22-171 UK MPA Project

Phase 5 Report

Marine Management Organisation

IFCA

OCEAN MIND

BECHT FOUNDATION

Area of interest (AOI)	United Kingdom
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Report compiled by	Andy Richardson, Greg Brown
Quality controlled by	Sam Elliott, Pablo Trueba

Acronyms and Abbreviations

AIS	Automatic Identification System	MPA	Marine Protected Area
BVLOS	Beyond Visual Line of Sight	NIMEG	National Inshore Marine Enforcement Group
CAA	Civil Aviation Authority	OSC	Operational safety case
DEFRA	Department for Environment, Food & Rural Affairs	RF	Radio Frequency
EO	Electro-Optical (imagery)	SAC	Special Area of Conservation
EVLOS	Extended Visual line of sight	SAR	Synthetic Aperture Radar
GPS	Global Positioning System	SPA	Special Protection Areas
HPMA	Highly Protected Marine Areas	UAV	Unmanned Aerial Vehicle
IFCA	Inshore Fisheries and Conservation Authority	UK	United Kingdom
IUU	Illegal, Unreported and Unregulated	VIIRS	Visible Infrared Imaging Radiometer Suite
I-VMS/VMS	Inshore Vessel Monitoring System/Vessel Monitoring System	VLOS	Visual Line of Sight
MCZ	Marine Conservation Zone	WG	Working Group
MCS	Monitoring Control and Surveillance	WUF	Wide Ultra Fine
MMO	Marine Management Organisation	XF	Extra Fine

Contents

Executive Summary

The United Kingdom (UK) Marine Protected Area (MPA) Project has been a collaboration between the Becht Foundation and OceanMind. The project worked with key partners responsible for MPA protection and enforcement to assess the effectiveness of a range of new Monitoring, Control and Surveillance (MCS) tools for use in English waters. This partnership was able to provide cost-effective, high-impact, deterrence-through-detection solutions that are scalable and can be applied to all MPAs around the globe. The solutions and technology tested increased the visibility of activity, including non-compliant behaviour and this information was passed to the relevant competent authorities.

The UK MPA Project arose from a review of the HPMA Report issued by Richard Benyon[1] in 2020[2]. This report identified a number of gaps and need for increased protection for a range of existing MPAs around the UK.

The project aimed to address some of these gaps and consisted of 5 phases:

- Site Identification
- Risk and technology assessment
- Plan and Methodology
- Technology pilot
- Final report

For each phase a summary report is available, displaying the main outcomes with the phase 5 report also summarising the overall project and its outcomes. The technology tested during the project is as follows:

Vessel tracking

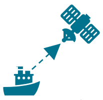
Vessel tracking data was obtained and analysed with OceanMind specifically testing the use of AIS, VMS and I-VMS in conjunction with Machine Learning algorithms, to create alerts of high-risk and potentially non-compliant activity. Key outcomes included the identification of 45 instances of fishing in restricted areas, with 25 vessels reported to the authorities.

Satellite Remote Sensing Tools:

[1] Now Rt Hon Lord Benyon

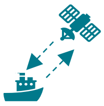
[2] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/890484/hpma-review-final-report.pdf

Various satellite sensors were evaluated for their use and benefit during the early phases of the project, with two main types scoped in for further testing during the project.



Electro-Optical (EO)

EO imagery was scoped into the project, as it collects high-resolution imagery and within the context of the UK it can collect data over a large area. The resolution of the imagery means that it has the potential to collect valuable and actionable intelligence. Key outcomes included: 15 vessels of risk detected and reported to the competent authorities.

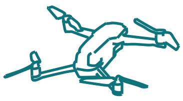


Synthetic-Aperture Radar (SAR)

SAR was also scoped in due to its utility and ability to operate in all weather conditions as well as being capable of easily covering even larger areas than a typical EO image. Key outcomes included the detection of almost 600 vessels, 54 of which were 'dark' vessels (not transmitting on AIS).

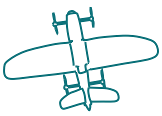
Unmanned Aerial Vehicles (UAVs):

A key component of the project was also testing the applicability and practicality of deploying UAVs within different MPAs in the UK, testing both the technology and the regulatory process in relation to their use for fisheries MCS. Two UAV types were trialled during the project:



Short Range UAV

Prior to the project, limited testing of this technology had occurred directly in the fisheries space. OceanMind, working with an expert team of pilots from Marble flew a small quadcopter UAV from the NW IFCA patrol vessel in the West of Walney MCZ over the course of several patrols. Key outcomes included: checking and identifying static gear markers with in the MPA and demonstrating the utility and ability of the UAV to assist the effectiveness of seaborne patrols.



Beyond Visual Line of Sight

In addition to the small UAV flown, OceanMind in conjunction with Marble obtained the relevant licence to carry out flights beyond visual line of sight in the Eddystone part of an important MPA in the southwest of England. Currently, the licence application has taken more than 6 months, which has been compounded by a change in staffing of the drone operators that required resubmission of the licence due to name changes, further delaying the application process. Therefore, at the time of report production, we await final licence approval and we have been unable to test the capabilities of the technology. These difficulties do however show that whilst there is evidence to show the excellent capabilities for MCS support from a long-range UAV, significant challenges remain to effectively use them in the UK.

Cost-Benefit Analysis

As part of phase 5 of the project, a cost-benefit analysis was carried out, focusing on what technology is the most useful (i.e. benefit) whilst also assessing cost when compared to more traditional MCS methods. The assessment was completed for different site types (inshore or offshore) and by size. The below table summarises the key results of this analysis.

Site Type	Cost/ Benefit	SAR	EO	Machine Learning	UAV Quadcopter	UAV Fixed wing (shore launched)	UAV Fixed wing (Vessel launched)
Inshore Site, <150 km^2	**Cost**	2	2	1	2	4	N/A
	Benefit	Very limited usefulness	Limited Usefulness	Useful	Extremely useful	Limited Usefulness	N/A
Offshore Site, <150 km^2	**Cost**	2	2	1	4*	4	5
	Benefit	Very limited usefulness	Useful	Useful	Limited Usefulness	Limited Usefulness	Extremely useful
Inshore Site 150-1,500 km^2	**Cost**	4	5	1	2	4	5
	Benefit	Very limited usefulness	Useful	Useful	Limited Usefulness	Useful	Useful
Offshore Site 150-1,500 km^2	**Cost**	2	5	1	4*	4	5
	Benefit	Useful	Useful	Extremely useful	Limited Usefulness	Useful	Limited usefulness
Inshore Site >1,500 km^2	**Cost**	2	5	1	2	4	5
	Benefit	Limited Usefulness	Limited Usefulness	Useful	Limited Usefulness	Extremely useful	Limited Usefulness
Offshore Site >1,500 km^2	**Cost**	2	5	1	4*	N/A	5
	Benefit	Limited Usefulness	Limited Usefulness	Useful	Extremely useful	N/A	Extremely useful

Table summarising the costs and benefits of the technologies tested in the project by site type. The cost (per day) scale is as follows: Level 1 ≤ £500, Level 2 £501 to £1,500, Level 3 £1,501 to £3,000, Level 4 £3,001 to £5,000 and Level 5 ≥ £5,001.

**Based on launching quadcopter from vessel*

From the cost-benefit analysis the following conclusions were made:

- EO images can deliver significant benefits at a cost lower than traditional enforcement patrols, with the level of benefit vs cost increasing for offshore and larger sites.
- Short Range UAVs can deliver significant benefits across a range of different site types. For inshore sites, their benefit is most felt when they are flown from shore, as this can be a very

cost-effective solution. When used offshore with a vessel, they improve the utility and effectiveness of a patrol, with limited additional cost.

- Applying OceanMind's machine learning algorithm to I-VMS data could result in efficiencies relating to analysis and improve the overall quality of monitoring.
- There is still a requirement for more traditional MCS methods (land and seaborne patrols), but their effectiveness can be increased through the use of technology.

Recommendations

Based on the outcomes of the UKMPA project the following recommendations are made:

- Competent authorities continue monitoring VMS and I-VMS using machine learning-based alerts, as it will reduce possible human errors and resource burdens on governmental organisations.
- Explore future options to increase the accuracy and utility of alerts by incorporating catch data from vessel logbooks, this could provide further information to support fisheries management options, particularly when considering real-time catch limits.
- Investigate options to initiate a rolling data-sharing agreement with the MMO and devolved governments, including the associated infrastructure to allow VMS and I-VMS data to be run through OceanMind's Machine Learning algorithm.
- Seek further funding to develop the OceanMind Machine Learning Algorithm and associated infrastructure for these alerts to automatically be sent to the relevant authorities.
- Competent authorities explore options for utilising high-resolution EO to monitor specific high-risk areas. The imagery could be tasked and reviewed for entire MPAs to understand both site use and compliance.
- It is recommended that purchasing quadcopter drones and training staff are explored as a viable option for the Inshore Fisheries Conservation Authorities to support seaborne patrols both for monitoring and enforcement.

1 Introduction

The United Kingdom (UK) Marine Protected Area (MPA) Project has been a collaboration between the Becht Foundation and OceanMind. The Becht Foundation believes in the fundamental importance of restoring marine biodiversity, in England and globally.

"With the increasing negative impacts of mankind on the Earth's natural environment, the health and prosperity of many species, as well as people around the world, are suffering. As a result, Becht Foundation allocates grants to activities or organizations which neutralize, reverse or at least materially mitigate these negative impacts"

The seas around the UK have a great variety of rare and important marine life and habitats, and MPAs can help ensure these habitats are guarded against the increasing pressures of human activity. MPAs also contribute to objectives in the 2020 Fisheries Act[3], 3 of the 4 objectives in the Department for Environment, Food & Rural Affairs (DEFRA) outcome delivery Plan[4] , and are an important component of the 25-year environment plan[5].

The UK MPA project worked with key partners responsible for MPA protection, compliance and enforcement, to identify a range of new Monitoring, Control and Surveillance (MCS) tools for use in English waters. This partnership aims to provide cost-effective, high-impact, deterrent-through-detection solutions that are scalable and can be applied to all MPAs around the globe.

Throughout England, the Marine Management Organisation (MMO) and Inshore Fisheries and Conservation Authorities (IFCAs) have made good progress in implementing byelaws to protect vulnerable features from the most damaging types of fishing activity. MCS efforts have also increased to try to improve compliance with these byelaws. Overall, it is perceived that compliance is high, however, challenges remain. One of the principal challenges is the lack of vessel tracking on smaller vessels, which influences the capacity to validate compliance or non-compliance of these vessels within closed area byelaws. The low reporting rate of vessel monitoring data from larger vessels in the same areas exacerbates the situation. The challenges of monitoring protected areas can be compounded by the physical environment (tide, weather, MPA location), as well as the expanding roles and responsibilities of the competent authorities within continuing resource limitations.

[3] https://www.legislation.gov.uk/ukpga/2020/22/contents/enacted

[4] https://www.gov.uk/government/publications/department-for-environment-food-and-rural-affairs-outcome-delivery-plan/department-for-environment-food-and-rural-affairs-outcome-delivery-plan-2021-to-2022

[5] https://www.gov.uk/government/publications/25-year-environment-plan

The project aims were to increase the visibility of activity, including non-compliant behaviour, by trialling a suite of tools previously unused in MPAs by UK authorities for this purpose. The project is split into 5 Phases, the first of which started 01Jun2021. The graphic below (Figure 1) shows an overview of the project Phases, the work to be completed within each Phase and completion dates.

This report has been designed for distribution to organisations and initiatives that would benefit from the project outputs to increase MPA and Highly Protected Marine Area (HPMA) protection. The outputs will inform potential management options designed to increase the operational capability of those with a remit to enforce MPAs, particularly those located in geographically-remote locations which have, up until now, been notoriously difficult to manage due to their location and the prohibitive cost of using patrol assets. The outputs from this report demonstrate how the use of remote sensing technology can increase visibility to tackle Illegal, Unreported and Unregulated (IUU) fishing by providing actionable intelligence that informs the bigger picture and enables action to be taken to protect these important marine areas.

Figure 1| Overview of UK MPA Project Phases including timelines.

2 Project Phases

Before project Phase 1 began, significant work was undertaken to facilitate expert input into the project. This involved the presentation of the project plan and scope to the National Inshore Marine Enforcement Group (NIMEG) and the DEFRA Marine and Fisheries Department and Ministerial Private offices. Decision-makers and experts were invited to join the Working Group (WG), including representation from 5 of the 10 IFCAs, with the WG Chair maintaining links to the other 5 for site selection purposes. There were also representatives from DEFRA and the MMO in the WG. Together with OceanMind's team, the WG was responsible for a significant amount of advice and support provided. This expertise ensured the project was robust and supported the dissemination of the results to monitoring and compliance officials outside of the working group members.

A meeting of the WG on the 02Jun2021 marked the start of the Project. WG terms of reference were agreed upon and an overview of the project was presented to consolidate the WG members' understanding and allow for initial questions.

2.1 Phase 1 | Evidence Gathering & Site Selection

Objective: In collaboration with the WG, evidence and information was collected and analysed to identify 5 MPAs suitable for remote sensing trials.

Outputs:

- Evidence-based approach to develop site selection criteria.
- Select five sites suitable for inclusion in the remote sensing trials.
- Interviews to be conducted with competent authorities to inform site selection and remote sensing options.
- Initial scoping plan for remote sensing options suitable for the UK maritime domain.
- Progress presentations and project facilitation.

Site Selection Criteria

To facilitate shortlisting of submitted sites, criteria that considered the ecological impact, management frameworks and enforcement capabilities within each candidate MPA were drafted. Potential criteria and the scoring system were presented to the WG during the initial meeting of the group (02Jul2022) and feedback was invited.

Key discussion points included:

- The need to define the difference between inshore and offshore sites

- The inclusion of a straddling site[6]
- The inclusion of a site without existing or only limited management, as the project outputs could be used to inform future management measures
- The use of a quantitative scoring system would be required to initially generate a shortlist of candidate sites for selection and agreement. This approach provided a method of justifying why sites were or were not selected, which was of importance if multiple, similar sites were submitted
- Ultimately, a qualitative approach would need to be applied to objectively shortlist sites.

The consensus of the WG was that the project would ideally aim to look at a range of diverse sites, approached holistically. To ensure robust testing of the technologies across different types of sites, OceanMind would provide an initial scoping of remote sensing capabilities and coverage over the suggested sites.

Site Selection

Partners were invited to submit potential MPA trial sites using a proforma web-based questionnaire which asked detailed questions about the site. A template of this document is made available in the appendix documentation (*Phase 1_Site Selection Criteria_Template.pdf*). The information submitted on these forms was used to inform the selection process, selection criteria, scoring and weighting are shown in Appendix 1. In total, seven sites were submitted for consideration, shown in Figure 2:

- Liverpool Bay Special Protection Area (SPA)
- Lundy SAC
- Start Point to Plymouth Sound and Eddystone SAC
- The Solent European Marine Sites (comprising multiple sites around the estuary).
- South Wight Maritime SAC
- West of Walney MCZ
- Wight Barfleur SAC

[6] A straddling site is defined as an MPA which is sited across two management districts, such as across both the 6 NM (IFCA) and 12 NM (MMO) boundaries.

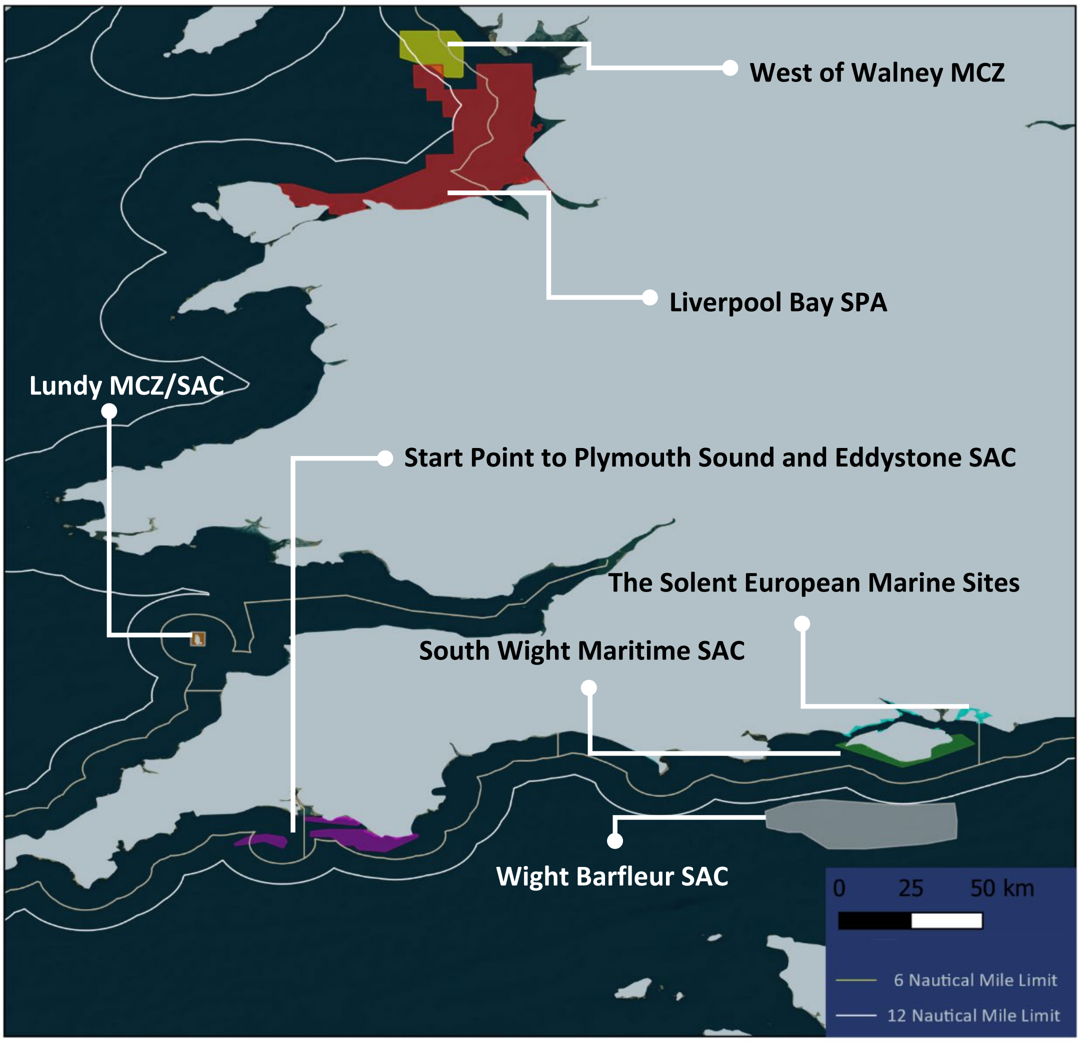


Figure 2 | Proposed MPAs trial sites submitted for selection.

The pre-agreed selection criteria were applied to produce a shortlist of 5 sites. These sites were presented to the WG (26Jul2022) and attendees unanimously agreed to proceed with five sites:

- Lundy Special Area of Conservation (SAC)/ Marine Conservation Zone (MCZ)
- Start Point to Plymouth Sound and Eddystone Special Area of Conservation (SAC)
- South Wight Maritime Special Area of Conservation (SAC)
- West of Walney Marine Conservation Zone (MCZ)
- Wight Barfleur Special Area of Conservation (SAC)

Initial Remote Sensing Scoping

Following the initial UK-wide technology options scoping, OceanMind undertook research into the various remote sensing tools that are available for use over the shortlisted MPA sites. Site-specific information was collected about technology option usefulness, cost and availability. A range of possible tools was identified for potential application to each site including Synthetic Aperture Radar

(SAR) in various spatial resolutions, Electro-Optical (EO), Visible Infrared Imaging Radiometer Suite (VIIRS), Unmanned Aerial Vehicles (UAVs) and traditional aircraft.

Interviews

Conducted in parallel to the technology scoping, a robust exercise in knowledge gathering and outreach was carried out with the relevant authorities for each of the sites. This was achieved through preliminary desk-based research, followed by semi-structured interviews with discussion covering key topics such as:

- Ecological features
- Site use
- Enforcement challenges
- Levels of non-compliance
- The current level of enforcement

The interview duration was approximately 90 minutes and, for sites which existed across multiple districts such as the West of Walney MPA (North-West IFCA and MMO), all relevant authorities were interviewed. Each interview followed the same question-and-answer format, the template used can be found in the annexe document (*Phase 1_Selected Site Interview Questions for Competent Authorities.pdf*). Following the completion of the interviews, summaries of the discussion points were written up and circulated to participants. These summaries were essential in informing the next Phase of the project.

2.2 Phase 2 | Risk and Technology Assessment

Objectives: Carry out a risk assessment for each selected MPA trial site to understand the type of activity that currently takes place, MCS challenges faced, current management solutions and their effectiveness. Identify appropriate technology applications which may facilitate insight into MCS challenges.

Outputs

- Individual risk assessments of each pilot site looking at the historical activity of commercial vessel activity within the pilot site based on AIS data.
- Conduct site visits and meet with stakeholders to better understand the needs of the MPA review output.
- Identify the different types of technology suitable for trial in each MPA: research technology capabilities, limitations, and suitability for each site.
- Collation of risk and technology assessment and analysis with recommendations for technology to trial.

To gain a complete, accurate and thorough risk assessment at each of the five selected pilot sites, OceanMind carried out enhanced desk-based reviews combined with site visits. Site visits consisted of the following activities:

- Meeting with key stakeholders
- Visiting the site to better understand the environmental conditions, vessels and challenges associated with the area
- Assessing logistical limitations
- Knowledge exchange with members of authority staff focused on the remote sensing solutions and explored the applicability and usefulness in use at the site.

During Phase 2 of the project, there was continued engagement with stakeholders through monthly WG meetings. To support knowledge exchange, an overview of the remote sensing tools and their capabilities and limitations was presented to members. This knowledge was expanded on during site visits, in which OceanMind Analysts presented further information about the tools available to be used. A report was prepared to detail the results of the technology assessment and site applications.

Following the end of Phase 2, work was paused over the winter months (December-February). This pause postponed the pilot Phase (Phase 4) of the project until summer 2022 when UK weather conditions were more favourable for monitoring and there were likely more vessels operating. This ensured valuable information about technology suitability could be explored without the limitation of vessel scarcity.

2.3 Phase 3 | Plan and Methodology

Objective: Create a pilot project plan and methodology to be carried out in collaboration with key stakeholders and staff from the competent authorities for the project MPAs.

Outputs

- Develop detailed trial plans and methodology for each site including timelines which target site-specific risk periods
- Scope technology costs to support financial impacts and benefits analysis
- Continued engagement to ensure outputs respond to the findings from Phase 2 and meet the requirements to protect MPAs from harmful activity
- Dissemination and presentation of the agreed plan to stakeholders

Phase 3 was initiated in March 2022. The cost, primary application and expected latency of each of the remote sensing tools were compared against the potential benefits and use and this was discussed with each competent authority. Additional value was also added by considering potential secondary applications of technology and tools, such as activities outside the boundaries of the MPAs and scientific support, as well as non-fisheries-related compliance monitoring. Satellite technology providers were engaged to discuss possible tasking and scheduling coverage, timing and resolution of satellite imagery available.

When scoping UAV options, it was necessary to investigate not only cost and coverage but operational factors such as licence requirements for operating beyond visual line of sight (BVLOS). This influenced project timings; applying for the BVLOS licence from the Civil Aviation Authority (CAA) for the offshore fixed-wing drone flight application was estimated to take up to 6 months to receive.

When considering the logistical and operational constraints of fixed-wing, shore-launched UAVs, and discussions with specialist service providers, it became apparent that there were limiting factors to operating the fixed-wing drone effectively over some sites. Our expectation of launching the drone from the mainland to fly over an MPA was limited by the range and flight time of the fixed-wing UAV model's operational limitations. Additionally, it was established that the application for the BVLOS licence would require temporary designation of danger areas over some sites, extending the lead time on the licence application beyond the scope of the project.

Alongside the field-based trials of technology for sites, OceanMind pursued access to Vessel Monitoring System (VMS) and Inshore Vessel Monitoring System (I-VMS) data for England. This data would be fed into OceanMind's Machine Learning Algorithm tool to test the capabilities in identifying non-compliant activities within MPAs, for instance trawling within closed areas.

Risk assessment profiles and planned technological options for the selected MPA sites were discussed with stakeholders. Details of the technology selected for trial at each trial site can be found in Table 1, for further information, please refer to the Phase 3 final report (*OM22-099_Phase 3 Technology Plan & Trial Methodology*) in the appendix documentation.

Table 1 | Remote sensing methods selected for trial at each trial MPA site.

Method \ Site	West of Walney MCZ	Lundy SAC/MCZ	Start Point to Plymouth Sound and Eddystone SAC	South Wight Maritime SAC	Wight-Barfleur SAC
Synthetic Aperture Radar (WUF)	×	✓	✓	✓	×
Synthetic Aperture Radar (XF)	✓	×	✓	✓	✓
Electro-Optical (VIIRS)	×	×	×	×	×
Electro-Optical (High Resolution)	Speculative[7]	✓	Speculative[5]	Speculative[5]	Speculative[5]
Unmanned Aerial Vehicles (UAV's)	✓	×	✓	×	×
Vessel Tracking (AIS)	✓	✓	✓	✓	✓
Vessel Tracking (VMS)	✓	✓	✓	✓	✓
Vessel Tracking (I-VMS)	×	×	✓[8]	×	×

[7] Speculative tasking is requested from the satellite provider under standard subscription costs and not paid tasking with specific parameters. Delivery and quality of imagery (colour and resolution) is dependent on satellite availability.

[8] *I-VMS was only available within the Start Point to Plymouth Sound portion of the MPA. The Devon and Severn IFCA district is the only district which currently operated I-VMS on their <12 m vessels.

2.4 Phase 4 | Technology Pilot

Objective: Trial a range of technologies in line with the Phase 3 plan to understand the most cost-effective and results-driven way of ensuring compliance and increasing the protection of vital marine habitats.

Outputs

- In partnership with competent authorities, carry out trials in the selected MPA pilot sites of previously identified technology
- Monitor each site for a minimum of 1 month period
- Provide Intelligence to project partners, discuss progress, risks, issues and lessons learned
- Compilation of trial outputs and presentation of trial outputs to project partners and stakeholders.

Phase 4 of the project ran from April through to July 2022. In total across all five sites, several technology methods were trialled including:

Synthetic Aperture Radar (Extra-Fine Mode and Wide-Ultra-Fine Mode)

High-resolution Electro-Optical Imagery

Automatic Identification System Vessel Tracking Analysis

Machine Learning Analysis (using VMS and I-VMS data)

Vessel launched quadcopter drone flights

Shore- launched fixed-wing drone flights (due for completion in October 2022)

Intelligence Reports were written and disseminated to the relevant competent authorities. The timeline for analysis is shown in figure 3 below.

A full report detailing each technology trialled and its suitability for supporting MCS in the UK was produced *OM22-175 Emerging Technology Assessment, a UK MPA Pilot* and is available in the annexe documentation.

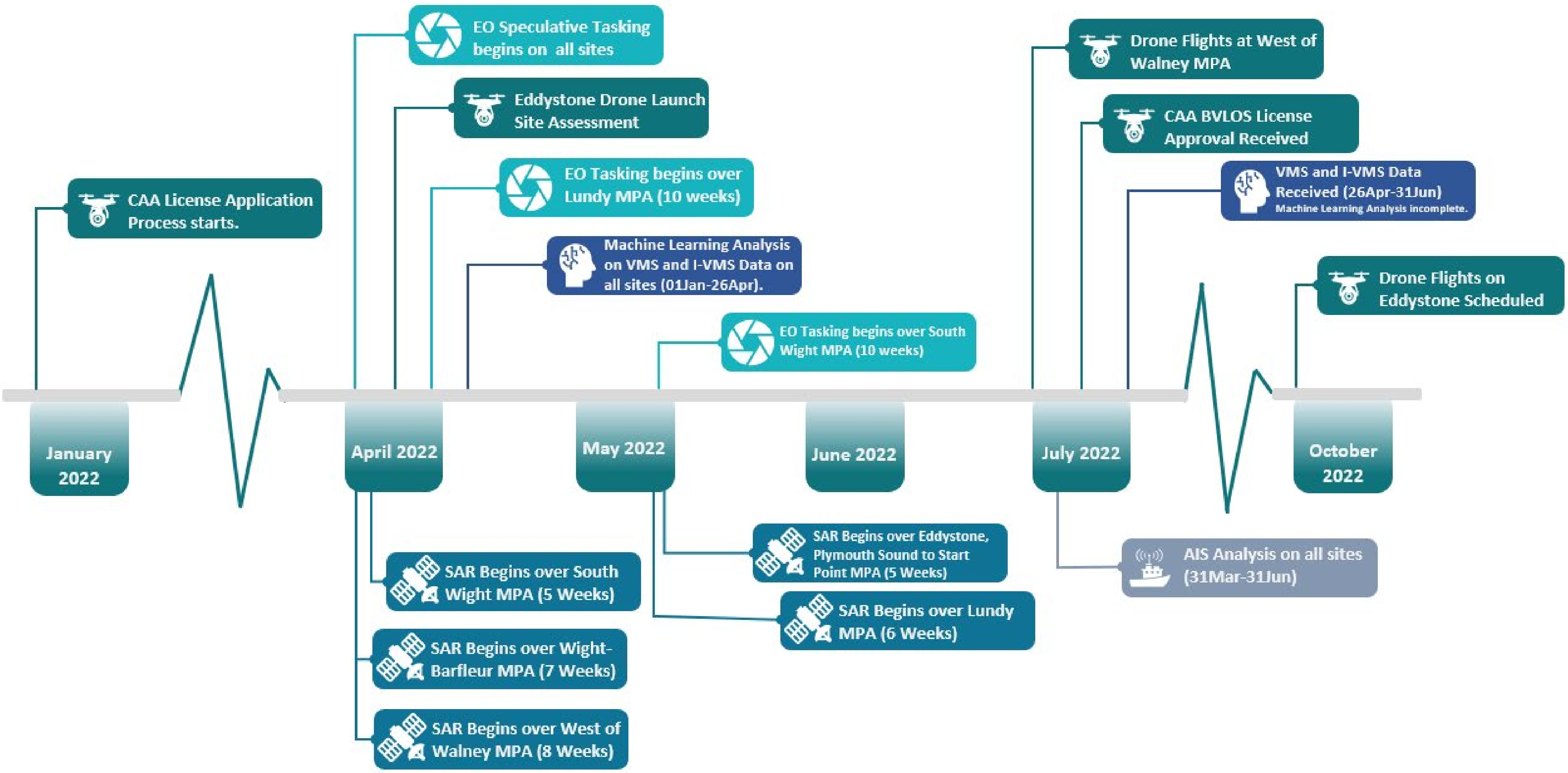


Figure 3 | Timeline of analysis over each of the five selected MPA sites.

2.5 Phase 5 | Final Report

Objective: Compilation of the final report to include, a summary of outputs from previous Phases, individual trial reports, cost-benefit analysis, impact, and suitability of technology from each trial. Recommendations on suitable technology applications for different sites, management challenges, location, environmental factors, implementation, applicability, usability and cost-effectiveness.

Outputs

- Compile the report in collaboration with project partners
- Reach cross-project agreement and clearance regarding the publication of the report

As part of the Phase 5 report, a cost-benefit analysis was carried out, to assess the usefulness and cost-effectiveness of the technology, compared to more traditional enforcement methods. The legislative review specifically focused on what using remote sensing methods are effective based on the current legislation in force.

3 Technology

3.1 Remote Sensing Solutions

Demand for technological solutions to the challenge of monitoring large Areas of Interest (AOIs) has led to much-improved remote sensing capabilities over the last decade. All of these solutions have relative strengths and benefits and so their application was assessed on a case-by-case basis.

A full technology and analytical assessment of different remote sensing methods are presented in the Phase 2 final report *OM21-359_Phase_2_Risk & Technology Assessment.pdf* available as part of the annexe documentation. This report introduces the technology, assesses its strengths, and demonstrates why each technology was selected for testing at each of the five selected MPAs.

This section provides a summary overview of each technology method we considered during this trial, with references to supporting material which can help guide managers who wish to further investigate the technology's capabilities.

3.1.1 Vessel tracking

From a monitoring and enforcement perspective, vessel tracking is a cost-effective way to determine the activity and identity of a vessel. Successful prosecutions can be mounted based on vessel tracking data, however supplementary evidence is often required. Every vessel which transmits positional information regularly shows a unique movement pattern, which allows the determination of the type of vessel and activity. One of the main uses of vessel tracking is as an indicator for risk (for example a vessel operating at fishing speeds within an area closed to fishing), which would need to be followed up with surveillance. Machine learning algorithm alerts can be generated when these patterns match specific activities in an area of interest, for example by associating the vessel track and speed with fishing activity types within an MPA.

There are three main vessel tracking systems in operation within the UK Maritime Domain, Automatic Identification System (AIS), Vessel Monitoring System (VMS) and Inshore Vessel Monitoring System (I-VMS).

Automatic Identification System (AIS)

AIS is a maritime collision avoidance system transmitted on marine Very High Frequency (VHF) radio and provides information on the position, speed, course, and identity of a vessel. The data is publicly accessible and can be received by terrestrial antennae and satellites. Under the Merchant Shipping Regulations 2004 (as amended in 2011), fishing vessels of 15 m or more in length overall, UK registered or operating in UK waters, must be fitted with an approved (Class A) AIS. Although there is currently no requirement for vessels under this 15m size to have AIS fitted, some vessels do choose to install units for safety purposes.

Vessel Monitoring System (VMS)

All commercial fishing vessels over 12m operating in the UK are required to carry VMS. The data is confidential and only shared between the vessel and the flag state. The frequency of transmission is usually once per 2-hour period for UK vessels.

Inshore Vessel Monitoring System (I-VMS)

I-VMS is a tracking system specifically designed for fishing vessels in the UK that are below 12 m in length. At the time of writing, I-VMS has only been rolled out as a pilot in certain parts of the UK but the system is scheduled for a wider roll-out in 2022. The frequency of transmission will be once every 3 minutes.

Further Reading:

NATO: AIS (Automatic Identification System) Overview
https://shipping.nato.int/nsc/operations/news/2021/ais-automatic-identification-system-overview

IMO: AIS Transponders
https://www.imo.org/en/OurWork/Safety/Pages/AIS.aspx

Statutory guidance: Vessel monitoring system devices
https://www.gov.uk/guidance/inshore-vessel-monitoring-i-vms-for-under-12m-fishing-vessels-registered-in-england

Inshore Vessel Monitoring (I-VMS) for under-12m fishing vessels registered in England
https://www.gov.uk/guidance/inshore-vessel-monitoring-i-vms-for-under-12m-fishing-vessels-registered-in-england

3.1.2 Satellite Remote Sensing Tools

Not all vessels transmit positional information and even for those which do transmit, activity cannot always be determined. Remote sensing tools can improve analytical confidence and support the detection of 'dark vessels' which are vessels not transmitting positional information on any known tracking system. Acquisition of satellite data is dependent on satellite orbit, constellation and orientation. These parameters impact revisiting times, coverage, size of the extent (km^2) and adaptability.

There are two main types of sensors used to provide satellite imagery, which complement each other well. Active sensors emit energy and measure the degree of its return after transmission to the Earth's surface (or atmosphere) and subsequent reflection, refraction or scattering. In contrast, passive sensors rely on an external energy source (for example, light emitted by the sun), and measure the return of this energy after reflection from the Earth's surface and/or atmosphere.

Electro-Optical (EO)

Electro-Optical sensors are passive sensors which receive visible, near infra-red and ultra-violet light from the sun once the light is reflected from the earth's surface or objects, captured in different bands in a similar way to a camera. The use-case for EO is highly variable depending on the resolution. Visible Infrared Imaging Radiometer Suite (VIIRS) detects light emitted by vessels and could be used to identify fishing vessels operating during the night. Other satellites which collect EO imagery provide higher resolution images, akin to aerial photographs (currently down to 30 cm) which in some instances can determine vessel types and activity. This type of sensor is more affected by environmental factors i.e. cloud cover.

Synthetic-Aperture Radar (SAR)

SAR is an active sensor which sends pulses of electromagnetic waves over a targeted area. A portion of each pulse is reflected back to the sensor by objects within the resolution detection range. The strength of this reflection is dependent on the material properties of the object. Reflection intensity is translated into a black (no reflection) to white (maximum reflection) scaled image. Images can cover large areas of interest with a single frame (up to 450 x 500 km^2). However, as the size of the image increases the resolution decreases, and therefore larger images are less useful for detecting smaller vessel types (<20 m). Higher resolution SAR imagery covers a smaller area (50 x 50 km^2) but can detect much smaller vessels (>3.6 m). This type of sensor is less affected by environmental factors, is not affected by cloud coverage and can detect 'dark vessels' day or night.

Radio Frequency

Nearly all offshore communication is conducted by either marine radar, satellite communications, VHF radio, or emergency beacons. Radio Frequency (RF) solutions use these technologies to detect signal sources, for example, the presence of navigational radars and radio communications systems used on vessels. This creates a high confidence in the presence of a target, however, insight into the identity of the source requires cross-checking with other tracking or remote sensing tools.

Further Reading:

The European Space Agency Sentinel- 2 MSI [EO] User Guide
https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-2-msi

NASA Earth Science Data Systems (ESDS) Program [VIIRS]
https://www.earthdata.nasa.gov/learn/find-data/near-real-time/viirs

NASA Earth Science Data Systems (ESDS) Program [What is Synthetic Aperture Radar?]
https://www.earthdata.nasa.gov/learn/backgrounders/what-is-sar

The European Space Agency Sentinel- 1 SAR User Guide
https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar

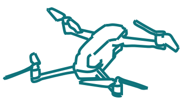
UNSEENLABS | Searching the Tasman Sea for dark vessels illegally fishing for Southern Bluefin Tuna https://unseenlabs.space/2022/04/29/searching-the-tasman-sea-for-dark-vessels-illegally-fishing-for-southern-bluefin-tuna/

3.1.3 Unmanned Aerial Vehicles (UAV'S)

Compared to other remote sensing methods discussed above, UAVs hold the ability to precisely record the activity and identity of a vessel over a desired area and period. This allows for a more direct enforcement application where supplementary evidence may not be required, for example in cases where vessels are operating in closed areas, or outside of curfewed hours. UAVs can be used at a distance where they remain unnoticed or fly in proximity for deterrence without compromising the health and safety of enforcement officers.

The use of UAVs is increasing, due to their affordability, flexibility and safety. The main two types of UAVs are fixed-wing and quadcopter designs. The capabilities of both drone types are very much dependent on the payload that is fitted. The greater a payload the drone can carry, the more flexible and fit for purpose the system can be; fixed-wing drones are capable of carrying much larger payloads and as such can operate an array of sensors on a single flight. Sensors can include Imaging equipment (wide zoom lenses, thermal imaging cameras, multispectral sensors etc), mapping tools or Global Positioning System (GPS) units. A live feed from the cameras also supports more effective evidence gathering, rapid response to developing situations and accurate and reliable deployment.

The Phase 3 final report *OM22-099_Phase 3 Technology Plan & Trial Methodology.pdf* has further information about UAV Applications, BVLOS permit application steps, challenges and solutions (*Section 2.9 UAV Applications (West of Walney (WoW) and Eddystone, Plymouth Sound to Start Point (E/PS-SP) only*) and can be found within the annexe documentation.



Short Range UAVs

Smaller models of UAV frequently take the form of quadcopters (helicopter design with 4 rotors), such as the Matrice 300 RTK (developed by DJI, https://www.dji.com/uk/matrice-300) which is used by enforcement officers from different departments and all around the country. UAVs which operate within the visual line of sight (VLOS) of the pilot are much cheaper to operate and do not require regular revision of flight permissions. Crucially, quadcopters require less training and logistic planning for the operation, and they can also be launched and landed from small, mobile platforms (e.g. a vessel).

Beyond Visual Line of Sight

Fixed-wing UAVs generally provide greater operation time and range and can carry heavier payloads of monitoring equipment. However, in the UK the extended range has a limited advantage because in accordance with the Civil Aviation Authority (CAA) special permits are typically required to fly UAVs beyond 500 m from the location of the pilot (BVLOS). Once the correct CAA permits have been requested and approved, operations can cover the territorial waters (up to 12 NM from shore). The fixed-wing UAV can have increased visual ranges (up to 6 km) and can operate for longer periods of time (one hour). While this performance is superior to other UAV solutions, the costs are also higher so currently the use case to replace possible deployments of patrol assets is limited.

Further Reading:

Civil Aviation Authority, Beyond Visual Line of Sight in Non-segregated Airspace
https://publicapps.caa.co.uk/docs/33/CAP%201861%20-%20BVLOS%20Fundamentals%20v2.pdf

Civil Aviation Authority, information site for remotely piloted aircraft and drones
https://www.caa.co.uk/consumers/remotely-piloted-aircraft/

3.1.4 Other tools

Terrestrial Monitoring Devices

Options for monitoring from land include visual tools like Closed Circuit Television (CCTV), shore-based radar, and acoustic detection such as radio communications. However, for all these tools a monitoring station is required, the presence of which is likely to be known to vessel operators. Ultimately, these supplementary tools may offer strong deterrence for a specific area but are very resource intensive and require a significant initial investment.

Patrol vessels and remote sensing

Deployment of patrol vessels can be both time and resource intensive. Patrol vessels require significant capital investment as well as continued maintenance and upkeep. Within the UK Maritime Domain, competent authorities already employ sea-going assets to enforce and ensure compliance with regulations at sea. However, with large areas to cover and conflicting priorities, combined with other limitations such as weather and sea conditions, the demand for patrol vessel assets is high. Using supplementary remote sensing tools to direct patrol efforts to high-risk areas can reduce costs, help make the best use of limited resources and ultimately improve environmental protection.

4 Cost-Benefit Analysis

The cost-benefit analysis was conducted to build upon the individual site trials carried out by assessing the viability and efficiency of the various technologies tested in the context of available budgets for MPA MCS. The cost-benefit analysis can be used to compare traditional MCS methods to remote sensing methods and to understand how much additional impact and support can be provided by using 'new' technologies as either a supporting tool for existing MCS methods or as an alternative to replace traditional methods.

The sites considered in this project were all multi-use sites and therefore the results of the cost-benefit analysis could vary significantly when considering single-use highly protected area sites with restricted entry and use. Additionally, the costs associated with a site that is managed by multiple authorities may also vary from sites under single management. It is also likely that some level of cooperation will need to exist between competent authorities to get the 'best value' from the remote sensing methods employed.

The remote sensing costs displayed are based on what is made available to OceanMind as a not-for-profit organisation and may vary when applied to commercial or government bodies.

The cost of analysis time has been included in calculations, however, training costs associated with using new technology have not been included, as there is an assumption that training as part of the execution of a role is included in the overall costs of an analyst's/officer's time.

General recommendations have been made but it is important to consider that site-specific factors will determine which MCS technologies and methods are most appropriate. The information presented in this section is intended to support informed decision-making on further research and scoping by site managers.

4.1 Methodology

Costs for the use of patrol vessels were obtained from publicly available information, provided by the IFCAs and the MMO in the format of impact assessments (which are written to show the potential impact of implementing new byelaws). The MMO publicly available costs relate to the tasking of a Royal Navy Patrol Vessel.

Average costs were used from amalgamated costs available from each regional IFCA (based on the availability of up-to-date data) however, there may be variability in costs between IFCAs.

Costs associated with monitoring can be relative to MPA size and location, to account for this in the cost-benefit analysis, sites are split into the following categories:

Type 1: Site **within** the **12 NM limit**, with a maximum area of **<150 km^2**
Type 2: Site **outside** of the **12 NM limit**, with a maximum area of **<150 km^2**
Type 3: Site **within** the **12 NM limit**, with a maximum area of **150 - 1,500 km^2**
Type 4: Site **outside** of the **12 NM limit**, with a maximum area of **150 - 1,500 km^2**
Type 5: Site **within** the **12 NM limit**, with an area **>1500 km^2**
Type 6: Site **outside** of the **12 NM limit**, with an area **>1,500 km^2**

For the purposes of this analysis, larger MPA sites (Type 5 and Type 6) are classified as sites over 1,500 km^2. No sites in this size range were selected during the project and therefore remote sensing methods were not trialled on any sites of this size during this analysis.

To protect commercial sensitivities and account for variations in pricing between satellite data providers, a scale was applied to costs in this analysis. Costs shown here represent the cost of obtaining a single image or a single day of patrol/ flights and conducting the subsequent analysis. The scale indicates the costs of both data collection and analysis and is intended to support informed decision-making with further research and scoping by site managers. For the purposes of this report, it is assumed that the analysis of remote sensing will be carried out using a suitable software platform that incorporates the collected remote sensing data, alongside AIS, VMS and I-VMS data.

The costs are shown as follows:

Cost Level 1.	≤ £500
Cost Level 2.	£501 to £1500
Cost Level 3.	£1501 to £3000
Cost Level 4.	£3001 to £5000
Cost Level 5.	≥ £5001

Scales of usefulness, identified as the benefit score are defined as follows:

1. Not useful
2. Very limited usefulness
3. Limited usefulness
4. Useful
5. Extremely useful

Usefulness is based on the ability to carry out MCS effectively and the benefit score is defined as providing the most benefit for each site based on the results of the trial assessment.

The scales of usefulness range from not useful (considered as unable to observe and monitor effectively) to extremely useful (able to effectively monitor and observe all relevant activity, or able to obtain high-quality information of evidential value).

4.2 Monitoring technology feasibility by site types

The following sections will provide additional detail on the benefits of each monitoring method against the cost for each type of site (Table 2 to Table 7). Conclusions are drawn from the results of the pilot trials at the relative sites, for example, Lundy MCZ was categorised as a Type 1 site. Further details about each site and the assigned category can be found in section 5 of this report.

4.2.1 Type 1 Site: Inshore Site, <150 km^2

Table 2 | Cost-benefit analysis of monitoring options for sites within the 12 NM limit, with a maximum area of <150 km^2

Method	Pros	Cons	Benefit Score	Cost Score
Seaborne Patrol (Vessel only)	Vessels can both observe and interact with non-compliant vessels (for example carry out boardings). A fisheries patrol vessel presence provides a strong deterrence effect. Gear and catch inspections can take place.	Resource intensive. High visibility affects covert operations.	Useful	3
Foot Patrol	Highly effective for engagement. Multiple vessels can be checked (in port). Vessels' landed catch can be checked. Can view activity within the area (weather dependent).	Cannot deal with any 'at sea' related legislation, specifically many of the MPA-related byelaws i.e. spatial closures.	Limited usefulness	1
SAR	Often covers a large area. Low resource use.	Intelligence gathering purposes only with lower intelligence value than other available remote sensing techniques. Cannot intervene with non-compliance. Likely to cover a large area outside the MPA, reducing cost-effectiveness.	Very limited usefulness	2
EO	Higher intelligence value than other remote sensing techniques. Can cover the whole site. Can be tailored to meet the specific requirements of the area. Low resource use. Imagery can be used to supplement evidence of non-compliant activity. Possible to positively identify vessels and activity.	Cannot intervene with non-compliance. Weather dependent (collections limited by cloud cover). Lead times for imagery delivery and analysis can reduce effectiveness.	Limited usefulness	2

Method	Pros	Cons	Benefit Score	Cost Score
Vessel Track Analysis	Allows for the detection of potentially non-compliant activity. Provides intelligence to inform strategic and tactical risk assessments and taskings.	Analysing even small areas can be time-consuming and requires resources to constantly monitor this. Requires devices that have a high 'ping rate' such as I-VMS or AIS.	Useful	1
Machine Learning	Low resource use. Allows for the detection of potentially non-compliant activity. Provides intelligence to inform strategic and tactical risk assessments and taskings.	Requires devices that have a high 'ping rate' such as I-VMS or AIS.	Useful	1
UAV – Quadcopter	When used with a vessel it can be used to increase the capability of the patrol vessel and save costs. When used from shore it can effectively monitor small inshore MPAs.	Limited range when operated from a vessel or shore. It may not cover the whole site Need trained operators to fly it.	Extremely useful	2
UAV – Fixed wing	Potential to carry out a full patrol of the area and collect visual data for multiple MCS purposes. Could be flown from shore to cover the whole site.	Need trained operators to fly it. The potential need for a BVLOS licence to operate to operational limits. Logistically less practical than UAV- Quadcopter options due to technological complexity. Limited direct action against non-compliant vessels, through potential deterrence effect.	Limited usefulness (Shore Launched)	4[9] (Shore Launched)

[9] When flown from shore i.e. no cost for patrol vessel operations.

4.2.2 Type 2 Site: Offshore Site, <150 km^2

Table 3 | Cost-benefit analysis of monitoring options for sites outside of the 12 NM limit, with a maximum area of <150 km^2

Method	Pros	Cons	Benefit Score	Cost Score
Seaborne Patrol (Vessel only)	Vessels can both observe and interact with non-compliant vessels (for example carry out boardings). A fisheries patrol vessel gives a strong deterrence effect.	Cost of getting to the location and potentially minimal benefit, compounded by the small size of the site. Potential for non-compliant vessels to see patrol vessels transiting to the area, allowing them to cease activity or change behaviour.	Useful	3
Foot Patrol	No direct benefit to this MPA type.	No direct benefit to this MPA type.	Not useful	1
SAR	Can be more cost-effective than traditional MCS methods. Easy to cover the entire site with a single frame. Low resource use.	For smaller sites, it is more likely that imagery will cover areas outside of the MPA. Lead times for imagery delivery and analysis can reduce effectiveness. Intelligence gathering purposes only with lower intelligence value than other available remote sensing techniques.	Very limited usefulness	2
EO	Higher intelligence value than other remote sensing techniques. Can cover the whole site. Can be tailored to meet the specific requirements of the area. Low resource use. Imagery can be used to supplement evidence of non-compliant activity. Possible to positively identify vessels and activity.	Cannot intervene with non-compliance. Weather dependent (collections limited by cloud cover). Lead times for imagery delivery and analysis can reduce effectiveness.	Useful	2

Method	Pros	Cons	Benefit Score	Cost Score
Vessel Track Analysis	Allows for the detection of potentially non-compliant activity. Provides intelligence to inform strategic and tactical risk assessments and taskings Provides intelligence about potential non-compliant activity, which is important for this site type as it is more resource intensive to monitor with traditional methods.	Analysing even small areas can be time-consuming and requires resources to constantly monitor this. Requires devices that have a high 'ping rate' such as I-VMS or AIS.	Useful	1
Machine Learning	Low resource use. Allows for the detection of potentially non-compliant activity. Provides intelligence to inform strategic and tactical risk assessments and taskings. Provides intelligence about potential non-compliant activity, which is important for this site type as it is more resource intensive to monitor with traditional methods.	Requires devices that have a high 'ping rate' such as I-VMS or AIS.	Useful	1
UAV – Quadcopter	Can be used to increase the range at which a patrol vessel can detect non-compliant activity.	Needs to be flown from a patrol vessel to reach the site.	Limited usefulness	4
UAV – Fixed wing	Can be launched from shore, with lower resource implications than a seaborne patrol. UAV is unlikely to be seen and therefore more likely to detect non-compliance than a seaborne patrol.	Limited range when operated from the mainland if the site is at the operational limits of the drone. The potential need for a BVLOS licence. Long lead times to organise the relevant permits. Limited direct action against non-compliant vessels, through potential deterrence effect.	Useful (Shore Launched) Extremely useful (Vessel Launched)	4[7] (Shore Launched) 5 (Vessel Launched)

4.2.3 Type 3 Site: Inshore Site, area of 150-1,500 km^2

Table 4 | Cost-benefit analysis of monitoring options for sites within the 12 NM limit, with a maximum area of 150 -1,500 km^2

Method	Pros	Cons	Benefit Score	Cost Score
Seaborne Patrol (Vessel only)	Vessels can both observe and interact with non-compliant vessels (for example carry out boardings). A fisheries patrol vessel gives a strong deterrence effect.	Potential for non-compliant vessels to see patrol vessels transiting to the area, allowing them to cease activity or change behaviour. It may not be possible for larger patrol vessels to access all areas, and smaller vessels may not be able to patrol the whole area effectively in a day.	Useful	3
Foot Patrol	Low cost. Highly effective for engagement. Multiple vessels can be checked (in port). Vessels' landed catch can be checked. Can view some activity within the area (weather dependent).	Cannot deal with any 'at sea' related legislation, specifically many of the MPA-related byelaws which are spatial closures. May be difficult to cover the whole area dependent on access. There are limits to how far out vessels can be seen, and it can be difficult to verify the exact vessel location.	Very limited usefulness	1
SAR	Covers a large area. Can be tailored to meet the specific requirements of the area. Low resource use.	Intelligence gathering purposes only with lower intelligence value than other available remote sensing techniques. Cannot intervene with non-compliance. Likely to cover some areas outside the MPA, reducing cost-effectiveness.	Very limited usefulness	4
EO	Covers a large area. Can be tailored to meet the specific requirements of the area. Low resource use. Imagery can be used to supplement evidence of non-compliant activity. Possible to positively identify vessels and activity. Images are of higher value as they enable analysts to determine if vessels are likely to be fishing or	Cannot intervene with non-compliance. Weather dependent (collections limited by cloud cover). Lead times for imagery delivery and analysis can reduce effectiveness.	Useful	5

Method	Pros	Cons	Benefit Score	Cost Score
	recreational vessels (which are more prevalent in this area).			
Vessel Track Analysis	Allows for the detection of potentially non-compliant activity. Provides intelligence to inform strategic and tactical risk assessments and taskings Provides intelligence about potential non-compliant activity, which is important for this site type as it is more resource intensive to monitor with traditional methods. Can be applied to VMS data.	Analysing even small areas can be time-consuming and requires resources to constantly monitor this. Requires devices that have a high 'ping rate' such as I-VMS or AIS.	Useful	2
Machine Learning	Low resource use. Allows for the detection of potentially non-compliant activity. Provides intelligence to inform strategic and tactical risk assessments and taskings. Provides intelligence about potential non-compliant activity, which is important for this site type as it is more resource intensive to monitor with traditional methods. Can be applied to VMS data.	More robust when vessels have a high 'ping rate' such as I-VMS or AIS, which many vessels do not currently have.	Useful	1
UAV – Quadcopter	When used from shore it can help monitor the area.	Unlikely to be able to cover the entire area with this technology type.	Limited usefulness	2
UAV – Fixed wing	Carry out a full patrol of the area. Highly effective at covering a large area, could potentially cover a larger area than a patrol vessel, if not the whole MPA. UAV is unlikely to be seen and therefore more likely to detect non-compliance than a seaborne patrol. Lower carbon footprint compared to traditional patrol vessels.	Limited direct action against non-compliant vessels, through potential deterrence effect. Need for trained operators to fly it. The potential need for BVLOS licence. Long lead times to organise the relevant permits. Limited flight time based on the operational limits of the drone, may limit coverage.	Very limited usefulness (Shore Launched) Useful (Vessel Launched)	4 (Shore Launched) 5 (Vessel Launched)

4.2.4 Type 4 Site: Offshore Site, area of 150-1,500 km^2

Table 5 | Cost-benefit analysis of monitoring options for sites outside the 12 NM limit, with a maximum area of 150 -1,500 km^2

Method	Pros	Cons	Benefit Score	Cost Score
Seaborne Patrol (Vessel only)	Vessels can both observe and interact with non-compliant vessels (for example carry out boardings). A fisheries patrol vessel gives a strong deterrence effect.	Potential for non-compliant vessels to see patrol vessels transiting to the area, allowing them to cease activity or change behaviour. It may be difficult.	Useful	4
Foot Patrol	No direct benefit to this MPA type	No direct benefit to this MPA type	Not useful	1
SAR	Covers a large area. Can be tailored to meet the specific requirements of the area. Low resource use.	Intelligence gathering purposes only with lower intelligence value than other available remote sensing techniques. Cannot intervene with non-compliance. Likely to cover some areas outside the MPA, reducing cost-effectiveness.	Useful	2
EO	Covers a large area. Can be tailored to meet the specific requirements of the area. Low resource use. Imagery can be used to supplement evidence of non-compliant activity. Possible to positively identify vessels and activity. Images are of higher value as they enable analysts to determine if vessels are likely to be fishing or recreational vessels (which are more prevalent in this area).	Cannot intervene with non-compliance. Weather dependent (collections limited by cloud cover). Lead times for imagery delivery and analysis can reduce effectiveness.	Useful	5
Vessel Track Analysis	Allows for the detection of potentially non-compliant activity. Provides intelligence to inform strategic and tactical risk assessments and taskings Provides intelligence about potential non-compliant	Analysing even small areas can be time-consuming and requires resources to constantly monitor this. Requires devices that have a high 'ping rate' such as I-VMS or AIS.	Extremely useful	2

Method	Pros	Cons	Benefit Score	Cost Score
	activity, which is important for this site type as it is more resource intensive to monitor with traditional methods. Can be applied to VMS data.			
Machine Learning	Low resource use. Allows for the detection of potentially non-compliant activity. Provides intelligence to inform strategic and tactical risk assessments and taskings. Provides intelligence about potential non-compliant activity, which is important for this site type as it is more resource intensive to monitor with traditional methods. Can be applied to VMS data.	More robust when vessels have a high ‘ping rate’ such as I-VMS or AIS, which many vessels do not currently have	Extremely useful	1
UAV – Quadcopter	Can be used to increase the range at which a patrol vessel can detect non-compliant activity.	Needs to be flown from a patrol vessel to reach the site.	Limited usefulness	4
UAV – Fixed wing	Highly effective at covering a large area, would be able to cover a larger area than a patrol vessel, if not the whole MPA. Can be launched from shore, with lower resource implications than a seaborne patrol. UAV is unlikely to be seen and therefore more likely to detect non-compliance than a seaborne patrol	Limited direct action against non-compliant vessels, through potential deterrence effect. Limited range when operated from the mainland if the site is at the operational limits of the drone. Limited flight time based on the operational limits of the drone, may limit coverage. The potential need for BVLOS licence. Long lead times to organise the relevant permits.	Useful (Shore Launched) Very limited usefulness (Vessel Launched)	4 (Shore Launched) 5 (Vessel Launched)

4.2.5 Type 5 Site: Inshore Site, >1,500 km^2

Table 6 | Cost-benefit analysis of monitoring options for sites within the 12 NM limit, with area >1,500 km^2

Method	Pros	Cons	Benefit Score	Cost Score
Seaborne Patrol (Vessel only)	Vessels can both observe and interact with non-compliant vessels (for example carry out boardings). A fisheries patrol vessel presence provides a strong deterrence effect.	Resource intensive. High visibility affects covert operations. A Patrol Vessel is unable to cover the entire area daily. Intelligence is required in order to get to high-risk areas or areas with non-compliance.	Useful	3
Foot Patrol	Highly effective for engagement. Multiple vessels can be checked (in port). Vessels' landed catch can be checked. Can view activity within some of the area (weather dependent).	Cannot deal with any 'at sea' related legislation, specifically many of the MPA-related byelaws i.e. spatial closures.	Very limited usefulness	1
SAR	Often covers a large area Low resource use Can be used to direct patrol vessels to high-risk areas	Intelligence gathering purposes only with lower intelligence value than other available remote sensing techniques. Cannot intervene with non-compliance. Likely to cover a large area outside the MPA, reducing cost-effectiveness.	Limited usefulness	2
EO	Higher intelligence value than other remote sensing techniques. Can be tailored to meet the specific requirements of the area Low resource use. Imagery can be used to supplement evidence of non-compliant activity. Possible to positively identify vessels and activity.	Cannot intervene with non-compliance. Weather dependent (collections limited by cloud cover). Lead times for imagery delivery and analysis can reduce effectiveness. More time-consuming than other remote sensing methods to analyse a large area. To reduce cost, it is likely that only part of the site could be covered.	Limited usefulness	5

Method	Pros	Cons	Benefit Score	Cost Score
Vessel Track Analysis	Allows for the detection of potentially non-compliant activity. Provides intelligence to inform strategic and tactical risk assessments and taskings	Analysing even large areas is time-consuming and requires resources to constantly monitor this. Intelligence gathered will be more valuable when analysing tracks from devices that have a high 'ping rate' such as I-VMS or AIS.	Useful	3
Machine Learning	Low resource use. Allows for the detection of potentially non-compliant activity. Provides intelligence to inform strategic and tactical risk assessments and taskings	Intelligence gathered will be more valuable when analysing tracks from devices that have a high 'ping rate' such as I-VMS or AIS.	Useful	1
UAV – Quadcopter	When used with a vessel it can be used to increase the capability of the patrol vessel. When used from shore it can effectively monitor parts of the MPA.	Limited range when operated from a vessel or shore. It may not cover the whole site Need for trained operators to fly it.	Limited usefulness	2
UAV – Fixed wing	Potential to carry out a patrol of a large amount of the area and collect visual data for multiple MCS purposes.	May not be able to cover the entire MPA. The potential need for BVLOS licence. Long lead times to organise the relevant permits. Limited direct action against non-compliant vessels, through potential deterrence effect. Limited flight time based on the operational limits of the drone, may limit coverage.	Extremely useful (Shore Launched) Limited usefulness (Vessel Launched)	4 (Shore Launched) 5 (Vessel Launched)

4.2.6 Type 6 Site: Offshore Site, >1,500 km²

Table 7 | Cost-benefit analysis of monitoring options for sites outside the 12 NM limit, with an area of >1,500 km²

Method	Pros	Cons	Benefit Score	Cost Score
Seaborne Patrol (Vessel only)	Vessels can both observe and interact with non-compliant vessels (for example carry out boardings). A fisheries patrol vessel presence provides a strong deterrence effect.	Resource intensive. High visibility affects covert operations. Transit times to both reach and patrol area A Patrol Vessel is unable to cover the entire area daily. Intelligence is required in order to get to high-risk areas or areas with non-compliance.	Useful	4
Foot Patrol	No direct benefit to this MPA type.	No direct benefit to this MPA type.	Not useful	1
SAR	Covers a large area. Can be tailored to meet the specific requirements of the area. Low resource use. Can be used to direct patrol vessels to high-risk areas	Intelligence gathering purposes only with lower intelligence value than other available remote sensing techniques. Cannot intervene with non-compliance. Likely to cover some areas outside the MPA, reducing cost-effectiveness.	Limited usefulness	2
EO	Higher intelligence value than other remote sensing techniques. Can be tailored to meet the specific requirements of the area Low resource use. Imagery can be used to supplement evidence of non-compliant activity. Possible to positively identify vessels and activity.	Cannot intervene with non-compliance. Weather dependent (collections limited by cloud cover). Lead times for imagery delivery and analysis can reduce effectiveness. More time-consuming than other remote sensing methods to analyse a large area. To reduce cost it is likely that only part of the site could be covered.	Limited usefulness	5

Method	Pros	Cons	Benefit Score	Cost Score
Vessel Track Analysis	Allows for the detection of potentially non-compliant activity. Provides intelligence to inform strategic and tactical risk assessments and taskings	Analysing even large areas is time-consuming and requires resources to constantly monitor this. Intelligence gathered will be more valuable when analysing tracks from devices that have a high 'ping rate' such as I-VMS or AIS.	Useful	3
Machine Learning	Low resource use. Allows for the detection of potentially non-compliant activity. Provides intelligence to inform strategic and tactical risk assessments and taskings	Intelligence gathered will be more valuable when analysing tracks from devices that have a high 'ping rate' such as I-VMS or AIS.	Useful	1
UAV – Quadcopter	When used with a vessel it can be used to increase the capability of the patrol vessel.	Limited range when operated from a vessel. It will not cover the whole site Need for trained operators to fly it.	Extremely useful (Vessel Launched)	4 (Vessel Launched)
UAV – Fixed wing	Potential to carry out a patrol of a large amount of the area and collect visual data for multiple MCS purposes.	May not be able to cover the whole MPA Limited range when operated from the mainland if the site is at the operational limits of the drone. Therefore, the most viable option would be to launch the UAV from a vessel Need for trained operators to fly it. The potential need for BVLOS licence. Cannot take direct action against non-compliant vessels.	Extremely useful (Vessel Launched)	5 (Vessel Launched)

4.3 Summary of Cost-Benefit Analysis

Using the cost-benefit analysis, it is possible to draw some broad conclusions regarding the most useful cost-effective option for monitoring certain site types. These conclusions are not definitive, and consideration should always be given to the unique characteristics of specific sites.

The most effective monitoring option for the Type 1 sites was identified as the quadcopter drone (Table 2 and Table 8) while remaining cost-effective (Cost Level 2).

In contrast, the most useful monitoring method identified for the Type 2 sites (Table 3 and Table 8) was the vessel-launched drone option however, this was also the most expensive option (Cost Level 5) due to the operation of the patrol vessel as well as the drone. The most cost-effective method, still showing a degree of usefulness was vessel tracking and machine learning.

SAR was identified as the least suitable option for monitoring Type 3 sites, all other options were considered useful, but the cheapest monitoring option again was vessel tracking analysis using Machine Learning (Table 4 and Table 8).

Vessel tracking and machine learning was identified as the most useful and most cost-effective MCS supporting tool for Type 4 sites (Table 5 and Table 8).

For Type 5 sites, the most useful monitoring method was identified as shore-launched drones, with some restrictions around BVLOS permit application to be considered (Table 6). A combination of seaborne patrols and vessel-launched quadcopter drones may provide the most cost-effective options which provide the most beneficial support option (Table 8).

For the largest sites, Type 6 sites, Drones were considered the most useful but most expensive method of monitoring (Table 7 and Table 8). The most cost-effective option while still providing some usefulness was again vessel tracking analysis using Machine Learning.

Drone options ranged in usefulness across all sites, with the fixed-wing drone options always representing the costliest option. Quadcopter options could provide a lower cost-effective option for monitoring on all sites, particularly when used during scheduled seaborne patrols to increase the range and usefulness of monitoring and surveillance during patrols.

Across all sites, Vessel Tracking and Machine Learning was considered useful or extremely useful, consistently Machine Learning was the most cost-efficient option when monitoring all MPAs.

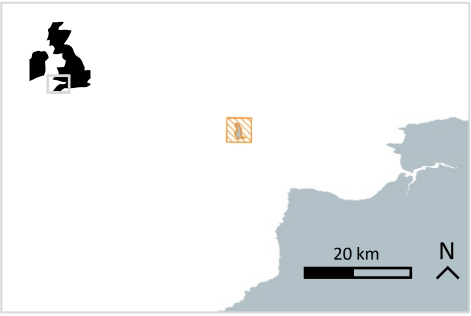
Site Type	Cost/ Benefit	Seaborne Patrol	Foot Patrol	SAR	EO	Vessel Track Analysis	Machine Learning	UAV – Quadcopter	UAV – Fixed wing (shore launched)	UAV – Fixed wing (Vessel launched)
Type 1: Inshore Site, <150 km^2	**Cost**	3	1	2	2	1	1	2	4	N/A
	Benefit	Useful	Limited Usefulness	Very limited usefulness	Limited Usefulness	Useful	Useful	Extremely useful	Limited Usefulness	N/A
Type 2: Offshore Site, <150 km^2	**Cost**	3	1	2	2	1	1	4	4	5
	Benefit	Useful	Not useful	Very limited usefulness	Useful	Useful	Useful	Limited Usefulness	Limited Usefulness	Extremely useful
Type 3: Inshore Site 150-1,500 km^2	**Cost**	3	1	4	5	2	1	2	4	5
	Benefit	Useful	Very limited usefulness	Very limited usefulness	Useful	Useful	Useful	Limited Usefulness	Useful	Useful
Type 4: Offshore Site 150-1,500 km^2	**Cost**	4	1	2	5	2	1	4	4	5
	Benefit	Useful	Not useful	Useful	Useful	Extremely useful	Extremely useful	Limited Usefulness	Useful	Very limited usefulness
Type 5: Inshore Site >1,500 km^2	**Cost**	3	1	2	5	3	1	2	4	5
	Benefit	Useful	Very limited usefulness	Limited Usefulness	Limited Usefulness	Useful	Useful	Limited Usefulness	Extremely useful	Limited Usefulness
Type 6: Offshore Site >1,500 km^2	**Cost**	4	1	2	5	3	1	4	N/A	5
	Benefit	Useful	Not Useful	Limited Usefulness	Limited Usefulness	Useful	Useful	Extremely useful	N/A	Extremely useful

Table 8 | Summary table of Cost-benefit analysis by site type

5 UK MPA Site Reports

Each selected site has a unique setting which allowed for the consideration and subsequent deployment of the most suitable MCS applications to different scenarios. All technology options for each site were considered, but only those which had the highest potential benefit were piloted for each site (Table 1). Further details on the selection of technology for each site are discussed in the Phase 2 final report *OM21-359_Phase_2_Risk & Technology Assessment.pdf* and the Phase 3 final report *OM22-099_Phase 3 Technology Plan & Trial Methodology.pdf* available as part of the appendix documentation.

5.1 Lundy



Lundy was proposed as a site for the project by Devon & Severn IFCA (D&S IFCA). The Lundy MPA encompasses several designations associated with different protections including a Marine Conservation Zone (MCZ) and Special Area of Conservation (SAC). Wider information about the site can be found at the JNCC website[10], features at the site include:

- Reefs
- Sandbanks which are slightly covered by sea water all the time
- Submerged or partially submerged sea caves
- Grey seal, *Halichoerus grypus*
- Spiny lobster, *Palinurus elephas* (MCZ)
- Harbour porpoise, *Phocoena phocoena*

5.1.1 Machine Learning and vessel tracking

No alerts were generated over the Lundy MPA from AIS analysis with Machine Learning.

Summary Assessment

- *No non-compliant activity was detected using AIS within Machine Learning, although trials indicated that ingestion and use of AIS in this manner was an effective tool in monitoring vessel movements at the site.*

[10] Lundy: Designated Special Area of Conservation (SAC) https://sac.jncc.gov.uk/site/UK0013114

5.1.2 Satellite sensors

Based on the site assessments, it was determined that Lundy was the most suitable location for tasked high-resolution EO imagery. Lundy is the smallest MPA in the project, as such its full extent can be covered by a single image. Additionally, the area has several byelaws in place that require an understanding of the activity type (both fishing and gear type), and EO imagery allows for an understanding of this, providing valuable intelligence to D&S IFCA. Additionally, there are other restrictions around site use around the Lundy MPA (recreational vessels, anchoring and diving) and high-resolution EO images allowed OceanMind to monitor compliance with these in addition to fisheries-related monitoring.

Based on this, imagery collection was requested weekly for the duration of Phase 4 (April 2022 to June 2022) of the project and a total of 16 images were collected during the project.

EO imagery was evaluated as being a highly effective remote sensing technique for this site, with cloud cover being less of a limitation than initially expected. The utilization significantly increased surveillance of the area compared to traditional patrolling. EO in conjunction with SAR resulted in imagery being collected on around 25% of days during the monitoring period.

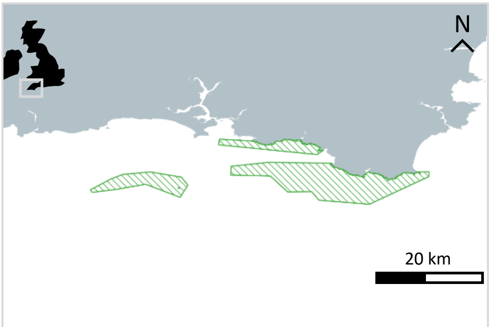
Analysis of EO imagery suggested that the area has a high level of compliance with existing fisheries regulations, with no large fishing vessels observed operating in the area, and compliance with the D&S IFCA Mobile Permit Byelaw (prohibiting bottom towed gear) appeared to be high. Fishing vessels detected in EO imagery suggest that the fishing vessels are likely to be small potting vessels, that are permitted to operate within the site, and there was a low risk of potentially unauthorised vessel activity over the Lundy MPA.

Summary Assessment

- *Trails using EO remote sensing imagery over the Lundy MPA were successful, although no non-compliant activity was observed during trials.*
- *EO technology offers the provision of versatile high-resolution imagery for use in dissemination and communications media.*
- *SAR was useful to understand levels of activity within the area, but provided limited actionable intelligence over the Lundy MPA, due to the diverse nature of vessel types and the delay between image acquisition and delivery of the risk assessment.*

5.2 Start Point to Plymouth Sound and Eddystone

This SAC was proposed as a site for the project by Cornwall IFCA. The area is a straddling site with multiple competent authorities including the Cornwall IFCA, D&S IFCA and the MMO. The site has three distinct areas, Eddystone, Bigbury Bay to Plymouth Sound and Start Point to West Rutts, with the whole site spanning 340.89 km^2. Features at the site include numerous areas of inshore and offshore reef, notably bedrock reef[11].



The reefs are closed to bottom towed gear under a Cornwall IFCA byelaw, along with the appropriate margin and buffer. This prohibition includes any part of the gear being in the water. Within the Devon & Severn IFCA district, activity-based Permit byelaws are in place for mobile fishing and potting. The prohibition of bottom towed gear is extended through an MMO byelaw, and within this site, the MMO's byelaw applies between 6 and 12 NM from the coast.

5.2.1 Machine Learning and vessel tracking

Machine Learning was a very useful tool when applied to I-VMS and VMS data, as it highlighted when vessels are likely to be fishing in prohibited zones. I-VMS was only accessible in the D&S IFCA part of the site, alerts generated using data from the I-VMS pilot show that ML is highly effective when analysing I-VMS data. 2 alerts were generated over the Eddystone area, and 31 over the Plymouth Sound areas. The difference is due to the number of vessels operating with I-VMS in the D&S IFCA district.

Summary Assessment

- *Vessel tracking alerts generated by machine learning proved to be one of the most useful tools to detect possible non-compliance with closed areas byelaws within the MPA.*
- *Ingestion and use of I-VMS in Machine Learning was particularly effective in detecting vessel tracking alerts, and further rollout of this technology would likely further increase the effectiveness of this technology at this site in providing actionable intelligence.*

5.2.2 Satellite sensors

High-resolution SAR was planned over the site to detect both fishing and recreational vessels with imagery covering the area twice per week. 8 images were collected with 9 vessels of risk detected.

[11] Start Point to Plymouth Sound & Eddystone (SAC) https://sac.jncc.gov.uk/site/UK0030373

There were a greater number of potential non-transmitting or 'dark' vessels in the size range of possible fishing vessels in the offshore areas of the site, as indicated by SAR. Another remote sensing tool, EO, was an effective tool for monitoring activity in the MPA but had limited availability during the monitoring period. However, the results indicate that EO imagery could, alongside SAR, provide useful intelligence over offshore sites.

Summary Assessment

- *There was limited EO imagery collected over the area during the project, although it is considered useful for intelligence gathering, and verification of machine learning alerts.*

5.2.3 Unmanned Aerial Vehicles (UAVs)

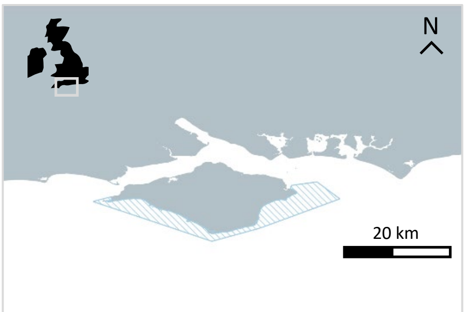
This site was considered ideal for testing the capabilities and applicability of the larger BVLOS UAVs. The offshore Eddystone site can be reached from shore with the larger drone to support MCS efforts, and the extended inshore sites are coverable with a flight from a single take-off/vantage point.

Summary Assessment

- *Due to unexpected delays, flights had not been undertaken at the time of reporting.*

5.3 South Wight Maritime

The South Wight Maritime SAC spans over 198 km² and sits wholly within the Southern IFCA. Wider information on the site is available on the JNCC website[12], and features at the site include:



- Bedrock and chalk reefs
- Vegetated sea cliffs of the Atlantic and Baltic Coasts
- Submerged or partially submerged sea caves

The Southern IFCA manages dredging and trawling activities in the site to ensure they do not interact with the sensitive habitats found through a byelaw which protects vulnerable features from bottom towed gear.

[12] South Wight Maritime: Designated Special Area of Conservation (SAC) https://sac.jncc.gov.uk/site/UK0030061

5.3.1 Machine Learning and Vessel Tracking

Machine learning and AIS analysis identified several vessels of risk, with AIS detecting vessels operating in and around the MPA. Vessel tracking enabled an understanding of vessel behaviour and broadly showed good compliance with local byelaws.

Summary Assessment

- *It is recommended to apply Machine Learning to I-VMS data upon completion of the national rollout, to efficiently and effectively identify any non-compliant activity which occurs within the restricted byelaw areas.*

5.3.2 Satellite sensors

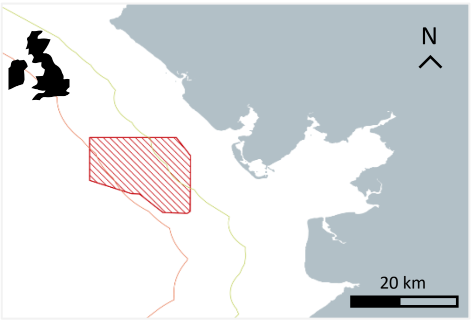
Since vessel tracking and on-site monitoring have limitations for this site due to the lack of I-VMS and the challenges associated with carrying out a vessel patrol in the area, remote sensing was a suitable option to support MCS efforts. EO and SAR were selected for use in this site. SAR was able to identify targets as small as 3 m in the South Wight MPA. These detections were generally located close to shore, potentially indicative of possible dark fishing vessels or pleasure traffic, operating without AIS. However, SAR was limited to determining presence and could not be used to determine vessel type or activity.

The capabilities of SAR make it suitable for describing vessel size and presence. However, due to the relatively small size of the site SAR was not useful as a patrol support tool. This is due in part to the limited persistence of vessels in the inshore location. Also, once a patrol vessel has committed to surveying the area, it is likely to cover the whole site rather than target a specific location within the site. EO high-resolution imagery, though limited in its coverage, proved a valuable tool to characterise vessel types and possible behaviour. A total of 15 SAR and 4 EO images were collected, and 3 high-risk vessels were reported.

Summary Assessment

- *SAR was useful for establishing a general picture of activity, identifying high-risk areas and times and informing patrol planning and resources.*
- *It is recommended to use EO to supplement additional remote sensing and monitoring sources.*

5.4 West of Walney



West of Walney was proposed as a site for the project by the North-Western IFCA. The West of Walney MCZ is situated 8 km west of Walney Island and was formally designated in January 2016. The West of Walney MCZ is situated in the Irish Sea, encompassing around 388 km². Further information on the site is available on the JNCC website[13]. The largest proportion of the MCZ is within the 12 NM limit, but a small part of it lies outside of this limit. This location places the feature across the MMO and North Western IFCA's jurisdiction. The West of Walney MCZ also falls within the Liverpool Bay SAC. Protected features at the West of Walney MCZ site include:

- Subtidal sand (Broad-Scale Habitat)
- Subtidal mud (Broad-Scale Habitat)
- Sea-pen and burrowing megafauna communities (Habitat Feature of Conservation Importance)

The soft mud habitat found in the West of Walney MCZ is also characterized by the presence of burrowing animals such as the Norway lobster (*Nephrops norvegicus*) and mud shrimp (*Callianassa subterranea*). Species such as *N. norvegicus* are of commercial interest to bottom towed gears. The site is subject to a byelaw that closes much of this habitat to bottom towed gear within both the 6 NM and 12 NM limits, however the byelaw stops at the 12 NM limit.

Energy infrastructure is a major presence in and around the MCZ, including a small number of gas wells and 5 associated pipelines. There are 4 large windfarms whose footprint overlaps with the MCZ (Ormonde, West of Duddon sands, Walney 1 & 2), with another one in development (Walney extension) which will also overlap. Furthermore, one telecommunications cable runs through the MCZ, as do several power cables from renewable energy sites.

There have been incidences of mobile gear use by UK and non-UK registered vessels within the West of Walney MCZ, including demersal otter trawling (targeting *Nephrops*) and beam trawls. Potting and static bottom gears are present and currently permitted within the MCZ boundaries. Fishing activity tends to be tidal dependent, and vessels operating within the site range from small to large (<10 m to >15 m).

[13] West of Walney: Marine Conservation Zone (MCZ) https://jncc.gov.uk/our-work/west-of-walney-mpa/

5.4.1 Machine Learning and vessel tracking

Vessel tracking with associated machine learning detected potential non-compliant activity and is an effective tool for use in this MPA

Summary Assessment

- *Machine Learning analysis of VMS data identified likely fishing activity within the byelaw areas, as did analysis of AIS data.*
- *Further rollout of I-VMS technology would likely further increase the effectiveness of Machine Learning as a monitoring tool.*

5.4.2 Satellite sensors

Wide Ultra-Fine (WUF) mode SAR was the primary remote sensing tool employed for the West of Walney MCZ, due to the profile of the likely vessels of risk (<24 m length, steel hull construction). These vessel profiles of concern may be potentially operating in and around the site and possibly not transmitting on vessel tracking systems. EO was planned as a verification tool only, due to the size of the MCZ. It is important to acknowledge that SAR is unable to capture all activity over an area, and infrequent events may have gone unobserved on SAR.

SAR detections within the MPA were dominated by wind turbines, platforms, rigs and survey vessels. Fishing vessels were detected to the southeast of the MPA with some operations encroaching into the 3 NM buffer and MPA, although they remained outside the 12 NM bottom towed gear restricted area.

Summary Assessment

- *SAR was unable to capture all activity over the MPA and infrequent events may have gone unobserved.*

5.4.3 Unmanned Aerial Vehicles (UAVs)

The use of UAVs was considered an option for monitoring the West of Walney MCZ, although the site distance from shore would necessitate the use of a fixed-wing design of UAVs to operate beyond the visual line of sight. However, a smaller, alternative design was also viable for launch from the NWIFCA patrol and enforcement vessel at sea. Options for this were explored with the NWIFCA who offered the potential use of their vessel if a suitable UAV could be sourced. The key drivers for this were: interest in innovative tools from the NWIFCA; the position of the site (spanning both the 6 and 12 NM limits) and the availability of the NWIFCA patrol vessel to launch the UAV from. This latter innovation and testing were important as only the innermost area of the MCZ is within flight range of shore launched fixed-wing UAVs, with no access to the outer boundary where incursions have been indicated. Under current regulations, the use of a UAV from a vessel is likely to negate the requirement for BVLOS permits and may ultimately inform a streamlined process for NWIFCA/MMO planning to use UAVs in the region and elsewhere within the UK in the future.

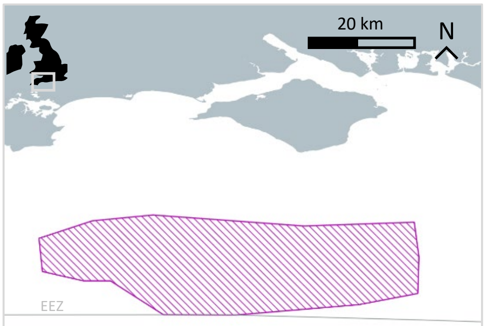
UAVs were able to observe and identify vessels operating in the MPA, identify markings on static gears and support scientific surveys of habitats and site features. The presence of a UAV is likely to have a deterrence effect on potential non-compliance.

Summary Assessment

- *Vessel-launched UAVs are likely to be a useful complementary tool to established enforcement patrols and scientific surveys.*
- *UAVs were able to observe and identify vessels operating in the MPA, identify markings on static gears and provide a deterrence effect.*

5.5 Wight Barfleur

The Wight-Barfleur MPA is in the English Channel and is managed in its entirety by the MMO. The SAC was established in 2019 and covers an area of 138 km^2. Features at the site include:



- Bedrock and stony reefs with rocky outcrops, which support a large array of reef fauna
- Bedrock ridges
- Channels

All fishing activity is from large and industrial vessels. Sizes range from 10 to 15 m to up to 80 m. Both national and foreign-flagged vessels (from the EU) are operational within the site. National vessels are mainly potting vessels operating to the west outside of the MPA. Other methods include dredging and beam trawl however, this is more common in the foreign-flagged vessels operating in the vicinity. Due to its offshore location, there is limited persistent recreational activity in the vicinity. However, a large number of recreational vessels pass through the MPA, transiting in a north-south direction. The site is subject to high volumes of merchant vessel activity, including through multiple shipping lanes, due to its location in the channel between France and England.

There are no byelaws currently in place at this site. The potential need for future management is currently under review by the MMO.

5.5.1 Machine Learning and vessel tracking

There appeared to be a limited number of vessels carrying out trawl operations in the area (AIS analysis highlighted three vessels). The majority of vessels identified on tracking data were either small pleasure vessels or large cargo vessels transiting. Fishing is currently permitted in the SAC, if future restrictions for mobile gear are introduced the large numbers of passing merchant vessels will reduce the opportunity for dark vessel activities to go unnoticed and any passing vessel could play a role in aiding monitoring of the SAC.

Summary Assessment

- *Machine Learning may be an effective tool for monitoring vessel activity at this site, with trials detecting movement patterns likely associated with trawl fishing operations.*

5.5.2 Satellite sensors

Wight Barfleur was a good candidate for Extra-Fine (XF) SAR, as the size of SAC is well covered by the extent and the medium and large-sized vessels inside it may be detected with a high degree of accuracy. Detections were often persistent over time, which increased the suitability of SAR as a monitoring tool. AIS vessel tracking was able to correlate most detections, suggesting that most vessels in the SAC were transmitting on AIS.

Imagery extending outside the SAC gave insights into activities within the surrounding waters. For example, the proximity to the South Wight MPA meant that SAR imagery could provide coverage over both areas. Remote sensing indicated the Wight Barfleur SAC had a moderate presence of 'dark vessels' with 21 detections over the monitoring period. SAR imagery identified dark targets between 44 and 154 m in length.

Summary Assessment

- *XF SAR was shown to be effective in detecting the presence of vessels of the type and size known to operate in the Wight Barfleur MPA, however, in isolation SAR is unlikely to provide actionable and timely intelligence to support management.*

6 Conclusions and Recommendations

6.1 Vessel Tracking Conclusions

6.1.1 Automatic Identification Systems (AIS)

Whilst AIS use by fishing vessels in the UK is not widespread, it did provide a useful insight into general activity levels, particularly in relation to the larger vessels. A historic review of AIS was carried out during Phase 3 of the project. During Phase 4, AIS analysis was used in conjunction with satellite imagery in order to corroborate and better understand vessel activity.

6.1.2 VMS & I-VMS | Machine Learning

VMS & I-VMS are considered to be a lot more robust than AIS, as any changes to the data output violates fisheries regulations and would be subject to investigation. Whilst on occasion I-VMS devices will not be able to send positional data (due to lack of network coverage), the devices themselves have a store-and-forward function. Furthermore, authorities generally understand the location of areas with poor or zero network coverage and can take these into account, while adapting MCS strategies accordingly.

During the trial 2318 VMS and I-VMS vessel tracks, creating nearly 1.3 million data points were analysed using OceanMind's Machine Learning Algorithm. It would require large resource allocations to monitor these tracks manually. OceanMind's machine learning algorithm was trained on global AIS data and can analyse all tracks for vessel type, fishing activity and possible risks (alerts) in real-time. The alerts allowed analysts to focus on vessels with potential non-compliant activity, enabling efficient monitoring.

The accuracy of alerts could be further improved by incorporating catch data from vessel logbooks to help better train the algorithms. This could be achieved by setting up a rolling data sharing agreement, including the associated infrastructure to allow VMS and I-VMS data to be run through OceanMind's Machine Learning algorithm. During the project, there was a significant delay in the provision of data from the MMO to OceanMind, which meant data could not be analysed in real-time. Any infrastructure established would need to allow for real-time or near-real-time data sharing.

Due to data protection concerns, the MMO supplied anonymised data (vessel identifier was removed) to OceanMind, which severely limited the analysis capability and did not allow for the comparison of VMS/I-VMS data with other tools. Limitations to the analysis included: being unable to correlate SAR/EO detections against I-VMS, not being able to check VMS/I-VMS against AIS records and overall it reduced the value of the intelligence provided to the IFCAs as they could not easily associate potential non-compliant activity to an identified vessel without supplementary information.

ML identified that vessels on both I-VMS and VMS have unexpected gaps in their reporting. Further analysis and scrutiny of these vessels' tracks is required to understand if this signifies systematic non-compliance, as the presence of these gaps reduced the accuracy of ML alerts and meant that the vessels' activities could not be verified.

6.2 Satellite Remote Sensing Conclusions

6.2.1 Electro-Optical (EO)

The quantity and quality of EO images of UK MPAs exceeded initial expectations. The main benefit of the high-resolution EO is that it allows verification of vessel activity, and therefore means that competent authorities can check compliance with closed area byelaws in MPAs. EO imagery generates intelligence that can be applied at the local, regional or national level. Collected intelligence can be used for both strategic planning and tactical tasking. The intelligence value of collecting EO images was clearly established through the project, with images collected generally showing good compliance in the selected sites.

6.2.2 Synthetic Aperture Radar (SAR)

OceanMind has found SAR to be an incredibly useful tool for intelligence gathering in other MPAs globally, however not around the UK. Whilst the high-resolution SAR used in this project was very effective at detecting targets as small as 3 m, the low persistence of vessels (many of them fish in the area for a short period of time) means that even if dark vessels are detected, by the time they are reported they are likely to have already left the area. This is compounded by the relatively high levels of traffic, which reduce the certainty of any analysis carried out. SAR can still be successfully used to gather information about activity levels and to carry out monitoring, in particular when understanding site use and especially in relation to recreational vessels that may not have tracking units installed.

6.3 Unmanned Aerial Vehicle (UAV) Conclusions

Unmanned Aerial Vehicles (UAVs) were investigated for their value as a complementary tool to satellite remote sensing methods currently employed across the UK MPA project.

UAV flights in inshore areas showed that there may be benefits to using UAV technology to facilitate fisheries monitoring. The use of UAVs may improve health and safety when operating in high-risk tidal areas and habitats. Furthermore, inspections of static gear markings can be improved through the use of the units. A wider shift towards painted buoys may further increase the suitability of UAV technology in MCS.

The various applications of UAV technology were tested using a vessel-launch approach from 29Jun-01Jul2022 over the West of Walney MCZ, which showed clear potential benefit to monitoring, control and enforcement activities both within the boundaries of the West of Walney MCZ, and across the wider NWIFCA district.

The key identified risks to the West of Walney MCZ (vessels towing mobile bottom gears), were not encountered during the test flights. Nonetheless, trials using a potting vessel demonstrated that a small UAV unit, capable of being launched from a patrol vessel in offshore areas, can allow observation and recording of footage of active fishing operations such as hauling of gear.

UAVs operating within VLOS provide benefits to traditional shore-based and vessel-based patrol. Benefits will be most pronounced in high-risk areas, or areas where there is evidence of systematic or planned non-compliance. In relation to UAV vessel-based use, the benefits may be greater when operated from smaller, less visible vessels, such as those frequently and increasingly deployed by the IFCAs. This method can support intelligence and evidence gathering while lowering the risk of alerting non-compliant vessels of the patrol vessel presence. UAVs operating within VLOS are unlikely to replace traditional MCS methods entirely as their range is limited.

In order to extend the range of the UAVs, it is necessary to deploy drones capable of BVLOS operations. These operations require a BVLOS licence to be obtained from the CAA, which can be costly and time-consuming. During this pilot, our application for a BVLOS licence took 6 months to acquire including completing the relevant documentation for submissions and carrying out risk assessments of suitable launch sites. Once our licence had been awarded, a change in staffing of the drone operators required resubmission of the licence due to name changes, further delaying the application process. These difficulties would need to be addressed for fixed-wing drone operations to become normalised within the maritime domain. At the time of report production, we await final licence approval and we have been unable to test the capabilities of the technology.

These difficulties impact the current utility of this technology within the UK however, trials conducted by OceanMind in Senegal and Costa Rica showed excellent capabilities as MCS support within the maritime space. Deploying fixed-wing UAVs with the relevant BVLOS licence in the UK sea space would provide an additional MCS tool in high-risk areas, or potentially replace traditional MCS efforts in more low-risk or resource-intensive areas (offshore or remote MPAs).

6.4 Recommendations

6.4.1 General Recommendations

It is recommended that at the UK level a remote sensing working group is established, comprising of the IFCAs/MMO and devolved fisheries administrations, to coordinate use of remote sensing tools in the future. These tools could supply valuable information about non-compliance, but also evidence for the implementation of management regimes. A working group is the best platform to achieve this coordination as this would help prioritise data collection and enable a 'collect once, use many times' approach to be taken.

6.4.2 Vessel Tracking Recommendations

- It is recommended to continue the monitoring of AIS tracking data, using Machine Learning alerts to detect possible non-compliance with MPA byelaws as this would increase efficiencies in analysis. Further work to carry out this analysis and disseminate the intelligence with the relevant competent authorities should be considered.
- We recommend that the competent authorities continue monitoring VMS and I-VMS using machine learning based alerts, as it will reduce possible human errors and resource burdens on governmental organisations.
- We recommend an investigation by the competent authorities into the VMS and IVMS data gaps to explore the reasons behind limited transmissions from vessels using both VMS and I-VMS units. The presence of these gaps reduced the accuracy of ML alerts and meant that the vessels' activities could not be verified.
- Explore future options to increase the accuracy and utility of alerts by incorporating catch data from vessel logbooks, this could provide further information to support fisheries management options, particularly when considering real-time catch limits.
- Investigate options to initiate a rolling data-sharing agreement with the MMO and devolved governments, including the associated infrastructure to allow VMS and I-VMS data to be run through OceanMind's Machine Learning algorithm. It is recommended that any infrastructure established allows for real-time or near real-time data sharing.
- It is recommended to work on a way for non-anonymised data to be supplied to OceanMind by the competent authorities so that the full benefits of OceanMind's analytical capabilities can be realised.
- Seek further funding to develop the OceanMind Machine Learning Algorithm and associated infrastructure for these alerts to automatically be sent to the relevant authorities.

6.4.3 Satellite Remote Sensing Recommendations

- It is recommended that competent authorities explore options for utilising high-resolution EO to monitor specific high-risk areas. The imagery could be tasked and reviewed for entire MPAs to understand both site use and compliance. Vessel detections should be reviewed by local experts who may be able to confirm the identity of dark vessels.
- SAR Imagery has limited usefulness across UK MPAs and it is recommended that SAR is considered for larger and offshore MPAs in cases where more information is required around activity levels.

6.4.4 Unmanned Aerial Vehicle (UAV) Recommendations

- It is recommended that options to purchase quadcopter drones and train staff are explored as a viable option for the Inshore Fisheries Conservation Authorities to support Seaborne patrols both for monitoring and enforcement.
- At the time of report writing, the use of fixed-wing drones to support MCS in the UK have not been practically tested however, the preparatory documentation has been issued.
- When including fixed-wing drone operations, it is recommended to seek CAA approval for a BVLOS Licence at least 12 months before the application of the technology to prevent delays to operations.

Practical Examples

In order to provide the maximum protection for marine protected areas, it is ultimately recommended to use a combination of different tools, this may change based on the perceived risk or intelligence received at any given time. Following are some example situations and how different technology types could be used for MCS:

Situation 1 | Patrol officers suspect non-compliance in a Type 1[14] MPA.

> **Action** | For cost-effective actionable intelligence and monitoring of the whole site it is recommended for patrol officers to deploy a quadcopter UAV, whilst conducting onshore patrols to support intelligence or evidence gathering.
>
> **Action** | For long-term monitoring, high-resolution electro-optical monitoring could provide cost-effective intelligence gathering and identify non-compliant activities and vessels.

[14] **Type 1**: Site **inside** the **12 NM limit**, with a maximum area of **150 km^2**

Situation 2 | Information is required to further inform management plans and it is not known what vessel types operate within a Type 2[15] MPA.

Action | A combination of freely available and on-demand (commercial imagery) for high-resolution EO imagery could be obtained and analysed to understand activity levels and vessel types that operate in the area.

Situation 3 |Within a Type 4[16] MPA, where the perceived compliance is good, patrols have not detected non-compliance. Intelligence is received that bad actors are leaving the area when they believe the patrol vessel will be in the area.

Action | High-resolution EO could be tasked over the area to help corroborate the intel and decide if further action is necessary. If it is deemed necessary, a solution could be to deploy a fixed-wing UAV from shore to collect intelligence or evidence of non-compliance without alerting to patrol presence.

Situation 4| Activity levels in a Type 6[17] MPA are not fully known, a routine patrol is scheduled.

Action |AIS (VMS where available) track analysis could be conducted to understand current activity levels within the MPA. SAR imagery should be tasked ahead of the planned patrol to determine potential high-risk areas and 'dark vessel' hotspots in support of patrol route planning to maximise asset resources and 'time on target'. For very large MPAs (>10,000 km^2), live patrol support is recommended; imagery should be tasked, analysed and disseminated to the patrol vessel within 6 hours of image acquisition to provide 'eyes on the sea' for patrol vessels and help zero in on targets.

[15] **Type 2**: Site **outside** of the **12 NM limit**, with a maximum area of **150 km^2**
[16] **Type 4**: Site **outside** of the **12 NM limit**, with a maximum area of **150-1,500 km^2**
[17] **Type 6**: Site **outside** of the **12 NM limit**, with an area **>1,500 km^2**

Appendix

Appendix 1 | Selection criteria and the associated scoring applied to the proposed sites.

Criteria	Question	Scoring
Basic Information about the site	Location	Inshore = 1 6-12 NM = 1 Offshore =1 1 Point for each, Max Score = 3
	Size	Sort by size (largest to smallest) and rank. Largest site is ranked highest. Group sites and rank, top 20% score 5, next 20% score 4 etc
	Competent authority	No Score
	Designation	1 point for each designation type. Max score = 3
	Features	More sensitive features should have a higher score Max Score = 3
	Conservation Objective	Scale Score 5 points for recover/restore 2 for maintain 1 for unknown
	Non fishing activity	No Score
	Why was the MPA suggested?	Scale score 5 - Fully justified, with solid information and overall rational. 4 - Good rational, some missing information 3 - Moderate rational given, some supporting information 2 - Some rational, doesn't appear of particular importance 1 - little or no rational explaining why the site should be chosen 0 - no rational given.
Management	Management Questions	1 for byelaw 1 for national Max score = 2
	Restrictions in place.	1 point per restriction Max score = 6
	Description of management measures in place	Scale score 5 - specific measures which include some form of spatial component 3 - measures that include some form of additional monitoring or data collection 1 - permits or measures only technical in nature
Fisheries	Types of vessels	No Score
	Length of vessels	0 to 10 m = 1 point 10 to 15 m = 2 points >15 m = 3 points For sites with mixed vessel sizes, score to largest vessel size.
	Quota Species	Yes = 2 points No = 0 points
	Spawning ground	Yes = 2 points No = 0 points

Criteria	Question	Scoring
	Reporting requirements	1 point for each. Max score = 3* *noting that most sites cannot have both a paper-log and e-logs or VMS and IVMS
Current Monitoring and Enforcement	Limitations to enforcement	Scale score 5 - Well explained and clear limitations to the enforcement of the site (e.g Offshore, remote, size or vessel availability). 4 - Clear limitations, but less complete than above category 3 - Some limitations, explained, but could be resolved in other ways than remote sensing 2 - few limitations with other options 1 - almost no limitation, enforcement could be almost completely carried out in other ways
	High risk activities observed	Scale Score 5 - information that shows or demonstrates that a high-risk activity occurs on a regular basis 4 - information that shows or demonstrates that a high-risk activity occurs, but not on a regular basis 3 - information that shows or demonstrates that a high-risk activity rarely occurs 2 - information that shows or demonstrates that no high-risk activities occur
	Are remote sensors used	1 if not used 0 if already used
Ecological Vulnerability	Impacts on protected features	Scale Score 5 - High Impact 3 - Medium Impact 1 - Low Impact
	impacts on fish stocks	Scale Score 5 - High Impact 3 - Medium Impact 1 - Low Impact
	Impacts on other species of fish stocks	Scale Score 5 - High Impact 3 - Medium Impact 1 - Low Impact
Additional Criteria	Similarity to other sites	Yes/No answer. For sites which are similar; only one should be selected.
	Suitable remote sensors	1 point for each (SAR, EO, AIS, VMS, I-VMS, UAVs). Max score = 6
	Patrol support possibilities	Yes = 6 points No = 0 points
	UAV Monitoring suitability	Yes = 6 points No = 0 points