisely what AIS maps do for the movements of fishing vessels. As Blomley (2019) observes, territorial boundaries function "as a powerfully encoded container, organizing and grounding legal identity in particular ways. As law is diverse, so legal territory takes different forms" (p. 235). While most critical geography is terrestrially focused, mapping maritime EEZs and examining the ways in which fishing vessels navigate these territorial extensions highlight similar patterns of movement, governance, surveillance, and enforcement.

By mapping the movement of Taiwanese vessels within their national EEZ, and within the EEZs of the Falkland/Malvinas Islands and the Seychelles, we can see how ships follow geopolitical boundaries. In this way, AIS maps can be considered part of a social process whereby vessels and ship captains track and affirm, despite those who transgress, the production of maritime territory. AIS maps showing the boundaries of maritime EEZs are critical components of maritime "territorialization": they help define, communicate, and enforce a set of relations of access and exclusion, through the deployment of spatial arrangements including boundaries, zones, and inside/outside distinctions. Territory, in this sense, is not a product of property relations but serves as a means for its production, legalization, and enforcement (Sack, 1986; Blomley 2019). Anchoring the maritime movements of Taiwanese vessels to terrestrial geopolitics highlights an avenue through which nations can seek to govern working conditions at sea.

With over 1100 Taiwanese-flagged vessels, Taiwan is one of the world's largest distant water fishing (DWF) countries (Greenpeace 2020). Since 2015, a series of reports have highlighted ongoing labour abuse on Taiwanese ships; the most recent report details how IUU fishing and forced labour remain commonplace in Taiwan's distant water fishing fleet where over 20,000 migrant workers mostly from Indonesia and the Philippines are employed (Marschke & Vandergeest, 2021). The geopolitics of fishing arrangements that allow Taiwanese fishing vessels to fish within the exclusive economic zones (EEZs) of other countries are made visible by mapping vessel movements.

By examining the movements of Taiwanese vessels with Global Fishing Watch mapping software, I illustrate key geographies where Taiwanese vessels are fishing. The mobility of the Taiwanese distant water fishing fleet is tied to arrangements that provide access to fishery grounds in distant waters. A focus on EEZs where access has been granted provides an opportunity to study how these arrangements impact ship movements and workers. My analysis of fishing activity within EEZs where I observed high concentrations of Taiwanese vessel activity is meant to highlight the relationship between fishing, labour, and governance. Mapping fishing activity within specific EEZs provides a snapshot of how international maritime conventions structure the human geography of fishing space.

Automatic identification system (AIS): from collision avoidance to machine learning

This section connects the development of AIS technology and the spread of detailed vessel movement data to the recent paradigm shift in research on fishing, supply chain governance, fisheries governance, and even labour governance. A brief history of AIS data and the origins of Global Fishing Watch provides some background on how the production of AIS data relies on information from workers and maritime organizations. While initially AIS was primarily meant as a collision avoidance tool (see Silveira et al. 2013) and a platform for the exchange of navigation of information among ships or between ships and Vessel Traffic Service ashore, the data it produces is increasingly employed in a range of studies: from logistics (Tu et al. 2017; Yan et al. 2020) to conservation, illegal unreported and unregulated fishing, transhipment, and forced labour in fishing (Miller et al. 2016; Dunn et al. 2018; Ferrà et al. 2020; McDonald et al. 2021). The GFW map is an example of how AIS has produced a paradigm shift, when applied to fishing, in how it enables detailed vessel movement data to be applied to research in fisheries governance, supply chain governance, and labour governance.

The scope of what can be seen through AIS mapping and ship tracking software is tied directly to the reach of AIS frequencies. AIS became a near-universal navigational instrument in 2004 when the International Maritime Organization (IMO) mandated its use for all commercial and passenger vessels with 300 gross tonnages and over (IMO, 2015). Today, more than 40,000 vessels carry AIS devices that broadcast vessel location, speed, course, and identity information, out of an estimated 3 million fishing vessels. It is mostly the larger vessels, more than 65 ft, which carry these devices (GFW, 2020). All Automatic Information System (AIS) transponders must be connected to Very High Frequency (VHF) and Global Positioning System (GPS) antennas to send and receive AIS information. The transponders broadcast a ship's information, including its name, MMSI, speed, course, port of origin, size, and draft. The information is updated constantly and can be viewed by any other ship equipped with an AIS unit, as well as online through vessel tracking websites and apps.

Although there is a single standard for the transmission of AIS data, there are two different ways that VHF signals are received and transmitted: via terrestrial stations or via satellite. Terrestrial AIS has been around since the 1990s and these communications are ship-to-ship or ship-to-shore. Shore stations connected to the internet make the data available in near real-time to online vessel tracking services, allowing for up-to-date images of the coastal traffic within their range. With terrestrial AIS, the quality of the data relies on the availability and density of shore-based monitoring stations, which can be less than optimum in remote and underdeveloped parts of the world. The second way VHF signals are received and transmitted is through satellite. Since 2005, organizations began to discover that short-range signals can be picked up 400 km vertically upward, above the Earth's atmosphere. This was unexpected given the maximum horizontal range at sea level is around 50 nautical miles (74 km). The primary advantage of satellite AIS over terrestrial AIS is that the whole earth can now be monitored for AIS signals. The partnership between fishing vessel monitoring organization Global Fishing Watch and satellite-producing organization, Spire, highlights the significance of this development. Before the GFW and Spire partnership, tracking fishing vessels outside the range of terrestrial receivers was unreliable and incomplete. In 2017, these two organizations partnered: GFW drew on Spire's AIS feed to upload the data onto an interactive, public map that provides a visual of global fishing activity (GFW, 2020).

The way AIS is being used to track fishing vessels is rooted in a shared history of the global sensing apparatus as a global surveillance tool. The dramatic increase in maritime transportation in the 1990s led Vessel Traffic Services to shift to AIS, from manual or visual tracking with voice and radar communications between vessels and shore. This shift is responsible for making vessel reporting increasingly automatic and instrumental in collision prevention along busy maritime lanes and checkpoints (Mullins 2007). According to Pezzani and Heller (2019), the evolution of AIS into a global sensing apparatus is similar to technological advancements that facilitated the development of an "integrated, multi-purpose, continual data collection system of a global scale" in oceanographic science (Lehman, 2016). They compare the impacts of the evolution of AIS with the introduction of modern astronomical navigation in the fifteenth century, when Portuguese sailors were able to navigate independently with the development of celestial navigation tools (see also Law 1984; Sharpe 2016). These developments, they argue, allowed seafarers to undertake oceanic voyages on a global scale and were critical for the expansion of European trade, domination, and European colonial expansion (Pezzani & Heller 2019).

Today, AIS is a critical instrument within a system of logistics that is central to the global supply chain and border surveillance. For shipping, AIS is employed to plan the movements of large fleets of ships to optimize fuel consumption and maintenance costs. In commodity markets, AIS data has been used to predict prices in ports around the world. The use of satellite receivers to extend the coverage of AIS beyond coastal areas is a recent development that emerged as part of the "war on terror" in response to perceived risks to global maritime traffic. Thomas (2003) argues that these developments in the technological capabilities of AIS and the applications for which it is employed, coupled with the growth of cloud processing, and big data analytics combined with GPS technology, have precipitated the global spread of this geospatial technology (Thomas 2003). It signifies "the largest paradigm shift in the maritime world since the introduction of the steam engine and the screw propeller over 100 years ago" (ORBCOMM 2016). The Global Fishing Watch map is an excellent example of how AIS has produced a paradigm shift when applied to fisheries management and labour in fishing.

Map-making and global fishing watch (GFW)

The map and data that are produced by Global Fishing Watch are separate but connected with the various applications and partnerships that have been organized around its use. Here, I briefly outline the organizational background of GFW, define how the program defines fishing activity, and describe how I used it to track Taiwanese fishing vessels. Global Fishing Watch (GFW) was started in 2015 by three organizations: Oceana, an international ocean conservation organization; SkyTruth, a technology firm using satellite imagery and data for marine conservation; and Google, whose instruments and contributions work to process big data. The organization was established as an independent, international non-profit organization that works together with governments, research institutions, nongovernmental organizations, and the fishing sector. In addition to providing free online mapping and vessel-tracking software, GFW funds different research and innovation projects that employ satellite technology and machine learning to analyse big data and publish findings on issues in the fishing industry. GFW partners in the academia, science, and advocacy communities use remote sensing and vessel positioning data to publish research on forced labour, illegal fishing, or transhipment data in an effort to "achieve more sustainable ocean governance" (GFW, 2020). An understanding of how vessel monitoring, mapping, and data are produced provides a necessary background for analyses that seek to incorporate this information into research that investigates work at sea.

A review of the definitions taken from GFW provides some context for how they shape the way the site can be navigated by users. For example, the data set they call Global Fishing Activity "monitor(s) vessel-based human activity at sea in near real-time based on the global automatic identification system (AIS) and vessel monitoring system" (2021). The GFW map allows you to choose an "activity": either "fishing" or "presence." If you choose "fishing," then you have the additional option to toggle on "apparent fishing effort" (2021). The GFW algorithm categorizes vessels as either "fishing" or "not fishing" by analyzing data broadcasted by AIS and displays the vessels that are fishing on the fishing activity heat map (GFW, 2022). Apparent fishing activity is determined based on data that detects changes in vessel speed and direction.

Ground truthing at sea: representing workers with machine learning algorithms

Critical analysis of the relationship between machine learning algorithms and bias in ground-truthing research is necessary to help identify how research design, objectives, data collection, methods, and study populations influence results. Complementing information from workers with remote data is different from selectively building machine-learning algorithms with limited ground-truthing research. While I argue that more ground-truthing research with workers could help address limited data sets and variations in the data, this does not negate the possibility of what Noble (2018) termed algorithmic oppression. Jaton (2021) identifies a number of examples of algorithmic oppression: search engines that marginalize women (Carpenter, 2015); health prediction algorithms that consider Black patients riskier than White patients (Obermeyer et al., 2019); and crime prediction systems that are more influenced by skin colour than by criminal record entries (Angwin et al., 2022). However, Jaton (2021) points out that bias is necessary for building machine-learning models and should not be viewed as inherently negative (p. 11). Instead, the role of ground-truthing research should include critical and transparent analysis of data sets on which machine learning algorithm data sets are developed.

Recent efforts to model and identify vessels with a high risk of using forced labour depend on information from organizations like the ILO, worker support organizations, and organizations comprised of workers. Researchers require information gathered from workers by environmental, union, and support organizations to identify vessels that have been associated with labour abuse and/or forced labour to correlate with vessel movement patterns. Without the testimonies of workers and the existence of labour standards like those outlined in ILO's Work in Fishing Convention (C188) and their framework of forced labour risk indicators, there would be nothing to model (Vandergeest et al., 2021; McDonald et al. 2021).

The application of machine learning models to the study of forced labour at sea can extrapolate from this data to produce estimates on the scope of labour abuse at sea. To determine whether AIS data can be used to identify vessels that represent a high risk of using forced labour depends on the development and application of specialized machine learning algorithms that analyse vessel movement patterns. According to McDonald et al. (2021), fishing vessels using forced labour behave differently than the rest of the global fishing fleet: "longliners and trawlers using forced labour travel further from port and shore, fish more hours per day than other vessels, and have fewer voyages and longer voyage durations" (p. 3). To establish the significance of maximum distance from the port and average daily fishing hours as indicators of high-risk movement, McDonald et al. (2021) rely on information from satellite vessel-monitoring data, ILO indicators of isolation and excessive overtime, and human rights practitioners (p. 1). Specifically, the predictive model of high-risk fishing vessels exploits these insights "by using machine learning to identify high-risk vessels from 16,000 industrial longliner, squid jigger, and trawler fishing vessels" during each year they operated between 2012 and 2018 (p. 1). They found that between 2300 (14%) and 4200 (24%) vessels were considered to be high risk for labour abuse during at least 1 year of operation and that the number of crew who could be potential victims is between 57,000 and 100,000 (McDonald et al. 2021, p. 3). The model identified risk across many fisheries, with Taiwanese longliners; Chinese squid jiggers; and Chinese, Japanese, and South Korean longliners consistently showing the largest numbers of high-risk vessels.

The vessel movement patterns and the countries that have been identified by the algorithm developed by McDonald et al. (2021) using AIS vessel movement data are consistent with reports on labour abuse in distant water fisheries. Nevertheless, issues remain with using their algorithm as a predictive model, or more generally, with estimating the degree that we can use vessel movement patterns as indicators of labour abuse at sea. Machine learning algorithms use AIS data to identify and model the movement patterns of vessels that are positively linked to labour abuse. This predictive tool is marketed as a way to model and estimate the prevalence of labour abuse aboard maritime vessels that often operate outside of national boundaries. These technical developments in machine learning can be used to support existing research and highlight risky maritime geographies that require further examination and study. However, there are a number of challenges and details about how the data is produced that reinforce the significance of having reliable information from workers and maritime professionals to guide and corroborate the use of AIS data.

Ground truthing, bias and "dark vessels"

The use of AIS alongside information provided by workers, organizational publications, media reports, and other research on labour at sea is not new (ILO, 2013; Marschke et al. 2020; Lozano et al. 2022). The purpose of this section is to examine how using AIS data to identify fishing vessel movements relies on human inputs that are subject to manipulation and bias, and how using this data to develop machine-learning algorithms is problematic. I argue that more extensive ground-truthing research with workers could help address variations in the data and limited data sets. As the history of AIS shows, the data produced by this geospatial technology can be used in a variety of contexts. While remote sensing data can be used to complement and corroborate the experiences of workers aboard distant water fishing vessels, they should not be considered as a substitute for ground-truthing analyses. Focusing on whether we can use these data as indicators of vessels where working conditions are not acceptable or where there is forced labour can distract from some of the analytical value AIS data has to offer. AIS is a geospatial technology that researchers can use to position labour abuse in time and space, aboard moving maritime vessels. The data can help illustrate a previously unseen maritime geography that captures the movements of the vessels where labour abuse transpires.

Identifying gaps and examining how the data sets and associated machine learning algorithms are produced is part of ground-truthing. According to Kang (2023), "ground truth" is the "referential repository" that serves as the base from which machine learning algorithms are produced: "literally where the truth and possibility of an algorithm are grounded" (p. 3). Kang (2023) argues that tracing the "epistemic limits" of machine learning algorithms reveals a "task-bounding process and a form of intentional biasing that hardlines the limits of the algorithm and the possible range of outcomes" (p. 3). The growth of AIS users has produced a growth in available data and an accompanying temptation to market its uses for different applications, not just in fishing. AIS works best as a device for tracing vessel activity when satellite reception is strong. Strong reception means vessels can consistently and accurately transmit identifiers, and other resources, such as registry records. However, consistent vessel data are not always available, and therefore, when analyzing AIS data, several factors should be considered: (1) AIS transmitters vary—there are differences between Class A and B; (2) global satellite coverage to detect AIS varies; (3) high-density areas of vessel traffic can lead to lower activity estimates; and (4) other considerations—ports and manual identification. With respect to ways vessel information can be manipulated and therefore impact the resulting data on fishing vessel movement patterns, I would add to this list with reference to (1) ships that turn off AIS (as described for the Falklands EEZ), (2) vessels flying flags of convenience (as described for Seychelles), (3) operator error in entering vessel information, and (4) not enough data as evidenced by a small sample of 58 vessels that have been positively associated with documented labour abuse, as described by McDonald et al. (2021).

According to Swartz et al. (2021) "existing evaluation methods for positive-undefined learning systems require some positive/negative-class knowledge of unlabeled cases in the training or test datasets" and their performance "given unbalanced data (with many more "undefined" than "positive" cases) is questionable" (p. 1). Nonetheless, the algorithm is designed by researchers who rely on information produced by GFW and other maritime humanitarian organizations that document worker abuse at sea. Without a model of how vessels are positively *not* associated with labour abuse, the predictive model as it currently operates will produce results that have the possibility of generating both false positives and false negatives.

Without surrounding context, the big data provided by organizations like Global Fishing Watch cannot capture the nuance in fisheries, both in conservation and labour. There is no testing of vessels with similar profiles that have not engaged in labour abuse. The current model is based on tracking vessels that have been positively identified and associated with forced labour. The movement patterns that have been identified as being associated with labour abuse (extended time at sea, port avoidance, gaps in AIS transmission, and transhipment) resulted from the "literature review, and also through discussions with NGOs" (McDonald et al. 2021, p.6). Out of 193 cases that were positively identified and associated with forced labour, 58 vessels transmitted AIS data that could be monitored. According to Swartz et al. (2021), only 21 of the 58 vessels yielded AIS data that could be used to create the model, and "the use of the 21 positive cases to both train and validate the model violates the golden rule of machine learning in that the test data cannot influence the training phase" (p. 1). This means that machine-learning algorithms that use the same datasets to both create and test their models risk undetected errors in databases that can lead to prediction mistakes (Hawkins 2004, p. 1). In the end, with a database of 16,000 vessels, the algorithm identified 4200 vessels as being at high risk for labour abuse.

The use of AIS devices varies by region and is more common in larger vessels and fleets from wealthier countries. According to Kroodsma et al. (2022), "this incomplete use of AIS might greatly limit our ability to estimate the total amount of fishing activity in a given region without accounting for the non-broadcasting, sometimes referred to as 'dark' vessels" (p. 12). These "dark" vessels are associated with illegal, unreported (IUU) fishing, and "of the few hundred vessels on the illegal, unreported, and unregulated vessel list, only a handful broadcasted AIS in 2020 and 2021" (Koordsma et al., 2022). Similarly, an examination of about 200 vessels with reported cases of forced labour showed that only about a quarter broadcasted AIS (Koordsma et al., 2022). With many "dark vessels" either turning off AIS and/or smaller vessels not equipped with AIS transmitters, the associated data sets will continue to offer limited analytical value to the algorithms that rely on this information to build predictive models. However, understanding and investigating these sources of bias provides opportunities for critical analysis of the variables used to study work at sea.

Unpacking Taiwanese fishing across three EEZs

This section examines how maritime territorial boundaries are represented and reinforced through AIS maps. The findings reinforce the capabilities and limitations of AIS data and support the need for further research that connects with workers and examines how different geographical positions may impact labour conditions aboard distant water fishing vessels.

To begin mapping annual movement patterns of Taiwanese vessels on the GFW website, I started by choosing "FISHING" as opposed to "PRESENCE" under "ACTIVITY" and toggling on "Apparent fishing effort" (GFW, 2022). To eliminate the presentation of non-Taiwanese vessels, I used the filter function. Located beside the "Apparent fishing effort" toggle a filter symbol produces a drop-down menu that includes the following filtering options when clicked: SOURCES, FLAG STATES, and GEAR TYPE. For the purposes of this research, I chose AIS for SOURCES, Chinese Taipei for FLAG STATES, and All for GEAR TYPE. In addition, and in the interest of focusing on the movements of Taiwanese vessels, I toggled off the second "Apparent fishing effort" category that is dedicated to displaying vessel movements transmitted by select countries using the Vessel Monitoring System (VMS). Eliminating non-Taiwanese vessels allows the map to focus on the particular country under study without the distraction of other vessels: this is advantageous from both a computing standpoint and also from a visual perspective. Moreover, Taiwan is not one of the seven countries with VMS agreements; therefore, filtering for this does not impact the breadth of available coverage for Taiwanese vessels.

After filtering for Taiwanese vessels specifically, I also chose to map exclusive economic zones (EEZs). Under the category "REFERENCE LAYERS" there are four subcategories: EEZs, marine protected areas (MPAs); regional fisheries management organizations (RFMOs); high seas pockets. Exclusive economic zones (EEZs) extend up to 200

Fig. 1 Global map of exclusive economic zones

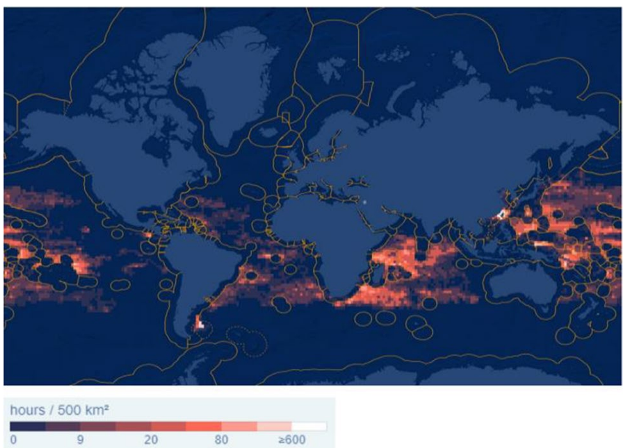


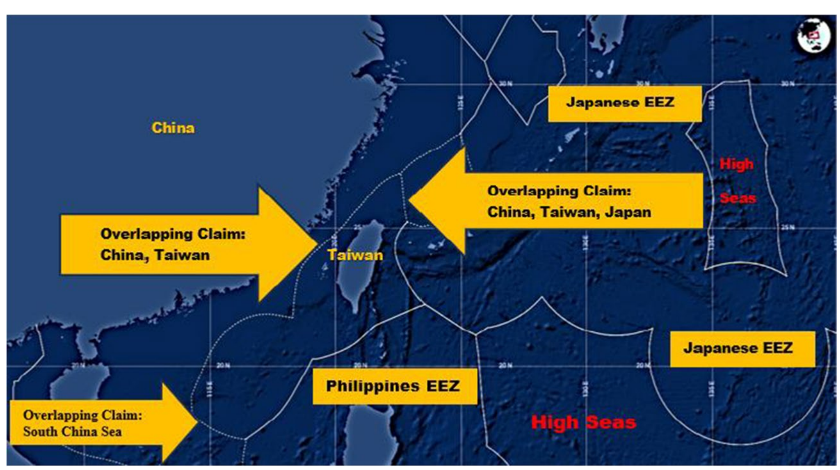
Fig. 2 Map of Taiwanese global fishing effort

nautical miles from a country's coast. How Global Fishing Watch defines, and maps exclusive economic zones is as follows: EEZ boundaries are shown as solid lines for "200 NM", "Treaty", "Median line", "Joint regime", "Connection Line", and "Unilateral claim (undisputed)" and dashed lines for "Joint regime", "Unsettled", and "Unsettled median line" based on the "LINE_TYPE" field. Mapping EEZs allowed me to focus on key geographies where Taiwanese vessels were operating within these established or contested boundaries. In addition to mapping EEZs and filtering for Taiwanese vessels, I set the time scale to capture 1 year from January 1st, 2021, to January 1st, 2022.

Based on these methods, I produced seven maps: (1) a gloabal map of EEZs (Fig. 1), (2) a map of the Taiwanese global fishing effort (Fig. 2), (3) a map of EEZs surrounding Taiwan, (Fig. 3), (4) a map of fishing activity within Taiwanese EEZ (Fig. 4), (5) a map of Taiwanese fishing within the contested EEZ claim of Falkland/Malvinas Islands, (Fig. 5), (6) a map of EEZs surrounding Seychelles (Fig. 6), and (7) a map of Taiwanese fishing activity in Seychellois EEZ (Fig. 7). I use these different maps to highlight the way fishing activity and vessel movement are governed and influenced by terrestrial geopolitics and how vessel movement data can be manipulated.

In part, fishing vessel movements are shaped by EEZ boundaries but in diverse ways depending on the coastal state's agreements with the flag states and/or states where the vessel is owned. These geopolitical maritime boundaries are visible through satellite imagery (see Fig. 1). Figure 2 is a snapshot of a heat map of the annual global movement patterns of the Taiwanese fishing fleet from January 1st, 2021, to January 1st, 2022. From a global perspective, this open-source GFW map that I filtered for Taiwanese vessels showed considerable global fishing activity by Taiwanese-flagged vessels. The heat map showed a high concentration of fishing activity within three EEZs: the first was within the national—yet contested—Taiwanese EEZ (see Figs. 3 and 4); the second was within the "overlapping claim Falkland/Malvinas Argentina–UK" (see Fig. 5); and the third was within Seychelles EEZ (see Figs. 6 and 7).

Fig. 3 Map of EEZs surrounding Taiwan



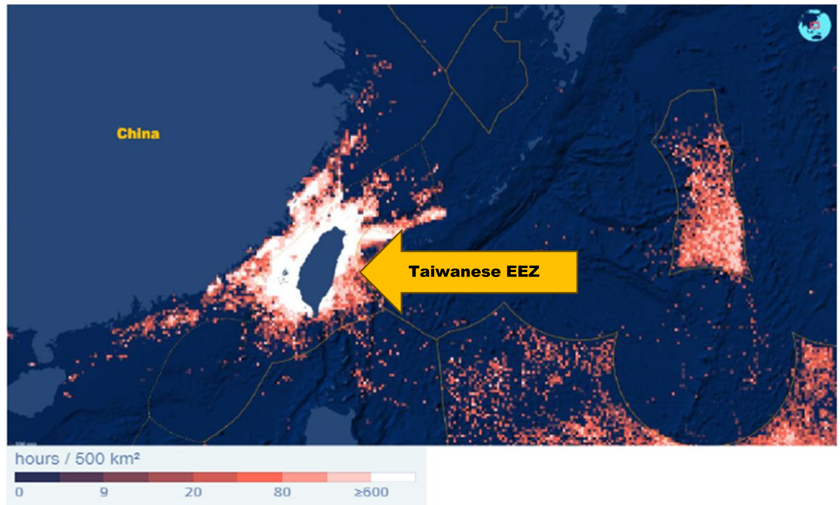


Fig. 4 Map of fishing activity within Taiwanese EEZ

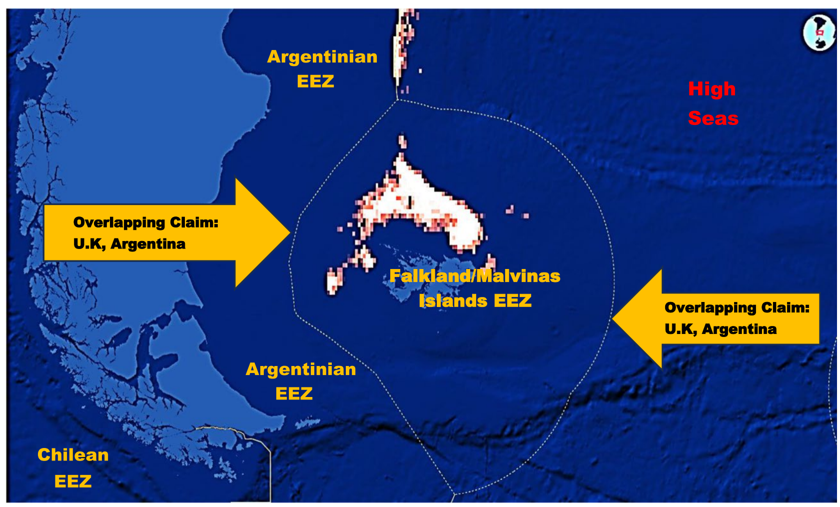


Fig. 5 Map of Taiwanese fishing activity within contested EEZ claim Falkland/Malvinas

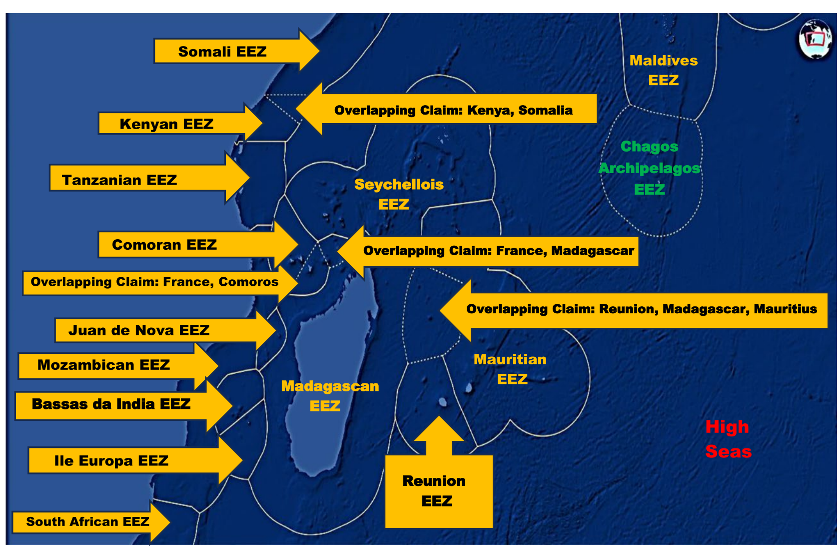


Fig. 6 Map of EEZs surrounding Seychelles

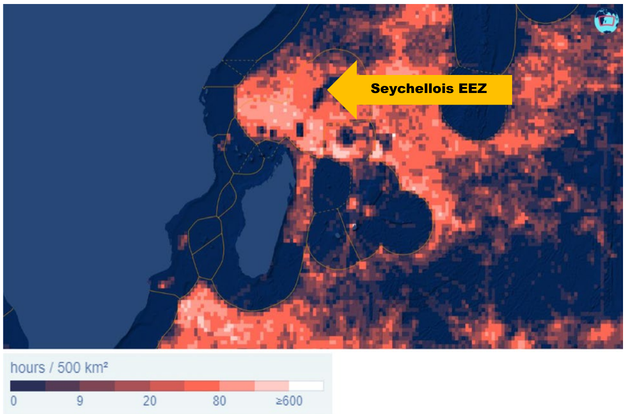


Fig. 7 Map of Taiwanese fishing activity in Seychellois EEZ

Mapping the annual Taiwanese fishing effort illustrates its global coverage. While the maps included in my analysis are static, the Global Fishing Watch maps can be set in motion. The annual movement patterns of the vessels that make up the Taiwanese fleet reflect the movement of the various species of fish they target; however, the GFW map shows how, for the most part, vessels follow geopolitically established boundaries like RFMOs, marine protected areas, high seas pockets, and EEZs. The static map with imposed EEZs draws attention to the overwhelming amount of time large numbers of Taiwanese vessels spend fishing inside the EEZs of a select few countries, as well as their own. The boundaries of the EEZs create a visual limit that governs vessel movements. However, the global reach of this massive fishing effort is more easily perceived when the map illustrates both space and time in motion. The real-time depiction of fishing vessels adds a layer of experience to the maps that contribute to an understanding of the patterns and fluidity that define the ongoing cycle of global fishing efforts.

The maps of Taiwanese fishing activity are representations of maritime "territoriality" through which states attempt to influence behaviour and relationships "by delimiting and asserting control over a geographic area" (Sack 1986, p. 19). In the same way as terrestrial borders and boundaries are necessary for the surveillance and control of movement and property, digitally rendered EEZs and AIS vessel details allow borders and property to be surveilled and controlled at sea. The digital plotting and surveillance of maritime boundaries shape vessel movement patterns as ship captains navigate these controlled geographies. The GFW map highlights substantial Taiwanese vessel activity inside three EEZs the Falkland/Malvinas Islands, the Seychelles and Taiwan's contested EEZ. Exploring vessel movement patterns in areas where EEZ borders are contested and where economic agreements facilitate access reinforces the relationship between geopolitical agreements, mapping, surveillance, and control. Reports on the ground reveal more going on in these maritime geographies. The combination of AIS data produced with Global Fishing Watch and on-the-ground media reports highlights critical geographies where evidence of labour abuse is connected to geopolitical actors.

Taiwanese fishing inside their national EEZ

When operating the GFW map in real-time and with the ability to zoom in on specific geographies, the heat map of fishing activity, filtered for Taiwanese vessels, appears the most concentrated within the Taiwanese national EEZ (Fig. 2), named Chinese Taipei by GFW. Fishing in the Taiwan EEZ is distinct from fishing in foreign EEZs, not just because Taiwan-based vessels do not need to negotiate a fishing agreement, but also because the workers on those vessels are under Taiwan labour laws and regulations. Their labour relations and working conditions are governed by the same laws and regulations as those for terrestrial workers in Taiwanese national territory.

On the map, the borders of the Taiwanese EEZ are solid in some areas and dashed (contested/overlapping); in others, the western border of the EEZ is contested with China; the eastern border is solid between the Philippines and Japan; to the north, there is an overlapping claim surrounding the Senkaku Islands contested between Japan, Taiwan, and China; and to the south, there is an overlapping claim with the South China Sea. The contested EEZ boundaries that surround the island are evidence of how the ongoing dispute over territory extends beyond terrestrial borders. When the map of fishing activity is overlayed onto the EEZ map, it highlights the large number of vessels fishing around the island and illustrates the complexity of managing both fishing and workers in this contested geography. To the West, the overlapping claim that runs the length of the Strait of Taiwan is one of the world's most renowned disputed territories. The Strait of Taiwan has been a political theatre for historical and ongoing efforts to exert control over this highly militarized and strategic maritime geography (see Lee 2022). While the US may not officially support Taiwan independence, the US State Department has maintained that the Taiwan Strait is an international waterway and has openly defied China's claims of sovereignty by sending navy ships and anti-submarine aircraft to patrol the area on more than one occasion (Blanchard, 2023, para. 2). The GFW map demonstrates how large numbers of Taiwan-flagged vessels are present on both sides of the boundary that divides the Strait in this highly militarized geography. Identifying fishing vessel traffic in militarized maritime geographies can provide context and impetus for further examination of how working conditions are impacted in contested maritime spaces.

To the north-east, Taiwan's EEZ is contested by China and overlaps with that of Japan, while the EEZ in the South

China Sea overlaps with those claimed by China, Vietnam, and the Philippines. These overlaps are the source of ongoing conflicts over maritime rights, marine resources, and fisheries. Efforts to enforce and control fishing access in these contested maritime spaces reinforce the impact these geopolitical and geoeconomic disputes have on people working aboard these vessels.

For example, in 2013, while operating in the overlapping exclusive economic zones (EEZs) of Taiwan and the Philippines, a 15-ton Taiwanese fishing vessel was attacked by a Philippines patrol vessel. The attack resulted in the killing of a 65-year-old Taiwanese fisherman aboard the Guang Da Xsing No. 28, and jurisdictional disputes over how to hold the perpetrators legally responsible further highlighted the impact contested maritime spaces have on people fishing in these geographies (Shih et al. 2020, p. 1). Taiwan cannot be a signatory to the 1982 United Nations Convention on the Law of the Sea (UNCLOS), but its ability to both declare and exercise the rights and legal mechanisms prescribed in the convention was emphasized in the international response to the incident involving Guang Da Xsing No. 28. After the incident, the embassy of the People's Republic of China (PRC) in Manila called on countries with diplomatic ties with Beijing to defer to its "one China" policy, and the Philippines government complied in its first public comments on the killing (Shih et al. 2020, p. 7). In response, the Taiwanese government criticized the Philippines for politicizing the incident, imposed a number of sanctions against the country, and deployed military and coast guard vessels to protect fishermen (Shih et al. 2020, pp. 7–8). Taiwan's self-proclaimed EEZ, much of which overlaps with the Philippines' EEZ, is not recognized by the Philippines. The Guang Da Xsing No. 28 case is not an isolated incident and not the first time the Philippines has used violence against Taiwanese fishermen and a number of Taiwan's fishing vessels have been accused of poaching and detained. For its part, Taiwan has declared a temporary enforcement line to protect its maritime rights and to guarantee the safety of its fishermen (Shih et al. 2020, p. 5). As it stands, without international legal status, this enforcement line requires bilateral or multilateral agreements to become effective as a means of fisheries law enforcement.

The Falkland/Malvinas Islands EEZ is a popular geography for fishing squid and is known for selling fishing licences to outside countries (Harte & Barton 2007; Arkhipkin et al., 2013). The global map of Taiwanese fishing showed a high concentration of fishing within the Falkland/Malvinas Islands EEZ. The Islands are southeast of Argentina's mainland, and there is currently a territorial dispute between the UK and Argentina over the Falkland/Malvinas Islands' EEZ. The dashed lines that surround the islands represent these contested boundaries. In February, squid-jigging vessels typically enter Port Stanley in the Falkland/Malvinas Islands to obtain fishing licences from the Falkland/Malvinas Islands Fisheries Department.

The high concentration of foreign vessels and attempts to regulate their activity within this contested EEZ highlights the relationship between labour, fishing, and governance. Fishing vessels can fish legally on the high seas but are not authorized to fish within the EEZs of foreign countries without proper authorization. Nearly 200 vessels from Taiwan, South Korea, and Spain "fished for 251,000 visible hours" during squid season, from January to May, just outside Argentina's EEZ in stretches of sea eastward from Argentina's San Matias Gulf and San Jorge Gulf (Oceana, 2021). More than half of the foreign-owned vessels had at least one significant gap in AIS, which indicates the gap was deliberate (Oceana 2021). In the past, there have been reports of worker abuse aboard Taiwanese vessels that fish within the Falkland/Malvinas Islands EEZ. In 2015, nine Vietnamese workers jumped overboard from two separate Taiwanese fishing vessels in an attempt to reach the shores of the Falkland/Malvinas Islands, and two of them died, and reports suggest this was not an isolated incident (Maritime Executive 2015).

Allegations that ship captains deliberately turn off their AIS systems to avoid detection while fishing illegally are not uncommon and links between illegal fishing and labour abuse are also part of these claims (International Labour Office 2013; Farthing 2021). According to a representative from Taiwan's International Economics and Trade Section, Deep Sea Fisheries Division Fisheries Agency, in response to allegations that 71 Taiwanese vessels allegedly turned off their AIS for extended periods while fishing within the Falkland/Malvinas Islands EEZ and close to the Argentinian border, vessels turning off their AIS may not necessarily indicate labour abuse or IUU fishing (Alberts, 2022). The representative argued that Taiwanese vessels fishing inside the Falkland/Malvinas Islands EEZ are not required to use AIS but were required to use the vessel monitoring system (VMS). Unlike AIS, vessel tracking data produced by VMS is not publicly available unless national governments decide to release it (Alberts, 2022). Nevertheless, the situation highlights implications for research that relies on this data transparency to predict and analyse vessel activity as it relates to worker abuse at sea. If vessels can simply refuse to reveal their movements, then machine learning algorithms and NGOs that rely on identifying vessels and tracking their movements will be without the data that sustain their efforts.

While the enforcement of acceptable working conditions remains with the vessel's flag state, access to fishing within EEZs is organized geopolitically—before any licences are sold. It is important to note that even when vessels flagged to Taiwan are fishing inside another country's EEZ, labour relations and working conditions remain under the jurisdiction of Taiwan. For these distant-water fishing (DWF) vessels, unlike those in the Taiwan EEZ, labour relations are exempted from terrestrial labour law. Instead, the Taiwan government has formulated labour regulations specific to their Distant Water Fishing (DWF) fleet, which is supposed to be monitored and enforced by their Fisheries Agency, rather than their labour department (Vandergeest & Marschke 2021). Nevertheless, coastal/EEZ states can leverage their control over access to fishing to pressure flag states to respond and do more to ensure decent working conditions.

Working conditions on Taiwanese DWF vessels have been subject to considerable international scrutiny and criticism; in response, the government has been reforming these laws; although, we do not know yet if they will be able to monitor and enforce. In response to requests for a review made by seafarer organizations including The Sailors Society, The Apostleship of the Sea, The Fisherman's Mission, The Mission to Seafarers and Human Rights at Sea, and the Falkland/Malvinas Islands Executive Council announced new measures of reform in the fisheries sector (Maritime Executive 2015). These efforts indicate the relationship between governance and maritime boundaries, in that when labour abuse occurs inside EEZs, respective national governments can be pressured to respond by local organizations. It also suggests that NGOs have started to advocate for AIS signals to be required on all fishing vessels so that they can be publicly tracked. Vessel monitoring allows coastal states to track and document vessel movements within their respective geopolitical and economic boundaries. In addition, free online vessel-monitoring services have the potential to allow workers to document how long ships remain at sea without returning to port and lend credibility to worker testimonies by helping to position claims geographically.

Taiwanese fishing in Seychelles EEZ

The Seychelles EEZ boundary is bordered by Madagascar's EEZ and by the Indian Ocean high seas. The GFW map shows that large numbers of Taiwanese vessels operate within the boundaries of the Seychelles EEZ. In 2020, the Seychelles government published a registry of the 180 large-scale vessels granted access to fish in the country's EEZ; 66 of them operated under the Taiwanese flag. However, due to confidentiality clauses, the agreements with the Taiwanese fishing interests have not been published and the data on longliners, transhipments, landings and catches are not made public. According to Alberts (2022), fishing vessels from EU countries have to pay to operate in Seychelles' EEZ each year (para. 28). In addition to selling fishing access within their EEZ, the entire Seychelles purse seine fleet is flying "flags of convenience"/ "[the] 13 vessels that fly Seychelles' flag are "effectively in European hands," with countries like Spain and France having lengthy histories of substantial ownership (Vyawahare 2021, para. 21). This means that in addition to selling fishing access to vessels flying flags from outside countries, the vessels flagged to Seychelles are also owned by business interests from outside the country. Legally, this means that labour relations on those vessels are under the jurisdiction of Seychelles.

Vessels that fly flags from a nation that is not where the vessels are owned is a common practise; however, AIS is not designed to identify which vessels are flying flags of convenience. GFW and AIS systems in general rely on information about vessels including the flag state that is inputted into the transponders by ship owners and ship captains. Information on the ownership of vessels is not immediately apparent with AIS data. For vessels fishing in the Seychelles EEZ, the government publishes an online registry which reports on fishing access agreements; however, this registry does not provide ownership details for Seychelles-flagged vessels. These transparency issues reinforce how the production of AIS data relies on information from ship owners and ship captains.

Discussion and conclusion

The geopolitics of mapping technology at sea impacts the movement patterns of fishing vessels that navigate in and through these maritime borders. AIS vessel tracking only works when ship captains are broadcasting the position of their ship, and satellites are not witnesses to working conditions. The idea that future research, policy, and action should involve consultation with multiple sources of information on maritime working conditions, particularly with workers themselves, is not new (see Lozano, et al., 2022). Ship movement data produced by ship tracking technology—the automatic identification system (AIS)—can contribute to research on work at sea. Can satellite imagery really identify vessels where labour might be forced? Recent research that claims to be able to use satellite imagery and machine learning to identify vessels that have a significant probability of using forced labour has received considerable attention (McDonald, 2021). There are challenges and limitations with this approach, and it should not be considered a substitute for analyses based on ground-truthing research that focuses on worker testimony and experience. Analysis of vessel movements across three EEZs where high concentrations of Taiwanese vessels are operating highlights similar limitations and gaps in relying on AIS data to observe the varying degrees of worker abuse aboard fishing vessels.

Making connections between labour issues and how vessel movements are governed deepens the study of work at sea. The ship tracking and mapping capabilities that geospatial technology (AIS) and the Global Fishing Watch mapping software provide create an opportunity to observe fishing vessels as they move through established maritime boundaries. My focus on EEZs is designed to inspire further investigations into other maritime geographies like RFMOS, marine protected areas (MPAs), or high seas pockets and how these boundaries influence the surveillance and movements of vessels. While mapping the movements of vessels is not a substitute for research that engages with worker experience, the capabilities of AIS have the potential to provide context and to support worker testimony thereby enhancing the study of working conditions at sea. The analysis in this paper focused on identifying patterns of a global fleet of fishing vessels that have been identified as having a record of labour abuse and tracking their movements within established geopolitical boundaries. Future research can use AIS data to focus on specific vessels by name, vessel type, or other variables to produce maps that contribute to research projects that move beyond global patterns to more local geographies.

The examination of Taiwanese fishing inside their national EEZ and the EEZs of the Falkland/Malvinas Islands and Seychelles was facilitated by the capabilities afforded by remote sensing. Observing the global movement patterns of Taiwanese fishing vessels on a map inscribed with EEZ boundaries illustrates the way vessel movements are dictated by geopolitically established maritime borders. The uniformity that defines adherence to EEZ boundaries, with respect to global vessel patterns, makes instances of border transgression particularly noticeable on AIS maps. These border anomalies, where national boundaries are contested or where geoeconomic agreements facilitate entry, provide insight into the way maritime space is governed, and how vessel movement patterns are manipulated by terrestrial geopolitics. My analysis also illustrates the ways AIS data is subject to manipulation through flags of convenience, ship captains switching off their transponders, and variations in satellite coverage. Connecting surveillance technologies to geopolitical and geoeconomic contexts does not directly address the challenges facing workers aboard distant water fishing vessels. However, identifying how geospatial technology can be manipulated and understanding the ways in which it is being used to reinforce existing methods of control are necessary first steps in unlocking and democratizing its future use.

Finally, as the use of AIS becomes more prevalent attempts to do more with the data will likely increase. In addition, increasing pressure for transparency including the release of national VMS data and other sources of vessel tracking will likely continue to add depth to data sets and provide avenues to investigate the human manipulation of AIS usage. While this paper has explored the limits of using algorithms based solely on limited data sets of bad actors, the intention is not to discredit or discourage ongoing research that seeks to better working conditions at sea, including machine learning. The value of an algorithm is inextricably linked to the quality and depth of data on which it relies. Existing machine-learning algorithms are based on data gathered through ground-truthing research. Continued ground-truthing research that focuses on worker experience and increases the availability of evidence that focuses on working conditions at sea can contribute to the production of data necessary for the production of machine learning algorithms. In conclusion, if the reach of AIS capabilities continues along the path of other geographic information systems, then the technology and accompanying transparency should also diffuse into the hands of those experiencing exploitation at sea.

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Declarations

Conflict of interest The authors declare no competing interests.

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