The importance of maritime domain awareness in fighting illegal, unreported and unregulated fishing

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Introduction

The fight against illegal, unreported, and unregulated (IUU) fishing (FAO 2001) is a multifaceted activity that reflects a range of harmful fisheries practices. IUU fishing is defined as activities that violate laws or occur outside of existing laws and regulations within the national jurisdiction of a state or on the high seas (Brush 2019). Briefly, "illegal" refers to direct violations of laws and regulations, such as fishing without a licence, fishing with gear that is banned, or fishing for prohibited species. Unreported fishing occurs when fishers report the wrong volume of catch or species to the relevant fisheries management authority. Unregulated fishing includes fishing activities in areas or for fish stocks where there are no applicable conservation or management measures in place.

IUU fishing-related activities at sea are extremely difficult to spot because infringements occur in remote areas and operators actively hide their practices using a range of measures, such as not reporting their positions via automated geolocation devices, making frequent flag changes, and transshipping on the high seas. Ultimately, misconduct has to be proven in order for legal action to be effective, and the evidence for this proof has to be gathered directly by manual inspection of catch volumes, species, logbooks and onboard chartplotters. Furthermore, to be effective, IUU fishing must be fought at large spatial scales, so that perpetrators do not just move on to other regions. Therefore, the most successful operations against IUU fishing are conducted when nations get together to share intelligence, coordinate the deployment of patrol assets, and work across national boundaries.

In this article, we demonstrate the current tools used in the fight against IUU fishing, and show how different types of information come together and lead to the identification of highly suspicious vessels that make targets for physical interrogation. To do this, we follow the thought processes and methods of Megan Charley, Senior Intelligence Analyst at the Australian Fisheries Management Authority (AFMA). To understand Megan's work, we first discuss the indicators that are potentially related to IUU fishing activities. Because most of these indicators in and of themselves are not evidence of IUU fishing, Megan must forensically uncover multiple hidden relationships, weigh environmental and geopolitical factors, and collaborate with other analysts to prioritise targets for further investigation. This is illustrated using Megan's contribution to the successful multilateral anti-IUU fishing Operation Nasse between May and August 2022.

Indicators of IUU fishing

IUU fishing activities are seldom observed directly and unequivocally, and implicating a vessel with suspected nefarious practices requires gathering intelligence. Such intelligence includes illegal or suspicious behaviour at sea, suspicious activities in ports, and a vessel's onshore ownership structure. One example of illegal at-sea behaviour is the disabling of

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vessel monitoring systems in areas where their operation is mandated. Other at-sea behaviours are not illegal per se, but often also occur during illegal misconduct. For example, two ships encountering one another on the high seas may legally exchange supplies and crews, but in some cases such activity has been linked to the transfer of catch to avoid reporting, labour abuses, and the trafficking of narcotics, weapons and humans (Belhabib and Le Billon 2022).

A vessel's at-sea behaviour is usually assessable from ship tracks of self-reported position transponders of the automatic identification system (AIS) or vessel monitoring system (VMS) (see Box 1). When these are turned off, a vessel "goes dark" and the resulting disappearance from monitoring platforms is a strong indicator of illegal activity (Welch et al. 2022). We describe how dark vessels can be detected using satellites in the case study below and in Box 2.

Box 1. What are AIS and VMS?

Two key sources of vessel position information are automatic identification systems (AIS) and vessel monitoring systems (VMS). What can we expect from each of these for fisheries monitoring, control and surveillance?

Automatic identification systems are required on vessels of 300 gross tonnage and upwards engaged on international voyages, cargo ships of 500 gross tonnage and upwards not engaged on international voyages, and all passenger ships irrespective of size, by the International Maritime Organization (IMO 2015). Boat owners may voluntarily install AIS units and some countries have additional requirements as part of their vessel regulations, so coverage of smaller fishing vessels can vary significantly between flag states.

The primary purpose of AIS is safety at sea, including collision avoidance. AIS transponders provide information such as the ship's identity, type, position, course, speed, and navigational status automatically to other ships and shore stations, and the transmissions need to be received without permission. This availability has led to the common use of both satellite and terrestrial receivers to harvest all available AIS signals, achieving global monitoring of vessel positions. This makes AIS the largest and most significant source of geospatial ship movement data. But because vessel tracking is not its core purpose, it is notoriously messy to work with.

What to watch out for when using AIS data for fisheries monitoring? One of the primary issues with AIS is that it is not tamper proof. That means operators can intentionally manipulate geolocations to appear in the wrong location (spoofing) or turn transmissions off altogether (a vessel going dark). The static vessel data, such as vessel type and size, is also prone to intentional or unintentional misdeclaration. Furthermore, a large number of AIS messages may overwhelm receivers in busy shipping areas, causing some messages to be lost, but because the transmit rate for AIS messages is every few seconds some data usually gets through.

On the plus side, investigation into suspicious AIS data can be used to identify "red flag" vessels that warrant further investigation. AIS data are also reported in near real-time, and provide a high-resolution track of a vessel's journey. When coupled with other information – such as vessel monitoring systems, regional fisheries management organisation vessel lists, lists of IUU vessels, and ownership information – AIS provides a valuable real-time resource for fisheries analysis.

Vessel monitoring systems are a key component for managing national and regional fisheries. They provide a reliable source of vessel position and catch data, and are generally mandated by coastal states or regional fisheries management organisations (RFMOs). However, VMS messages are typically not transmitted as often as AIS, with common intervals from one to six hours.

For commercial fisheries, the requirement for VMS is high and most vessels will be tracked in this way. However, VMS data are owned by the managing nation or RFMO, and are not necessarily shared with others, so there is often a lack of transparency. Organisations such as Global Fishing Watch are encouraging nations and RFMOs to share VMS data publicly.

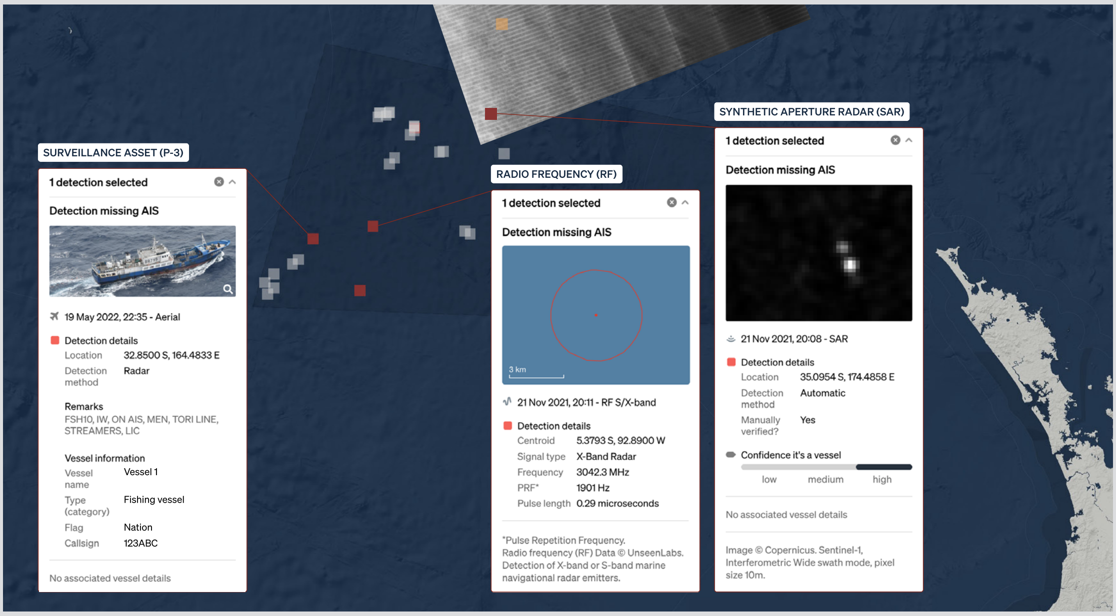
Positive efforts have also been made to increase the number of fishing vessels tracked by VMS. For instance, in the United Kingdom, an iVMS system using the cellular network has been leveraged to enable the tracking of vessels at a lower cost. Despite these initiatives, expanding VMS tracking into small-scale fisheries in developing countries is still challenging due to the cost of the technology.

Box 2. Satellite surveillance technologies

Satellite surveillance is a rapidly growing area for the monitoring of fisheries. Dark vessels that do not self-report their positions using automated geolocation systems pose a risk to nations' fishery resource, and are a challenge to maritime domain awareness. Satellite technology enables the monitoring of large areas of ocean for the detection of dark vessels, and different sensor types offer complementary modes of detection with consequences for specific applications. The most common types of space-based sensors used by fisheries analysts include radio frequency emitter detection, synthetic aperture radar, and optical sensors.

- Radio frequency (RF) detectors can scan vast areas of ocean (up to 10 million km^2) in a single overpass. Emissions from X- and S-band marine navigational radars and VHF and L-band communication devices can be geolocated from RF sensors. Vessels can only be detected if they are actively transmitting RF signals as the satellite passes overhead, which can reduce the detection rate compared to alternative technologies.
- Synthetic aperture radar (SAR) is an active sensor that locates vessels by transmitting radio signals towards the ocean surface and detecting backscattered energy at the satellite receiver. Using large-area modes, regions up to 225,000 km^2 can be scanned by SAR, typically detecting vessels over 20 m in length. Higher resolution SAR sensors can be used to detect and, in some cases, categorise smaller vessels, but have a significantly smaller spatial footprint.
- Optical imagery has limited utility compared to RF and SAR technology due to the relatively small footprint provided by these sensors and the requirement for a cloud-free field of view. Under specific circumstances (e.g. constrained areas of interest) optical sensors can provide high-resolution images that can be used to detect and identify vessels.

Results from surveillance operations in the Pacific have demonstrated that satellite technology is an important component of an effective maritime domain awareness tool and the fusion of data from multiple types of satellite technology provides a more complete picture of maritime activity than a single sensor in isolation. Satellite technology should be used in conjunction with targeted aerial and surface patrols which means reducing the time between the satellite data collections and the provision of actionable information to patrol assets is critical to the success of these operations.



Example of vessel detection by SAR and RF satellite scans. Verification of satellite-identified targets by surface or airborne surveillance assets is required for target vessel identification.

At-sea behaviour makes up only a subset of IUU fishing risk indicators. Ultimately, vessel operations are sustained by corporate stakeholders, and vessels conducting IUU activities often have extremely complex ownership structures where shell companies across multiple jurisdictions attempt to hide the ultimate beneficial owner of a vessel (Brush 2019; Carmine et al. 2020). Ownership obfuscation often goes along with alterations and manipulations of a vessel's flag (i.e. the nation where a vessel is registered). For example, an owner may register a vessel in a state with limited regulatory oversight, and not their own home nation, to avoid the scrutiny of catch reporting.

An extensive list of IUU fishing indicators is published in Ford and Wilcox (2022). Top-priority indicators are:

- Captain from different country than crew
- Stopped near another vessel (encounter)
- Last port of call
- Home port
- Country beneficial owner
- Near protected area
- Location last six months
- Most frequent port
- AIS vessel name "Nauticast"
- Crew from country with record of labour abuse
- Area mismatch to activity
- Ship type incorrect
- Navigational status
- Flag from high corruption country
- Change in vessel length or beam

Because any single risk indicator is insufficient to verify whether IUU fishing activity has taken place, analysts must consider multiple indicators simultaneously for several ships.

Practical application of IUU fishing risk indicators

Megan is an analyst at the National Intelligence Unit of AFMA, and her day-to-day role is to uncover the patterns and behaviours of vessels that display risk factors that are consistent with IUU fishing activity. She takes an investigative approach to her analysis, combining as many sources of intelligence as available to gather evidence of vessels that are likely to be engaged in IUU fishing. The more defined the profile of IUU activity becomes, the more targeted enforcement actions can become.

Megan often starts by investigating recorded and real-time ship tracks and identifies movement patterns. Although many movements and characteristics of at-sea activity on their own appear innocuous, patterns and connections over time create a clearer picture of whether a ship is engaged in IUU fishing activities or not. Indicators that raise red flags include:

- Fishing activity in distant high-sea pockets – areas far from exclusive economic zones that are not covered by any nation's jurisdiction and are hard for authorities to reach;
- Gaps in the vessel location tracking where positional transponders have been disabled in locations that have a history of IUU fishing; and
- Anomalous movement patterns where vessels take unusual diversions or move into an area they are not authorised to fish in.

She explains that analysing IUU risks is not as simple as evaluating the risk indicators listed above. While the indicators in principle are applicable globally (Brush 2019), their expression and relative importance vary by region, target species, gear type, and season. For example, in the western and central Pacific tuna fishery, the biggest IUU fishing risk comes from misreporting (89% of the quantified annual volume of IUU fishing-implicated Pacific tuna harvested or transshipped), while illegal, unlicensed fishing is estimated to account for only 5% (MRAG 2021). Characteristic for this region is the prominence of longline vessels that make up 65% of all active Western and Central Pacific Fisheries Commission (WCPFC) registrations.[3] This affects the type of catch, bycatch, and relevant conservation management measures, creating a different risk profile for IUU fishing than, say, a purse-seine vessel-dominated Indian Ocean tuna fishery.

Factors such as climate, economic and market variability also influence the weighting of the risk factors. For example, large-scale ocean–atmosphere variations such as the El Niño-Southern Oscillation (ENSO) dictate where target species of fish are found, and volatility in fuel prices determine how much it costs to reach those areas. Therefore, Megan investigates potential recipients of government subsidies that help offset the high costs associated with fishing in high seas waters, where the lack of oversight increases the risk of IUU fishing.

Encounters and vessel networks

The basic unit for IUU fishing activity is the fishing vessel, but vessels at sea do not operate in isolation. Fleets of ships often fish in the same area, and supply vessels, refrigerated fish carriers, and tankers all form complex interrelationships. Therefore, Megan is particularly interested in fishing fleets and encounters between vessels at sea (Fig. 1) because these can sustain a ship's operation away from ports and regulatory oversight for a long time. This makes time since last port visit and the length of encounters important risk indicators.

Megan says that, "When I see patterns where ships are coming together, I want to dig deeper and understand what is happening there. With this type of behaviour, I look at what types of vessels are meeting up, who owns those ships, what is the ownership history, and any historical IUU fishing prosecutions connected to this network. Combining that external information alongside geospatial data will give me a much clearer view of what is going on there."

Considering encounters with other fishers and support vessels adds a whole new dimension to the problem because the number of ships involved grows exponentially. One tool to help analysts to capture and simplify the complex interconnected web of interactions formed by encounters over time is network analysis. Network analysis allows Megan to look deeper into relationships that may at first be hidden (Box 3). For example, it allows her to uncover a connection between two vessels of interest that

[3] Analysis of the WCPFC record of fishing vessels https://www.wcpfc.int/record-fishing-vessel-database

have not had direct encounters, but can have a relationship via a common carrier vessel that encounters with both. Importantly, inspecting encounter networks also allows her to discount connections between certain vessels, so she can focus the time-consuming investigation of onshore networks on high-risk candidate vessels.

Armed with comprehensive historic and up-to-date vessel tracking information, lists of vessels of good standing and of vessels with a history of IUU fishing, and data science tools, Megan can achieve an effective maritime domain awareness (MDA). This MDA allows her to provide vital intelligence to direct military and civil assets to targets for boarding, inspection, and prosecution in the field. A prime example where these complex layers of intelligence are woven together to result in operative action is "Operation Nasse" (Op Nasse).

Case study: Operation Nasse 2022

Op Nasse is an annual, multilateral maritime monitoring, control and surveillance (MCS) operation to actively fight IUU fishing in the western and central Pacific Ocean (Fig. 2). It is a multilateral effort between Australia, New Zealand, France and the United States. Under the framework of the Pacific Quadrilateral Defence Coordination Group (Pacific Quad), these nations have worked together to conduct Op Nasse on the high seas of the southwest Pacific Ocean each year since 2015, with the United States joining in 2016 (AFMA 2022).

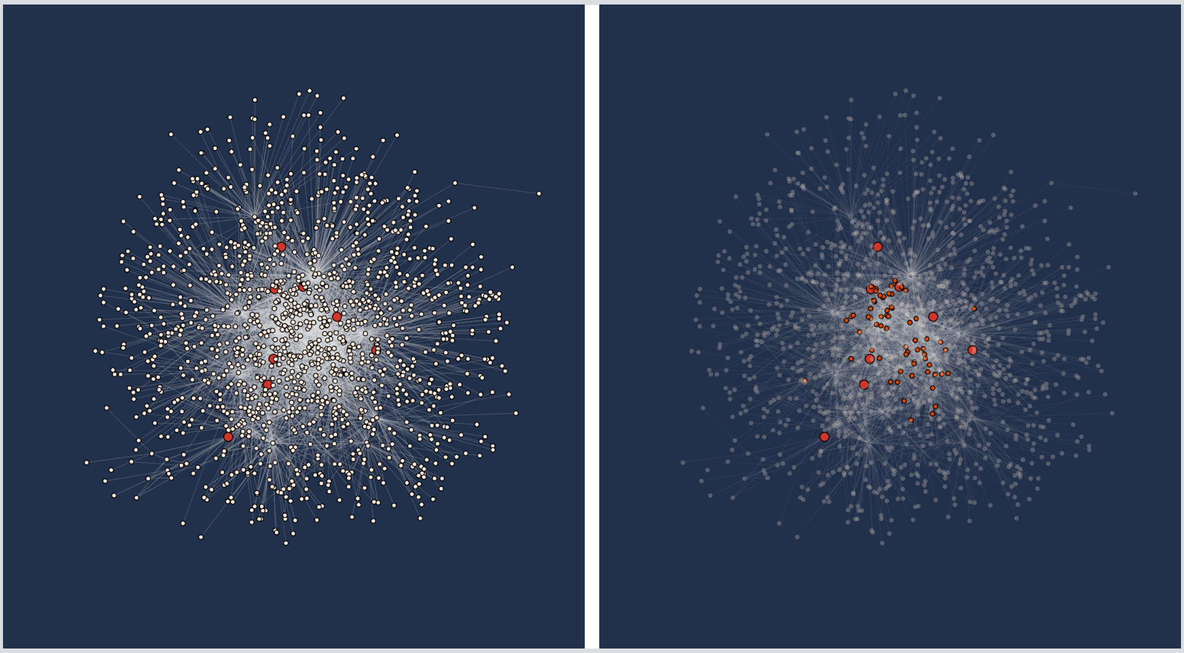
Op Nasse's aim is to target high-risk fishing vessels for high seas boarding and inspection and aerial surveillance.

Box 3. Network analysis as a tool to capture complex relationships

Network analysis is a mathematical method to analyse a group of objects and relationships between them. A network structure consists of nodes and edges. In the case of at-sea networks, nodes represent the vessels while edges represent vessel encounters. Network analysis using Starboard Maritime Intelligence's encounter database and a list of 40 vessels currently or historically implicated with IUU fishing, uncovered relationships to 5000 other vessels.

The high yield of related vessels can be reduced by applying weights to edges based on factors such as current versus previous IUU listing, when an encounter occurred, and the number of encounters. Applying these weights to the 5000 linked vessels reveals a more manageable number of 300 closely linked ones. Close links do not necessarily mean that they are involved in IUU fishing, but rather signals that further investigation may be helpful.

Implementing this analysis into a real-time platform means that decaying weights and new relationships appear dynamically and can provide an efficient and objective basis for intelligence gathering.



Visualisation of a network of vessels linked to IUU-listed vessels. The image on the left shows 40 IUU vessels (red dots) and 5000 vessels with a relationship to those (white dots). In the image on the right 300 closely linked vessels are shown as small red dots.

Note: Some dots are hidden in the 3-dimensional structure of the point cloud.

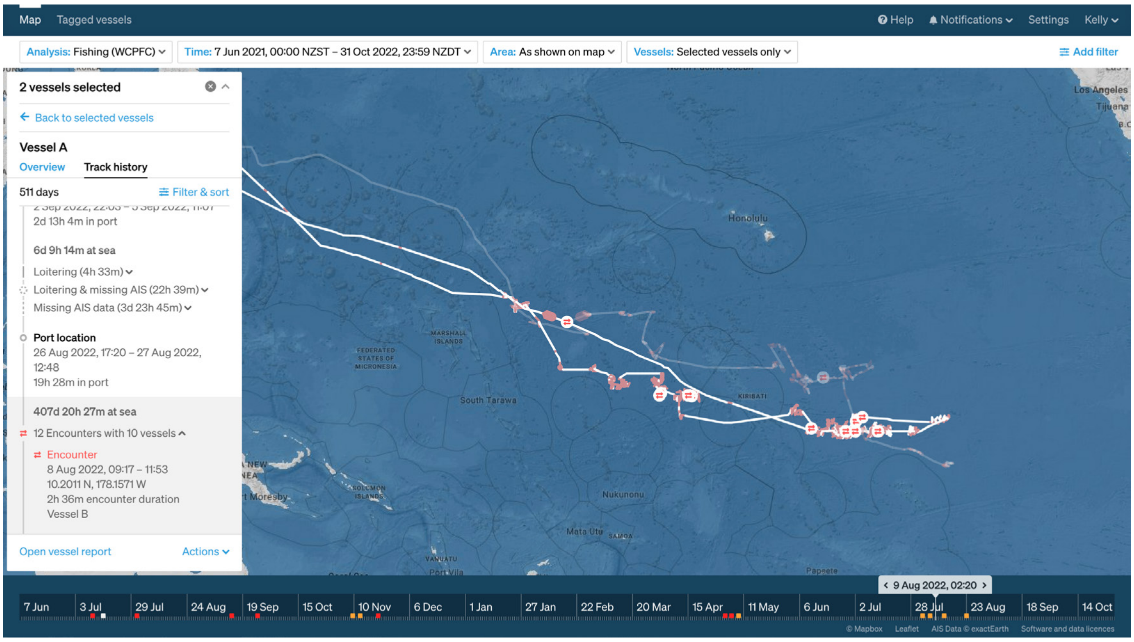


Figure 1. After over 400 days at sea, including fishing in areas of the WCPFC Convention Area, which are generally harder for surveillance to reach, this vessel is returning to port. En route, it encounters another fishing vessel for just over two and a half hours. These potentially high-risk behaviours are clearly identifiable when the extended history of this vessel is visualised.

The goal of the annual operation is to combat IUU fishing activities and better understand the level of compliance among high seas fishing vessels in respect to the WCPFC conservation management measures. The size of the area of the operation and the remoteness of many parts within it necessitate an intelligence-driven approach with effective information sharing and target priorities between the Pacific Quad partners.

During Op Nasse 2022, a joint coordination centre (JCC) was established at the French Armed Forces Headquarters in Noumea, New Caledonia, to coordinate the regional surveillance effort (AFMA 2022). As AFMA's Senior Intelligence Analyst, Megan Charley developed a significant part of the preoperative intelligence and provided recommendations and intelligence to the JCC for operational response.

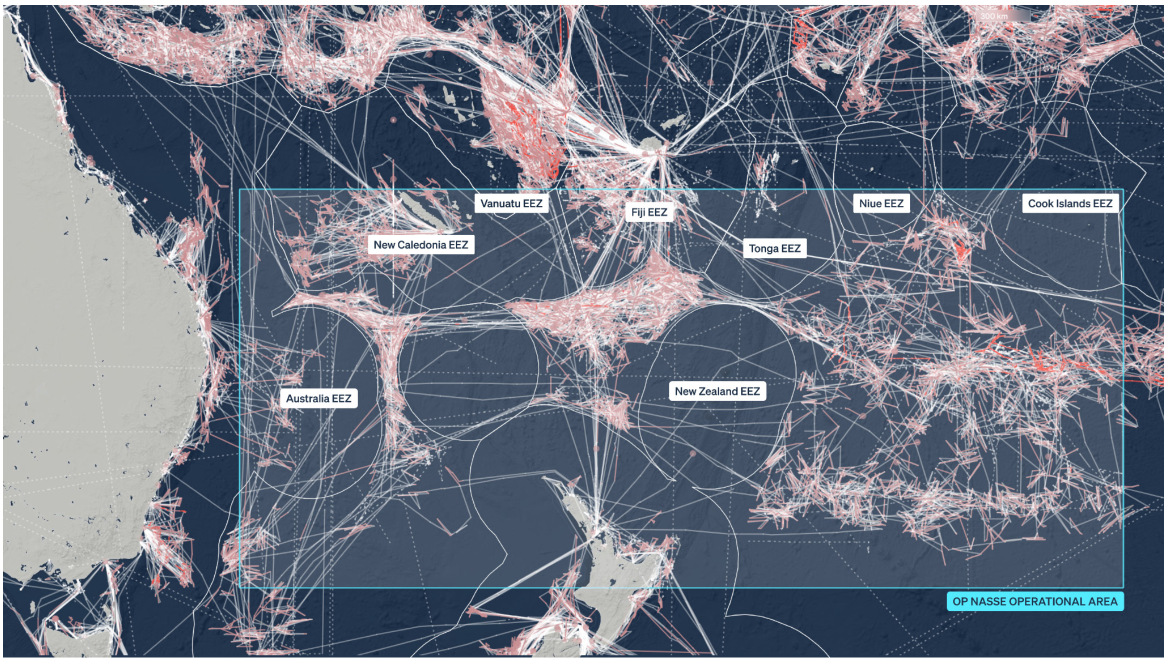


Figure 2. The western and central Pacific with the Op Nasse operational area and national exclusive economic zones. Tracks of 978 fishing vessels from 1 June to 31 July 2022 show intensive fishing activity in the high-seas pockets. Pink tracks indicate active fishing as identified by the Starboard Maritime Intelligence platform's classification algorithm.

Starting with the big picture

Concentrating on the potential of IUU fishing activity in the WCFPC means taking into account over 2700 vessels currently registered and with the authorisation to fish and tranship in the region by the WCPFC.[4] To reduce the number of vessels to just those with potential IUU fishing risk indicators, Megan began by first analysing key environmental and socioeconomic factors in 2022. Specifically, the ENSO climatic pattern was in the La Niña phase during 2022, with strong surface tradewinds piling up warm water in the western Pacific (NOAA 2022). In La Niña years, tuna catches generally shift from east to west (Fig. 3, Zhou et al. 2022).

In addition, Megan focused on distant-water fishing vessels that travel several thousand miles from their home port into remote areas of the Pacific where perceived enforcement efforts may be lower. This may seem a viable business model under government subsidies and reasonable fuel and logistical costs, but the conflict in Ukraine saw fuel prices skyrocketing. As a result, distant-water fishing in the eastern Pacific was likely to incur high operating costs, thus incentivising IUU fishing practices through their potential financial benefit.

Taking into account environmental and geopolitical factors, Megan knew what to look for: a westward shift of fishing vessels that usually target remote areas of the Pacific. She found several such vessels and noticed that their current positions intersected with the Op Nasse area of operations.

Looking deeper into networks

To further validate and prioritise the vessels of interest, JCC analysts investigated several IUU fishing indicators. They sought to identify the beneficial owners, fleet structure, and shareholder networks of the companies, especially where connections may be obfuscated through vague WCPFC records of fishing vessel details, separate ownership listings among shareholders, or using third-party addresses and flags of convenience.

These ownership networks allowed vessels to be grouped into extended fleets that could be analysed for correlations with other potential IUU fishing indicators (Fig. 4). Geospatial analysis of AIS data was conducted using the Starboard Maritime Intelligence platform to determine the operational patterns of fleets, transshipment indicators, time at sea, port visits, anomalous movements, and WCPFC registration details. Notable patterns included:

Figure 3. Fishing effort in the western and central Pacific in May–July 2019 (top panel) and the same time period in 2022 (bottom panel) from Global Fishing Watch Marine Manager app. Using such plots, the intensity of distant-water fishing can be correlated against factors such as El Niño-La Niña conditions (2019 versus 2022, respectively) and geopolitical factors.

4 Analysis of the WCPFC record of fishing vessels https://www.wcpfc.int/record-fishing-vessel-database

- Vessels that routinely travel extensive distances to fishing grounds (Fig. S1), without any identified record of government subsidies or foreign port use. This apparent uneconomic behaviour is an indicator for potential IUU fishing (Brush and Utermohlen 2022).
- Vessels that have a history of:
  - avoiding surveillance areas (Fig. S2) and ports that have robust counter IUU fishing measures in place;
  - making efforts to avoid ports completely, spending long periods at sea (up to two years); or
  - fishing activities such as shark finning, which is illegal.
- Concerns for crew welfare can be inferred from anomalous movements and encounters. Where vessels appear to behave in an abnormal fashion, this will naturally elevate the risk of IUU fishing activity and forced labour concerns (Fig. S3).

Going even deeper, Megan and the analysis team used publicly accessible information, including non-English sources, to discover potential IUU fishing allegations (among other prosecutions) or prior convictions for the vessels, masters, crew, companies, or shareholders. This investigative research identified some vessels and companies as having both IUU fishing allegations and officially recorded court proceedings in foreign and domestic records. Even fleet constituents that do not operate in the Pacific were identified and noted for future use.

Satellite support of Op Nasse

During Op Nasse 2022, radio frequency and synthetic aperture radar satellite acquisitions were used to identify vessels that were not self-reporting their position (i.e. dark vessels). Satellites have a unique advantage in dark vessel detection because they can scan larger ocean areas more often than any other surveillance technology (Box 1). Several satellite scans were scheduled in advance of deploying patrol aircraft and ships, and the satellite ship detections were matched against known ship locations from AIS transmissions to reveal potential dark vessels for the patrol missions (Fig. 5).

A successful operation

Amassing all this intelligence, the JCC analysis team created a prioritised list of vessels of interest within the Op Nasse area of operations and deployed aerial surveillance and patrol boats to intersect with suspicious vessels.

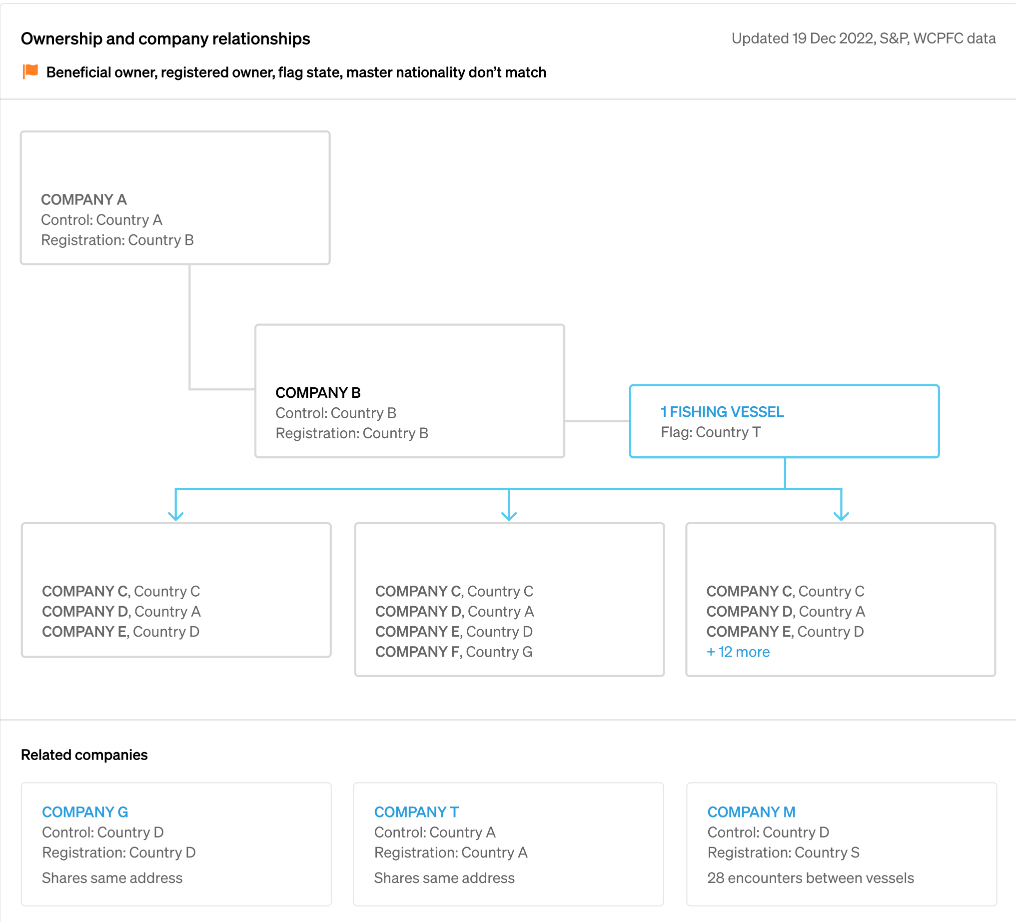


Figure 4. This vessel report prototype from Starboard Maritime Intelligence shows how the inclusion of vessel ownership information in MDA platforms will be able to assist with ownership analysis that incorporates real-time geospatial data.

In total, 18 surveillance flights and 14 high-seas boardings and inspections were carried out. These engagements uncovered 19 potential breaches of WCPFC conservation management measures and at least 8 infringements, with further infringements pending investigations (AFMA 2022).

Infringements included situations where: 1) officers were unable to easily identify shark carcasses and the corresponding fins as required; 2) bycatch mitigation was not deployed correctly; 3) daily catch and effort reporting was not captured accurately; and 4) crew made allegations of poor labour standards (MPI 2022).

Conclusions and outlook

Averaged over the years 2000 to 2003, the global volume of IUU fishing has been estimated to be between 11 and 26 million tonnes of fish taken annually, corresponding to financial losses between USD10.0 billion and USD 23.5 billion (Agnew et al. 2009). The effect of IUU fishing on ecosystem health, the sustainability of fish stocks, and the economy of individuals, communities, businesses, and coastal states can be devastating (FAO 2002). In the Pacific, tuna plays a vital role in economic development and, for many states, food security (Bell et al. 2021; Terawasi and Reid 2017).

The scale and complexity of IUU fishing means that no single institution or nation can fight it on its own. International agreements and cooperation can increase the effectiveness of the fight against IUU fishing as demonstrated by Op Nasse over the years. In 2022, analysis and intelligence provided by Megan and other JCC analysts meant assets such as patrol boats and defence force aircraft were able to be used very efficiently and effectively, resulting in positive outcomes that demonstrate the coordinated capabilities and collaborative intelligence-gathering across partner nations.

Technology has an important role to play in this fight. Megan stresses the importance of a common operating picture as being the foundation of effective collaboration. A cloud-based MDA platform facilitates information sharing with minimal latency, enabling command centres such as the JCC and their outposts, including patrol asset operators, to operate 24 hours a day, seven days a week.

Cloud computing also allows access to cutting edge data science and machine learning tools, such as network analysis, at minimal requirements for computing resources by the end user. Specifically, the software-as-a-service model allows rapid co-development of platform features and bespoke analyses with experts at agencies such as AFMA and the Pacific Islands Forum Fisheries Agency. Expert analysts like Megan are central to this development. When their knowledge influences the development of shared systems, it can transfer to others and build capacity where it is needed, thereby creating long-lasting benefits. Then, when software performs the mechanistic portion of Megan's work, such as determining IUU risk indicators, she can focus on the investigative research and on interpreting the activities in the context of ever changing IUU fishing practices and environmental change.

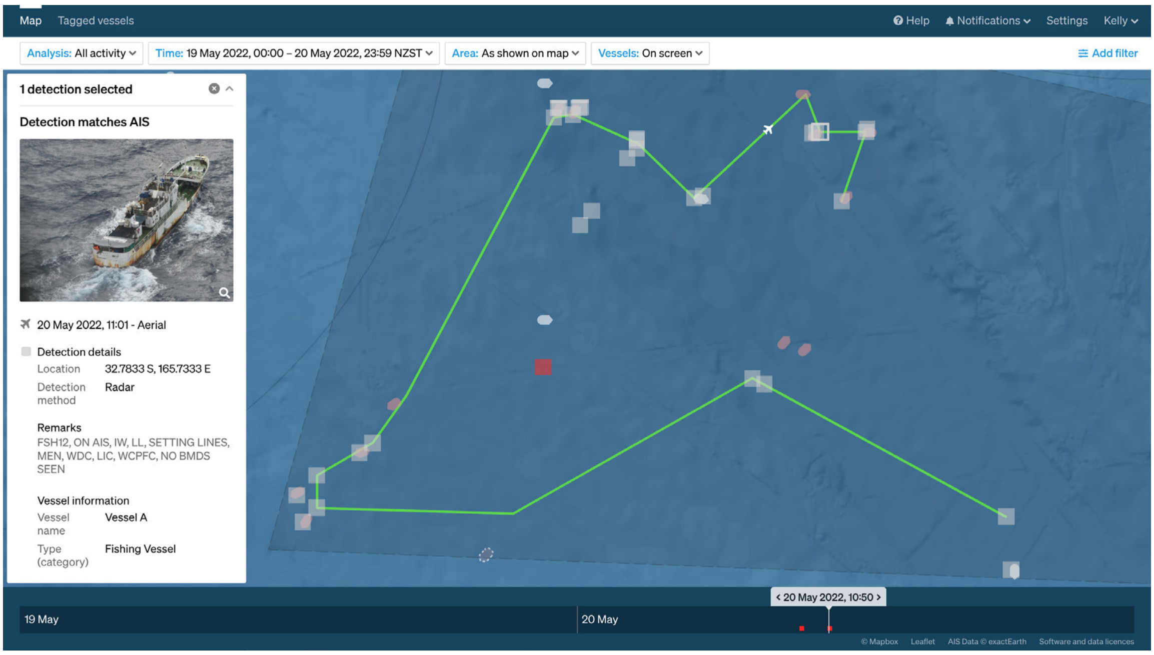


Figure 5. Radio frequency (RF) scan from Unseenlabs shows X- and S-band marine navigational radar detections that matched with AIS positions (white squares). An aerial surveillance patrol flight (green line) validated many of these RF detections and provided photographic evidence of the vessels. The red square identifies a potential dark vessel, a satellite detection that did not match a known vessel position.

Supplementary figures

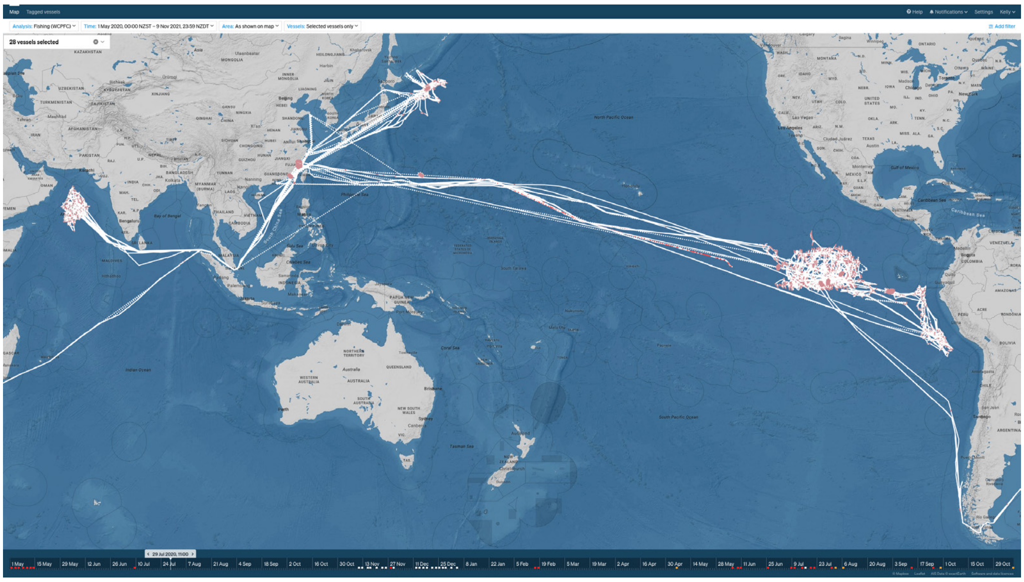


Figure S1. These vessels travelling long distances to fish exclusively in high seas areas are all owned by a single company (Brush and Utermohlen 2022).

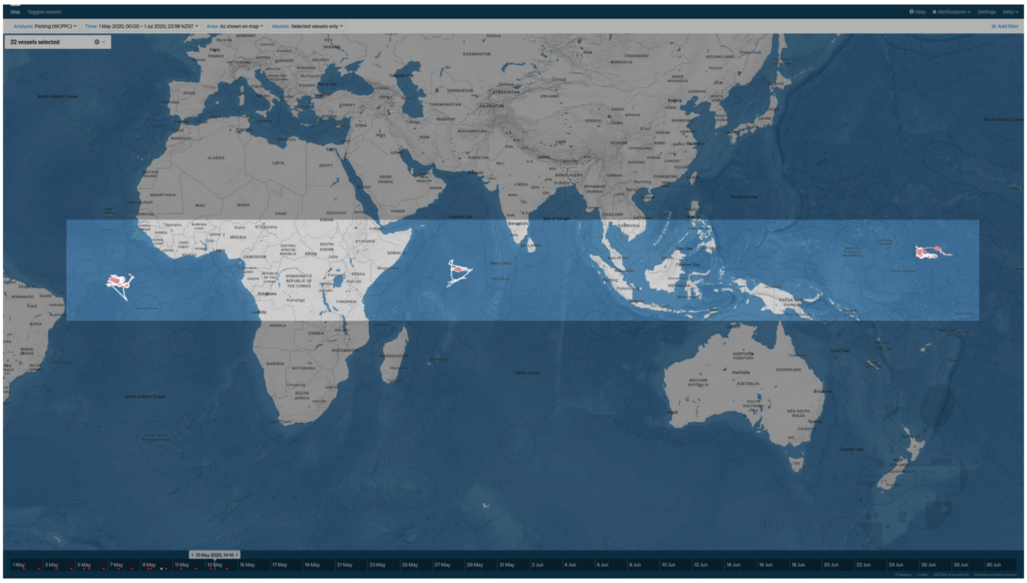


Figure S2. These vessels were all owned by the same company that used banned fishing gear to deliberately catch and illegally cut the fins from sharks in international waters (Jacobson and Gokkon 2022). The vessels' activities prior to discontinuing their operations in mid-2020 were concentrated in distant high-seas locations.

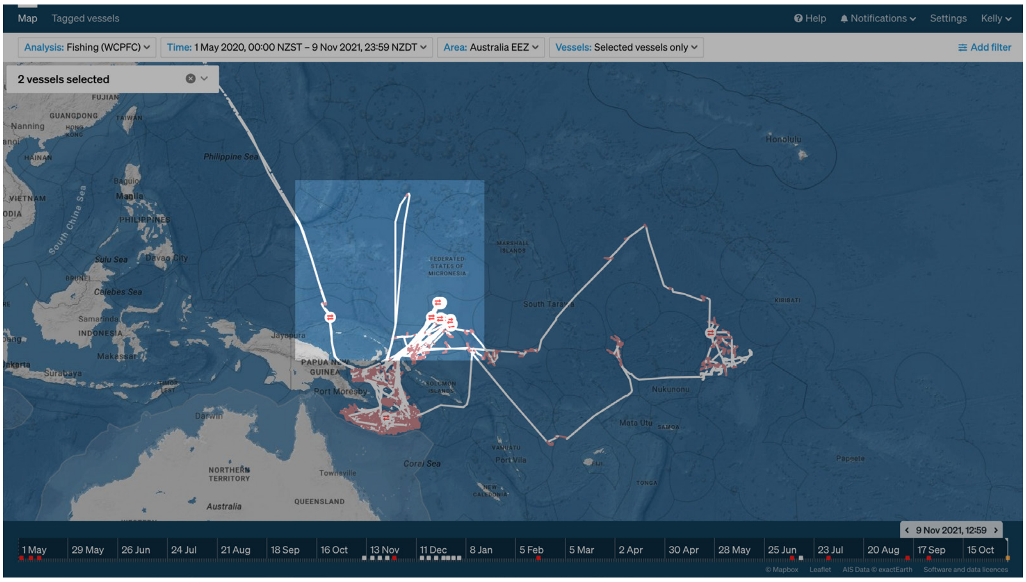


Figure S3. These vessels were identified departing their routine fishing grounds to conduct several fleet encounters in remote areas of the Pacific, while also refraining from further fishing efforts. Subsequent media reporting identified that forced labour was occurring on board the vessels, and that crew members were attempting to contact the local authorities via mobile phone (Jakarta Post 2020). The vessels were forced to depart the region and disembark the crew to avoid detection.

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