

# Satellite surveillance of fishing vessel activity in the Ascension Island Exclusive Economic Zone and Marine Protected Area



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## ABSTRACT

Designation of large expanses of the ocean as Marine Protected Area (MPA) is increasingly advocated and realised. The effectiveness of such MPAs, however, requires improvements to vessel monitoring and enforcement capability. In 2014 commercial fishing was excluded from the Ascension Island Exclusive Economic Zone (EEZ). In 2015, through updated regulations, a licenced fishery re-opened in the northern half of the EEZ while the southern half remained closed. To assess compliance with these closures and regulations, several promising satellite technologies (Satellite Automatic Identification System (S-AIS), Synthetic Aperture Radar (SAR), Vessel Monitoring System (VMS) of two vessels), were trialled alongside at-sea patrols. Use of SAR enabled assessment of 'dark' (non-AIS transmitting) vessels, the scope of whose activities are hardest to gauge. The high level of compliance with regulations observed, suggests the MPA may prove effective, yet a need for vigilance remains. Vessels aggregate near the EEZ border and a quarter of vessels tracked across three years exhibited S-AIS transmission gaps and present a heightened compliance risk. Use of remote, rather than local, expertise and infrastructure provide a blue-print and economies of scale for replicating monitoring across similarly sized MPAs; particularly for large (> ~ 25 m) vessels with metallic superstructures conducive to SAR detection. Funding ongoing monitoring in Ascension is challenged by current levels of license uptake, which provides insufficient offsetting revenue. Satellite-derived intelligence, can be used to set risk thresholds and trigger detailed investigations. Planning long-term monitoring must, however, incorporate adequate resources for follow-up, through patrols and correspondence with flag-states and fisheries management organisations.

## 1. Introduction

Marine Protected Areas (MPAs) are increasingly applied at large spatial scales [1–3]. This trend is promoted by the adoption of international protection targets of 10% of the ocean area, through the Convention for Biological Diversity's Aichi Target 11 [4], reiterated in United Nations (UN) Sustainable Development Goal 14, Life Below Water [3–5]. Since 2005 a number of Very Large MPAs (VLMPA) have been established through designation within the 200 nautical mile (nm) Exclusive Economic Zones (EEZs) of coastal states [1]. VLMPAs are variously defined as areas over 30,000 km<sup>2</sup> [6], or over 100,000 km<sup>2</sup> [7]. The latter include Papahānaumokuākea National Monument, the Chagos Marine Reserve, Easter Island and the Phoenix Island Protected Area [1–3]. The 2020 Aichi target has not as yet been reached, though trends in VLMPA designation have reduced the projected time to its achievement [8].

The adoption of VLMPAs raises issues of monitoring and enforcement over vast, often remote, areas of the ocean, where deployment of surveillance tools such as patrol vessels, shore-based radar, and aircraft is impractical to implement or prohibitively expensive [3,5,9,10]. The argument that remote VLMPAs are difficult to effectively enforce is a barrier to their wider establishment, and is pertinent to ongoing negotiations on a new implementing agreement for the United Nations Convention on the Law of the Sea (UNCLOS) aimed at successful protection of Biodiversity Beyond National Jurisdiction (BBNJ) [11–14].

In May 2015 the United Kingdom (UK) government announced the Blue Belt Programme [15]; an intent to protect ~ 4 million km<sup>2</sup> of ocean around the UK Overseas Territories. The programme is being rolled out between 2016 and 2020 under the management of the Centre for Environment, Fisheries and Aquaculture Science (Cefas) and the Marine Management Organisation (MMO). The initial focus is on UK overseas territories which have designated or committed to the

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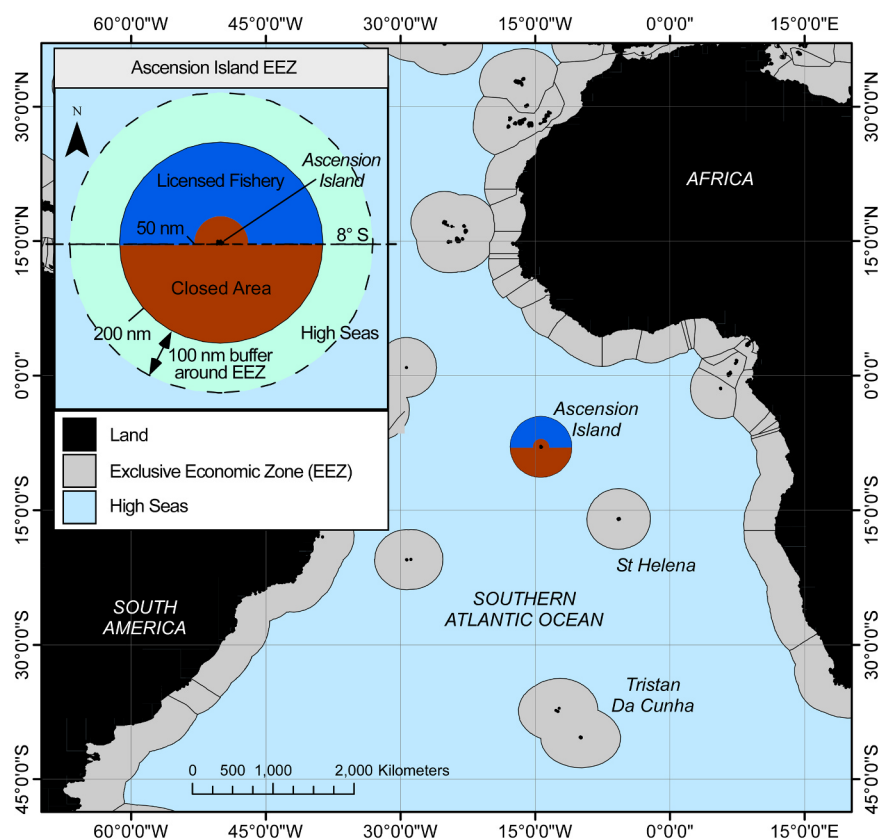
designation of VLMPAs or spatial management measures in [16]: British Indian Ocean Territory (BIOT); South Georgia and the South Sandwich Islands; British Antarctic Territory; Pitcairn; St Helena; Ascension Island and Tristan da Cunha. These remote and expansive oceanic areas comprise small islands with limited infrastructure including the provision of port facilities capable of handling ocean-going patrol vessels. BIOT and Ascension Island host airbases but operation of regular aerial surveillance is economically inviable and logistically complicated.

Designating VLMPAs in regions of limited economic importance is not without criticism, and may be convoluted by wider geopolitics and issues of sovereignty as well as conservation and fisheries aims [6,17]. VLMPAs offer governments relatively easy green wins towards international commitments such as Aichi and SDG14, whilst not necessarily being representative in terms of habitat and species conservation [17,18]. However, to balance this it is clear that VLMPAs such as proposed through the UK Blue Belt programme offer the potential to protect a significant range of marine biodiversity at global scales [8]. Regardless of viewpoint, effective and well-resourced monitoring and enforcement of MPAs is critical to realise biodiversity and fisheries goals [19–22].

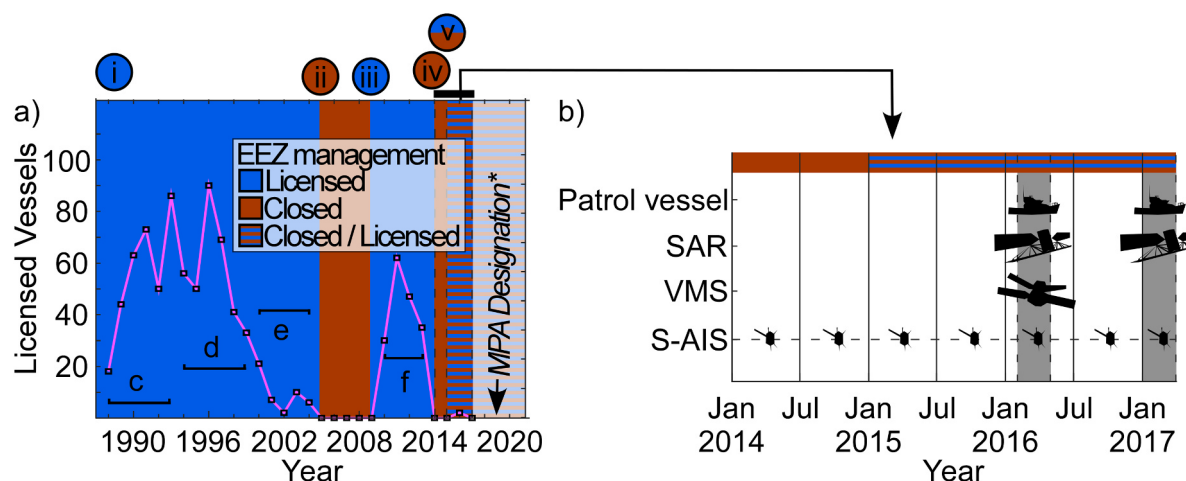
Application of satellite remote surveillance in monitoring offshore fisheries is relatively mature. Vessel Monitoring Systems (VMS) incorporate satellite transponders designed specifically for tracking vessel movements by flag-states [11,23,24]. To assess patterns of fishing, VMS has recently been supplemented with Satellite Automatic Identification System (S-AIS) [2,24–27], a transponder system designed for navigational safety, but promoted as a route to remote surveillance of MPAs [2,11]. Both systems face challenges in that they cannot detect vessels which do not carry or reliably operate transponders. Although manufacturers of VMS have taken progressive measures to prevent tampering [28,29], many systems can be switched off or electronically subverted rendering the vessel “dark” [28,30]. Detection of many dark vessels can be achieved, however, through satellite-borne Synthetic Aperture Radar (SAR) or optical sensors [24,31–34].

A monitoring solution for a VLMPA is reported: the proposed Ascension Island MPA in the south-western Atlantic (Fig. 1). The solution uses a patrol vessel, S-AIS and SAR technologies, as well as the VMS of two licenced vessels. Spatial management of commercial fishing within the Ascension EEZ has oscillated (Fig. 2a) between periods of licenced activity, closure to commercial vessels, and a mixed management approach (Fig. 1). Management of the EEZ has proceeded as follows. Licensed fisheries targeting tuna have operated within the Ascension EEZ since 1988 (Fig. 2a-i). Though the fishery was closed between 2005 and 2009 (Fig. 2a-ii), it was reopened in 2010 (Fig. 2a-iii), before being closed again between 2014 (Fig. 2a-iv) and 2015 to allow a review of the fishery and consider Blue Belt MPA proposals. A compromise was reached balancing goals for the regional economy (a licenced commercial fishery) against conservation aspirations (a fully protected MPA). In 2015 (Fig. 2a-v) the EEZ south of 8°S, encompassing the three main seamounts of Ascension, was closed to commercial fishing, along with waters within 50 nm of the island (red area, Fig. 1); a relatively small scale fishery servicing domestic markets and recreational fishers continues to be permitted within 50 nm of the island. For £20,000, vessels can obtain a license to fish within the EEZ outside of the closed area (dark blue area, Fig. 1) [35]. Pending final review, this closed area is scheduled for designation as a Blue Belt MPA in 2019.

The 2015 spatial provisions, were accompanied by a Fisheries (Conservation and Management) Ordinance from the Ascension Island Government (AIG) [35]. This ordinance formalised: arrangements for licensing, fisheries regulations, powers of the fisheries management authorities, and higher fines for transgression of regulations. Licence uptake since 2015 has, however, been minimal, such that the waters of the Ascension EEZ have been effectively closed to all but two commercial fishing vessels since 2014 (Fig. 2a). Vessels fishing within and around the Ascension EEZ are expected to be registered with the International Commission for the Conservation of Atlantic Tunas (ICCAT); the Regional Fisheries Management Organisation (RFMO) with oversight of fisheries for large pelagic predators in the Atlantic. ICCAT



**Fig. 1.** Ascension Island EEZ, Southern-Atlantic Ocean. Since 2015 the EEZ has been split in to two management regimes: 1) Closed Area (red) within 50 nm of the island and south of 8°S closed to commercial fishing; 2) Licenced Fishery (dark blue) where vessels can operate upon purchase of a license [35]. Vessel analysis conducted within the EEZ, and a 100 nm buffer extending into the surrounding high seas (pale green). Ascension Island: 7° 56'S, 14° 2'W. See online version for color.



**Fig. 2.** Management and monitoring of vessel activity within the Ascension Island EEZ: a) Estimated annual numbers of fishing vessels (all gear) sourced from [57] active in the EEZ based on reported date of entry. Background shading indicates whether the Ascension Island fishery was licensed, closed to all commercial fishing or under mixed management regime (Fig. 1 inset). Dates in coloured circles (i to v) indicate points of changing spatial management indicated in main text. MPA Designation\* - closed area set to be designated as a Blue Belt MPA ~ 2019; b) Satellite monitoring within Ascension Islands January 2014– March 2017 showing periods of observation by vessel patrol, SAR, VMS and S-AIS. See online version for color.

maintains a number of vessel registries: vessels authorised to fish for tuna and swordfish; vessels authorised to receive transshipments (transfer of catch from one vessel to another, typically refrigerated, vessel); and vessels presumed to have carried out Illegal, Unreported, and Unregulated (IUU) activities within the convention area.

Ascension Island has marine and terrestrial biodiversity worthy of conservation efforts. About a million seabirds breed on and forage around Ascension Island [36], and the island is home to one of the largest and healthiest green turtle rookeries in the Atlantic [37]. Bigeye tuna are the principal target species of the offshore commercial fishery, however, yellowfin tuna, albacore, swordfish, sailfish, blue and other marlin species are also taken when caught [36]. The Grattan, Harris-Stewart, and an unnamed seamount are all located within the southern closed area (Red Area, Fig. 1) [36]. Large seamounts such as these often host diverse fish and benthic communities [38,39]. The nearshore includes 77% of the total 173 species of fish estimated for Ascension waters. Eleven species (8.3%) are endemic to Ascension Island and Grattan Seamount while a further 16 species (12%) are endemics shared with St Helena [40]. Black fish are a dominant herbivore and abundant to 50 m depth [41,42]. Photographic surveys of the slopes of Ascension Island to depths of ~ 1000 m indicate a diverse seabed fauna including vulnerable marine ecosystems (VMEs) formed by the cold-water reef-forming coral *Lophelia pertusa* [43].

The main threat to the marine conservation status of Ascension Island is fishing, chiefly by pelagic (drifting) longlines targeting bigeye tuna [36]. Longline gear has the highest levels of bycatch of the Atlantic tuna fisheries, followed by purse seine and gill nets [44]. Other teleost fish are the most at risk of bycatch, however, sharks, rays, seabirds and turtles are also caught [45–47]. The Atlantic blue shark (IUCN: Near Threatened [48]) made up 18% of the Taiwanese Atlantic longline catch [49], while other sharks threatened to varying levels with extinction comprised 3.8% of catch. Across the Atlantic as a whole bigeye comprises about 40% of the overall longline catch, yet around Ascension bigeye comprises about 74% of overall catch and shark bycatch is likely lower [45]. Seabird bycatch in the tropical Atlantic is relatively low compared to fisheries at higher latitudes [50], yet anxiety over bycatch reflects a wider global concern with longline fisheries and interaction with non-target predators [51,52]. The indirect impacts of fishing on marine food webs are of great concern. Seabirds are highly reliant on sub-surface predators such as tuna to drive prey within reach [53]; the population densities of sooty tern for example, appear linked to the density of yellowfin tuna [54]. Many fish species targeted in and

around Ascension waters, such as bigeye tuna are in a state of over-exploitation [55]. Management of species such as blue marlin and blue shark is challenged by uncertainty in catch, discard and stock productivity data [55]. Establishing areas closed to fishing may reduce interactions between commercial fisheries and non-target species, and thereby reduce directed or incidental mortality of species of conservation concern. The effectiveness of closed areas in protecting migratory species remains, however, controversial [56].

Here, the use of S-AIS in concert with SAR and a manned patrol vessel, is assessed with respect to the 2014 EEZ closure and the subsequent zoning of a closed area and implantation of licencing regulations in 2015 (Fig. 1; Fig. 2b). Interpretation of results of this applied study is informed through an examination of regional trends drawing on historical data from licensed fisheries within the EEZ (1988–2013) and ICCAT region (1995–2015). The advantages and challenges to using satellite data to monitor VLMPAs are identified and clarified. Spatial and temporal trends in fishing in and around Ascension Island EEZ are described along with their implications for the application of monitoring and enforcement, as well as the efficacy of the proposed MPA. Finally, the financial underpinnings of the current area based management strategy are considered as a model for Ascension and other proposed VLMPAs.

## 2. Material and methods

### 2.1. Historical trends in fishing activity

S-AIS vessel tracking data were unavailable prior to 2014. A number of data were therefore explored to assess use of the Ascension EEZ by fisheries prior to its closure in 2014 and the subsequent rezoning in 2015 (Fig. 1). Positional data for the licensed fishing fleet (1998–2013) were digitised from [57], and aggregated to a  $0.2^\circ \times 0.2^\circ$  grid to examine spatial and temporal trends in relation to the Ascension EEZ. Monthly estimates of longline fishing effort were assessed from ICCAT  $5^\circ \times 5^\circ$  grid resolution data between January 1995 and December 2015 [58,59].

### 2.2. Satellite monitoring and surveillance

Vessel activity was monitored and analysed by OceanMind (<http://www.oceanmind.global>; formerly known as *Eyes on the Seas*), a technology and service program developed in partnership between the Pew

Charitable Trusts and Satellite Applications Catapult, Harwell, UK. Monitoring was conducted both within the Ascension EEZ as well as a 100 nm buffer extending onto the high seas around the EEZ (Fig. 1). This buffer region was included to provide a full context of vessel activities in the vicinity of Ascension, and identify the location and potential risk level to compliance. OceanMind's platform utilises multiple data sources including S-AIS, SAR satellite imagery, and vessel databases cross-checked against the publicly available ICCAT vessel registries, the International Telecommunications Union and International Maritime Organisation databases. High resolution optical satellite imagery did not form part of this study because of the relatively high cost of the data and the influence of cloud cover precluding reliable vessel detection, while VIIRS night time vessel detection products are locally ineffective because of the South Atlantic magnetic anomaly [60].

Vessel monitoring was commissioned in two phases (Fig. 2b). Phase 1: three months of daily S-AIS and SAR monitoring (1st February – 30th April 2016). Surveillance was timed to fit periods with highest historical catches, but also to provide real time monitoring in support of a patrol vessel. Presence of the patrol vessel allowed the assessment of the value of SAR and AIS data for real time patrol planning. Monitoring and surveillance activities concentrated on the closed and licensed areas of the Ascension Island EEZ as well as the surrounding high seas to a distance of 100 nm (Fig. 1). Phase 2: three months of daily S-AIS and SAR monitoring (1st January and 31st March 2017), and a broader compliance review using just S-AIS and vessel databases to assess activities (1st January 2014–31st December 2016).

S-AIS positional reports were sourced from the data provider exactEarth<sup>®</sup> Cambridge, Ontario, Canada (<https://www.exactearth.com>), and include commercial vessels over 300 gross tons and passenger vessels required to carry AIS under International Convention for the Safety of Life at Sea (SOLAS), as well as many fishing vessels, transshipment and refuelling vessels. Using the exactEarth<sup>®</sup> satellite constellation, the position of vessels fitted with a correctly operating AIS transceiver can be detected globally. Vessels are identified in the first instance by their Maritime Mobile Service Identity (MMSI) number. Fishing buoy markers were also identified based on distinctive MMSIs and low movement characteristics. In the case of the Ascension fishery these buoys likely mark the ends of a drifting longline set, rather than a Fish Aggregating Device (FAD). VMS data for the two licensed vessels in 2016 were transmitted to AIG authorities. All identifiable vessels were checked against OceanMind's databases to verify vessel identity, type, and compliance with AIG [35] and ICCAT Conservation and Management Measures (CMMs).

SAR vessel detection reports, obtained using the RADARSAT-2 satellite, were sourced from MDA (<https://mdacorporation.com/>). In 2016, SAR detections were produced from 32 images acquired in Ocean Surveillance mode (OSVN), while in 2017 SAR detections were produced from 44 images acquired in Detection of Vessels Wide Far (DVWF) mode. In both cases, it was not possible to image the entire EEZ in a single image. The entire EEZ was, however, imaged over the course of the 2016 and 2017 three-month SAR surveillance windows (Fig. 3c–d). Commercial fishing and merchant ships active in and around Ascension Island are composed of highly reflective materials (principally steel), and cause high SAR sensor returns. Additional vessel sightings were provided by the patrol vessel. Individual SAR detections were independently assessed by a team of trained OceanMind analysts and categorised using a three tier high, medium or low 'detection score'. In assigning detections analysts accounted for wave height, a visual assessment of the satellite image, and the confidence estimate provided by MDA. Longliners operating on the high seas in the region of the Ascension Island EEZ are typically longer than 25 m, while purse seine and transshipment vessels are typically longer than 80 m, and can be expected to have a high/medium-likelihood detection scores. Low-likelihood detections were discounted from further analysis, though it is recognised that a small proportion of these detections may represent

true detections, particularly when sea state was rough.

During daily monitoring in early 2016 and 2017, S-AIS provided the first layer of vessel activity and identity information. SAR was used to corroborate the accuracy of AIS data transmitted, to inform anomaly interpretation, such as data gaps in a vessel's reported AIS position, and to identify dark vessels not apparent on AIS. Data sources were analysed and correlated on a daily basis, and used to refine patrol planning by directing the patrol vessel towards areas of high vessel activity. Both dark targets and vessels exhibiting suspicious behaviour were identified and communicated through email to the patrol vessel, and via phone to the AIG's Conservation & Fisheries Department. The patrol vessel was in daily satellite phone contact with this department to obtain and discuss information and communicate ground intelligence.

### 3. Results

#### 3.1. Historical fishing effort

The number of vessels licensed to fish each year within the Ascension Island EEZ has varied (Fig. 2a). Since 1988, the majority of effort has been focussed in the north west, just inside the border of the EEZ, and vessel activities have also extended seaward of this boundary (Fig. 4a). This distribution largely reflects activity during periods of high license uptake in 1994–1999 and 2010–2013 (Fig. 2a, Fig. 4b–e). Peak fishing occurred January–March, again in the north west of the EEZ (Appendix A).

It is hard to apportion fishing effort within the Ascension Island EEZ from ICCAT data, as the EEZ intersects several ICCAT reporting grids (Fig. 5). Ascension sits at the south-eastern edge of the area of highest mean effort (35,000–47,000 estimated hooks set per month; Fig. 5a). This region of high effort extends north west of the EEZ to ~10°N, 35°W. Effort varies spatially and between years (Fig. 4; Appendix B). Hotspots of fishing effort appear close to, or intersecting with the EEZ regardless of whether a licensed fishery was in operation or not during the period analysed (Fig. 2a; Appendix B).

#### 3.2. Monitoring and surveillance

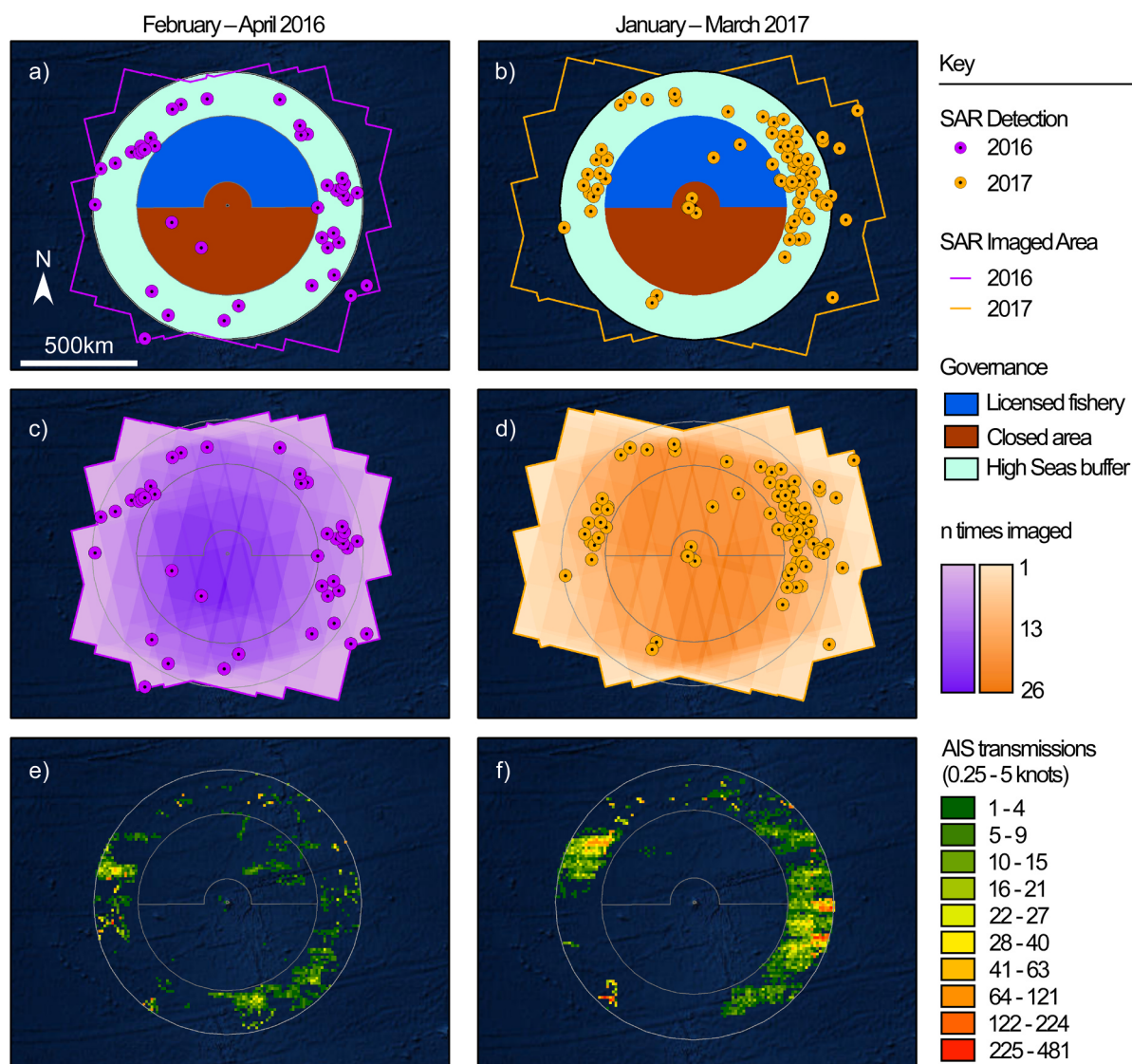
##### 3.2.1. Three-year review (Jan 2014 – Mar 2017)

**3.2.1.1. Fishing trends.** Fishing vessels represent less than 6.5% of the overall vessel traffic (Fig. 6a). Two main fishing fleets were observed. The first fleet is comprised of at least 60 longline vessels, primarily Taiwanese-flagged, operating to the west of Ascension. The second fleet is comprised of at least 29 purse seine vessels, mostly European-flagged, operating away from the EEZ to the North.

Between January 2014 to March 2017 the number of unique fishing vessels visible on AIS increased each month (blue line, Fig. 6b), but with notable seasonality and low vessel numbers between July and September. Peak activity was between November and April, however, the month with greatest vessel numbers varied between years. Through the study, AIS transmitters were increasingly used to mark drifting longline gear (Purple line, Fig. 6b). The number of buoy markers was particularly notable from May 2016, and increased to almost three-fold that of vessels by March 2017. Seasonal trends in the number of buoys deployed mirror seasonal vessel activity. Different spatial trends between vessels and buoys (Fig. 7c and e), however, suggest their use is limited to a small proportion of the fishing fleet.

The three-year S-AIS analysis shows the majority of fishing vessel activity was located to the west, outside of the EEZ, and more than 25 nm from the boundary (Fig. 7d). The spatial distribution of fishing effort, however, did vary between 2014 (Fig. 7a), 2015 (Fig. 7b) and 2016 (Fig. 7c) with a greater intensity of effort to the east of the EEZ in 2016 compared to the other years. There was little discernible effect of the 2015 ordinance (Closure Area and Licencing restrictions) save for a small amount of vessel activity largely reflecting slow speed transit across the north east of the EEZ in 2016.





**Fig. 3.** a) Medium and high likelihood uncorrelated SAR detections within the vicinity of the Ascension Islands EEZ February – April 2016; b) Medium and high likelihood uncorrelated SAR detections within the vicinity of the Ascension Islands EEZ January – March 2017. c) SAR image sampling density February – April 2016; d) SAR image sampling density January – March 2017; e) Density of S-AIS transmissions for vessels type ‘Fishing’ operating between 0.25 and 5 knots from February – April 2016; f) Density of S-AIS transmissions for vessels type ‘Fishing’ operating between 0.25 and 5 knots from January to March 2017. See online version for color.

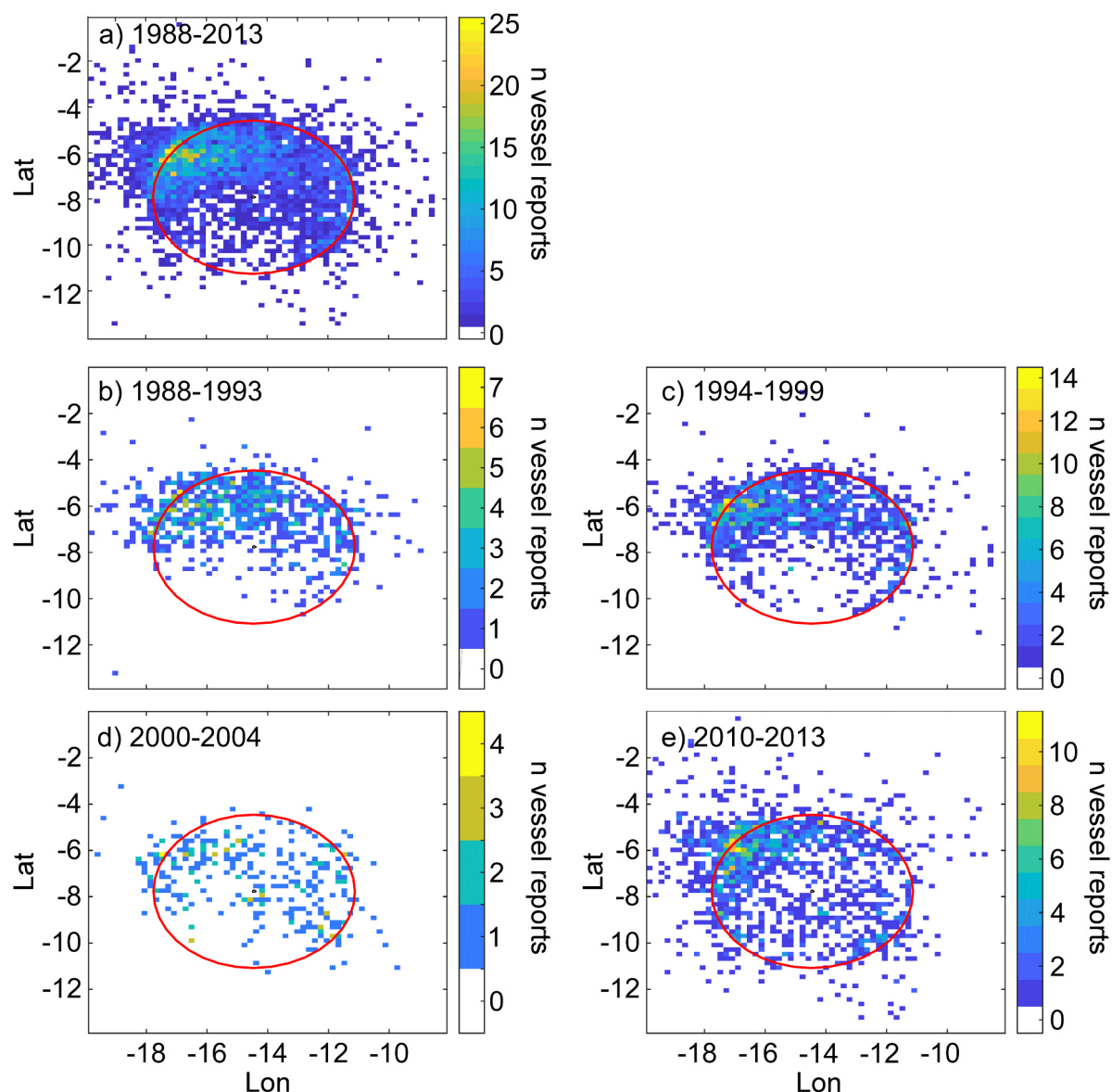
**3.2.1.2. Possible unlicensed fishing, transshipment or bunkering.** A number of vessels were identified using SAR and S-AIS to be engaged in possible licenced and unlicensed fishing, or rendezvous behaviour suggesting possible transshipment or fuel bunker activity (Fig. 8a). In each case the precise nature of activities could not be confirmed through ground investigations. Over the three-year review (1st January 2014–31st March 2016), nine vessels were observed engaged in possible unlicensed fishing, described as either not possessing appropriate ICCAT authorisation or operating within the EEZ without the appropriate AIG license and exhibiting speeds below 5 knots and track behaviour consistent with set and recovery of fishing gear (Fig. 8a). Fourteen vessels exhibited tracks suggesting possible rendezvous with another vessel, which might allow transshipment to occur, often without a second vessel visible on S-AIS within the vicinity. The majority of this potential rendezvous activity occurred outside the EEZ, yet five vessels engaged in such movements within the EEZ. Ten fishing vessels engaged in rendezvous movements with possible fuel bunker vessels, three within the EEZ.

**3.2.1.3. Transmission gaps.** Of the 135 unique fishing vessels

monitored, 33 exhibited prominent gaps in their AIS transmissions (Fig. 8b and c). Such gaps indicate enhanced compliance risk, particularly when associated with the licenced fishing area, closed area and EEZ boundaries. The majority of gaps occurred away from the EEZ and its boundary, however, 11% of gaps occurred within or, based on interpolated path, suggested transit across the EEZ. A further 30% of gaps were of sufficient length to allow a vessel to transit into the EEZ, engage in fishing activity, and relocate back outside of the EEZ and occurred less than 10 nm outside the boundary. Gaps that initiated or terminated within the EEZ, the highest risk class, were restricted to three vessels and occurred between June 2014 and July 2015 (Fig. 8c red line). There were eight gaps from four vessels whose time and position suggested transit across the EEZ. A further 38 gaps were seen in the transmit records of 16 vessels in close proximity to the EEZ.

**3.2.2. SAR correlations and ‘dark vessels’ (Feb–Apr 2016 and Jan–Mar 2017)**

The proportion of vessels identified on AIS as fishing vessels in 2016 (55 of 501 vessels [~ 10%]) was comparable to the number of vessels identified as fishing in 2017 (47 of 406 [~ 9.5%]). However, in 2016,



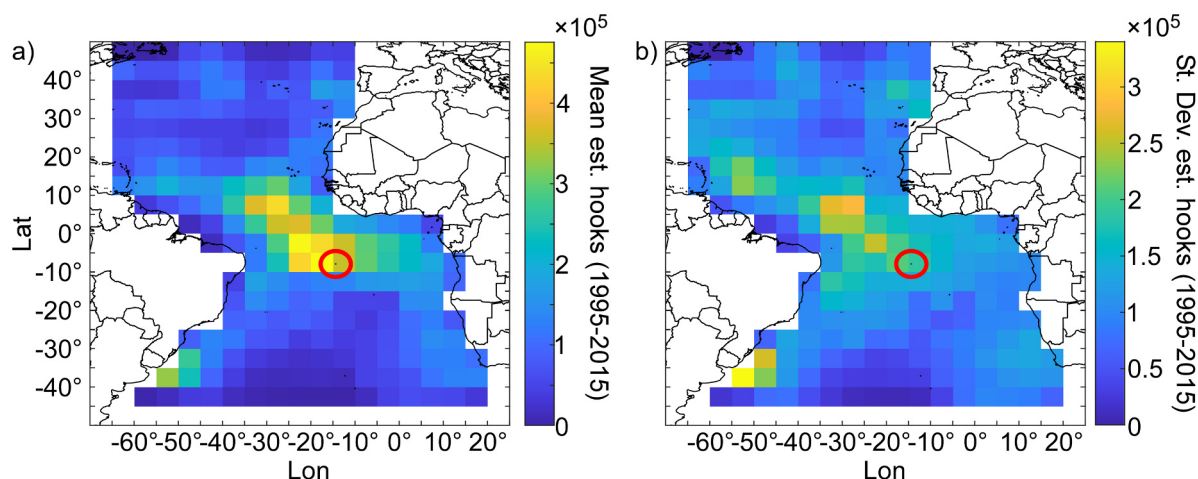
**Fig. 4.** a) Weekly catch and position reports (1988–2013); b–e) Weekly catch and position reports for four temporal blocks shown in Fig. 2a. Red line depicts the EEZ boundary with Ascension Island in the centre (Fig. 1). Number of reports aggregated to  $0.2^\circ \times 0.2^\circ$  grid; colour axis scaled from zero to the maximum number of reports received. See: Appendix A for monthly comparison; and online version for color.

up to 13 of these detections may have been fishing buoys. No vessels were licenced to fish within the Ascension EEZ in 2017. Of the two vessels licenced to fish in the EEZ in 2016 and visible on VMS, one was also visible on S-AIS. The ability of SAR to detect vessels is well known [31,33], but further confirmed here through comparison of detections with the licenced longline fishing vessel transmitting on both AIS and VMS. This vessel was detected six out of seven times when within the SAR image boundary. For the single non-observation, the vessel was located at the extreme edge of the footprint; an area of reduced likelihood of detection. Cross correlation of SAR detections against the positions of known vessels on S-AIS, including merchant and passenger vessels, provides a list of ‘uncorrelated’ detections. On the waters within and surrounding the Ascension EEZ, the vast majority of these detections fit the size profile of longline fishing vessels. While it is not possible to assess whether a vessel is fishing or transiting an area from a SAR detection alone, the presence of unidentified vessels may be an indicator of fishing activity and a compliance risk to be investigated.

In both 2016 and 2017 SAR imagery was tasked to maximise coverage across the EEZ, however, the resultant image effort was not

evenly distributed (Fig. 3c–d). Areas within the EEZ were imaged between 15 and 26 times ( $\sim 1.2$ – $2$  times a week). Nonetheless the majority of uncorrelated vessel detections were located outside of the EEZ (Fig. 3a–b), in areas with a lower image density of between 10 and 20 times ( $\sim 0.8$ – $1.5$  times a week).

In 2016, there were 214 possible SAR vessel detections, of which 93 (43%) could not be correlated to known vessels on S-AIS (Fig. 9). In 2017, 303 possible vessel targets were detected, and 40% were uncorrelated to AIS tracks. The number of high/medium likelihood detections in 2017, both within the EEZ and in the high seas 100 nm buffer, was almost double that of 2016 (Figs. 3 and 8). In both years, the majority of vessel targets were located north west and east outside of the EEZ. All three detections within the EEZ in 2016 were located within the closed area, while in 2017 detections were also located within the licenced fishery area. The positions of ‘dark’ vessels with high/medium likelihood align with observed fishing vessel activity on S-AIS, sharing spatially if not temporally the same fishing grounds (Figs. 3a–b, 3e–f). Broad observations from S-AIS across the Atlantic fishery (not presented) indicate the longline fleet as a whole fished



**Fig. 5.** Longline fishing effort (estimated hooks set) in the central and southern Atlantic (1995–2015), Ascension Island EEZ shown in red outline: a) monthly mean of estimated hooks set; b) monthly standard deviation of estimated hooks set.  $5^\circ \times 5^\circ$  grid ICCAT data [58,59]. See: Appendix B for comparison of January data during licensed and closed periods; and online version for color.

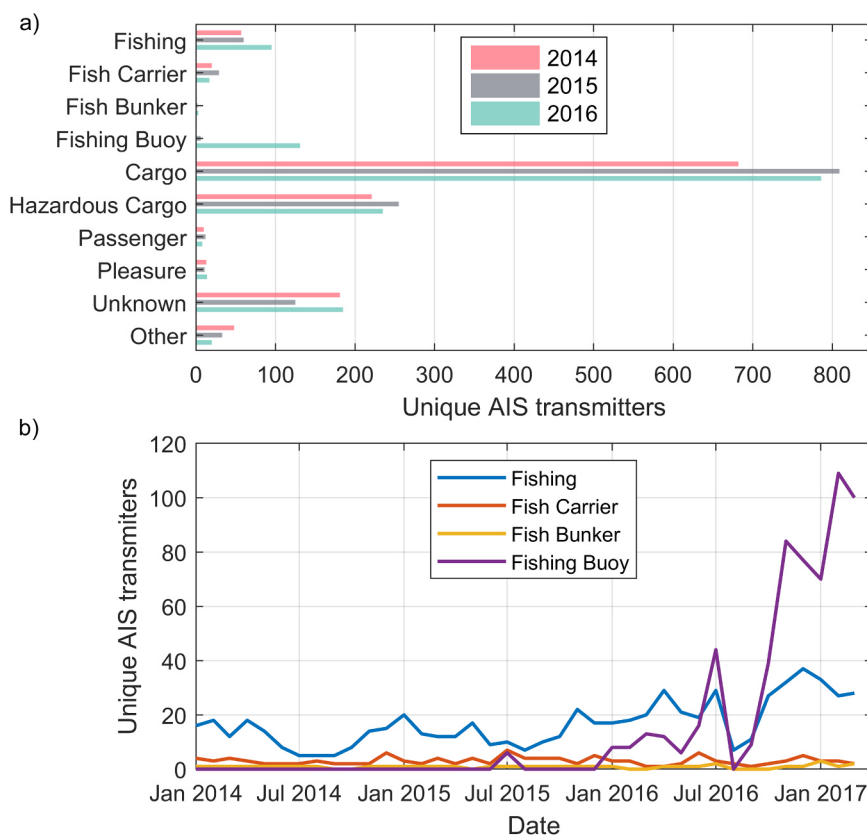
further south and closer to the Ascension EEZ in 2017 compared to 2016.

#### 4. Discussion

Focused on Ascension Island, this paper provides one of the first demonstrations of the combined use of SAR and S-AIS technologies for monitoring compliance in both a large fully closed area (intended to be designated as an MPA in 2019) and the adjoining licensed fishery. These technologies were trialled in conjunction with patrol vessel operations. Studies of predominantly small MPAs suggest they can deliver positive outcomes for biodiversity, the sustainability of fish stocks, economies and local communities [19,20,61]. Can the recent spate of

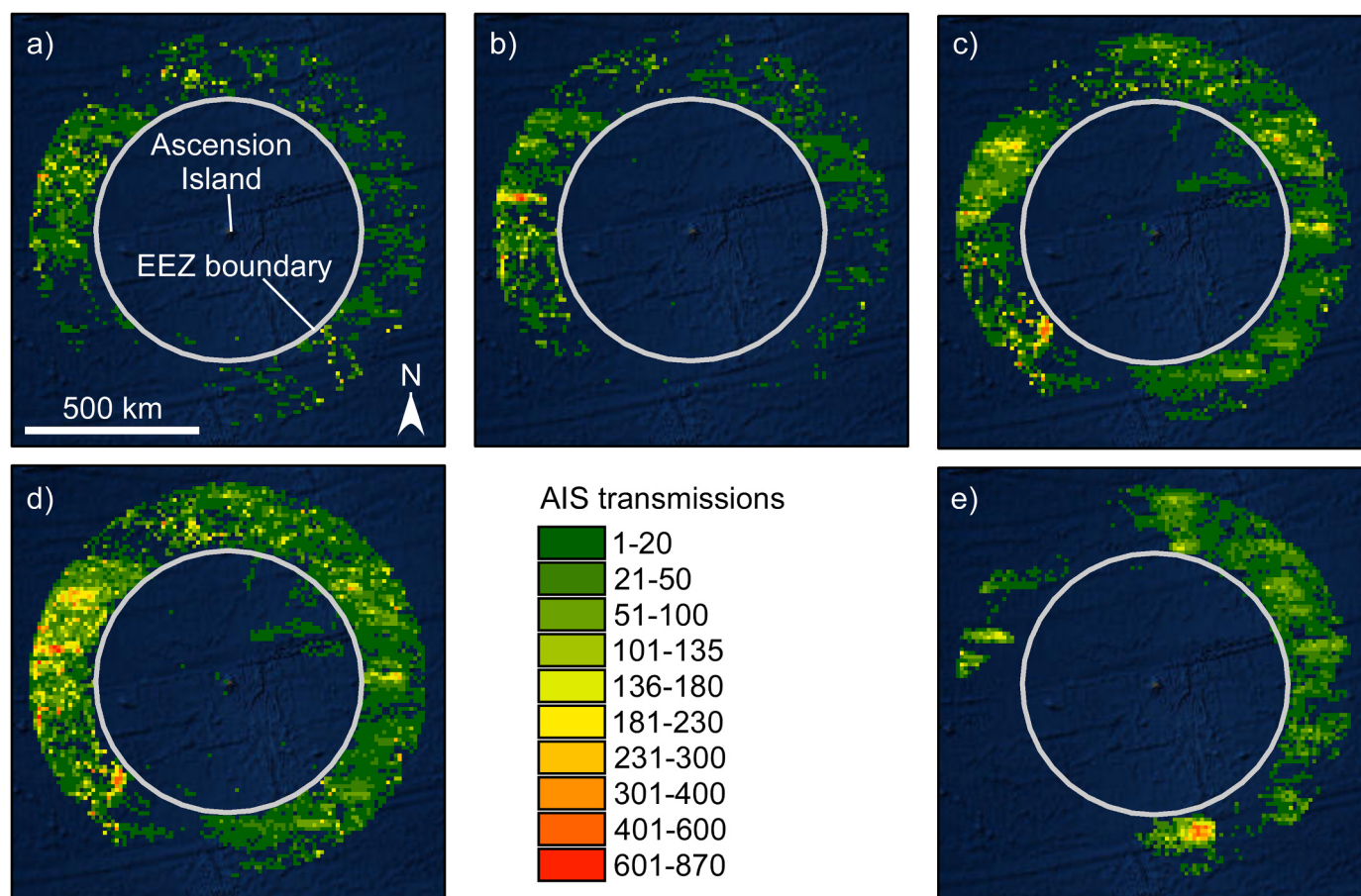
VLMPAs deliver a comparable result? Success will likely hinge on designations with scientific justification and developing monitoring and enforcement capacity, across large and remote expanses of the ocean. Satellite technologies, combined with recent legal instruments such as the Port States Measures Agreement [62] are seen as among the best solutions for ensuring compliance [2,11]. Fisheries organisations must continually wrestle with the value and costs of various technologies and platforms, and make decisions about their frequency and location of use.

In the case of Ascension there is no room for complacency in management of closed and licensed fishing areas. The fishing grounds are clearly desirable, as evidenced by substantive use of the EEZ for fishing in the past (Figs. 4 and 5). Contemporary (2014–2017)



**Fig. 6.** a) Number of unique AIS transmitters grouped by month for each vessel class and year (2014–2016); b) Temporal trends in unique AIS transmitters for fishing related classes within the Ascension Island EEZ and 100 nm buffer. Vessel types: Fishing - longline and purse seine vessels; Fish carrier – refrigerated cargo vessel capable of at sea transshipment; Fish bunker – fuel vessel capable of at sea refuelling of fishing vessels; Fishing Buoy – fishing gear marker; Cargo; Hazardous Cargo; Passenger; Pleasure; Unknown – purpose not defined; Other – e.g. research vessel. See online version for color.





**Fig. 7.** Density of S-AIS activity (number of AIS transmissions): a) vessels type 'Fishing' operating between 0.25 and 5 knots from 1st January 2014 to 31st December 2014; b) vessels type 'Fishing' operating between 0.25 and 5 knots from 1st January 2015 to 31st December 2015; c) vessels type 'Fishing' operating between 0.25 and 5 knots from 1st January 2016 to 31st December 2016; d) vessels type 'Fishing' operating between 0.25 and 5 knots from 1st January 2014 to 31st December 2016; e) type 'fishing buoy' from 1st January 2014 to 31st December 2016. Areas of greatest S-AIS activity shown red, graded through to low activity in green. Areas of no activity shown as dark blue background. See online version for color.

movements of fishing, refrigerator, and supply ships in close proximity to the EEZ meanwhile indicate significant operational capacity and an ongoing risk to compliance. Nonetheless, the fisheries in and around the Ascension Island EEZ appear largely compliant with the 2014 closure, and subsequent rezoning and regulation in 2015 (Figs. 1, 2a, 3, 7, 8; [35]). Indeed, since 2014 there is no evidence of sustained and persistent non-permitted fishing within the EEZ. Since 2014 fishing vessels active around Ascension showed a clear awareness of both the closed area and EEZ boundaries, whether mapped from S-AIS or SAR (Figs. 3 and 7).

Compliance with VLMPA boundaries has been demonstrated using S-AIS for the Phoenix Island Protected Area [2]. In Ascension, confidence in this response is, however, heightened, by the few SAR detections observed within closed areas. This observation is further reinforced by the relatively high SAR sampling effort within the EEZ compared to the 100 nm high seas buffer (Fig. 3c-d).

S-AIS and SAR provide different, yet complementary, information on compliance. Analysis of S-AIS revealed a number of suspicious behaviours: vessels authorised under ICCAT with gaps in their AIS transmissions; vessels with MMSIs for which details confirming authorisation under ICCAT could not be verified; a vessel operating within the region without apparent ICCAT-authorisation. The large number of data gaps at distances greater than would allow transit into, or through the EEZ reinforces the view that vessels may choose to 'go dark' for a number of reasons besides masking an intended compliance violation; for example, hiding fishing activities from competitors. Inference of behaviour from S-AIS data gaps, should be a trigger for more detailed

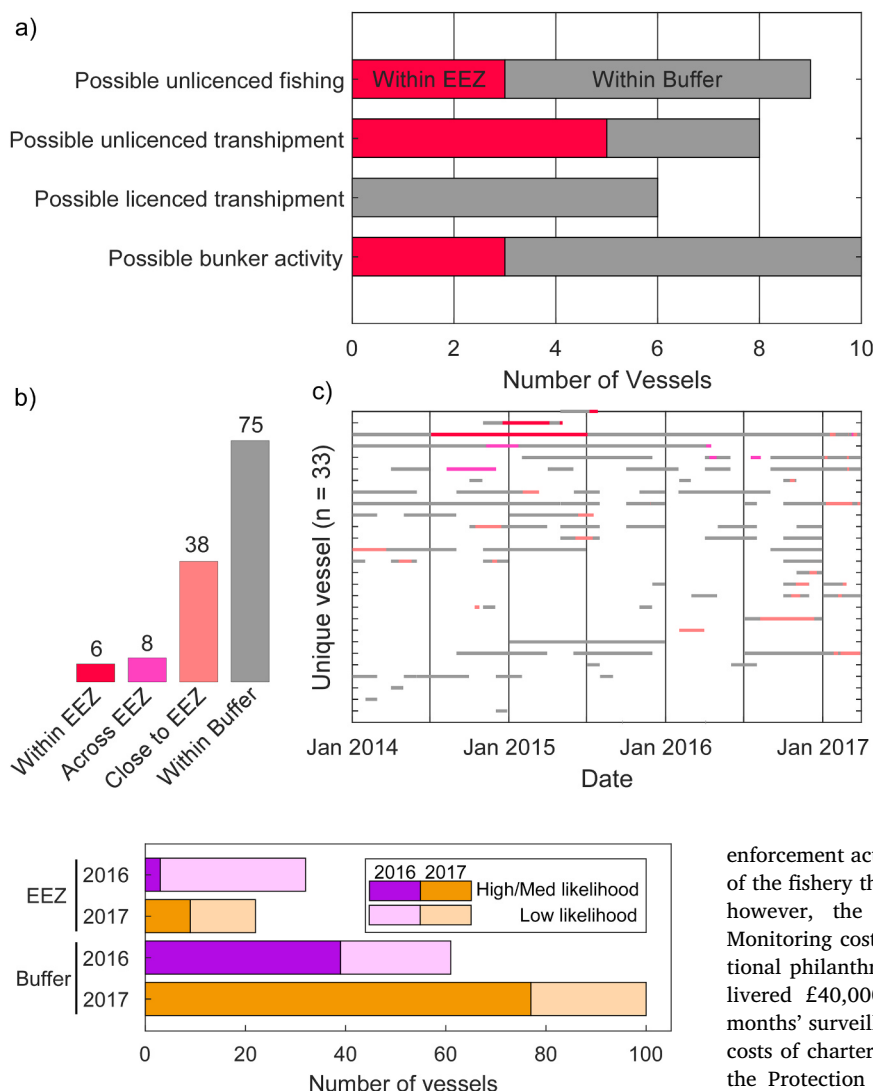
investigations involving flag- and port states.

Through SAR, the high-levels of compliance within EEZ boundaries are confirmed for the 'dark' fleet - perhaps the greatest compliance risk. The higher number of unique vessels recorded on S-AIS, coupled to more SAR detections in 2017 compared to 2016 indicates an increase in fishing pressure around Ascension. This interpretation must be tempered by the possibility of: 1) increased AIS installation on vessels rendering a greater proportion of the Atlantic fleet visible; 2) improvements in space-based sensor networks; 3) the different SAR sensor mode used in 2017 compared to 2016, or 4) inter-annual variation in response to environmental conditions altering the geographic location of targeted fish stocks [63].

During the 2016 and 2017 three-month studies, the patrol vessel was not able to directly investigate the identity and activities associated with the majority of uncorrelated SAR detections. Despite higher imaging frequency within the EEZ where the patrol vessel has jurisdiction to board and inspect foreign flagged vessels, only 12 high/medium confidence uncorrelated SAR detections were detected. In each case, interception and investigation was hampered by the detected vessel appearing to rapidly transit out of the closed area soon after detection on S-AIS and SAR. The temporal lag between subsequent SAR acquisitions precluded determination of direction of travel of the detected vessel, hampering efforts to direct the patrol vessel to intercept.

There were numerous examples of vessels altering transmission or passage behaviour in response to the EEZ boundary which may indicate heightened risk to compliance. 'Dark' behaviour can be inferred for vessels tracked on AIS, with gaps in transmission consistent with





**Fig. 8.** a) Number of vessels engaged in possible fishing or rendezvous suggesting possible transshipment or fuel bunker activity within the Ascension Island EEZ or 100 nm buffer; b) Number of gaps in AIS transmission for fishing vessels operating within the Ascension EEZ or 100 nm buffer; c) Temporal distribution of gaps in AIS transmission for fishing vessels. Colours indicate relative risk. Vessels appearing or disappearing from AIS within the EEZ are considered highest risk and shown in red, while lowest risk are shown in grey. All data are for vessels operating between Jan 2014 and Jan 2017, and online version for color.

**Fig. 9.** Uncorrelated SAR vessel detections within the Ascension Island EEZ (445,390 sq km; see Fig. 1) and 100 nm high seas buffer (560,430 sq km) during the 2016 (Feb–Apr) and 2017 (Jan–Mar) SAR surveys. Mean number of vessel detections per satellite image: 1.31 in 2016; 1.95 in 2017. See online version for color.

transiting the EEZ. Under UNCLOS, vessels have freedom of navigation through the EEZ however AIG regulations [35] set out that unlicensed vessels “shall not fish or attempt to fish” and “shall transit in a continuous fashion”. Vessels exercising the right of free passage across the EEZ must notify AIG and provide information on “vessel identity”, “quantity of fish” and “species of fish” aboard [35]. Multiple vessels were tracked via S-AIS, or the interpolated path within a S-AIS data gap suggested, transiting the EEZ, yet only one vessel reported it was in transit. Despite penalties of up to £100,000 [35], the potential for lost fishing time and inconvenience arising from any stop and search, may sufficiently outweigh the perceived risk for master and/or owner of the vessel failing to disclose a transit. Indeed, one vessel tracked on AIS appeared to deliberately travel around the border of the EEZ to a new fishing ground; a decision with adverse economic and opportunity costs of fuel spent and fishing forgone. Further evidence of unwillingness on the part of vessels to subject themselves to the costs of compliance may be inferred from the limited licenses taken up for 2016, and lack of licenses taken up in 2017.

The mixed management strategy of a Closed Areas and Licenced Fishery presents an opportunity to fund, or subsidise, monitoring and

enforcement activity and to improve safety and employment standards of the fishery through the licensing terms. Across the three-year study, however, the economics do not appear locally self-sustaining. Monitoring costs were largely born by the UK Government with additional philanthropic support. Since 2015, the sale of two licenses delivered £40,000 revenue to AIG, approximately the cost of three months’ surveillance with SAR and AIS. Yet in comparison to monthly costs of chartering a patrol vessel, estimated by the Royal Society for the Protection of Birds (RSPB) at £100,000–200,000 [64], satellite observation is both fiscally prudent and delivers a broader scope of temporal and spatial intelligence than patrols alone achieve.

Designation of a VLMPA in Ascension is clearly justified by the desirability of the fishing grounds set against the conservation benefits of locally significant species. Moreover, high levels of compliance observed to closure in 2014 and rezoning in 2015 suggest the area may become an effective no take VLMPA. Further study will be required to fully assess the positive or negative affect of the MPA on bigeye tuna and other target species and ultimate conservation benefit. Historical vessel reports combined with three years of S-AIS vessel tracking suggests the Ascension EEZ is not perceived as critical to meeting ICCAT Total Allowable Catch (TAC). For bigeye tuna, the Atlantic catch (2012–2014) has been lower than the adopted TAC, yet stocks have continued to decline [55]. Recovery will likely require a longer rebuilding period and/or reduction in TAC.

Conservation management measures are most likely to be successful if economically self-sustaining. Revenue from the uptake of Ascension Island commercial fishing licenses will be linked to stock management measures at ICCAT, creating a precarious model for the sustainability of a well-regulated licensed fishery and ongoing surveillance. Reeves and Lapikhovsky [57] suggest alternate licensing structures might be considered, for example tiered access where vessels of different size, target species or gear type are subject to different fees. Yet, rather than structure, reduced uptake of licenses appears driven by the increased spatial restrictions and stricter regulation coupled to the clear willingness on the part of AIG to enforce. Regardless of license structure, determining the proportion of the fleet willing to pay a particular fee

will take time to establish. Monitoring closed areas in Ascension using VMS, S-AIS and at times a patrol vessel is estimated to cost ~ £400,000 per annum [64], yet maintaining a sustainable licensed fishery would require additional outlays, such as the costs of observer coverage. Reeves and Laptikhovsky [57] considered revenue generating options of approximately £700,000 per annum, based on a working model of 35–50 permitted vessels (2010–2013 comparison; Fig. 5a). However, since reopening the fishery in 2015, license uptake falls far short of this target. In the near term, expectations of revenue must be tempered by the broader health and management of the Atlantic bigeye fishery.

Within this study, AIG outsourced technical vessel monitoring requirements to OceanMind and were reliant on the UK Government funding and philanthropic donations. Small island states are the focal point of Blue Belt activities yet have limited internal revenue streams, and budget cycles may be inflexible to ongoing needs. Use of remote technical capacity, such as represented here by OceanMind, may provide both cost-effective, timely and responsive monitoring service for VLMPPAs. The fixed and recurring costs of maintaining local or regional infrastructure (e.g. [27]) are removed, and knowledge may be transferred across a diversity of fishing areas and fleets and to neighbouring EEZs. The service solution can be scaled or dialled back in line with risk and the budget available.

Use of a remote monitoring facility can, however, create its own challenges. Time must be minimised between vessel detection and alerting patrols. The value of certain types of vessel intelligence to a patrol vessel decreases with time, thus rapid communication is critical. Recommendations include installation on patrol vessels of AIS systems capable of being set to receive-only, providing real-time information, but not at the expense of covert patrolling. Multiple communication channels are needed between remote monitoring facilities, shore-stations and patrol vessels and could include email, phone, SMS, and satellite phone links. Across an area the size of the Ascension Island EEZ it is unlikely the patrol vessel will be near to the initial detection. Advanced indication of the footprint of upcoming SAR image acquisitions would assist strategic positioning and improved reaction times of patrol vessels. Flexible acquisition arrangements with multiple SAR providers (not explored in this study) could also assist in deriving speed and direction of travel of detected vessels and aid patrol interception.

The full costs of satellite surveillance and monitoring programs are often not appreciated in advance [65]. The costs of satellite data are comparatively easy to budget and project, yet provision of human resource will depend on perceived and observed levels of compliance, as well as the desire and capacity of organisations to respond to the intelligence obtained. Post-surveillance, the most common recommended action to AIG was to solicit ICCAT and the flag-state of the vessel in question for information to determine the precise nature of activities around a suspected infringement. Small island states may have limited institutional capacity to conduct and coordinate such work. For the UK overseas territories, centralised responsibility within the MMO can be expected to improve this function, deriving cost savings, as well as increased efficiency and effectiveness of communications. Provision of personnel and funding to the MMO must, however, reflect this increased responsibility.

The Ascension trial has highlighted a number of trade-offs between different modes of monitoring. Despite turning off AIS and updating systems to ensure covert patrols, all fishing vessels were likely aware of some patrol activity. At the beginning of the 2016 monitoring period, the patrol vessel boarded the two licensed fishing vessels to check documentation, compliance against a number of gear and safety measures, and deploy mandated fisheries observers on board [35]; one vessel was fined for a safety standards breach. Information of the boarding and fine was likely to have been communicated by the fishing vessels to the surrounding Taiwanese-flagged fleet leading to altered and more compliant behaviour. Awareness and possibly the expectation of being caught and/or punished for any infringement would have been raised. In 2010, contact between a patrol vessel and fishing vessel

initiated a change in fleet behaviour, increasing the number of license applications. Yet in 2017, possibly bolstered by improved regulations [35], license uptake behaviour ran contrary to this. Interception of vessels is also traded-off against the need for observer data. Beyond enforcing license terms, observers on licensed vessels provide valuable information to assess the efficacy of management actions against stock and species preservation targets, providing bycatch and effort data.

There have been few, if any, fisheries prosecutions based solely on SAR and/or S-AIS data. Satellite monitoring could, however, lead to further evidence being supplied by a flag-state that fishing occurred illegally. Enhanced outreach to flag- and port-states, improving investigative interventions is another important mechanism for building compliance. The value of active vessel patrols is not supplanted by satellite monitoring, and planning patrols to board and inspect vessels of interest will remain a challenge. Here, patrols and satellite surveillance were focused on the period of the year with historically high fishing (Fig. 6; Appendix A), yet infractions may not be limited to this period.

Vessel behaviour can be expected to react to management policies enacted and modes of surveillance adopted. No wholesale change in patterns of fishing activity indicating non-compliance, such as repeated incursions into the EEZ of vessel activity were observed in response to either the 2014 closure or the 2015 zoning and licencing regime [35] (Fig. 7b, c). There was, however, some evidence of increased sophistication in the selective use of AIS in 2015. After July 2015 for example vessels did not turn their AIS on or off within the EEZ - the highest data gap compliance risk. Those few unexplained incursions into, or transits across, the EEZ that did occur were located away from the greatest concentrations of fishing effort. Such selective use of AIS could be a response to awareness of the increased co-option of S-AIS for maritime surveillance since ~ January 2014 [2], but also the improved and stricter regulations enacted by AIG [35].

While this paper has concentrated on monitoring fishing activities, the majority of unique vessels passing through Ascension waters are large 'cargo' or 'hazardous cargo' ships, typically on transatlantic routes. A significant petrochemical or hazardous waste spill, such as might result from a ship grounding on Ascension, could have disastrous impacts, especially to nearshore species and habitats and the globally important populations of nesting seabirds and turtles. Though the risk of pollution to these species of concern is generally considered small [54], the likelihood and potential for ecological harm of such 'accidents' is difficult to effectively quantify. Oil spills in other Atlantic overseas territories have been particularly damaging [66]. Beyond their ecological sensitivity and value, the geographic isolation of the United Kingdom overseas territories presents particular challenges to effective clean-up. With plans to designate spatial protection in Ascension in 2019, it is important that pollution risk is minimised through policies effecting appropriate routing of vessels away from the island and protected area. Here, S-AIS and SAR again provide valuable data, tracking vessels and alerting authorities of possible pollution events [67]. Satellite data can also play a role in monitoring impacts of any future (as yet unplanned) aquaculture or marine mining activity. There is considerable cross over in data, analysis and expertise which should be efficiently combined to provide marine situational awareness to relevant authorities.

## 5. Conclusion

In designating MPAs, the coastal state must grasp its responsibility for monitoring and enforcement which is so often lacking. Funding such activity is, however, beyond the means of many small island states. Licenced fisheries offer an opportunity to bring money into the local economy, subsidise, and offset the costs of ongoing monitoring. The sustainability of this economic model, however, rests on the willingness of fishers to take on license costs and restrictions, and their need to access an area to maximise profits. In the case of the UK overseas

territories, an ongoing financial and institutional commitment on the part of the UK government, backed by public support is required to provide a long-term conservation benefit. Used in isolation, S-AIS and SAR do not present an enforcement solution. In Ascension Island, however, continued monitoring with both S-AIS and SAR will assist efforts through an understanding of spatial and temporal risks from fishing and other human activities at sea. Such knowledge can be used for long-term resource planning and allow management thresholds and triggers to be set determining where and when more expensive patrols should be deployed. Effective monitoring of VLMPAs requires a commitment to follow-up with flag- and port-states, to determine the precise nature of possible violations identified through satellite monitoring. Information on vessel activities derived through satellite and vessel patrols must be understood with this full context, and investigations then pursued based on what is actually known. Such on-ward investigations may be beyond the institutional capabilities of many territories. To provide the most comprehensive solution, responsible agencies should be provided sufficient flexibility in funding, allowing managers to adjust effort and expenditure year on year relative to an accepted threshold of compliance risk.

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## Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.marpol.2018.11.006](https://doi.org/10.1016/j.marpol.2018.11.006).

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