Emerging Technologies and their Application in Fisheries Management

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"Technology, training and respect for the expertise of fishers can together deliver enhanced safety, economic growth and environmental sustainability."

verumar

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EMERGING TECHNOLOGIES AND THEIR APPLICATION IN FISHERIES MANAGEMENT

1 INTRODUCTION

The world relies on fish like never before. In the 1960s, the world's population consumed just under 10kg of fish per person per year, a figure that had more than doubled to over 20kg per capita by 2016, according to the United Nations' (UN) Food and Agriculture Organization (FAO). Furthermore, combined production from capture fisheries and aquaculture is predicted to reach 201 million tonnes by 2030, an increase by some 18% from 2016 levels (FAO).

That growth projection presents challenge enough to the world's fishing sector and associated environmental agencies, but is rendered additionally problematic when current fish sustainability levels are taken into consideration. More than a third of the major commercial fish species that FAO monitors is considered to be fished at biologically unsustainable levels, with 60% being fished at biologically sustainable levels and the remaining 7% under fished. These concerning figures attract an additional layer of alarm when you consider that the global share of marine fish stocks that are considered within biologically sustainable levels stood at 90 per cent in 1974, a worryingly steep decline.

Thankfully, these challenges are being faced at a time when we stand at the threshold of major technological advances. Building on the profound digital revolution that started in the last century, the Fourth Industrial Revolution, (also known as 4IR or Industry 4.0), promises to fuse together a wide range of technologies across the physical, digital and biological worlds. For example:

- The new space revolution is opening up in-orbit activities to a wide range of new actors – commercial enterprises, universities and other research organisations and governments with smaller budgets. It is estimated that 1,000 smallsats (anything up to 500kg in mass and operating 450-650km above the Earth's surface) will be launched every year in this decade, against a benchmark of 385 in 2019.
- Sensors – detecting events or change in the environment – are becoming smaller, more durable and more affordable. Crucially for marine and maritime applications, they also often require less power so have greater endurance.
- Autonomous and remotely piloted vessels of all descriptions are being launched on land, in the air, on the ocean surface and being sent to the sea.
- Satellite communications are becoming more ubiquitous and affordable, enabling all this new data to be transferred back to shore for more, and more timely, analysis more effectively.
- The ultimate enabler of all these sector advances is the step change being seen in computing power, which in turn enables Machine Learning (ML) and Artificial Intelligence (AI) systems that can extract value from all this new data being collected from space and airborne, seafaring and sub-surface platforms and sensors.

While forward-thinking governments, commercial entities, non-governmental organisations (NGOs), and academia are committed to investigating the potential of new technologies to promote sustainable fisheries management, it is not an easy task. As we see in many industries, new technology options can be seen to be over-hyped, sometimes pushed into the market before they are ready and sometimes not particularly well explained. Quite often, the underpinning technological advances that make new products and services possible are not adequately explained or referenced.

Perhaps most importantly, we are often told that commissioners and potential customers of new technologies often face decision fatigue – unsure if they have the full picture of what is coming to market, and if their precious investment is likely to have the greatest impact over the longest time, before the next big thing sails into view.

This white paper aims to bring some clarity on these issues by providing a detailed overview of a broad range of key emerging technologies (emtech), and explaining how they are beginning to be applied to have a positive impact within fisheries management.

Each section presents a different emerging technology, and contains three main elements:

- An accessible technical explanation of the range of emerging capabilities within that segment.
- Technical case studies illustrating how such capabilities are being used to create value.
- Specific use cases within the broad reach of fisheries management – from autonomous fish stock assessments to the intelligent use of satellite data to help counter Illegal, Unreported and Unregulated Fishing (IUU Fishing) – the main focus of the Verumar project.

The Verumar project is made possible by generous support from the International Partnership Programme (IPP), a UK Government initiative led by the UK Space Agency which is part of the Department for Business, Energy and Industrial Strategy's Global Challenges Research Fund.

We are also indebted to our international partner within the Philippines, the Bureau of Fisheries and Aquatic Resources within the Department of Agriculture. It is in trying to match their ambition and drive to embrace as many potential innovations as possible in order to protect Mother Nature's resources that we were inspired to write this report.

Finally, sincere thanks also to all contributions from project staff within the Verumar consortium's partner agencies:

- **NLA International** Ltd is a blue economy solutions company creating concepts and projects that provide socio-economic benefit in the marine and maritime environments.
- **OceanMind** works to increase the sustainability of fishing globally through actionable insights into fishing and fishing vessel compliance by providing unbiased, independent monitoring, verification and validation of all 'at sea' activities.
- **MDA** is an innovative leader in earth intelligence and space infrastructure trusted to deliver solutions for the most critical government and commercial missions.
- **Poseidon** are fisheries consultants working globally to provide advice in support of sustainable fisheries and aquaculture, marine planning, and blue growth.

We hope you enjoy and are stimulated by this report.
Please visit www.verumar.com should you wish to contact us.

2 EXECUTIVE SUMMARY

The space sector is embracing huge change – we are entering the era known as 'new space' where both public / private sectors are investing significantly in the space ecosystem. **Space-based (Geostationary and Low Earth Orbits) capabilities** are a very effective way of monitoring and surveillance across the oceans, providing relevant levels of revisit and persistence, resolution, access timescales (near real-time, real-time, etc.) and at a price point that is feasible for the fisheries management and Monitoring, Control and Surveillance (MCS) community. With new **Earth Observation (EO) satellites** launching and becoming operational, fisheries authorities are recommended to put in place an EO exploitation strategy or plan. The use of free and open data sources as well as the establishment of a specialist remote sensing cell inside an organisation are good starting points.

Space-based weather services and underlying data are becoming more accessible with access direct from user systems through published Application Programming Interface (API) services and more user-friendly business / data licensing models. Many of these innovations are of direct relevance and benefit to fisheries management and MCS systems.

Helicopters and fixed wing aircraft platforms are long-established capabilities for both commercial fishing and fisheries authorities' day-to-day operations. **Unmanned Aerial Systems** (UAS), also known as **Remotely Piloted Aircraft Systems** (RPAS) platforms, are also entering use in the maritime domain. Fisheries management uses for UAS include for local monitoring of fisheries related infrastructure (e.g. aquaculture, marine and coastal environments) and small area of interest remote sensing requirements.

High Altitude Pseudo Satellites (HAPS) are stratospheric platforms that can stay over a fixed point on Earth for long durations (weeks to months). As HAPS vehicles can travel vast distances over long periods of time, toggling between moving and strategically hovering over an area to collect data, they can be used to monitor large stretches of oceans for illegal fishing, pollution, and piracy.

On and beneath the ocean surface, **Unmanned Surface Vehicles** (USVs) and **Unmanned Underwater Vehicles** (UUVs) are beginning to proliferate. Systems may also be remotely piloted and be tethered or untethered. They bring increased health and safety, reduce human error risks in operations and in principle offer costs savings for marine data collection. USVs are being used for fish stock surveys, pelagic fish location and for surveillance.

Global Navigation Satellite System (GNSS) is a satellite infrastructure that allows users to determine their position, velocity, and time by processing signals from 'in range' satellites. It underpins all marine navigation and is a fundamental technology supporting **Position, Navigation and Time** (PNT). New satellite constellations are offering new levels of disaster warning and protection to aligned fishing fleets. Vessel Monitoring Systems (VMS) that automatically transmit location and time data are bringing new levels of transparency to fisheries management. Smaller Global Positioning System (GPS) locators are helping fishermen to avoid their gear accidentally floating into no-fish zones.

New **sensors** are emerging that are small, inexpensive and passive, requiring very little power. Such sensors are already providing value on-vessel, to aid fish traceability and to support advanced sensing and measurement within the aquaculture sector. Nanotech biosensors are emerging that can significantly reduce the time to test fish freshness in port or in the supermarket.

New **data infrastructures** are developing to provide overarching data policy and governance frameworks to enable the definition and maintenance of data technical standards and specifications in a rapidly-changing world. Electronic Catch Documentation and Traceability (eCDT) is the collection, documentation, sharing, and analysis of verifiable ecological, economic, and social data related to captured wild fisheries as they move through the supply chain. Such new structures help to ensure that fish products are "traceable" throughout all points in the supply chain— from point-of-catch through to export.

Robotic Process Automation (RPA) – where computers learn and then manage structured, repetitive digital tasks – are being used in fishing company back offices to free up staff for customer-facing duties.

Data analysis involves the ingestion, processing, classification, modelling, mapping, interpretation, and evaluation of data in support of a business requirement or to inform a business decision. **Big Data** involves undertaking data analysis and visualisation on a large scale. This often involves the use of multiple data types, is automated, likely to occur in real-time or near real-time, and may be self-learning through the use of **Artificial Intelligence** (AI) and / or **Machine Learning** (ML).

Computer Vision and Big Data techniques are being used in aquaculture to analyse how much feed should be made available in pens and to provide early warning of outbreaks of sea lice. AI is also combining past fishing effort data with weather condition and ocean current information to forecast the locations of the most fertile fishing grounds.

Communications and **cybersecurity** are traversal technologies that enable the implementation and exploitation of wider technology innovations. EO, PNT, the transfer of voice, video, and data and in-situ scientific research (sensors, etc.) all rely on and are enabled through communications networks and their associated security framework. Low-cost satellite communications (satcomms) capabilities have been deployed in Southeast Asian fisheries to protect human life at sea by enabling fishers to call for help when in distress. The fishing sector as a whole is vulnerable to cyber-attack as more of their day-to-day operations are digitalised.

Monitoring, Control and Surveillance (MCS) systems are now able to adopt a blended capability of many technologies to provide optimal, bespoke approaches: satellite data and wider intelligence can be used to focus patrol operations; patrol vessels can be deployed supported by UAV, or patrol aircraft can be mobilised; for longer term deployments and deployment in selected operational settings, monitoring and surveillance using fleets of USVs / floating buoys may be deployed. With flexibility to support a range of strategic and tactical operational enforcement requirements, a robust monitoring and surveillance capability is emerging available for fisheries authorities' use. National Maritime Security Centres and bodies such as the Philippines' Bureau of Fisheries and Aquatic Resources (DA-BFAR) are showing leadership by trialling and investing in such blended systems.

3 EMERGING TECHNOLOGIES OVERVIEW: KEY FEATURES AND AREAS OF POTENTIAL DISRUPTION

Space Based Earth Observation Technologies and Meteorology

DISRUPTION

New Space EO platform / payload (sensor) options

Real-Time / Near Real-Time Space Data Access

Persistent EO Coverage and Tasking Flexibility

Commercial Weather Services

Open Data and Large Historic Data Archives

FEATURES

- Automated processing to Analysis Ready Data (ARD)
- Data Cubes
- Space infrastructure convergence and streamlining (Sensor, Platform, Connectivity, Ground Station, Cloud)
- Increasing data resolution and acquisition revisit frequency
- Video from space
- Increasing range of sensors / Provider Options: SAR, Electro Optical, VIIRS, Multispectral
- Edge compute and sensor miniaturisation
- Range of platform options (SmallSats / CubeSats, etc.)
- Increasing industrial experience and expertise in the space operational setting (upstream -launchers, payloads, sensor manufacture and operation)
- New business / data licensing models
- Government long term investment and planning – Core mission continuity: E.g. Earth observation: Copernicus Series; and weather: NASA GOES-R Series, JMA Himawari 8 and 9 missions, etc.

Unmanned Aerial Systems (UAS) and High Altitude Pseudo Satellites (HAPS)

DISRUPTION

HAPS mission persistence (Months) and Covert

HAPS Mission and Payload flexibility (Mapping, Intelligence Surveillance and Reconnaissance and Communications)

HAPS 5G Networks and Connectivity

Drone/UAS rapid mobilisation, deployment and recovery

FEATURES

- Complementary and interoperable with wider fisheries management ISR / Aerial patrol capabilities
- ISR resolutions (imaging to a few cm)
- Real-time data streaming
- On board Augmentation Systems for high accuracy location awareness and navigation
- Mission and payload flexibility (Mapping, ISR and Communications)
- HAPS solar power enabling mission endurance
- Drone / UAS options based on size, payload and mission endurance requirements
- VLOS / BVLOS capability options
- RLOS / BRLOS capability options
- Straightforward commissioning / implementation with quick win operational impact
- Achievable CAPEX/OPEX Cost Base
- Fisheries management is benefiting from wider military / civilian domain investment and implementation references

Marine Autonomous Systems

DISRUPTION

MAS EmTech advances will generate large volumes of data on ocean space informing ocean, marine and fisheries research, understanding and insights

Ability to deploy autonomous marine systems at scale

MAS improvements in endurance, range, speed, payload capacity, displacement coupled with capability to withstand and operate in weather and sea conditions

FEATURES

- Smart Navigation / Vessel Operation (Applied AI)
- Tailored Payloads (survey, sensing and measurement, robotic engineering toolsets)
- Tailored Mission Planning Command and control system/user interface
- Real-Time Data Transfer and Publication
- Integrated AIS, etc. transceiver and other communication equipment for real-time communications
- Collision Avoidance and Navigation
- Self-righting
- Vessel self-powered (propulsion) by wave, sail and solar and/or Vessels motor powered (fuel, electric (battery) or hybrid) options
- Vessels configurable between manned and unmanned modes
- Launch and recovery capabilities (from vessel / from vehicle from land or fixed asset platform)
- USV
- UUV (Including ROV)
- Tethered MAS
- Fisheries management is benefitting from MAS start up and investment in wider maritime domains (Oil / Gas/exploration/ Military-Navy)

Position, Navigation andTime (PNT)

DISRUPTION

Blockchain timing supply chain traceability

S-AIS / T-AIS cooperation providing global AIS coverage

Expansion of vessel AIS transceiver uptake to smaller vessels

Galileo GNSS fulfils maritime navigation requirements both for inland waterways and approach to/ inside port and on open seas

FEATURES

- Tailored AIS, Enhanced Analysis and Visualisation Products and Services coming to Market
- Increased accessibility to AIS data (via WiFi networks / data service streaming direct into legacy systems)
- New AIS Services Brokerage and Business Models
- Terrestrial AIS from land to ~40nm / Satellite AIS beyond
- Collision Avoidance and Surveillance Systems Enabled via GNSS (AIS and LRIT)
- HAPS PNT Services Feasibility Work Underway
- GNSS Receiver and Chipset advances leading to smaller, more performant platforms and devices
- Increasing Ground-Based Augmentation (GBAS) options, (inc. Differential GNSS, RTK, WARTK, PPP)
- Satellite-Based Augmentation supporting wide area or regional augmentation
- Increasing Global and Regional GNSS constellation Options

Sensors and Internet of Things (IoT)

DISRUPTION

M2M

Edge Compute and Embedded AI

Sensor Networks

Sensor Affordability

FEATURES

- Real-time Monitoring, Measurement and Alerts
- Advanced Analytics
- Edge Compute and Embedded AI
- Sensor Networks
- Synchronous Sensor Systems/Payloads
- Embedded Sensors (Advanced Materials)
- Static and Mobile Sensors on range of platforms (IoT/ IoMT)
- Simultaneous Localisation and Mapping (SLAM)
- Smart Devices (Phones, Wearables, etc.)
- Barcode, RFID, QR Codes
- Reduced Sensor Power Needs
- Sensor Durability
- Sensor Miniaturisation
- Wide range of sensors: Physical, Material, Optical, Chemical and Biological
- Standards and Sensor Interoperability

Data Infrastructure

DISRUPTION

Movement towards Digital Twins

Connected and Interoperable Data

Digitalisation

Open Data

FEATURES

- Automation
- Applied AI/ML
- Advanced Data Analysis
- Data Mining
- Data Fusion
- Data Lakes
- Metadata (for M2M)
- Cloud / Hybrid Cloud (Data Collection, Storage, Archive, Processing, Analysis and Dissemination)
- Structured / Unstructured Data
- Data Cubes / Analysis Ready Data
- Enterprise Data Management
- Data Warehouse / Data Mart
- Engineered Data Models
- Metadata (for Human Interrogation)
- Linked Data
- Authoritative Data
- Information Security Management
- Renewed Focus on Data Governance and Policies (MOU/MOA, Data Sharing Agreements, Data Ethics)
- New business / data licensing models

Big Data

DISRUPTION

Automation reducing human intervention and workflow streamlining at scale

Applied AI

GAFA Action esp. Cloud Storage, Compute, AI + ML, Analytics…

Real Time Data Processing and Analysis

Platform Based Processing, Production and Analytics 'As A Service'

FEATURES

- Specialist interactive user interfaces: Touch Table, VR, AR and MR
- Modelling, Analysis and Visualisation at Scale
- Business Intelligence (BI) toolsets (Dashboard Visualisation)
- Computer Vision
- Predictive Analytics
- Machine Learning
- Data Fusion providing enhanced modelling/analysis outcomes
- Data Mining with Applied AI
- History Analysis
- Geospatial Analysis and Locational Intelligence
- 2d, 3d and 4d Modelling/Analysis
- Remote Sensing, Point Cloud and Hydrography Platforms, (Cloud / AI Processing, Production and Analysis)
- Edge compute, enabling sensor-based processing /analysis
- Increasing Workflow Digitalisation and Data Integration (legacy / enterprise systems)

Communications Technology and Cybersecurity

DISRUPTION

Ubiquitous Connectivity (Always On)

New Commercial Models and Options

New Space Satellite Communications

Mobile Technology Companies and GAFA Action

FEATURES

- Quantum and 6G Research
- Space Data Relay and Laser
- 5G and Secure SatComms
- Mobile 3G, 4G and 5G
- Nation Full-Fibre WAN
- Mainstreaming use of WiFi, Bluetooth, etc. wireless standards/protocols
- Antenna Technology Enhancements (power/edge compute, etc.)
- Drone Monitoring and Counter Drone Systems
- Interference Monitoring Systems (Counter jamming/spoofing)
- 'End to End' Encryption
- Information Security Management Plans
- CyberSecurity Risk Assessment aligned to Tiered Security Models
- CyberSecurity Nation-based Policy and Regulations

Maritime Domain Awareness Systems

DISRUPTION

'Systems of Systems' Interoperability

Single common operating picture and shared levels of situational awareness

Provision of Actionable Intelligence for use by maritime law enforcement actors, (targeted patrols, and evidence for investigation and judiciary case work)

FEATURES

- Satellite, high altitude, aerial, UAV and USV platforms and sensors providing range of IMINT / GEOINT / SIGINT Options
- Floating Buoy-mounted sensing – imaging, radar, passive acoustic sensors using hydrophone
- Vessel CCTV
- Enhanced Vessel Analysis (e.g. Vessel Activity/Behaviour, Dark Vessels, Vessel Histories)
- Vessel detection using AIS / VMS
- National Coastal Radar Coverage
- Electro Optical, Infrared Sensors
- Maritime Security Centres and Maritime Monitoring Information Centres (National / Sub-national (regional) locations
- Port monitoring centres (VTS)
- Joint Operation Context Training and Exercising
- Standards, defined data, systems and operating protocols / CONOPS
- Security Risk Assessment Security Planning (Threats, Vulnerabilities and Maritime Security Priorities)

4 SPACE-BASED EARTH OBSERVATION TECHNOLOGIES AND METEOROLOGY

Space-based Earth Observation

Space-based EO offers a unique perspective and represents a huge opportunity for leverage by the maritime sector generally, and especially for fisheries management and MCS. The sector has seen global and regional action to leverage these space-based EO capabilities, e.g. European Union 'Copernicus Maritime Surveillance'. Further, at national level we are seeing leading fisheries authorities such as DA-BFAR (Philippines) through their work with United States Agency for International Development (USAID) with Visible Infrared Imaging Radiometer Suite (VIIRS) and the Verumar Project (with Optical and SAR solutions) deploying space-based EO as key MCS tools supporting the fight against IUU Fishing.

Today, electro-optical (Optical), Synthetic Aperture Radar (SAR), and other specialist spectrum sensors such as VIIRS are already providing support, but this is only scratching the surface – the opportunity for space-based EO for both the public and private sector is genuinely immense.

The oceans cover 70% of the Earth. Space-based (Geostationary and Low Earth Orbits) and emerging high altitude (e.g. HAPS) capabilities are the most effective way of monitoring and surveillance, providing relevant levels of revisit and persistence, resolution, access timescales (near real-time, real-time, etc.) and at a price point that is feasible for the fisheries management and MCS community.

The London Economics report on emerging EO trends states[1]:

> *"Ongoing developments in EO data, application innovation and the emergence of other enabling technologies are driving the potential for EO use and its associated value. Specific advances in imagery by 2020 are likely to include: higher spatial and temporal resolution, multi/hyperspectral images, increasing data frequency, video imaging, enhanced SAR capabilities, and improvements in atmospheric, weather, and climate data. These developments will be mirrored by developments in complementary EO data sources (e.g. drones) and technologies that will improve the storage, processing, analysis and application of EO data (e.g. cloud based computing, big data analytics, artificial intelligence, machine learning, robotics and automation)."*

1 Value of satellite-derived Earth Observation capabilities to the UK Government today and by 2020; London Economics 2018 : https://londoneconomics.co.uk/blog/publication/value-satellite-derived-earth-observation-capabilities-uk-government-today-2020-july-2018/

The space sector is embracing huge change – we are entering the era known as 'new space' where both public / private sectors are investing significantly in the space ecosystem. For EO this is leading to downstream user opportunities, more user choice with services being tailored to meet specific sector needs. Underpinning space-based EO technology trends include:

Platforms: New platforms (LargeSats, SmallSats, CubeSats and HAPS (covered in greater detail in section 5 below). Huge increase in number of platforms in space, through new and enhanced constellations, offering better revisit and access timelines and in the case of HAPS persistent coverage

- **Payload technologies**: Increasing sensor options, sensor miniaturisation, and edge compute
- **Ground Segment**: Leveraging space to ground communications options (laser/broadband), enhanced user tasking options, and use of Cloud
- **Downstream data processing**: Cloud, Analysis Ready Data (ARD), automation, applied AI/ML and data fusion
- **Fourth Industrial Revolution impacts:** Advances in computer processing (and in the future quantum), edge compute, AI/ML, Internet of Things (IoT), advances in connectivity

EXPLAINER

Space Platforms for Earth Observation include:

Large / Medium Satellites, where large satellites are > 1000 KG and medium satellites are 500 to 1,000 KG.

Small Satellite / Miniaturised Satellites, including mini satellites 100 to 500 KG, micro satellites 10 to 100 KG, nano satellites 1 to 10 KG, pico satellites 0.1 to 1 KG and femto satellites <100 grams.

CubeSats, a specified type of miniaturised satellite that is 10cm x 10cm x 10cm cubic units, used for space research and based on a common CubeSat design specification.

In 2019 UK Space Agency announced its 10-year vision for the UK to be a world leader in new EO technologies[2]. This identified eleven EO technologies that will underpin this ambition, namely: Radar/SAR, Passive Microwave, Optical/Video Imaging, Optical Spectroscopy, Infrared (IR) Imaging, IR Radiometry, IR Spectroscopy, Light Detection and Ranging (LiDAR), Radar Altimetry, Ultra-violet (UV) Spectroscopy and Quantum Technologies.

For the fisheries management and MCS community, these will bring wide ranging opportunities in fisheries MCS (especially for IUU fishing in relation to Exclusive Economic Zone (EEZ) and territorial waters incursions), fisheries science, aquaculture, marine management and conservation.

Further, as we look forward across the next 10 years also contributing to the national, regional and international response to marine resources degradation and depletion, and climate change.

2 UK EO Technology Strategy, Prepared by CEOI on behalf of the UK Space Agency, October 2019; https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/844129/EO_Technology_Strategy_2019.pdf

Space / High Altitude EO Technology	EO Technologies Anticipated Relevance for Fisheries Management & MCS and other Fisheries Application Areas					
	Fisheries Management and MCS			**Other Fisheries Applications** Including fisheries research, aquaculture, marine management and conservation, and evidence for fisheries and climate marine policy development and implementation.		
	Commonly Used	Used Sometimes	Not Used	Commonly Used	Used Sometimes	Not Used
Radar/SAR	✓				✓	
Passive Microwave					✓	
Optical Imaging	✓			✓		
Video Imaging	✓			✓		
Optical Spectroscopy		✓				
IR Imaging					✓	
IR Radiometry					✓	
IR Spectroscopy					✓	
LiDAR		✓*			✓	
Radar Altimetry					✓	
UV Spectroscopy					✓	
Quantum Technologies	Research required but anticipated commonly used			Research required but proposed commonly used		

**LiDAR can be used but today is seen as expensive – this may change going forward as new LiDAR capabilities are deployed for other purposes (e.g. wider Maritime Domain Awareness see section 12 below)*

With new EO satellites launching and becoming operational, fisheries authorities are recommended to put in place an EO exploitation strategy or plan. The use of free and open data sources such as Sentinel-1 (SAR), Sentinel-2 MultiSpectral Instrument (MSI) and including optical, Landsat 8, etc., as well as the establishment of a specialist remote sensing cell inside an organisation, are good starting points, following which engagement with specialist advisory, satellite data and fisheries analysis service providers can be progressed.

Verumar has found in our work with Philippine Government and others that VIIRS data can be used to provide a density of vessel detections but cannot be used consistently to differentiate vessel type or an individual vessel. Through applying wider commercial satellite data sources, it is further possible to detect individual vessels over 30m length using high resolution satellite data and vessels over 6m length using very high resolution and more focussed satellite modes. Further, it is possible to identify and interpret individual vessel type, from optical satellite sources (the best commercial resolution today being 30cm) and through fusion with other data sources such as Automatic Identification Systems (AIS).

MCS Example Use Cases:

- Vessel Detection (monitoring of vessels of interest, vessel movements in restricted areas and the detection of non-reporting vessels (aka. dark vessels).
- Vessel Type (Fish carrier, Purse Seiner, Longlines, Trawlers, Super trawlers, Reefers and Sailing vessels).
- Vessel Activity: Fishing grounds monitoring, Fishing Behaviours – Fishing Activity Patterns, At Sea Rendezvous - transhipment, at-sea refuelling.
- Port monitoring, Port State Measure Agreement (PSMA) control.

Fisheries Management Example Use Cases:

- Aquaculture (fish farm, cages, and traps monitoring).
- Fisheries science and research.
- Maritime pollution detection, response, and clean-up (e.g. oil spill).
- Bathymetry and habitat / resources mapping and monitoring.
- Climate change (marine and coastal management context).

SAR offers operational benefits also for fisheries management and MCS, with its ability to detect through rain and cloud and operate during both day and night; SAR can also be adjusted for local meteorological conditions during downstream processing.

Example established satellite data sources for fisheries management and MCS, include:

SAR data: Airbus TerraSAR-X, Hisdesat PAZ, MAXAR RadarSAT-2, Copernicus Sentinel-1

Optical data: MAXAR WorldView 1,2 and 3, Beijing Space View Tech Co Ltd Superview 2 and 3, MAXAR GeoEye-1, Airbus Pleaides 1A/1B, ImageSat International Eros-B, Deimos Imaging Deimos2, Airbus Spot 6 and 7, Copernicus Sentinel-2

Example emerging satellite data sources for fisheries management and MCS, include:

SAR data: SSTL NovaSAR, ICEYE SAR

Optical data: MAXAR WorldView Legion, Airbus Pleaides Neo, Planet PlanetScope / SkySat, Blacksky SmallSat Constellation

Optical Video from Space: Earth-i Vivid-i

Technology in Action: Fisheries Use Cases

NovaSAR - Synthetic Aperture Radar (SAR) with Maritime Mode

NovaSAR, the first all-British radar satellite, launched in 2018. Manufactured by UK company Surrey Satellite Technology Limited (SSTL), its SAR payload was built by Airbus United Kingdom and the AIS receiver by Honeywell Aerospace. On orbit 580km above the Earth, NovaSAR brings strong new capabilities to environmental monitoring and protection. Activities in scope range from oil spill detection to flood and forestry monitoring, but the maritime mode also brings new opportunity to the fisheries sector, as its 400km-plus swath mode can help to identify vessels that have disabled their Automatic Identification System (AIS) radio signals, also known as 'going dark'.

New partnerships are emerging to put these new capabilities to use. In 2019, the Philippine Department of Science and Technology's Advanced Science and Technology Institute (DOST-ASTI) signed an agreement with SSTL for the Philippines' share of the data tasking and acquisition services of NovaSAR-1.

The collaboration is of particular interest to the Philippines as NovaSAR can penetrate the cloud cover frequently experienced in its tropical climate.

> ***"It is important to be able to monitor large areas of the ocean – something we don't do at the moment."***

Meteorology

The UK Space Agency states that

> *"Satellites provide the only meteorological information available for large parts of the oceans, polar regions and atmosphere, and are critical when it comes to measuring changes in climate variables such as sea level rise globally and in regional detail.*[3] *"*

As with EO systems above, we are seeing significant investments in space meteorology missions and downstream exploitation. Agencies such as National Aeronautics and Space Administration (NASA) / National Oceanic and Atmospheric Administration (NOAA) in the USA, European Organisation for the Exploitation of Meteorological Satellites (EUMET SAT) in the European Union, and Japanese Meteorological Agency (JMA) in Japan among others globally are continuing and launching new meteorology space missions.

For instance, NASA will ensure continuity of Terra MODIS / Aqua MODIS *(MODIS – Moderate Resolution Imaging Spectroradiometer)*, that view the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands; and will continue the Geostationary Operational Environmental Satellites (GOES) Missions through its GOES-R Series. GOES R Series is a four-satellite program (GOES-R/S/T/U)) that will extend the availability of the operational GOES satellite system through to 2036. The R Series is the nation's most advanced fleet of geostationary weather satellites, providing advanced imagery and atmospheric measurements of Earth's weather, oceans and environment, real-time mapping of total lightning activity. Further, this series will continue the legacy function of the Search and Rescue Satellite Aided Tracking (SARSAT) system on board NOAA's GOES satellites. This system uses a network of satellites to quickly detect and locate signals from emergency beacons onboard aircraft, vessels and from handheld personal locator beacons, locating mariners, aviators, and other recreational users in distress.

JMA will ensure continuity of Himawari-8 and 9 missions, while launching future missions Earth Cloud, Aerosol and Radiation Explorer / Cloud

3 London Economics: Value of satellite-derived Earth Observation capabilities to the UK Government today and by 2020; citing (117) UKSA (2014). EUMETSAT Jason 'Continuity of Service' Satellite Programme; https://londoneconomics.co.uk/blog/publication/value-satellite-derived-earth-observation-capabilities-uk-government-today-2020-july-2018/

Profiling Radar (EarthCARE/CPR) and Global Observing Satellite for Greenhouse gases and Water cycle (GOSAT-GW) which is primarily designed to support climate change observations, including relating to the marine environment.

EUMETSAT, whose purpose is to supply weather and climate-related satellite data, images and products – 24 hours a day, 365 days a year – to the National Meteorological Services of the Member States in Europe and other users worldwide, is supporting future launches, including: the third generation of the METEOSAT constellation; a second generation of polar-orbiting satellites; and the Copernicus Satellites, including Sentinel-3 and 6 missions. Sentinel-3 and 6 are good examples of missions designed for oceanography and marine exploitation.

Copernicus Sentinel-3[4] measures the temperature, colour, and height of the sea surface as well as the thickness of sea ice. These measurements will be used, for example, to monitor changes in sea level, marine pollution, and biological productivity.

Copernicus Sentinel-6[5] will provide high-precision measurements of global sea-level, and collect high resolution vertical profiles of temperature, using the GNSS Radio-Occultation sounding technique, to assess temperature changes in the troposphere and stratosphere and to support Numerical Weather Prediction.

Fish seasonal patterns and fishing activity are weather dependent. Existing (traditional national weather service providers) are being joined by new meteorology commercial service providers. For example. DTN[6] (recently merged with MeteoGroup) are offering downstream weather services including nowcasting, forecasting, severe weather event services, weather, shipping/maritime and environmental related services. IBM – through its 'The Weather Company'[7] – offers IBM Global High-Resolution Atmospheric Forecasting System (IBM GRAF)[8]. Running on an IBM POWER9 supercomputer, this new global weather model updates hourly and at a 3-4 km resolution to help create a clear and reliable weather picture.

Weather services and underlying data are becoming more accessible with access direct from user systems through published API services and more user-friendly business / data licensing models. Many of these innovations are of direct relevance and benefit to fisheries management and MCS.

Fisheries management and MCS example Meteorology Use Cases:

- Ocean current, wave height, windspeed – data input to automated fishing vessel detection and fishing activity detection.
- Ocean temperatures and oxygen levels – for fish behaviour and species level fisheries management and aquaculture.
- Ocean current, wave height, windspeed, surface temperature – data input to disaster management early warning systems and response (e.g. maritime oil pollution oil spill dispersal modelling, tidal surge, and coastal flooding.)

Specifically, weather is a key input for SAR and electro-optical data analysis for fisheries management and MCS. Applied AI/ ML using SAR and electro-optical systems typically identify more vessel detections as weather conditions at sea become rougher. SAR can be processed automatically to eliminate these, e.g. the impact of waves, but in the case of electro-optical sources, resulting false positives require manual intervention by fisheries analysts to mitigate.

The advanced data analysis of space-based EO and meteorology is addressed in the Big Data section.

4 Sentinel 3 mission https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-3/Introducing_Sentinel-3
5 https://www.eumetsat.int/website/home/Satellites/FutureSatellites/CopernicusSatellites/Sentinel6/index.html#
6 DTN / MeteoGroup https://www.dtn.com/?utm_source=website&utm_medium=redirect&utm_campaign=meteogroup
7 IBM The Weather Company https://www.ibm.com/weather
8 IBM GRAF - https://www.ibm.com/weather/industries/cross-industry/graf

Technology in Action: Fisheries Use Cases

Japanese satellite brings sea vision to aquaculture farmers[9 10 11]

Umitron Pulse is a web-based ocean satellite data service that delivers real-time oceanographic data such as seawater temperature, salinity, dissolved oxygen, chlorophyll concentration and wave height.

The visualisation of this remote sensing and high resolution marine data can be filtered and zoomed in and out on screen and is being targeted at aquaculture farmers, who are always hungry for oceanographic data for risk management and environmental monitoring purposes. Farmed fish are highly susceptible to the threat of red tide algae blooms and seaweed or shellfish growth can be hampered by nutrient depletion. Ready information on the ocean environment such as the distribution of plankton and nutrients can mitigate these ever-present threats, and Umitron's 48-hour forecast predicting how water quality will change is even more welcome.

The company's capabilities will be strengthened further in 2022, when it will launch its own ocean observation satellite, as part of a consortium supported by the Japan Aerospace Exploration Agency (JAXA).

> *"Seaweed, shellfish, and fish farmers can all benefit from having access to additional information about the environment they are working in every day."*

Technology in Action: Fisheries Use Cases

Satellite project aims to improve the sustainability of the tuna industry[12 13]

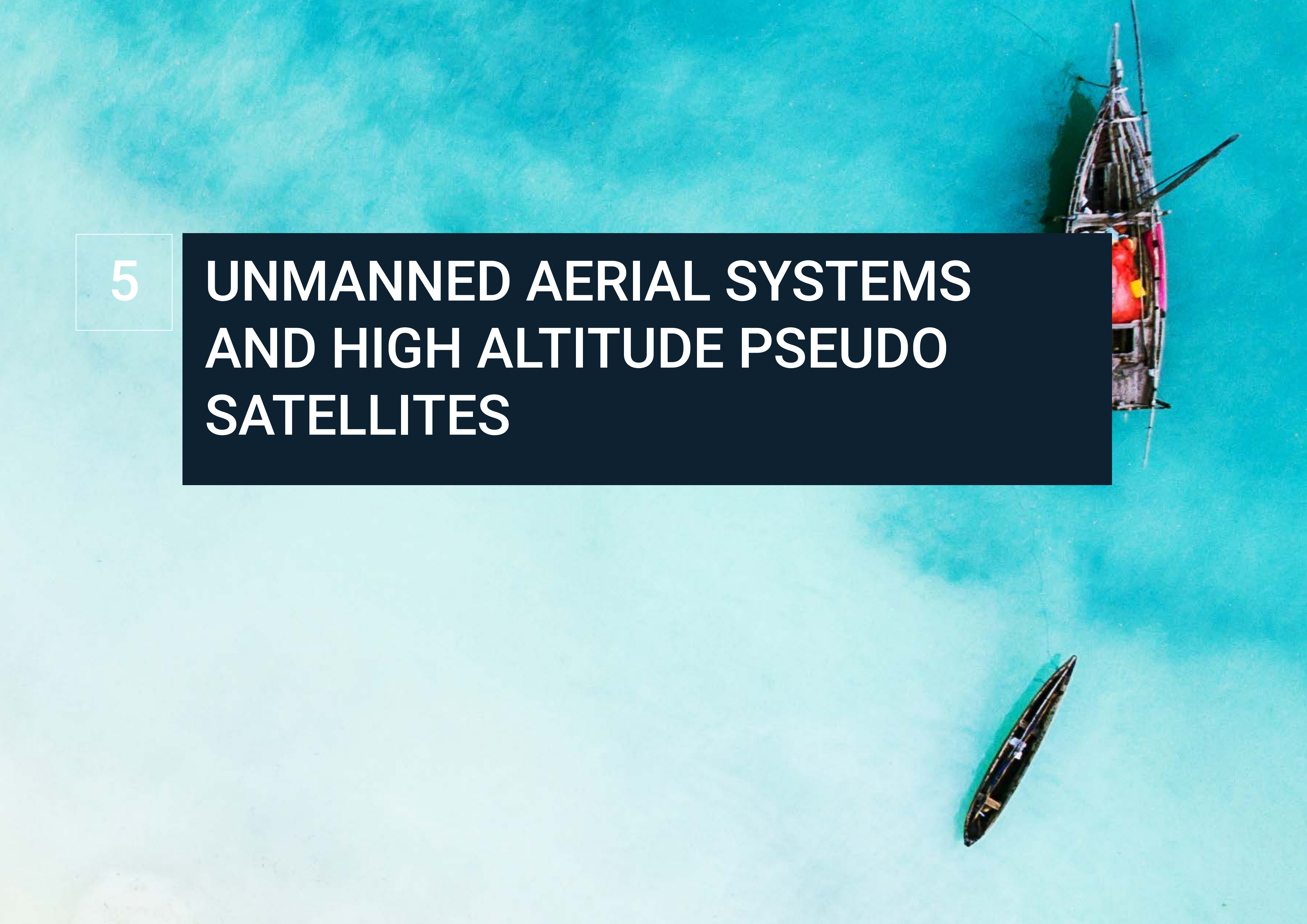
Reducing the tuna fleet's emissions and fuel consumption by up to 25% is the ambitious aim of a new European project. SUSTUNTECH (Sustainable Tuna Fisheries Through Advanced Earth Observation Tools). By combining EO data with many other datasets, the multi-disciplinary project hopes that intelligent modelling and navigation planning will lead to reduced time at sea for the same level of output.

The core information sets enabling this work include information gathered by satellite buoys from Spanish company Marine Instruments and oceanographic information obtained by Copernicus, the European Union's (EU) EO Programme. These are complemented by data collected by sensors placed aboard participating tuna vessels. ML techniques and AI algorithms will then provide tuna distribution maps which in turn will lead to recommendations on the best routes to follow so that fuel consumption can be minimized.

The project is funded by the EU's Horizon 2020 programme.

Researchers have suggested that 207 million tonnes of CO_2 were released into the atmosphere by marine fishing vessels in 2016 – roughly equivalent to the emissions of 51 coal-fired power plants. It is suggested that emissions intensity in the global fishing fleet started to grow in the 1980s, as artisanal and subsistence fishers began to install gasoline-powered engines on their boats.

9 https://thebridge.jp/en/2020/07/umitron-pulse
10 https://www.fishfarmingexpert.com/article/new-eye-in-the-sky-service-for-fish-farmers/
11 https://thefishsite.com/articles/start-up-braced-for-blast-off
12 https://echebastar.com/en/sustuntech-another-step-on-the-road-to-sustainability/
13 https://phys.org/news/2019-01-carbon-dioxide-emissions-global-fisheries.html



5 UNMANNED AERIAL SYSTEMS AND HIGH ALTITUDE PSEUDO SATELLITES

Helicopters and fixed wing aircraft platforms are established capabilities for both commercial fishing and fisheries authorities' day-to-day operations. Oceans 2017 conference[14] reported that 90% of the world's tuna catch is taken in by 2% of the world's fishing fleet, using helicopters to both find fish quickly and reduce fuel usage.

Fisheries authorities deploy fixed wing aircraft on patrol to identify instances of and capture evidence for IUU fishing enforcement and other illegal activities at sea. Unmanned Aerial Systems (UAS) including a range of Drone or Unmanned Aerial Vehicle (UAV) options (typically based on size, payload and mission endurance, etc.), as well as High Altitude Pseudo Satellite (HAPS), are emerging technologies that offer enhanced Intelligence, Surveillance and Reconnaissance (ISR) with lower whole life costs compared to existing airborne capabilities. These capabilities are gaining traction amongst the fisheries management and MCS community with instances of early adoption and operationalisation feasibility projects underway.

Unmanned Aerial Systems (UAS)

Unmanned Aerial Systems, also known as 'Remotely Piloted Aircraft System' (RPAS) platforms, are well established in defence and have now broken into civilian sectors, offering a wide range of civilian applications such as infrastructure surveillance, firefighting, disaster and environmental monitoring as well as border control and management.

There is a strong UAS industrial supply globally with many countries having established technology manufacture and distributorships in place. Examples of well-known UAS providers include: DJI, HQ Shenzhen, China[15], AeroVironment HQ California, USA[16], Parrot HQ Paris, France[17] and Aeronautics Defence Systems HQ Yavne Israel[18].

Each manufacture offers a range of UAS platforms providing a range of tactical capabilities determined by payload, communications capabilities, and operational coverage, endurance, and performance features.

Technical In Action Use Case

Royal Thai Navy (RTN) together with the Royal Thai Air Force (RTAF) Acquisition and Operationalisation of Orbiter 3 UAS platform

Royal Thai Navy (RTN) together with the Royal Thai Air Force (RTAF) tested several Unmanned Aerial Vehicles (UAVs) from Israel's Aeronautics Defense Systems including the Orbiter 2, Aerostar, and Dominator and selected the Orbiter 3 UAS platform which is a Small Tactical UAS (STUAS).

The Orbiter 3 UAS platform can carry payloads up to 5 kg in weight, including multi-sensor stabilized EO payloads carrying laser target-designation systems. Further, it is fitted with a digital datalink, extended endurance of 7 hours and operational radius of 150 km.

The system is fully compatible with industry standards, including STANAG 4586 (NATO Standardization Agreement No. 4586) for UAS controls and H.246 for the video streaming ensuring standards-based interoperability.

The system is operated and controlled by the Aeronautics Defense Systems proprietary Multi Operation Aerial Vehicle (MOAV) software; an advanced interface developed in-house. The system also comes with advanced image processing and catapult launch / net landing for maritime operations which are key for maritime operating / MCS requirements.

Royal Thai Navy (RTN) confirmed in November 2019[19 20] that they have acquired and have successfully brought into operation the Aeronautics Defense Systems (Israel) Orbiter 3 small tactical unmanned aerial system (UAS).

14 Using vessel-based drones to aid commercial fishing operations, OCEANS 2017; https://ieeexplore.ieee.org/document/8085014
15 DJI https://www.dji.com/uk
16 AeroVironment https://www.avinc.com/
17 Parrot https://www.parrot.com/uk/
18 Aeronautics Defence Systems https://aeronautics-sys.com/
19 Thailand makes Orbiter 3 unmanned aerial system operational https://www.asiapacificdefensejournal.com/2019/12/thailand-makes-orbiter-3-unmanned.html
20 Royal Thai Navy - Aeronautics Defense Systems (Israel) Orbiter 3 small tactical unmanned aerial system (UAS); https://www.asiapacificdefensejournal.com/2019/12/thailand-makes-orbiter-3-unmanned.html

Fisheries Management and MCS Primary Use Cases include:

- Intelligence, Surveillance and Reconnaissance (ISR) to inform MCS and IUU Fishing.
- Survey and mapping (photogrammetric mapping and 3D modelling).
- Remote sensing of the aquaculture, marine and coastal environments.

The **European Maritime Safety Agency (EMSA)** provides a **Remotely Piloted Aircraft Systems (RPAS) maritime surveillance operations**[21] to support authorities involved in Coast Guard functions undertaken by Member States. This includes for: maritime pollution and emissions monitoring, detection of illegal fishing, anti-drug trafficking, and illegal immigration and search and rescue operations. The EMSA RPAS service is used as a complementary tool in the overall surveillance chain which includes satellite imagery, vessel positioning information and surveillance by manned maritime patrol aircraft and vessels and provides increased maritime situational awareness with additional sources of data.

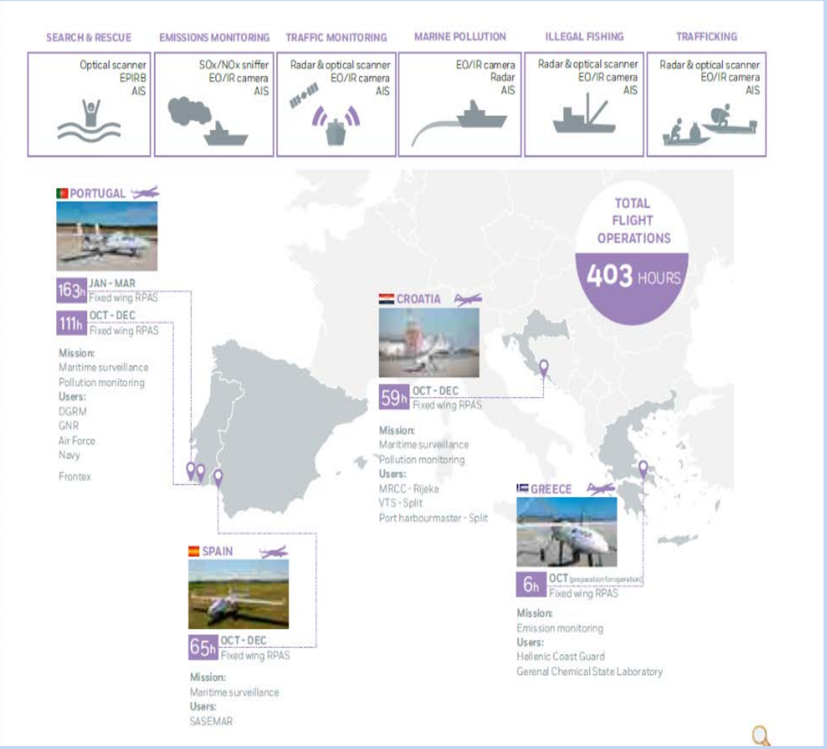


Figure 1: EMSA RPAS maritime surveillance operations provide pan European waters surveillance capability from 5 land-based operating settings

21 European Maritime Safety Agency provides a Remotely Piloted Aircraft Systems (RPAS) maritime surveillance operations; http://www.emsa.europa.eu/operations/rpas.html

The payload of each RPAS aircraft is adapted to the maritime surveillance activities requested by the user. Depending on the type of the mission, RPAS operate closer to shore, i.e. within the Radio Line of Sight (RLOS) or further offshore, i.e. Beyond Radio Line of Sight (BRLOS), which requires special equipment on board to communicate via satellite. All communications and aircraft control are via a Local Ground Control Station, a mobile unit set-up in the area of operation. Data and video recording collected during all RPAS missions is made available to the authority in charge of each operation via the RPAS Data Centre (currently in development).

In addition to the fixed wing RPAS platforms, a quadcopter capability is available and can be deployed from the EMSA Lundy Sentinel patrol vessel. This vessel operates in areas of interest including the Mediterranean Sea, western waters of the North-East Atlantic Ocean, North Sea and the Baltic Sea. By flying in the vicinity of a fishing vessel, the remote-controlled quadcopter can collect data on different activities on board. Acquired data is then transmitted in real time to European Fisheries Control Agency (EFCA) liaison officer deployed on board the Lundy Sentinel, as well as to EFCA's coordination centre in Vigo, and EMSA's headquarters in Lisbon.

Further fisheries management uses for UAS include for more local monitoring of fisheries related infrastructure e.g. aquaculture, marine and coastal environments and small area of interest remote sensing requirements. In these instances, smaller UAS aircraft are typically deployed in support and may be deployed from land or from vessel and are typically operated within Visual Line of Sight (VLOS).

High Altitude Pseudo Satellites (HAPS)

HAPS are stratospheric platforms that can stay over a fixed point on Earth for long durations (weeks to months). HAPS operate quasi-stationary at an altitude of approximately 20km. This allows them to complement or extend the capabilities of satellites in the domains of EO, telecommunications, and navigation with the potential to further integrate with ground-based infrastructure.

Until recently, HAPS predominantly has been considered a defence capability. However, over the last few years civilian requirements have begun to come through. Notably the European Space Agency (ESA), through its HAPS4ESA programmes in 2017 and 2019, reached out to industry from the EO, telecommunication and navigation communities to explore the future perspective of HAPS. More recently HAPS investments have begun to attract interest across civilian sectors, notably in support of EO – ISR, Survey and Mapping and Remote Sensing, and Telecommunications. Large industry actors including Airbus (Zephyr)[22], Thales Alenia Space (Stratobus™)[23], Altran (Ecosat Airship (prototype stage)[24], Boeing through its dedicated Aurora Flight Sciences (Odysseus)[25] and Alphabet (Loon)[26] offer HAPS platforms capabilities.

22 Airbus; https://www.airbus.com/defence/uav/zephyr.html
23 Thales Alenia Space (Stratobus™); https://www.thalesgroup.com/en/worldwide/space/news/whats-stratobus
24 Altran (Ecosat Airship); https://www.altran.com/es/es/case_study/ecosat/
25 Boeing, Aurora Flight Sciences (Odysseus); https://www.aurora.aero/odysseus-high-altitude-pseudo-satellite-haps/
26 Alphabet (Loon); https://loon.com/technology/

Figure 2: Illustration - Airbus Zephyr in Stratospheric Flight

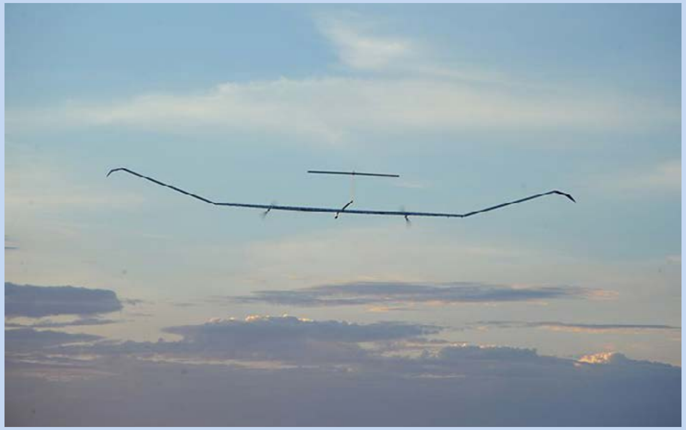


Figure 3: Airbus Zephyr in Flight - Zephyr is reaching the stratosphere, and will fly persistently around 70,000ft, meaning it can avoid conventional air traffic and operate without interfering with other airspace users

HAPS as a platform capability provide operational advantages compared to both satellite and drones, including:

- Higher manoeuvrability than satellites
- Availability to relocate
- Returnability for maintenance or payload reconfiguration
- Low signal delay and high imagery quality
- Lower overall mission cost
- Mission persistence (for up to months at a time)
- Payload flexibility
- Real-time data processing

Specifically, for PNT:

- When compared to a terrestrial network, HAPS provide wider coverage, less interference due to obstacles like buildings, ground elevations and have shorter time to deployment.
- In comparison to satellites, HAPS have lower latency (transmission delay) and could be called back for maintenance or payload reconfiguration.

Technology in Action: Fisheries Use Cases

HAPS provision of 'Multi-layer PNT for Search and Rescue'

ESA is investing in a programme investigating HAPS provision of 'Multi-layer PNT for Search and Rescue'. This programme will determine under which conditions, if any, the use of HAPS platforms can prove valuable in support of Search and Rescue systems. Better detection of signals in difficult terrain and weather conditions, precise detection of fast-moving beacons, and combination of HAPS data with Medium Earth Orbiting Satellites (MEOSAR) data are also noted as important aspects of this study.

Specifically, for EO the stratosphere enables new innovations in EO. Less than 1/1,000 of the distance of a geostationary satellite, HAPS can obtain much higher resolution imagery *(better than 10 cm resolution).* And, unlike drones/UAS, stratospheric vehicles can travel vast distances over long periods of time, toggling between moving and strategically hovering over an area to collect data. HAPS offer many promising EO advancements, including:

- Gathering data around natural and man-made disasters to enable more effective responses, e.g. of maritime interest oil spills, tsunami, etc.
- Tracking meteorology to improve weather forecasts.
- Monitoring marine resources and infrastructure.
- Watching large stretches of oceans for illegal fishing, pollution, and piracy.

A global HAPS Alliance[27] has come together in the telecommunication sector with a goal to address diverse social issues and create new value by providing telecommunications network connectivity worldwide based on the use of high-altitude vehicles. Current members of the Alliance include: SoftBank Corp.'s HAPSMobile Inc. ("HAPSMobile"), Alphabet's Loon LLC ("Loon"), AeroVironment, Inc. ("AeroVironment"), Airbus Defence and Space, Bharti Airtel Limited ("Bharti Airtel"), China Telecom Corporation Limited ("China Telecom"), Deutsche Telekom AG ("Deutsche Telekom"), Telefonaktiebolaget LM Ericsson ("Ericsson"), Intelsat US LLC ("Intelsat"), Nokia Corporation, SoftBank Corp., and Telefónica S.A. ("Telefónica").

Ultimately, through the HAPS Alliance, we may see the emergence of a stratosphere-based network of HAPS platforms supporting global or regional mobile communications, potentially closing existing communications network capability gaps, enabling faster and wider coverage roll out of 5G and providing a communications network to support Internet of Things and Sensor data exchange. This may provide future additional telecommunication options for the maritime community, enabling higher capacity data transfer and communications.

27 HAPS Alliance; https://hapsalliance.org/

Technology in Action: Fisheries Use Cases

UAV intercepts diesel smugglers masquerading as fishermen in Thailand[28 29]

UAVs are beginning to have a direct impact in fisheries enforcement measures – and not just to counter Illegal, Unreported and Unregulated Fishing (IUU Fishing). In July 2020, a Royal Thai Navy Orbiter 3B UAV drone was conducting search operations off Phuket's east coast and along the Krabi coast when it identified a fishing boat acting suspiciously. The *HMS Sriracha* was subsequently dispatched to intercept the boat five nautical miles east of the Koh Yao Yai islands.

The Navy's inspection found that – despite being registered as a fishing vessel – the boat had been modified to enable it to smuggle fuel. The boat was found to carrying about 1,000 litres of green-coloured diesel in the bow and another 400 litres in its own fuel tank. The captain was charged with using a fishing boat for a purpose other than its registered use.

The smuggling of fuel is a major issue in Southeast Asia, with some analysts estimating that approximately 3% of the region's consumed fuel – worth $10 billion – is sourced illegally each year.

The Thai Orbiter 3V example highlights how using UAVS to extend beyond visual line-of-sight (BVLOS) can be an important new, low-cost addition to Concepts of Operation in fisheries and broader marine enforcement strategies.

Technology in Action: Fisheries Use Cases

AI-powered drones provide eyes on the sea in the Seychelles[30 31]

The public, development aid and commercial sectors are combining forces in the Seychelles to strengthen counter-IUU Fishing measures using UAVs and AI. At a huge 1.3 million square kilometres, the Seychelles' Exclusive Economic Zone (EEZ) represents a significant Monitoring, Control and Surveillance challenge for authorities charged with protecting the country's marine resources.

Environmental foundation GRID-Arendal, fisheries intelligence NGO Trygg Mat Tracking (both headquartered in Norway) and Moroccan technology startup ATLAN Space have partnered on a drone that flies on a path determined by the automatic computer guidance system until the deep learning model identifies what it believes to be a boat. The system then analyses the image to identify whether it's a fishing vessel, then (using data such as the boat's name, flag and type of radio signals) attempts to determine whether it is legally permitted to operate in the region, and consulting a database of suspect vessels.
Relevant authorities can be alerted to potentially unauthorised boats via a satellite message.

A single drone can monitor 10,000 square kilometres a day, with land-based operators able to take manual control at any time to acquire more detailed evidence.

> ***"You increase your chances of documenting what is going on on board without approaching the vessel itself."***

28 https://www.thephuketnews.com/navy-drone-intercepts-diesel-smuggler-off-phuket-76783.php
29 https://www.reuters.com/article/us-singapore-oil-theft-southeast-asia-an/shady-triangle-southeast-asias-illegal-fuel-market-idUSKBN1F70TT
30 https://www.seafoodsource.com/news/environment-sustainability/drones-fisheries-enforcement-potential-remains-untapped-even-as-projects-advance
31 https://www.grida.no/activities/275

6 MARINE AUTONOMOUS SYSTEMS

Marine Autonomous Systems include all Unmanned Autonomous Systems within a marine / maritime setting. This includes Unmanned Aerial Vehicles (UAV), Unmanned Surface Vehicles (USV) and Unmanned Underwater Vehicles (UUV). For the purposes of this paper UAVs are addressed in the HAPS and UAS section, and we focus in this section on the emerging USV and UUV technologies. USVs are Unmanned Surface Vehicles interchangeable with Autonomous Surface Vehicle (ASV); and UUV are Unmanned Underwater Vehicles interchangeable with Autonomous Underwater Vehicle (AUV), also within UUV we include ROV (Remotely Operated Underwater Vehicles). Both USV / UUV may also be tethered / untethered.

EXPLAINER

The Association for Unmanned Vehicle Systems International (AUVSI):[32] https://www.auvsi.org/ is the world's largest non-profit organisation dedicated to the advancement of unmanned systems and robotics, representing corporations and professionals from more than 60 countries involved in industry, government and academia. AUVSI members work in the defence, civil and commercial markets.

Unmanned Surface Vessels (USV) and Unmanned Underwater Vessels (UUV) Technologies

We can envisage a time when USV/UUV will be prolific. Autonomous marine systems, USV and UUV ultimately bring increased health and safety, reduce human error risks in operations and in principle should become more cost effective as uptake of technology increases and new supplier options enter the sector. Lloyds Register through their 'Global Marine Technology Trends 2030'[33] research identify a number of ocean space knowledge benefits resulting from USV/UUVs, including enhancement of our understanding of the oceans, the climate and related environmental matters, as well as leading to the future exploration of the ocean space, and expansion of scientific understanding of ocean environment and ecosystems.

EXPLAINER

Ocean Space Advances resulting from USV/UUV, *(source Lloyds Register through their 'Global Marine Technology Trends 2030')*

- Advances in autonomous systems will rapidly increase our knowledge of the ocean space.
- The deployment of autonomous marine systems can help prepare coastal communities for extreme weather with advance warnings and improve our understanding of the ocean's role in the climate and environment. Autonomous marine systems will lead future exploration of the ocean space, with the goal of discovering vast subsea resources and making them available.
- Through subsea exploration, autonomous marine systems will help scientists expand their understanding of the ocean environment and ecosystems. Therefore, the autonomous systems will teach us how to effectively nurture the ocean space environment and could potentially actively work to protect it against damaging human activity, such as pollution or over-exploitation.
- Value of enabled data – Advances in this technology will make it feasible to effectively gather large volumes of data from the ocean space. This data will become a valuable commodity for governments, research organisations and associated industries that plan to extract value from the ocean space. New markets will emerge to complete the value chain, from the mass deployment of autonomous marine systems to big data analytics.

32 The Association for Unmanned Vehicle Systems International (AUVSI); https://www.auvsi.org/
33 Lloyds Global Marine Technology Trends 2030; https://www.lr.org/en/insights/global-marine-trends-2030/global-marine-technology-trends-2030/

For fisheries and fisheries management, the use of USV and UUV is in early adoption. There are excellent international examples of USV/UVV supporting commercial fishery, fisheries management and MCS requirements. We explore these further below.

In terms of USV/UUV platform technology manufacturers, we are seeing a mix of USV/UUV start-up companies (e.g. AutoNaut) and large companies, e.g. Fugro and Defence and Security companies (e.g. BAE Systems, etc.). Further we are seeing industrial merger and acquisition activity in this technology area, e.g. the acquisition of ASV Global by L3 Harris in 2018. Technology innovation and demand for USV/UUV platforms is primarily being driven by defence and security, oil and gas, offshore renewables, geophysical survey, deep sea exploration, underwater asset management and marine science requirements. A number of these applications resonate with fisheries sector requirements. Commercial fishers and fisheries management authorities today have a wide range of platform and operational capability options, some examples of which are identified below.

R&D is ongoing into autonomy for maritime cargo and passenger vessels and indeed we may well see future autonomous fishing vessels, but today these are more 'future' than 'emerging' and are not addressed in this paper.

Example USV/UUV platform manufacture companies	
USV	Atlas NA, Austral USA, AutoNaut, BAE Systems, Elbit Systems, Fugro, L3 Harris (ASV Global), Martac Florida, Sea-Kit International, TeledyneMarine, Thayermahan Seafloor systems (a Hydrography ASV/USV specialist platforms), Wave Glider
UUV (including ROV)	Deep Trekker, Fugro, RJE Oceanobotics, RTSYS, TeledyneMarine
Launch and Recovery System Specialist	Sealartec

A USV/UUV platform comprises the following key components: platform, launch and recovery capability, mission planning and command and control system/user interface, camera system unit, digital and/or video (wide angle view), payload housing (e.g. for survey equipment, sensors and / or robotic engineer toolset), collision avoidance and navigation capability, AIS, etc. transceiver and other communication equipment for real-time communications, data storage and capability for digital data transfer / physical data download. Platforms can be self-powered (propulsion), e.g. wave, sail or solar or can motor powered (fuel, electric (battery) or hybrid) and typically vessels are configurable between manned and unmanned modes.

USV platforms offer varied operational and performance capabilities based primarily on: endurance, range, speed, connectivity, power source, payload capacity, displacement and the vessels capability to withstand and operate in weather and sea conditions (e.g. including features such as self-righting).

An example USV range, in this case from L3 Harris ASV Global[34]

C-Cat 3 Small Multi-Purpose Work ASV, providing capabilities: river, lake, reservoir, harbour survey, water sampling/monitoring, current profiling, harbour security, Single Beam, Multibeam, Lidar and Metocean sensing; through to L3 Harris C-Enduro Long Endurance ASV, providing capabilities: built for all marine environments, self-righting hull, long endurance (30+ days), for Metocean and oceanographic data collection, Renewable energy surveys, Marine construction support, Environmental surveys e.g. CO2 monitoring, Seismic support e.g. passive acoustic monitoring, Data gateway e.g. AUV/ROV/Glider to satellite and Security and situational awareness. Sea-Kit International USVs come in 3 classes (12M, 24M, 36M)[35] designed with adaptable payload areas for multiple mission configurations. The 24M class vessel is stated capable of more than 100 days endurance pending operational profile.

UUV platforms offer varied operational and performance capabilities based primarily on: depth rating, endurance, operating temperature, battery charge, power rating, breaking strength, propulsion, crawling, caterpillar, tethering / untethered.

34 ASV Global, a L3 Harris Company; https://www.asvglobal.com/about-us/
35 Sea-Kit International Company; https://www.sea-kit.com/

UUV ranges are very diverse and tend to be mission orientated, and in this case from Deep Trekker[36], includes underwater camera pod, underwater ROV (3 models), CCTV pipe crawlers (2 models), utility crawlers (2 models) with a whole range of add on options including sensor and measurement, sonar and positioning, manipulators and tools and cameras and lighting. For aquaculture, UUV capabilities include submersible cameras, utility crawlers and remotely operated vehicles.

Both USV/UUVs offer support to fisheries management and MCS including:

USV: Fishing scouting capabilities – this has been applied for the efficient identification of swarms of Krill. In the instance of TASA, the largest fishing company in Peru, TASA has contracted with Kongsberg Marine of Norway to buy an unmanned surface vehicle that can hunt for fish essentially using a USV based fishery sonar and echosounder capability – see Robocatch case study.

Fishery surveying – in response to the COVID-19 pandemic, and the resulting cancelled ship-based fishery survey for this year, NOAA Fisheries is using autonomous surface vehicles to collect critically needed data to support management of the nation's largest commercial fishery for Alaska pollock – see NOAA case study.

For MCS, USV technologies in the UK are going through the operational feasibility testing stage. They are proving to be tangible operational capabilities in certain operational conditions and scenarios, and as part of a wider EEZ monitoring and surveillance approach. For example, as part of the Blue Belt Programme underway in the UK, the UK's Marine Management Organisation (MMO) has investigated and reported on two USV capabilities (i) Self-Powered USVs (based on WaveGlider and AutoNaut capabilities) and (ii) Motor-Powered USVs relating to vessel detection and surveillance and IUU fishing control.

USV Fisheries Management and MCS Example Use Cases:

- Commercial Fishing scouting.
- Commercial Fishing Sonar and Echosounding capability.
- Fishery Survey.
- Hydrographic Survey.
- Environmental Measurement, Survey, Monitoring and Mapping.
- Role in MCS in support of vessel detection and designated area monitoring and deterrent through UVS presence.

UUV Fisheries Management and MCS Example Use Cases:

- Aquaculture for Structure inspection, Monitoring Stock (Health and feeding), Scanning of Mooring Lines and Anchors, Detecting and Fixing entanglements.
- Robotic Cleaning of Nets.
- UUV for underwater sensing and measurement in support of fisheries and wider marine requirements.
- Port Inspection of vessel hull for presence of non-native invasive species and/or contraband.

36 Deep Trekker Company; https://www.deeptrekker.com/

USV/UUV are relatively new technologies and as such there are challenges to be considered to support their effective use in an operational setting, including:

- A need to understand and plan for USV/UUV operational setting constraints and risks, such as weather, sea conditions and platform vulnerability to tampering by 3rd parties and requirements associated with within Visible Line of Sight (VLOS) / Beyond Visible Line of Sight (BVLOS) mode of operation.
- Connectivity – ensuring appropriate connectivity is in place to support required *(likely continuous for the foreseeable future)* communication with the USV/UUV platforms, associated command and control and support data transfer from sensors and equipment on board.
- Skills and training, e.g. for new specialist units and operational personnel involved in USV, UUV platform operation, associated data transfer, analysis, and exploitation as well as ongoing support, maintenance, and servicing of platforms (In life Service).
- Regulatory framework – drawing on synergy with UAS and Air Traffic Management, a regulatory and legal framework is anticipated needed to support wide-scale use of marine autonomous systems. Considering topics such as navigation, collision avoidance and traffic obstruction as well as liability in the event of collision etc.
- Following on from regulatory framework, it is anticipated that some form of USV/UUV operator certification and insurance framework will be required.
- Ensuring the overarching business model, return on investment is understood and facilitates a reasonable price point for customers.

Further these platforms may be vulnerable to cyber-attack. Commercial companies and government authorities will be aware that drones (USV/UUV) can be used either intentionally or unintentionally for malicious purposes, and require consideration in maritime security risk assessment.

Technology in Action: Fisheries Use Cases

Konsberg USV reduces cost for pelagic fish location[37]

Finding fish can be a costly business. A large part of any fishing trip (and associated staff and fuel costs) will be expended on actually finding the fish in the first place, before retrieval can take place. Autonomous vessels promise new ways to mitigate these costs.

Norwegian company Konsberg has provided TASA, Peru's largest fishing company, with a 26.5-foot USV to search for fish in a much more cost-effective manner. Running fully autonomously or under supervised control, the USV can cruise for more than 20 days at 4 knots. Its mast reaches over 14 feet above sea level, to receive commands from remote operators on land or on other vessels (through laptop or radio control) and transmit data back via Maritime Broadband Radio/Iridium or VSAT *(a type of satellite communications)*.

The vessels' high-definition SX90 fishery sonar and ES80 Simrad echosounder enable fish location to take place over large expanses of ocean, to improve the catch efficiency of the main fleet.

When USVs first came onto the market, some considered them entirely 'disruptive' technologies – threatening traditional methods of survey, surveillance and other data collection. However, as the market matures – like here – we see unmanned systems are finding complementary roles, offering low-cost supplementary services to help enhance value in more traditional operations.

> ***"The Sonar USV will become a pivotal tool in the evolution of sustainable fisheries."***

37 https://www.nationalfisherman.com/national-international/robocatch-simrad-builds-unmanned-surface-sounders

Technology in Action: Fisheries Use Cases

Saildrones reduce COVID-19 impact on fish stock survey schedules[38]

The COVID-19 pandemic has driven new ways of thinking into many industries, especially when assessing, and in many cases accelerating, the use of new technologies. The USA's National Oceanic and Atmospheric Administration Fisheries section has also attempted to seize an opportunity within the crisis.

Anticipating that social distancing restrictions would severely restrict their standard fisheries survey schedules, they quickly pivoted towards autonomous delivery of those activities. Three Saildrones (unmanned wind-powered surface vehicles) were fitted with bespoke echosounders, which send sound pulses into the water column to enable estimates of the population of fish.

The vessels took roughly six weeks to sail autonomously from California to the eastern Bering Sea, where they began a 60-day survey. Despite being introduced as an emergency measure, the autonomous platforms are in fact expected to be able to cover roughly the same area as normally covered by standard research vessels to estimate pollock abundance, though it is noted that they are less proficient at differentiating between species.

The vessels will also collect wind, solar radiation, surface temperature, and salinity data as they progress, using onboard solar-powered instruments. Compressed snapshots of all collected data are transmitted to shore via satellite modem four times per hour.

> ***"If you had asked me six years ago, when I first heard about this, I wouldn't have thought it possible."***

Technology in Action: Fisheries Use Cases

Australian unmanned vessels to patrol the Indian Ocean[39 40]

The Australian Department of Defence's Innovation Hub has signed a ~£3m contract with a company based at the University of New South Wales to develop and deploy a fleet of six unmanned surface vessels for marine surveillance and enviromental monitoring purposes.

The drones – to be launched in 2021 – can travel at 5 knots and run entirely on solar, wind and wave power, so can stay out at sea until essential maintenance or removing of biofouling is required. They will initially patrol the Indian Ocean waters off The Northern Territory's Top End and will be fitted with sensors and radar equipment to autonomously detect illegal vessels. Once alerted, authorities can take control of the autonomous vessel to conduct further investigation and collect digital evidence.

The vessel type – named 'Bluebottle' – will also be able to sail into cyclones to measure the air pressure so as to determine ferocity, a task never before possible.

38 https://www.maritime-executive.com/editorials/due-to-covid-19-noaa-uses-drones-instead-of-ships-for-fishery-survey
39 https://dronedj.com/2020/07/09/drones-to-patrol-australian-waters-keeping-illegal-vessels-out/
40 https://www.abc.net.au/news/2020-07-08/domestically-made-ocean-drones-to-patrol-australian-waters/12420318

7 POSITION, NAVIGATION AND TIME

Global Navigation Satellite System (GNSS)

Global Navigation Satellite System (GNSS) is a satellite infrastructure that allows users to determine their position, velocity, and time by processing signals from 'in range' satellites. GNSS underpins all marine navigation and is a fundamental technology supporting Position, Navigation and Time (PNT). Automatic Identification System (AIS) is an automatic tracking system that uses transceivers on vessels that are transmitting between Terrestrial AIS (T-AIS) base stations (on land). Satellite-based AIS (S-AIS) works complementary to T-AIS detecting AIS transmissions to support vessel management and vessel traffic management services (VMS / VTS). Whilst marine radar continues to be the primary method of collision avoidance, AIS supplements marine radar in support of safety at sea.

An unintended consequence of AIS is that this also provides a rich source of intelligence to inform vessel location and is emerging as a key method for monitoring the movement and activities of vessels at sea. This section looks further at the emerging GNSS and AIS core technologies and how these are supporting fisheries management and MCS. Further, we see how GNSS is becoming a critical component of Blockchain in the area of supply chain logistics.

GNSS signals are provided by a variety of satellite positioning systems, including global, regional constellations and Satellite-Based Augmentation Systems:

- Global constellations: GPS (USA), Galileo (EU), GLONASS (Russian Federation), BeiDou (PRC).
- Regional constellations: QZSS (Japan), IRNSS (India), and BeiDou regional component (PRC).
- Satellite-Based Augmentation Systems (SBAS): WAAS (USA), EGNOS (EU), MSAS (Japan), GAGAN (India), SDCM (Russian Federation) and SNAS (PRC).

Of further future interest, the UK Government is currently investigating the feasibility of a new GNSS capability.

GNSS operates to an implemented set of performance parameters: including, Availability, Accuracy, Integrity, Time To First Fix (TTFF), Robustness to spoofing and jamming, Authentication. Other impacting requirements include Power consumption, Resilience, Connectivity, Interoperability and Traceability.

EXPLAINER

Key GNSS performance parameters:[41] *GNSS Market Report, Issue 6, copyright © European GNSS Agency* GNSS technology is used for many types of applications, covering the mass market, professional and safety-critical applications. Depending on user needs, important GNSS User Requirements are:

- **Availability:** The percentage of time the position, navigation or timing solution can be computed by the user. Values vary greatly according to the specific application and services used, but typically range from 95-99.9%.
- **Accuracy:** The difference between true and computed solution (position or time).
- **Continuity:** Ability to provide the required performances during an operation without interruption once the operation has started.
- **Integrity:** The measure of trust that can be placed in the correctness of the position or time estimate provided by the receiver.
- **Time To First Fix (TTFF):** A measure of a receiver's performance covering the time between activation and output of a position within the required accuracy bounds.
- **Robustness to spoofing and jamming:** A qualitative rather than quantitative parameter that depends on the type of attack or interference the receiver is capable of mitigating.
- **Authentication:** The ability of the system to assure the users that they are utilising signals and/or data from a trustworthy source, and thus protecting sensitive applications from spoofing threats.

Other parameters which do not directly relate to the GNSS performance are also important for GNSS-based technologies. Key requirements in this aspect comprise Power consumption, Resilience, Connectivity, Interoperability and Traceability.

GNSS Augmentation Technologies

Augmentation of GNSS is a method of improving the navigation system's attributes, such as accuracy, reliability, and availability, through the integration of external information into the calculation process.

Satellite-Based Augmentation (SBAS): supports wide-area or regional augmentation through the use of additional satellite-broadcast messages, providing enhanced PNT data, each SBAS method operating in line with their own set of performance parameters.

Ground-Based Augmentation (GBAS): uses either networks of reference stations (e.g. Differential GNSS, Real Time Kinematics - RTK - or Wide Area RTK (WARTK)), or localised just a few stations (Precise Point Positioning - PPP) for the computation of the augmentation information.

It is through applying different augmentation strategies that PNT accuracy and performance requirements are met, and these vary by sector and application. For instance, at the highest level of positional requirements civil engineering geomatics, including infrastructure engineering at sea, require very high levels of accuracy in the order of mm(s) and use GNSS with ground based augmentation strategies, *(e.g. Leica Geosystems GNSS receiver*[42] *achieves positional accuracy of (Static (phase) with long observations) 3mm in plan (x,y) and 3.5mm in vertical (z) at 99.99% reliability.* Compare this with the requirements for drone navigation which requires ~10m accuracy for flight in open areas and 1m accuracy for flight in urban and more complex environments. And fisheries management and MCS, maritime navigation on inland waterways and approach to and inside ports requires 1m accuracy, higher availability and higher continuity, and less than 10m accuracy, lower availability and lower continuity on the open seas.

The GNSS receiver and GNSS chipsets both receive and process the resulting augmentation. The table below identifies example technology companies demonstrating a range of GNSS equipment technologies applicable to fisheries management and MCS.

41 GNSS Market Report, Issue 6, 2019 copyright © European GNSS Agency; https://www.gsa.europa.eu/newsroom/news/european-gnss-agency-gsa-releases-6th-gnss-market-report
42 Leica Geosystems GNSS Systems Comparison Chart; https://leica-geosystems.com/products/gnss-systems/smart-antennas

Example technology companies providing technology manufacture and associated services in downstream GNSS for Maritime, Search and Rescue, Drones and Geomatics	
Components / receiver manufacture for the maritime sector	Beijing Electronics, Beijing Bdstar Navigation, Beijing Unistrong Science & Technology, Cobham, Cobra Electronics, Furuno, Garmin, GMT Co, Japan Radio Co Johnson Outdoors, Kongsberg Maritime *(Rolls Royce)*, Navico, Orolia, Samyung Enc
GNSS enabled Search and Rescue Receiver Manufacturers	Quectuel, STMicroelectronics, U-Blox AG
Search and Rescue Beacon Manufacturers	Emergency Position Indicating Radio Beacon (EPIRB) & Personal Locator Beacon (PLB): ACR Electronics, Jotron AS, Mobit Telecom, Ocena Signal, Orolia AIS-Search and Rescue Transponder (AIS-SART) & AIS Man Overboard (AIS-MOB): ACR Electronics, Jotron AS, Ocean Signal, Orolia Emergency Locator Transmitter (ELT): ACR Electronics, Astronics Corporation, Oroia, Anyung Enc., ELTA, ECA Group
GNSS Chipset for drones	Hexagon AB, Nobatel, Qualcomm, Septentrio, U-Blox
Augmentation services for the geomatics sector *(and*supporting sector requirements such as hydrography and survey for marine and maritime infrastructure asset engineering purposes)*	Deere & Co, Fugro*, Geoflex*, Hemisphere (Atlas)*, Hexagon*, Sapcroda*, Spaceopal, Swift*, Teria*, Topcon, Trimble, National and Regional RTK Network Providers
Geomatics Receiver Manufacturers	Beijing Bdstar Navigation Co, Beijing Unistrong Science & Technology, CHCNAV, Deere & Co, Hexagon Leica Geosystems, Novatel, Hi-Target Surveying Instruments Co., Kongsberg, Topcon, Trimble, Topcon, Trimble

Fisheries Management and MCS Example Use Cases:

- **Navigation at Sea Applications -** Safety of Life at Sea (SOLAS) vessels regulated and required to heavily reliant on GNSS for navigation and non-SOLAS vessels where GNSS use is widespread but not necessarily mandated by regulation.
- **Inland Waterways Navigation:** GNSS is also used to ensure safe navigation in inland waterways (rivers, canals, lakes, and estuaries).
- **Collision Avoidance and Surveillance:** Supported by GNSS-based systems including Automatic Identification System (AIS) and Long-Range Identification and Tracking (LRIT) both in sea and inland waters.
- **Search and Rescue** - *the search for and provision of aid to people in distress or danger.* Different types of devices can make use of GNSS positioning:
    - In the frame of the COSPAS-SARSAT programme (an International treaty-based satellite-aided Search and Rescue initiative), ship and person-registered beacons, i.e. Emergency Position Indicating Radio Beacons (EPIRBs) and Personal Locator Beacons (PLBs) transmit, once activated, the necessary information for rescue to authorities via satellite communication.
    - When activated, AIS Search and Rescue Transponders (AIS-SART) and AIS Man Overboard (AIS-MOB) devices continuously transmit an alert message including ID number and GNSS-based location, which triggers an alarm on all AIS equipped vessels within Very High Frequency (VHF) range.
- **Fishing vessel control:** GNSS positioning enables Vessel Monitoring Systems to check the position of fishing vessels, as well as the time spent in international and foreign waters, protected marine areas, etc.
- **Port operations:** Transit progress, docking and loading-unloading operations are monitored through GNSS-based technologies.
- **Marine engineering:** GNSS supporting marine construction activities (e.g. cable and pipeline laying).
- **Geomatics in support of marine applications** – e.g. bathymetry survey, and georeferencing of remote sensing data e.g. supporting fisheries research and habitat monitoring projects.
- **Drone navigation and associated data processing.**

As we look forward, GNSS use in maritime vessels is expected to double over the next decade, increasing from 20% to 40%. The European GNSS Agency reports that

> *“The use of satellite-based augmentation systems is becoming the primary source of accurate positioning across the maritime and inland waterway domains.*
>
> *A future trends workshop of maritime stakeholders (UCP2018, Marseille) identified the following GNSS (future) trends:*
>
> - *Enabling Autonomous vessels (manned and unmanned)*
> - *There is a need for Resilient PNT*
> - *Leverage Sensor fusion*
> - *Implementation of Portable Search and Rescue beacons (PLB) with return link capabilities and AIS-enabled*
> - *Drones to support surveillance*
> - *Confirmed the need for robustness against spoofing and jamming (see Cybersecurity section)”*

In addition, fisheries management is anticipated to drive the expanded use of GNSS-based / AIS services (notably to include smaller vessels). At a point in time it may become that all fishing vessels will be able to be located and potentially tracked, including in different settings such as fishing operations in Municipal waters, inside a National EEZ area and or where a flag state nation’s fishing fleet is fishing in international water (on the High Seas).

Automatic Identification System (AIS)

AIS is a maritime technical standard developed by the International Maritime Organisation (IMO). AIS operates at VHF in near real time ship to ship and ship to shore. Its range is typically between 30nm and 50nm and depends on the combined aerial heights of transmitter and receiver, and on the propagation conditions. The IMO SOLAS Convention requires ships of 300 gross tonnage and upwards engaged on international voyages, cargo ships of 500 gross tonnage and upwards not engaged on international voyages, and all passenger ships irrespective of size to be fitted with AIS transponders.

There are two classes of AIS – Class A and Class B – depending on the AIS transponder transmitting the AIS information.

EXPLAINER

AIS Class A and Class B Transmission: AIS information from a class A transponder will always be prioritised and, thus, be shown to other ships in the area, whereas AIS information from a class B transponder will not be shown until or if there is room on the AIS channel. AIS of class A, in order to avoid that the ships' AIS systems all speak at the same time, large ships use an AIS system of class A, which is called SOTDMA (Self-Organized Time-Division Multiple Access). An algorithm ensures that the AIS transmitter of a ship first notices how other ships transmit their messages and, subsequently, adjusts its own transmission pattern to that of the others. In case there are more ships fitted with AIS of class A in an area than the capacity of the bandwidth, the system will automatically limit the area of coverage so that the remotest ships in the area are discarded. AIS of class B small vessels fitted with AIS, such as recreational craft, can use a less expensive AIS station of class B, which transmits less frequently. This system is called CSTDMA (Carrier Sense TDMA). A class B station will listen for a couple of milliseconds to hear whether a large ship is transmitting before it transmits its own message.

AIS is not without its challenges. Globally, it is estimated that 2% of all AIS transmissions are lost either due to weak transmission signals not being detected and/or volume of traffic impacts in maritime chokepoint areas.

Class A AIS, *for larger commercial vessels*, can be detected by Low Earth Orbit (LEO) satellite and transmits at 12.5W every few seconds. Class B AIS is aimed at smaller commercial and recreation vessels, and transmits at 2W normally every 30 seconds. Until recently Class B transmissions were difficult to detect by satellite because of large satellite footprints, stronger Class A transmissions, and general electronic 'noise'. Satellite receivers are now much better at reliably detecting Class B AIS signals.

An AIS solution may comprise a range of products; from simple devices that are able to receive AIS data and plot targets onto a chart display to complex devices and systems such as Vessel Monitoring Systems.

AIS products include:[43]

- Class A transceivers, see above, both transmitting and receiving data
- Class B transceivers, see above, both transmitting and receiving data
- AIS receivers (these are a cost-effective way of seeing which vessels are in your environment, yet not being seen yourself),
- Aids to Navigation devices can be found out at sea, or near to port, generally on buoys. Aids to Navigation can perform many different functions from carrying out hydrological and metrological tests to extending the range of base stations; and from monitoring vessels to warning them of any hazards.
- Search and Rescue Transponders (SARTs) are only ever used in emergencies. SARTs enable a rapid rescue from vessels in distress, or from lifeboats that have been launched. AIS SARTs are a relatively new technology compared to radar SARTs; they enhance the safety aspect and aid rapid recovery as the heading and speed of the life raft is included in the transmissions. Rescue vessels are then able to plan a course to intersect the life raft quickly and efficiently.
- AIS units can be accessorised with a range of products including antenna splitters, antennas, man overboard alarms and displays.
- AIS base stations are shore side monitoring stations that pick up AIS data from devices within its range. Although they are situated on dry land, they behave just like any normal AIS device, both transmitting and receiving data. Base stations play a major role in national security, forming a chain of AIS receivers along the coastline. This chain is able to monitor vessels that are sailing through the waterways and alert authorities if any potential threats approach the coast before they reach dry land. Base stations also offer a central hub for any aids to navigation that may be within range. Aids to Navigation using Fixed Access TDMA (FATDMA) have their transmission timing controlled by AIS base stations. Base stations also offer a link from command centres further inland to the vessels themselves, allowing authorities to monitor traffic, carry out metrological and hydrological testing, and also react to emergencies.

Terrestrial Automatic Identification System (T-AIS) is a global standard for ship-to-shore, and shore-to-ship communications and contributes to collision avoidance, search and rescue operations, and maritime domain awareness through vessel tracking. T-AIS involves the transmission to coastal stations and is constrained by range *(up to ~ 40nm pending AIS transceiver type and propagation conditions at the time of transmission)*.

Satellite AIS (S-AIS) makes it possible to track seafaring vessels with AIS transceivers on board beyond coastal areas. S-AIS can in principle provide AIS service for any given maritime area on Earth and provides AIS coverage where T-AIS cannot reach.

In practice, both S-AIS and T-AIS are used together to provide enhanced maritime domain awareness.

43 http://allaboutais.com/index.php/en/ *All About AIS has been created to provide an authoritative single source of information about Automatic Identification System (AIS). Our site seeks to provide factual information about the AIS standards, technologies, products and applications. Our information is provided by authorities such as the IMO and IEC as well as experts in the AIS community.*

Example technology companies providing AIS equipment manufacture, AIS systems and downstream AIS Data Services	
AIS technology manufacture (e.g. AIS Transceivers and Base Stations)	Raymarine, SRT Marine, True Heading, Alltek marine, ComNav Marine, Letocean Telematics, Furuno, Weatherdock AG, Vesper Marine, Garmin, Japan Radio Company (JRC), ICOM Saab Group AIS-SART and AIS-MOB: ACR Electronics, Jotron AS, Ocean Signal, Orolia
AIS systems (e.g. Coastal Monitoring Solutions, VMS, Maritime Domain Awareness Systems)	Pole Star, Bluetraker, CLS – Fulcrum Maritime Systems, SRT Marine, Furuno, Wartsila, Kongsberg Gruppen ASA, Saab Group, Japan Radio Company (JRC), Navico (Simrad ECDIS) etc., L3 Harris, Airbus, Raytheon, Thales
AIS (T-AIS and/or S-AIS) Data Services	CLS, ExactEarth, GlobalFishingWatch, Orbcomm, Spire, OceanMind

The AIS market segment is experiencing strong growth with some key emerging technology trends coming through including:

- AIS data is becoming more accessible with the creation of WiFi networks that allow wireless devices including laptops, mobile phones and iPads to receive the AIS data using specially developed applications or in support of specific marine programmes out at sea, etc. For example, for NGO use, research, or public use.
- New S-AIS services constellations are coming to market, reflecting the lower cost of entering new space ecosystem and the increasing use of smallsat platforms.
- AIS data business models are becoming more service orientated with subscription revenue models emerging.
- Data brokering services are beginning to enter the segment, offering multiple AIS data sources and hybrid service options.
- AIS data can be integrated directly (streamed) in customer legacy systems, using published APIs and Web services enabling users to receive real-time data and alerts from multiple sources and undertake their own analysis and interrogation of AIS data.
- Tailored AIS Analysis and Visualisation Products and Services are becoming more common. For instance, the ability to receive data and a tailored intelligence report on historic vessel movement, vessel traffic mapping reports, or reports on vessel activities of interest, e.g. fishing activity near or within an area of interest (such as a marine protected area or a nation’s EEZ).
- Fusion analysis and enhanced analysis products that merge and exploit additional data sources such as satellite or UAS surveillance data, e.g. combining and analysing AIS data to generate enhanced and actionable intelligence.

AIS analysis, visualisation and fusion products are explored further in the Big Data section of this paper.

Fisheries Management and MCS Example Use Cases:

- SOLAS Regulatory compliance *(larger commercial fishing vessels)*.
- Safety at Sea and Search and Rescue.
- Vessel tracking and vessel management.
- Maritime vessel mapping.
- Port traffic management.
- Fuel consumption management / reduction.
- Securing fishing territories and protected areas.
- Fish catch verification, tracking and reporting, and an input data supporting traceability.
- Counter IUU fishing.
- Port State Measure Agreement (PSMA) data source.
- Protection of submarine assets, cables, etc.
- Marine assets policy development and planning, e.g. planning for aquaculture.
- Enhanced maritime domain awareness.

Technology in Action: Fisheries Use Cases

China's BeiDou navigation system promises new levels of security to fishing fleets[44]

As illustrated elsewhere, fishing can be a precarious occupation, with over 32,000 members of the fishing community losing their lives every year, according to the FAO.

China has begun to use satellite infrastructure to offer additional levels of protection to its own fisherfolk. In 2019, over 12,000 fishing vessels in *Fujian* province on the south-eastern coast of China installed new position indicators that connect to the BeiDou Navigation Satellite System (BDS), the 55th satellite of which was launched in June 2020.

With a built-in battery with a life of five years, the system can provide real-time location of vessels in open waters. The value of such geo-location was highlighted during typhoon Hagupit in August 2020. When the typhoon was approaching the coastal area, authorities were able to locate the exact position of all boats at sea and alert them to the impending danger. When a boat lost power, authorities were also able to locate neighbouring vessels to tow the stricken vessel back to shore before the typhoon struck, rather than wait five hours for an official vessel to arrive.

44 http://www.xinhuanet.com/english/2020-08/05/c_139266639.htm

Technology in Action: Fisheries Use Cases

Vietnam rolls out Vessel Monitoring Systems to safeguard fisheries exports[45 46 47 48]

Vietnam was given a 'yellow card' warning by the European Commission in October 2017 – signifying that unless the country increased efforts to fight illegal fishing, it would be given a 'red card', and unable to export seafood products to the European Union. According to Vietnam's Ministry of Agriculture and Rural Development (MARD), this led the country's exports to the EU to fall by 6.5% in 2018 and by 11.5% in 2019. Its energetic response included a robust commitment to the installation of vessel monitoring systems (VMS) across its fishing fleet.

By July 2020, MARD reported that nearly 80% of vessels over 15 metres long had been equipped with VMS. By August, the south central province of Binh Dinh reported that it had achieved 100% compliance on its 15m+ fleet, the first locality to do so. Its vessels installed the approved Movimar device, which transfers time and location data back to the inshore monitoring centre every two hours. This helps the centre keep track of the speed and direction of boats, highlighting suspicious activity as well as enabling timely support in case of emergency.

Technology in Action: Fisheries Use Cases

GPS provides enhanced environmental protection in the ocean[49]

It is not just fishing vessels that are benefiting from location satellites; the safe and targeted use of fishing gear is also being enhanced.

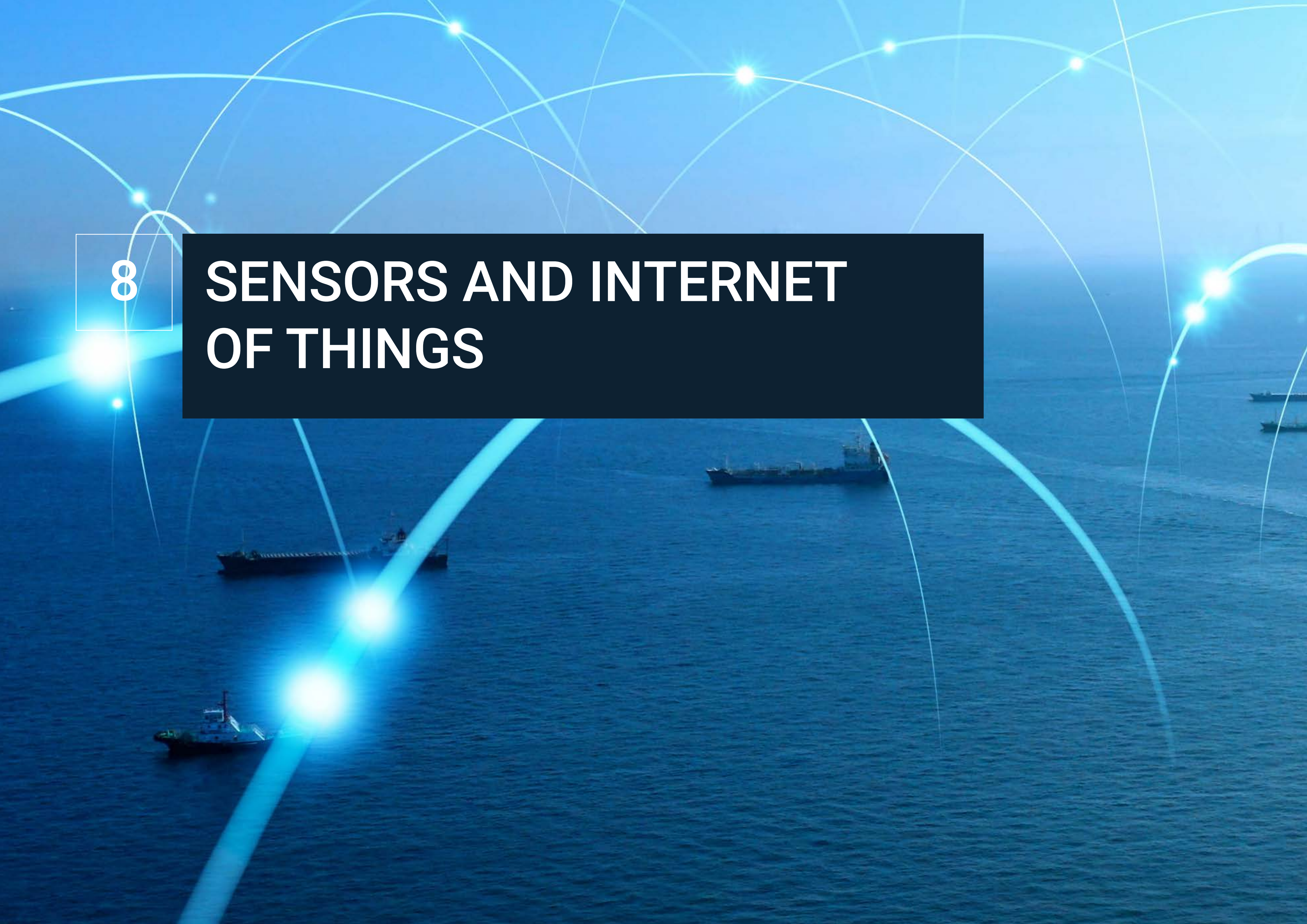
A project launched in Australia in May 2020 uses satellite telemetry data and GPS longline beacons to stop fishing gear accidentally drifting into areas where fishing is prohibited. Longlines are set at sea to move with the winds, currents and tides and fishers normally track their gear using radio beacons. The new satellite-enabled system offers greater location precision than traditional radio beacons. Initial trials by Tuna Australia show increased accuracy in positioning and tracking of their lines – improving overall operational efficiency and protecting marine habitats at the same time.

Similarly, the US non-profit Ocean Voyages Institute (OVI) is using GPS trackers to help tackle ocean plastic pollution. Up to 600,000 tons of abandoned fishing gear ends up in the oceans every year, killing approximately 380,000 marine mammals who either ingest it or get caught in it. OVI attach satellite trackers to fishing gear and other debris to better understand drift patterns. The trackers led them to areas of the ocean where much larger collections of plastic debris had gathered, which was subsequently removed.

> ***"The improvements in the tracking technology help our fishers rethink the way they set their longlines."***

45 https://ec.europa.eu/commission/presscorner/detail/en/IP_17_4064
46 https://en.vietnamplus.vn/binh-dinh-finishes-installing-fishing-vessel-monitoring-device/180251.vnp
47 https://www.thestar.com.my/news/regional/2020/03/05/vietnam-to-beef-up-fight-against-illegal-fishing
48 https://en.vietnamplus.vn/ministry-keeps-urging-installation-of-vessel-monitoring-systems/178845.vnp
49 https://parksaustralia.gov.au/marine/management/partnerships/our-marine-parks-grants/round-one/

8 SENSORS AND INTERNET OF THINGS



Lloyds Register - Global Marine Technology Trends 2030[50] states that the use of a wide variety of sensors capable of communicating data in real time via satellites and land- and ocean-based networks will revolutionise the way information is handled in the ocean space. As increasingly complex data is obtained more cheaply, advanced interpretation techniques, such as big data analytics, will thrive.

Two headlines are further emphasised relating to sensors by Lloyds: "Market demand will be the main driver, as the machines are getting smarter with minimal wiring" and "New sensor networks will be small, inexpensive, and passive, and will require very little power."

Sensors and IoT Technologies

In this section of the paper, we identify emerging sensor and Internet of Things (IoT) trends and then focus on sensors and IoT emerging technologies in nominated key areas of commercial fishing, fisheries management, namely:

- On-vessel sensors
- Fish Traceability Sensors
- Aquaculture Sensing and Measurement

MCS monitoring and surveillance sensors are subject to the same trends but are addressed in wider sections notably in the space-based Earth observation and maritime domain awareness sections.

Sensors in the fisheries sector include both static (these are sensors in situ, fixed on infrastructure or fixed sensor monitoring / measurement stations as in case of maritime may be buoy based); and mobile (these are sensors on moving platforms and may include sensors in/on Space, HAPS, Aircraft, UAS, USV, UUV and ROV platforms and also at a more micro level may include sensor tags on fish themselves or product related e.g. Radio-frequency identification (RFID).

Sensor and IoT Trends

Key sensor and IoT trends include:

- **Miniaturisation of sensors** – with resulting reduction of the physical size of the sensors, electronic components, and chip sets and leading us towards more cost-effective sensor manufacture.
- **Reduced sensor power needs** and the ability to leverage a wider range of power sources, facilitating persistent and real-time sensor monitoring and measurement and the ability to deploy a wider network of sensors.
- **Replacement of analogue with digital sensors and also a trend towards on-line (Cloud)** where reliable and good connectivity prevails.
- Improvements in **advanced materials**, will lead in time to the **deployment of embedded sensors**. In particular, this will enable through-life condition monitoring of assets and structures.
- **Edge Compute**, essentially enabling the processing of data at a sensor location, thereby facilitating real-time, automated transmission of reduced data volumes and data specifically tailored to support analytic requirements (Analysis Ready Data). Further, a combination of **edge compute with embedded AI** will enable automated management/response triggered by a sensor measurement.
- **Synchronous multiple sensor systems/payloads** – in particular, in aerial platforms (i.e. fixed wing, helicopter and UAS), Original Equipment Manufacturers (OEMs) are integrating multiple sensors in single payload sets, providing multiple sensor and synchronous data acquisition options, e.g. LiDAR and Red/Green/Blue (RGB) imaging, Thermal Infrared with RGB imaging / video, etc.
- **Simultaneous Localisation and Mapping (SLAM)** – essentially the ability to update and understand a location in local context on the fly is emerging and is being used in support of data acquisition of complex environments, navigation and robotic movement.

50 Lloyds Global Marine Technology Trends 2030; https://www.lr.org/en/insights/global-marine-trends-2030/global-marine-technology-trends-2030/

- **Sensors are supporting a wide range of requirements in fisheries management and MCS, and sensor use will continue to increase:** including physical sensors, materials sensors, optical sensors, chemical sensors, and biological sensors as well for oceanography, marine environmental, water quality requirements, and specialist requirements such as bathymetry and ISR (Intelligence, Surveillance and Reconnaissance), etc.
- **Standards and sensor interoperability** – industry is embracing open source principles to promote data sharing and interoperability, where we are seeing emerging alignment on common data standards for sensor data tasking, measurement, and publication.
- **Machine to Machine (M2M)** – integrated M2M interaction removes human intervention reducing 'error' and enables the optimised use of automation, with resulting efficiency benefits.
- **Connectivity and the importance of Cybersecurity** – the enablement of networks of sensors, the interconnection of sensors and persistent, real-time reporting requires appropriate connectivity to be available. This also introduces opportunities for malicious actors to exploit. *These topics are discussed in the Communication and Cybersecurity section of the paper.*
- **Removal of the need for or reducing the level of human action** – e.g. if we can remove or reduce the need for a human diver to enter water or humans to take physical measurement, this brings benefits in cost, time and health and safety.

These trends collectively support persistent, automated, and real-time monitoring and measurement. They allow for the deployment of larger numbers of sensors and wide-coverage interconnected networks of sensor to be deployed. They also enable the integration of one network of sensors with another enabling a 'system of systems' approach. With associated manufacture at scale efficiencies and automation of processing and analysis, and in some instances the reduced need for human involvement, sensors can introduce benefits in cost, time and health and safety benefits.

Where we can deploy sensor technologies in coordination with big data analytics, processes and operations can become more informed and data driven. The Big Data section explores this cooperation further.

The fisheries sector overall, and fisheries management and MCS community, already make good use of a wide range of sensors and sensor technologies. Below we consider a few specialist community areas where sensors and associated emerging trends are anticipated to have most impact.

Commercial fishers on vessel sensors: The ability to leverage health, safety and well-being onboard, workforce benefits, reduce costs of fishing at sea and reduce environmental impacts of operation, as well draw on enhanced fishing intelligence day to day, and be able to demonstrate compliance with regulation are drivers for commercial fishers to adopt sensor technologies. Sensors including interconnected sensors on the hull of a vessel, in the engine room, exhaust, and on gear can be implemented by vessel manufacturers using wireless connectivity, and micro- or nano-scale sensor technologies. In the future, these sensors will be able to report to bridge and external vessel partners, such as vessel onshore servicing and vessel operator HQ to enable more efficient vessel operation, reduce fleet fuel costs, reduce environmental footprints and support preventative maintenance. HQ will be enabled to collate data on all vessels and activities and present evidence to support company-level operations and environmental reporting.

In their fishing operation, and primarily aimed at larger vessels, we see the emergence of USV for scouting for fish, with resulting saving of fuel and time at sea. Sensors in support of USV scouting, e.g. Offshore Sensing AS - Sailbuoy[51] may include: wave sensors, meteorological sensors, echo sounder, acoustic modem with connectivity to / via Satellite Communications, e.g. Iridium. Other sensors such as Oceanographic and water quality could also be deployed.

51 Offshore Sensing AS - Sailbuoy; http://sailbuoy.no/

A further example, in this instance, of a UAS scouting technology comes from Raymarine, and is aimed more at smaller scale fisher operations.

Raymarine[52] state

> *The Axiom UAV app brings together the power and simplicity of Raymarine navigation with advanced unmanned aerial imaging. Compatible with the popular and highly capable DJI Mavic Pro drone, the Axiom UAV app automates many common tasks including launch, airborne imaging, in-flight navigation, and return-to boat. When fitted with an optional polarized lens, the Mavic Pro's 4K UHD camera system can see gamefish, baitfish, weed lines, sandbars, reefs and more. This technology allows smaller boats many of the fish-scouting advantages once limited to boats of a very specific size and cost.*

Fish Traceability Sensors

The use of barcode, radio-frequency identification (RFID) chip, Quick Response (QR) code, or alphanumeric (human-readable) code that journeys with the fish product as it moves through the supply chain is at the heart of fish traceability.

Future of Fish[53] is a non-profit fishery transformation organisation with a mission to end overfishing. Future of Fish have identified five core business functions of traceability technology. They state all five must be in place in order to address seafood's social and environmental ills effectively. Not only must robust end-to-end traceability track products on a batch-level basis, but it also must provide a level of corporate transparency at each step in the chain. The five Future of Fish stated core functions are: *(Source: 'Future of Fish')*

> 1. *Vessel Dock Capture – The ability to create a supply chain with verifiable, accurate, and traceable data starts with the capture of catch information at the point of harvest or with the first receiver (e.g. at the dock). Once collected, this information can be paired with a product and uploaded to a database, where it can be pushed through the supply chain via one or more traceability technology systems.*
> 2. *Product Data Pairing – Once data has been captured at the source, the physical attachment of product information to the product itself is critical for preserving the integrity of that data. This can be achieved with a barcode, RFID chip, QR code, or alphanumeric (human-readable) code that journeys with the product as it moves through the supply chain. Information thus accumulates through each step, eliminating the problem of data attrition that occurs with internal traceability.*

52 Raymarine - ; https://www.raymarine.com/view/Blog/News/details/index-ID=15032390346.html
53 Future of Fish Organisation; https://futureoffish.org/

3. *Internal Traceability – Also known as One-Up, One down product tracking, internal traceability is prevalent throughout the supply chain as it assists with basic supply chain management and is required by multiple regulatory agencies for food safety compliance. Many IT companies have roots in this form of traceability, which largely is designed to support business services such as inventory control, and to assist with product recalls. Internal traceability is a core function of robust end-to-end traceability, but is not sufficient as a stand-alone.*
4. *Supply Chain Visibility – The essence of supply chain transparency consists of information about the companies supplying products: where they are located, what they do, how they do it, and whether their licenses and practices fall within legal limits. The focus of this core business function is at the company or facility level, not at the product level. Its key value is proof of compliance and is relevant to particular requirements such as IUU fishing and sustainability certification, and with risk management.*
5. *Data Verification – The capacity to cross check product or company-level information at any point in the supply chain with data supplied by other players (or data vetted by third parties) is critical for proving the legitimacy of the data and for preventing what will inevitably develop as traceability fraud. Verification can include, but is not limited to: mass-balance, data entry checks, prohibition of belated data deletions and modifications, verification of data accuracy via fish tickets or landing documents, verification of legal fishing through vessel AIS operation, certificate status for sustainability, or health code compliance.*

Good examples of fish traceability implementation include:

- ABALOBI App Suite Product (South Africa).[54]
- A community led approach called 'Dock to Dish 2.0' (New York, USA).[55]
- A cooperation between WWF-New Zealand, WWF-Australia, and WWF-Fiji who have teamed up with global blockchain venture studio ConsenSys, information and communications technology (ICT) implementer TraSeable, and tuna fishing and processing company Sea Quest Fiji Ltd. to deliver the first blockchain traceability project of its kind for the Pacific region in a tuna traceability project in Fiji – see case study.[56]

Aquaculture Sensing and Measurement

Aquaculture globally is today and will become an increasingly important form of fish production. For example, in Philippines, the aquaculture sector constitutes over 50% of their total fisheries production.

Sensing and measurement are fundamental to aquaculture, with sensors used to support the planning and set up of aquaculture farms as well as the ongoing operations of the farms themselves. Sensor strategies also vary depending on the type of aquaculture farm. There are many types of farming systems including:

- Water-based systems (cages and pens, inshore/offshore).
- Land-based systems (rainfed ponds, irrigated or flow-through systems, tanks and raceways).
- Recycling systems (high control enclosed systems, more open pond-based recirculation).
- Integrated farming systems (e.g. livestock-fish, agriculture and fish dual use aquaculture and irrigation ponds).

Sensors provide monitoring and measurement to support:

- Aquaculture zoning, evidence to inform regulation and environmental management, e.g. incorporating sensor data in a Geographic Information System (GIS) for system level management,

54 ABALOBI App Suite; http://abalobi.info/
55 Dock to Dish; https://docktodish.com/how-it-works/
56 WWF Blockchain Tuna Project; https://www.wwf.org.nz/what_we_do/marine/blockchain_tuna_project/

measurement to provide an evidence base and data to inform carrying and holding capacity models and a farm's environmental impact assessment

- Decision-support systems for planning, farm management, monitoring equipment with requirements for reliable calibration and self-diagnosis (e.g. for biomass, environmental parameters, etc.)
- Ongoing inspection / condition assessment of aquaculture asset infrastructure, cages, nets and ponds, etc.
- Regular monitoring, measurement and testing across all areas of a farm and all phases of aquaculture including: broodstock holding, hatchery production of seed, nursing systems, grow-out systems, and quarantining.

A wide range of sensors are available including to support:

- Environmental impact assessment: e.g. acoustic profile, temperature, pressure, conductivity, oxygen (absolute oxygen concentration and % saturation), wave, tide and turbidity.
- Water quality: sampling and profiling, perform long term monitoring of sea and inland water, pH, redox, dissolved oxygen, salinity, water quality.
- Real-time continuous monitoring: e.g. wave direction, subsea observations, e.g. for measurements of dissolved oxygen, conductivity, temperature, current, pressure and tide. Water quality - oceanographic, estuarine, or surface water applications.
- Laboratory-based sensor systems: e.g. spectrophotometers, data loggers, benchtop meters for parameter monitoring: pH, mV, Ion-Selective Electrode (ISE), saturation, concentration, partial pressure, conductivity, special resistance, salinity, Total Dissolved solids (TDS), temperature.
- Imaging – Digital and HD, 4K, Still and Video, Wide angle field of view to 360-degree operation and CCTV and self-luminating (underwater lighting) with depth rating operation.
- Coastal Buoys based with wide ranging sensing capabilities with integrated satellite, line-of-sight radio or cellular telemetry options.
- 'Smaller' buoys more suited for lakes, rivers, reservoirs, and near coastal applications with dedicated instrument tubes and control hatch, and capable of hosting a wide range of measurement equipment including water quality, current profile, and wave sensors.

Note the need to withstand demanding aquaculture operational settings. The Deep Trekker (DTPod Product) Inspection and monitoring drop camera for underwater inspections and permanent installations, provides high-resolution video to the surface. This system is durable, has self-cleaning underwater inspection cameras, is depth rated to 1000 feet, fully submersible, and comes with a complete environmental / aquaculture sensor package.

The DTPod is portable, durable and easy to operate, designed to withstand lengthy installations and 360-degree inspections underwater. It is easy to operate, 'plug and play ' and use of the 360-degree pan and tilt camera enables the monitoring of fish health, feeding time or submerged infrastructure. The same splash-proof controller allows access to an entire fleet of installed cameras without having to manoeuvre large, bulky equipment or risk having a laptop close to the water.

To accommodate underwater geo-location challenges, the Deep Trekker remotely operated vehicle (ROV) uses a ROV Sensor Package for Navigation and Stabilization. This pack includes the ability to apply geo-location using auto heading, auto depth hold, active yaw stabilisation, pitch, roll and apply turns count (mitigation for tangling around objects), water temperature, depth data, and heading compass data.

In common with aquaculture, wider marine monitoring and measurement can draw on the similar aquaculture sensor capabilities as described above, albeit deployed on other platforms e.g. for use at sea. Further the use of sensors described elsewhere in this paper, such as the sensor payloads associated with space-based Earth observation, HAPS and UAS, and maritime domain awareness systems demonstrate a wide portfolio of sensing capability is available for marine monitoring and measurement use.

Technology in Action: Fisheries Use Cases

Nanotech biosensors reduce cost in fish testing[57 58 59]

Many of the larger sensors featured in this paper (imaging, acoustic, water quality, etc.) are now being joined with novel nanotechnology applications that enable new levels of quality and efficiency. Trials have been conducted that test the freshness and safety of fish using biosensors using graphene, a single layer of carbon atoms that is extremely thin and lightweight. These sensors – produced using high-resolution aerosol-jet-printing technology at Iowa State University – can detect the allergen histamine, which is indicator of spoiled fish and meat.

Such innovations are made possible by the development of carbon nanomaterials such as graphene that can significantly improve the performance of electrochemical sensors. Further innovations such as the inexpensive aerosol-jet-printing approach make their commercial application yet more feasible for ports, processing facilities and supermarkets.

With a response time of 33 minutes – much faster than a laboratory equivalent – the tests can be undertaken on-site, thus removing the additional cost of labelling, packaging and transport to testing facilities.

> ***"Any food sensor has to be really cheap. You have to test a lot of food samples and you can't add a lot of cost."***

Technology in Action: Fisheries Use Cases

Blockchain, RFID tags and QR codes bring transparency to the seafood sector[60 61 62]

Enlightened consumers are increasingly calling for fully-traceable seafood, so that they can be assured that they are supporting legal and sustainable practices. A new project in the Pacific makes that possible by replacing paper records with radio-frequency identification (RFID) tags and QR codes that capture essential catch information and carry it transparently throughout the supply chain.

The RFID tag – attached as soon as the fish comes on board the vessel – allows automatic registration at various devices positioned on the vessel, at the dock, and in the processing facility. The tag is replaced by a QR code once it enters the processing facility and is partitioned out into various products on the rest of its journey to retailer and right to the consumer's plate. Scanning the tuna packaging with a smartphone will reveal where and when the fish was caught, by which vessel and the fishing method used.

The project's NGO partners are three national WWF branches (New Zealand, Australia and Fiji); its technology partners are global blockchain company ConsenSys and ICT company TraSeable; tuna fishing and processing company Sea Quest Fiji Ltd completes the team as the industry partner. Many such commercial and NGO partnerships are emerging to maximise the potential of new technologies within environmental domains.

57 https://www.iinano.org/blog/printable-biosensors-detect-contaminated-fish/
58 https://www.foodprocessing.com.au/content/processing/article/printed-biosensors-to-monitor-freshness-of-meat-and-fish-628453981
59 https://engineering.cmu.edu/news-events/news/2017/08/01-graphene-yang-cohen-karni.html
60 https://www.wwf.org.nz/what_we_do/marine/blockchain_tuna_project/
61 https://oceanleadership.org/blockchain-strengthening-tuna-traceability-combat-illegal-fishing/
62 http://tuna.infofish.org/index.php?option=com_k2&view=item&id=89:revolutionary-traceability-technology-implemented-in-pacific-tuna-industry

9 DATA INFRASTRUCTURE

EXPLAINER

Data Infrastructure context:

- Marine Spatial Data Infrastructures (Marine SDIs) for marine authoritative data sharing and exchange
- Engineered data supporting application 'systems' to address specific business requirements
- Advanced data infrastructure capabilities (providing capabilities to fuse, analyse and exploit multiple data sources, perform data mining, and apply AI for ML, problem solving, prediction and planning).

Data Infrastructure Technologies

Many organisations across both fisheries management and MCS public and private sectors are embracing digitalisation and becoming more data driven.

True data-driven operations require facilitating access, dissemination and sharing or data as a key foundation step. This is where data infrastructure begins to contribute.

Firstly, data infrastructure provides an overarching data policy and governance framework, addressing key policy areas including: data access/use and information security policies, determining applicable regulations, the definition and maintenance of data technical standards and specifications, as well as establishing appropriate Memoranda of Understanding (MOU) / Agreement (MOA).

Secondly, it provides a technical 'system' infrastructure through which data is catalogued, accessed, disseminated, and potentially exchanged according to a user role and associated permissions.

Some underlying Data Infrastructure key trends relevant to fisheries management and MCS, include:

Data policy and governance trends:

- There is an increasing willingness to share and exchange data both between public sector bodies and between public and private sector to achieve common goals.
- Data typically remains federated (residing in either the data owner, producer or custodian organisation) and is accessible as per MOU / MOA arrangements.
- Increased focus on Data Ethics, especially in relation to the use of and the protection of personal data and ensuring data licensing requirements are appropriately implemented.
- New data licensing models are emerging driven by new business models.

Technical Systems' Infrastructure trends include:

- Increased use of Cloud or Hybrid Cloud approaches.
- Optimisation of automation across data workflow.
- Renewed focus on metadata (robust metadata is critical to both machine to machine (M2M) and human interrogation of data).
- Increased use of open source technologies and standards, ensuring interoperability and avoiding proprietary constraints being implemented at the data infrastructure core.

Marine SDIs are a good example of foundational data infrastructure implementations. Marine SDIs are providing data infrastructure to support day to day sharing and exchange of data and collaboration across and between marine entities. This ensures that authoritative reference data are used, and that common data is 'collected once and used many times'.

Technical Case Study[63] EMODnet - European Commission Directorate-General for Maritime Affairs and Fisheries (DG MARE)

The European Marine Observation and Data Network (EMODnet) is a long-term marine data initiative from the European Commission DG MARE underpinning its Marine Knowledge 2020 strategy. EMODnet is a consortium of organisations assembling European marine data, data products and metadata from diverse sources in a uniform way. The main purpose of EMODnet is to unlock fragmented and hidden marine data resources and to make these available to individuals and organisations (public and private), and to facilitate investment in sustainable coastal and offshore activities through improved access to quality-assured, standardised and harmonised marine data which are interoperable and free of restrictions on use.

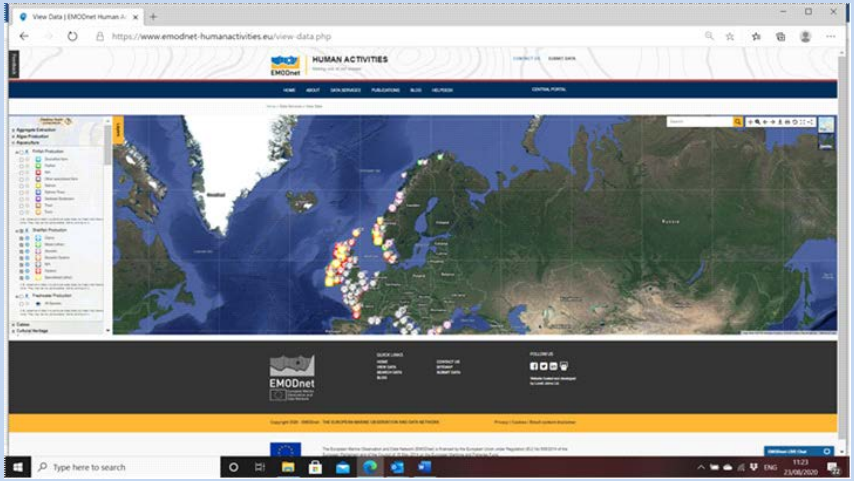


Figure 4: EMODnet Data Infrastructure - Human Activities Data, with example European Aquaculture Shellfish Production

Once a capability and a standardised approach to accessing, dissemination and sharing of data is addressed, then organisations can begin to build out their data-driven approach in support of their business operations. This can involve data exploitation through the collection and engineering of data, including (i) data collection of specific data, (ii) the development and building of underlying data models and database implementations and (iii) the development, customisation, or configuration of software applications e.g. a web application deployed on a mobile/handheld device.

Where data are structured (*or semi-structured i.e. where data has tags or links with other structured data)*, they can be analysed further using structured data analysis capabilities, e.g. using database analysis (SQL etc), GIS, and data mining based on underlying data models. This can scale to national and regional use and enable interaction and data exchange between public and private entities.

EXPLAINER

Structured data / Unstructured data: Structured data are data that have a well-defined 'structure' (e.g. data fields and attribution) making them easily searchable. Unstructured data is 'everything else' and comprises data that is not as easily searchable, including data types such as audio, video and social media postings.

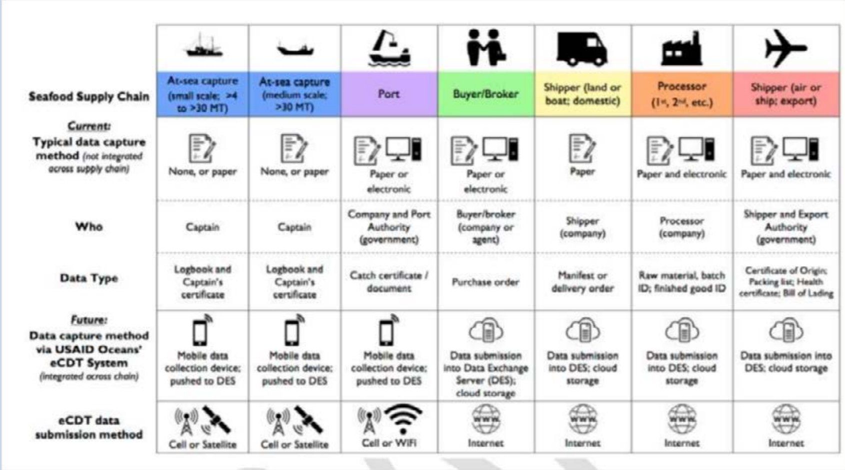
Electronic Catch Documentation and Traceability (eCDT) is a good example of an engineered data and developed system approach.

63 EMODnet - European Commission Directorate-General for Maritime Affairs and Fisheries (DG MARE); https://www.emodnet-humanactivities.eu/view-data.php

EXPLAINER[64]

Electronic Catch Documentation and Traceability (eCDT) - The collection, documentation, sharing, and analysis of verifiable ecological, economic, and social data related to captured wild fisheries (catch) as they move through the supply chain, such that they are "traceable" throughout all points in the supply chain— from point-of-catch through to export. Effective eCDT systems must be used by all actors in the supply chain, including fishers, buyers, processors, transporters, exporters, and national government agencies.

Many fisheries authorities are considering and looking towards implementing eCDT capabilities. In eCDT we see movement away from a 'paper based' to an end to end 'electronic' approach. The underlying data infrastructure is critical for the eCDT operation. For instance, mobile data collection strategies are employed (enabled through an engineered mobile *(handheld device)* software application), an engineered data model is implemented in the software application, live data exchange is enabled through the use of centralised data exchange servers, and the cloud supports the end to end eCDT implementation. Moreover, the end to end workflow accommodates multi-entity roles and responsibilities (e.g. supply chain, broker, enforcement officer etc.) as well as the storage, archiving and publication of data records to satisfying the reporting and audit requirements for all entities involved.



Seafood Supply Chain	At-sea capture (small scale: >4 to >30 MT)	At-sea capture (medium scale: >30 MT)	Port	Buyer/Broker	Shipper (land or boat: domestic)	Processor (1st, 2nd, etc.)	Shipper (air or ship: export)
Current: Typical data capture method *(not integrated across supply chain)*	None, or paper	None, or paper	Paper or electronic	Paper or electronic	Paper	Paper and electronic	Paper and electronic
Who	Captain	Captain	Company and Port Authority (government)	Buyer/broker (company or agent)	Shipper (company)	Processor (company)	Shipper and Export Authority (government)
Data Type	Logbook and Captain's certificate	Logbook and Captain's certificate	Catch certificate / document	Purchase order	Manifest or delivery order	Raw material, batch ID; finished good ID	Certificate of Origin; Packing list; Health certificate; Bill of Lading
Future: Data capture method via USAID Oceans' eCDT System *(integrated across chain)*	Mobile data collection device; pushed to DES	Mobile data collection device; pushed to DES	Mobile data collection device; pushed to DES	Data submission into Data Exchange Server (DES); cloud storage	Data submission into DES; cloud storage	Data submission into DES; cloud storage	Data submission into DES; cloud storage
eCDT data submission method	Cell or Satellite	Cell or Satellite	Cell or WiFi	Internet	Internet	Internet	Internet

Figure 5: Example eCDT data infrastructure

(Source: The Oceans and Fisheries Partnership (USAID Oceans) - Technical Guidance on the Design and Implementation of Electronic Catch Documentation and Traceability (eCDT) Systems in Southeast Asia). Note the data type, data capture method, use of data exchange server and cloud

Finally, in some specialist areas of fisheries management and notably in support of MCS, more advanced data infrastructure capabilities are emerging. These include the capability to fuse, analyse and exploit multiple data sources, perform data mining, and apply AI for ML, problem solving, prediction and planning. Note that in these instances data sources may be both structured and unstructured *(for instance enabling the concept of using any available source of intelligence and applying techniques such as computer vision)*. These topics are explored further in the Big Data section of the paper.

64 Technical Guidance on the Design and Implementation of Electronic Catch Documentation and Traceability (eCDT) Systems in Southeast Asia, The Oceans and Fisheries Partnership (USAID Oceans), 8 April 2020; https://www.seafdec-oceanspartnership.org/resource/technical-guidance-on-the-design-and-implementation-of-electronic-catch-documentation-and-traceability-systems-in-southeast-asia/

Technology in Action: Fisheries Use Cases

Software robot softens workload of seafood sales team [65] [66]

The successful integration of Robotic Process Automation offers business efficiencies by analysing and automating routine administrative tasks. Danish seafood company Royal Greenland has started to embrace this new technology in its offices to reduce staff workload and support customer value, especially during times of heavy workload.

Some pressure on the company's International Sales Department during the summer peak fishing season has been relieved by automating the repetitive and time-consuming task of creating, for example, essential health certificates. Previously, staff would enter a large amount of data manually on the Danish Veterinary and Food Administration's website in order to generate a unique health certificate number to be used as part of the sales documentation. Staff time of up to 40 minutes per certificate (of which there can be up to 1,700 a year) is now covered by a software robot that works 24 hours a day, 365 days a year. This means that over 1,100 staff hours can now be applied to adding value in other ways to the company's customers.

Technology in Action: Fisheries Use Cases

The Philippines leads the way with electronic catch documentation system [67] [68] [69]

The Philippine Bureau of Agriculture and Fisheries (BFAR) has since 2017 been embedding a bespoke electronic Catch Documentation and Traceability System (e-CDTS).

The system was developed in-house by a team of 15 BFAR developers, supported by USAID Oceans.

Initially focused on the user requirements of General Santos City – the Tuna Capital of the Philippines – a Value Chain Analysis and Gap Analysis helped to establish the port's priority needs and suggest a technology architecture to meet them.

The resulting system aims to streamline and digitize the Philippine documentation process and simplify the traceability of fisheries products. This supports a wide range of outcomes, including combating IUU fishing and ensuring food safety. Such initiatives sit comfortably within a broader drive for effective fisheries management, as part of recently appointed Agriculture Secretary William Dar's "New Thinking for Agriculture" framework.

> ***"Use this to increase productivity and sustain the ecosystems."***

65 https://fishfocus.co.uk/royal-greenland-uses-office-robot-to-enhance-efficiency/
66 https://www.royalgreenland.com/royal-greenland/news-and-seafood-insight/office-robot-a-big-help-in-summer-peak-season/
67 https://pia.gov.ph/press-releases/releases/1034134
68 https://www.da.gov.ph/phl-combats-iuuf-with-electronic-system/
69 https://www.seafdec-oceanspartnership.org/news/first-learning-site-cdt-system-launched-in-general-santos-city/

10 BIG DATA

Big Data Technologies

Big Data involves undertaking data analysis and visualisation on a large scale, the use of multiple data types, is automated, likely to occur in real-time or near real-time, and may be self-learning through the use of AI and/or ML. The goal is to enable full end to end automation, but – certainly in the fisheries management and MCS – includes human intervention gates at some key data processing and analysis steps.

Data analysis involves the ingestion, processing, classification, modelling, mapping, interpretation, and evaluation of data in support of a business requirement or to inform a business decision. The analysis output is presented for visualisation by a user or user community.

Visualisation is about how data analysis outputs are presented, viewed and able to be interrogated to inform a user. This may be as simple as an informing telephone call, an at workstation explanation of findings, or the production of Maps, Charts, Statistical Data and Graphics, Intelligence reports, or the publication of an alert or alarm. Digital data may be presented for integration in an enterprise system, viewed via a specialist application (desktop / mobile etc.), or presented in a dashboard or portal (e.g. supporting self-service). These are all well-established visualisation approaches.

Data Analysis and Visualisation emerging technology trends include:

- The wider use of digital and a preference towards integration of digital data in enterprise and legacy systems.
- Increased use of automation and automation of processes using programming frameworks such as python, C++, r (statistics/graphics), etc.
- The use of edge computation, enabling sensor-based processing and in some cases sensor-based analysis.
- The use of specialist data processing methodologies to remove human intervention and streamline efficiencies (e.g. in Remote Sensing and Imagery Intelligence (IMINT) approaches such as 'data cube', and automated processing to 'analysis ready data' (ARD).
- The increased use of AI and specific to imagery analysis specialist approaches such as computer vision.
- The fusion of multiple sources of data and intelligence, in particular the merging of structured and unstructured data sources to inform and support analysis. In particular, we are seeing the more use of IoT (especially the cooperation of sensors within a network and amongst multiple networks), the emergence of data lakes to complement data warehouses / data marts from which data for analysis can be accessed *(a data lake being a pool of data including both structured and unstructured data, whereas data warehouses and marts are tailored more towards structured data management)*.
- The use of data mining as a strategy to unlock access to siloed data and enable access to wider data sources that pre-exist in an organisation for use in analysis.
- The use of Business Intelligence (BI) toolsets, including from an end-user perspective, the use of dashboards (with a wide range of graphical visualisation options).
- The emergence of specialist more interactive user interfaces, ranging from Touch Table, through to Virtual Reality, Augmented Reality and Mixed Reality Platforms.
- With the emergence of big technology companies becoming more and more active in sector domain areas: e.g. Google, Amazon, Oracle, Microsoft, we see a supplier led drive towards the Cloud and Hybrid Cloud and their individual platform functionality driving user options.

Data Infrastructure and Cybersecurity as discussed in other sections of the paper are fundamental to data analysis. It is policies in these areas that inform how an organisation will be able to leverage Big Data opportunities (e.g. underpinning data standards, policies regarding the use of cloud, information security, etc.). Also, we emphasise the importance of understanding the provenance and quality of data analysis outputs, including applied accuracy and confidence level statements orientated towards a thematic user context.

Big Data, Analysis and AI application in Fisheries Management and MCS

Emerging technology referred to above are beginning to be applied in support of fisheries management and MCS. Below we present some interesting big data, data analysis and AI technologies and their applications in fisheries management and MCS.

Space, Aerial and UAS Remote Sensing Analysis and GIS Foundation Technologies: In the earlier sections (Space based EO, UAS and HAPS) we have identified the wide range of emerging remote sensing earth observation data options that are available for use in fisheries management and MCS. These provide a rich resource of data for use.

To analyse these data a range of foundation tools can be implemented, and these would likely reside in a dedicated specialist unit or cell within an organisation. These begin with a remote sensing and GIS foundation capability. Typically, a remote sensing processing, classification and analysis workstation would include access to a GIS desktop environment, e.g. provided by QGIS (Open source) [70]; Esri[71], or others; and specialist remote sensing desktop software environments, e.g. QGIS-GRASS Open Source, L3 Harris ENVI product range[72]; Hexagon ERDAS Imagine products range[73]; PCI Geomatics[74] or others. The remote sensor may be trained in the use of python to automate workflow or r to present outputs in statistical context.

Satellite data providers are also providing data processing and analysis toolsets and environments which remote sensing practitioners regularly use. Examples include: European Space Agency (ESA) provided Sentinel SNAP Toolboxes[75] - The SNAP architecture is ideal for Earth Observation processing and analysis due to a number of technological innovations: Extensibility, Portability, Modular Rich Client Platform, Generic EO Data Abstraction, Tiled Memory Management, and a Graph Processing Framework.

From a space-EO industry actor example, MAXAR, through its GBDX platform allows users to build, access and run advanced workflows to extract actionable information from MAXAR data. GBDX uses Amazon Web Service (AWS) for cloud-based access to all its 19-year global imagery archive and computational resources[76].

The emergence of aerial and UAS survey technologies have also led to the emergence of a number of aerial data processing, classification, and feature extraction (mapping) software products. These include (among others), the Pix4d product range for photogrammetry software suite for drone mapping[77]; and Certainty 3d TopoDOT range for the specialist processing and analysis of Point Cloud data (e.g. LiDAR data)[78].

70 QGIS; https://www.qgis.org/en/site/
71 Esri; https://www.esri.com/en-us/home
72 L3 Harris ENVI product range; https://www.harris.com/solution/envi
73 Hexagon ERDAS Imagine products range; https://www.hexagongeospatial.com/products/power-portfolio/erdas-imagine
74 PCI Geomatics; https://www.pcigeomatics.com/
75 Sentinel SNAP Toolboxes; http://step.esa.int/main/toolboxes/snap/
76 MAXAR GBDX Platform; http://www.digitalglobe.com/products/gbdx
77 Pix4d; https://www.pix4d.com/
78 Certainty 3d – TopoDOT; https://new.certainty3d.com/

Technology In Action: Fisheries Use Case

Plymouth Marine Laboratory (PML); Remote Sensing for Aquaculture and Marine planning[79]

PML reports that "remote sensing offers a cost-effective tool for carrying out observations and providing data which is valuable not only for water quality monitoring, aquaculture and fisheries management, but also for marine planning and protection purposes", including:

Early detection of algal blooms to protect aquaculture sites or recreational areas, and classification of harmful algal bloom risk for certain species and

Detection and mapping tools for ocean fronts (often biodiversity hotspots), used in helping to plan and define marine protected areas and with potential application in siting offshore renewable energy installations.

Coastal and Marine Specialist Remote Sensing and Hydrographic Applications. Further remote sensing and mapping technologies become relevant for specialized coastal and marine mapping requirements. One such example, the Optech Teledyne CZMIL Nova imaging system[80] is an aerial platform sensor system that incorporates a bathymetric LiDAR integrated with a hyperspectral imaging system and a digital metric camera. The Optech HydroFusion software suite handles all three sensors from mission planning through data acquisition, data processing, data analysis and the production of fused data sets including LiDAR and imagery data. Coastal and marine applications include: coastal and shoreline mapping, seafloor classification, harbour and navigation channel inspection, bathymetry, nautical charting, and the detection of submerged objects.

Hydrographic Survey requires further software technologies to process the specialised hydrographic data and produce a standardised range of charts and navigation products. The TeledyneCaris range[81] includes:

- Free Data Viewer: Easy View
- Hydrographic survey: CARIS Onboard, HIPS and SIPS, and Bathy DataBASE,
- Chart Production: BASE Editor, HPD, S-57 Composer, Paper Chart Composer, LOTS limits and Boundaries.
- Spatial Data Analysis: Base Editor, Engineering Analysis Module (EAM)

And a new cloud based platform dedicated to AI solutions (CARIS Mira AI Platform). This new platform, backed by Amazon Web Services, makes the transition to cloud-based hydrographic data processing, analysis, and production.

Technology In Action: Fisheries Use Case

TCarta Satellite Derived Bathymetry[82]

TCarta are an expert hydrographic survey company specialising in the use of Satellite Derived Bathymetry (SBD). SDB can be produced from numerous publicly available and commercial multispectral imagery providers including Landsat, Sentinel-2, WorldView, and SkySat with each sensor having comparable benefits. The low cost of Landsat and Sentinel products to the high collection repeat cycle from Planet imagery or the ultra-high precision and resolution of Maxar's WorldView imagery. TCarta also provide remote sensing analysis for coastal and marine habitat assessment and coastal change detection.

79 Plymouth Marine Laboratory (PML); https://pml-applications.co.uk/Centres_Services/Remote_Sensing_and_Aquaculture
80 Optech Teledyne CZMIL Nova imaging system; https://www.teledyneoptech.com/en/applications/coastal-and-marine/
81 TeledyneCaris range; http://www.teledynecaris.com/en/home/
82 TCarta; https://www.tcarta.com/

Monitoring Control and Surveillance (MCS) Applications.

Big Data (data analysis and AI) can make a significant contribution to Fisheries Authorities supporting their day to day MCS activities and can be a key part of their fight against IUU fishing.

In terms of technology, this can begin with the use of GIS, followed by more complex Big Data with applied AI and automation to support the analysis of multiple data sources.

GIS will be used on a daily basis across a fisheries management authority. For MCS, GIS activities can be undertaken using QGIS (open source GIS) or other commercial off-the-shelf (COTS) GIS products such as Esri among others. Essentially these tools provide a wide range of GIS production and analysis capabilities that can support MCS in:

- Production of geospatial reference data, e.g. EEZ, Municipal Waters boundaries, Marine Park Areas, etc.), and the management and provisioning of other reference data for use in wider MCS systems, such as charts, mapping, planning data, asset data, etc.
- Production of geofence data to underpin the MCS approach and ongoing monitoring.
- Provide analysis capability, including spatial and temporal analysis as well as analysis in both 2d and 3d as applicable.

The case study below shows the use of GIS to produce Vessel Density Maps, in this instance for EU Waters.

Technology in Action: Fisheries Use Case

EMODnet Production of Vessel Density Maps[83]

A vessel density map is a data product that shows the distribution of ships (i.e., of maritime traffic), based on the instantaneous number of vessels per unit area, such as a square kilometre, a square degree, etc. Vessel density maps are often generated starting from ship positions retrieved from the Automatic Identification System (AIS). Vessel density maps of e.g. as those produced for EU waters, show the average number of vessels of certain type (cargo, passenger, fishing etc.) in a given period within a grid cell. Vessel density maps are a frequently requested GIS data layer as they are used to inform a wide range of marine and coastal planning and research, as well in fisheries management to inform the planning of aquaculture and as one of the inputs to identify prioritised areas for MCS monitoring.

GIS technologies included in the EU methodology included: GIS desktop (Linux, PostgreSQL/PostGIS, GDAL, Esri, QGIS)

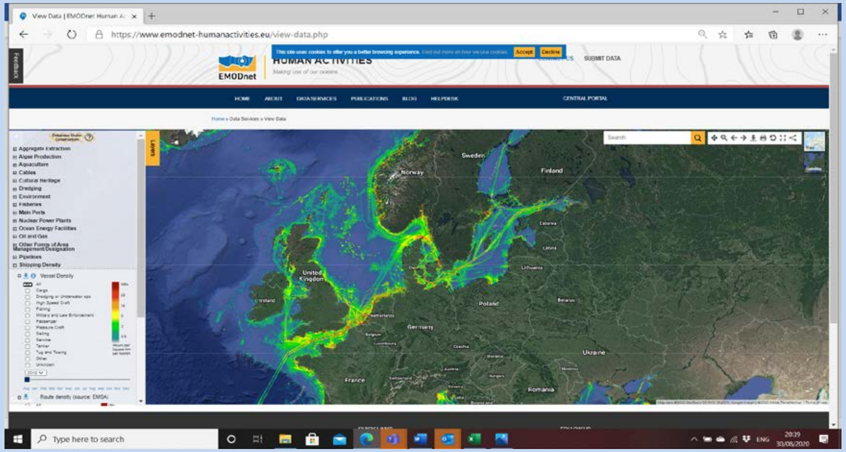


Figure 6: EU MODNET- Vessel Density Map (Europe - All Vessels)

83 EMODNET Production of Vessel Density Maps; https://www.emodnet-humanactivities.eu/view-data.php

An example more complex Big Data solution, the Verumar project, is implementing a Data-Driven Fisheries Management approach through the acquisition and analysis of a range of satellite data sources, to deliver actionable intelligence of potential IUU fishing activity to DA-BFAR. The project team are also further working with DA-BFAR to apply the intelligence provided so that DA-BFAR can target their wider MCS and Port State Measure activities.

Big Data with applied AI and automation is at the core of the Verumar solution. From a technology perspective this uses:

- Satellite EO Data: Sentinel -1 data (SAR), Sentinel-2 (Optical), Targeted tasking of RADARSAT-2 (SAR) two modes DVWF, XF modes via MAXAR, Landsat and VIIRS boat detections.
- AIS Data: Satellite-AIS and Terrestrial-AIS data (from Spire), historical Satellite-AIS (from ORBCOMM).
- GIS reference data: providing reference data coverage from Philippines coast to Philippine EEZ, and further the adjacent high seas as a buffer zone out to another approximate 100nm. This allows analysis of IUU fishing threats both from outside the EEZ as well as within.
- OceanMind Fisheries Intelligence Platform – The OceanMind Fisheries Intelligence Platform is based on the Microsoft Azure Technology. Within this a wide variety of machine learning techniques are used to essentially classify vessel behaviour. The machine learning is bespoke, using combinations of algorithms to model many different factors that can be used to identify behaviour. At a high level, OceanMind teaches the machine what the behaviour of interest are by giving it many examples. The machine then starts to learn what to look for and starts to identify examples of its own. Feedback is provided on its output, telling the machine where it is wrong and right, allowing it to improve over time.
- OceanMind machine learning is most effectively applied to categorising vessel behaviour, to identify fishing, transhipment, crew activity, and activities of interest with successful filtering applied. OceanMind reports they have been very successful in using ML to identify vessel activity types, whilst the accuracy is varied depending on activity of interest, in several cases accuracies over 99% have been achieved.
- Another key area of the OceanMind solution is the applied use of automation. Automation is required for data capture, transformation, and storage. There is too much data for manual intervention to be possible at the global scale. Automation is also required to analyse all of the data and highlight suspicious activity to analysts. Essentially the search space is cut down using automation, so that analysts can focus their time on vessels of highlighted interest.
- Analysis outputs are shared with DA-BFAR officers in the form of a series of regularly issued and tailored intelligence reports including details on:
    - Vessel detections correlated with tracking data
    - Risk-profiled uncorrelated vessel detections
    - Risk areas profiled to support patrols
    - Dark vessel detection port analysis
    - Pre-arrival (AREP) analysis reports.
    - Port and EEZ wide area monitoring for undeclared foreign-flagged fishing vessels and carriers.

Through the Verumar approach, the benefit of automation is one of reliability. Manual intervention brings human error and it reduces reliability. Robust automation saves time and effort, but also allows confidence in results. The overriding benefit of ML and AI is being able to do more with less. Meaning that a team of analysts can achieve more effective enforcement with less manual effort, by focusing efforts on non-compliance, not having to manually look through all the compliant vessels to find non-compliant ones.

Fisheries Management and MCS Example Use Cases:

- GIS and Remote Sensing Specialist Unit / Expert Cell Capability
- Remote Sensing for Aquaculture and Marine planning
- Coastal and Marine Specialist Remote Sensing and Hydrographic Applications.
- Protection of submarine assets, cables etc.

Monitoring, Control and Surveillance:

- Day to day GIS based data production and geospatial analysis capability
- Maritime vessel mapping
- Vessel Detection (including candidate Dark Vessels), Vessel Activity, EEZ Incursion, Intelligence-led IUU Fishing response,
- Advanced Reporting Analysis for Port State Measures

Other at sea 'illegal activity' source of intelligence and enhanced maritime domain awareness – *see Maritime Domain Awareness section of the paper.*

Technology in Action: Fisheries Use Cases

Machine Learning shows potential to revolutionise the aquaculture industry[84]

The aquaculture industry is currently witnessing a surge in innovation, linked to the estimated high-commercial growth potential of the industry, which in turn is driven by the projected increased need of farmed fish to feed a growing global population in the coming decades. Companies such as Aquabyte (Norway and USA) are harnessing advanced machine learning and data visualisation capabilities to bring fish farmers squarely into the 21st century. Its technology – which has received tens of millions of dollars of investment in recent years – aims to identify potential problems within fish pens and suggest ideal feed flows – ultimately, harnessing data to increase yields.

The high resolution camera that sits in the pen takes high quality pictures of the fish, analyses those images, and helps the farmer understand the health and weight of the fish. This enables two critical functions. First of all, the system uses image analysis to report on how much feed the individual fish (and, by extension, the entire pen) require. Secondly, advanced machine learning is able to spot patterns on the scales of each individual's fish that may suggest early onset of sea lice – an infestation of which can be potentially devastating.

As in many sectors featured in this paper, the potentially revolutionary product utilises advances in several technology areas – including computer vision and AI – to offer significant increases in efficiency.

> *"Eventually, we'll get to the point where that data allows us to run fully autonomous fish farms."*

84 https://siliconangle.com/2020/05/26/machine-learning-computer-vision-help-optimize-fish-farming-aquaculture-cubeconversations/

Technology in Action: Fisheries Use Cases

Artificial Intelligence systems extracts new meaning from old fishing data[85]

While many new systems create value from real- or near-real-time data, the potential value to be found in more traditional datasets should not be overlooked. For decades, fisherfolk and fishing companies have been amassing information about their activities – where and when they have fished, how long each trip took, what they caught, the gears they used to do so. While some of that information will over time seep into intuitive knowledge about where to focus fishing effort for maximum return, a new solution in Japan aims to complement that with the power of Artificial Intelligence. Significant amounts of past fishing data, weather conditions and ocean currents are being fed into a new system in Japan to help forecast the locations of the most fertile fishing grounds at any one time.

The system also takes fuel costs into account, to optimise navigation. Developed in Nagasaki Prefecture by Ocean Solution Technology Inc., the system's database of the location and catch volumes of the past is merged with up-to-date marine meteorology information in order to predict which prospective fishing grounds may offer the greatest return in the years ahead.

> ***"AI shows this is the area for a good catch today."***

85 https://www.japantimes.co.jp/news/2020/05/11/business/ai-japan-fishing-training/#.XzSVFZMzaqk

11 COMMUNICATIONS TECHNOLOGIES AND CYBERSECURITY

Communications Technologies

Inmarsat, a major global mobile satellite communications company[86], describes a future state through their Maritime Vision:

> *The maritime industry is changing. Regulatory, environmental, economic, and technical trends are driving a global data revolution. In the next decade, we will be measuring data in zettabytes that is 1,000 billion gigabytes. We will capture, share, and use that data to be more efficient, save costs and improve safety and well-being at sea. We will see a new ecosystem of maritime solutions. Business applications such as remote asset and engine monitoring (to keep things connected) and people connected with video calling, access to social media and the latest online entertainment.*

Communications and cybersecurity are traversal technologies that enable the implementation and exploitation of the wider technology innovations discussed in this paper. In particular, EO, PNT, the transfer of voice, video, and data and in-situ scientific research (sensors, etc.) all rely and are enabled through communications networks and their associated security framework.

As we look forward, we can expect a time when data will be by default, be communicated in real time using satellites, land, and ocean-based networks and this will revolutionise the way information is handled and exploited. This will lead to improved safety and well-being at sea, efficiency of operations, extended lifetime of infrastructure and assets as maintenance becomes more prescriptive through real time condition monitoring and reporting. The collection and processing of intelligence, surveillance, and reconnaissance in real-time will become more normal. And ultimately, we will be able to understand and model our environment and resources allow decisioning to be made in a more informed manner.

> *Lloyds Global Marine Technology Trends 2030[87] identify the following marine communication trends:*
>
> - *Cheaper worldwide transfer of information, even from remote locations, will be more accessible owing to dedicated satellite networks and their improved capabilities, such as those provided by laser data links.*
> - *Data transfer transferring large volumes of data from a wide range of sources and a variety of remote locations requires a technologically advanced approach to provide sufficient bandwidths at a low enough cost.*
> - *Transmissions have to be made from locations such as offshore platforms and ships, wave buoys, floating and submerged autonomous systems, marine infrastructures, and so on.*
> - *The advancements in satellite and related communication technologies will be a key enabler of big data analytics.*
> - *An increased data-storing capability, particularly for independent sensors, will allow more data to be collected per deployment, increasing efficiency.*

Communications will be required to manage ever increasing data traffic to mitigate for spectral congestion, while new capacity becomes available. Further communications equipment manufacturers will move towards being network provider agnostic enabling seamless movement of traffic between satellite communications and terrestrial networks, much the same as we have seen in our own handheld mobile devices where we can move seamlessly between mobile broadband, fixed network broadband and local Wi-Fi hotspots, etc.

86 Inmarsat Maritime Vision; https://www.inmarsat.com/maritime/
87 Lloyds Global Marine Technology Trends 2030; https://www.lr.org/en/insights/global-marine-trends-2030/global-marine-technology-trends-2030/

EXPLAINER

Spectral Congestion - The situation that occurs when many stations transmit simultaneously using frequencies that are close together. Today spectral congestion can occur e.g. in the communications relay of AIS in maritime chokepoints such as Malacca Straits, etc. and this becomes a greater risk as more and more data are transmitted. This may drive technology solutions to manage and optimise the use of existing networks and capacity, (e.g. dynamic spectrum sharing and management, high order modulation and pulse shaping, and optimisation of network topology).

Further, Lloyds states

> *"…satellite development will benefit from higher-resolution sensors, more accurate time references, high throughput and high frequency re-uses. Broadband satellite services will continue to expand. EuroConsult estimating that very small aperture terminals (VSAT) will quickly take over the conventional mobile satellite service (MSS) in five years' time (by 2024)."*

Several emerging technologies in the marine sector, including autonomous vessel operation, smart ship, smart port, etc. will require fast speed, low latency, and high capacity communications networks. From a layman perspective this can be considered as 5G and better.

New satellite communications companies are emerging to support this future requirement (5G using space), e.g. OneWeb and Starlink. Essentially these communications are using many SmallSats deployed in low earth orbit. As we can see in the case study details below, these companies are currently establishing their global constellation coverage and finalising their business models, so we probably will not see operational impact for fisheries management and MCS until 2022 onwards. *(Case study – Source: Starlink and OneWeb).*

Satellite Communications Disruptors – Starlink and OneWeb are both seeking to bring High Speed Internet access across the globe.

- Starlink[88] - With performance that far surpasses that of traditional satellite internet, and a global network unbounded by ground infrastructure limitations, Starlink will deliver high speed broadband internet to locations where access has been unreliable, expensive, or completely unavailable. Starlink is targeting service in the Northern U.S. and Canada in 2020, rapidly expanding to near global coverage of the populated world by 2021.
- OneWeb[89] is creating a new communications infrastructure using satellites in LEO to provide connectivity to communities, businesses, and governments everywhere. The intent is for everybody to have access to high speed, reliable, seamless broadband.
- SoftBank and e5 Lab[90] teamed to conduct trials using next-generation communication satellites to improve maritime broadband services, with the goal of developing remote-controlled ships. Under a recently signed MoU, the companies aim to first conduct tests using existing communication satellites for backhaul from January 2020 to end-May 2020. The vessels will be equipped with flat antennas and local wireless stations.
- Trials using next-generation communication satellites are planned for January 2021 to March 2022. SoftBank and UK-based OneWeb, which forged a partnership in July 2019, will run communication tests using LEO satellites and flat antennas. IoT devices will also be used onboard and tests conducted with the long-term view to remotely operate vessels from land.
- Based on the results, the companies have said they will study ways to commercialise marine broadband services using next-generation satellites.

88 Starlink; https://www.starlink.com/
89 OneWeb; https://www.oneweb.world/
90 Softbank and e5 Lab; https://www.mobileworldlive.com/asia/asia-news/softbank-e5-partner-to-enhance-maritime-connectivity

Above, we have described some new technology capabilities that are anticipated to support the maritime domain and by cascade these will emerge in time to support fisheries management and MCS. This cascade will likely begin with uptake by large commercial fishing and cargo operators, larger ports and government led investment e.g. implemented through MCS suppliers and systems integrators.

Today, Ports have communications coverage based on a blend terrestrial and mobile communications technologies. These may include:

- Fixed network copper, fibre, etc. and these may include both public and more secure government networks
- Operating within a higher-level security communications network (Tetra, Tetra Broadband, etc.)
- Access to Mobile coverage (3G and 4G)
- Other local network features, including, such as WiMAX, Wi-Fi, etc.

Feasibility projects are underway globally, investigating how 5G technologies can be leveraged as pre-cursors to smart ports and further forward autonomous operations within ports.

As we move away from port and out to sea, we anticipate the emergence of satellite and HAPS based 5G and secure communications. The use of existing VMS communications sources will continue (Global Service Mobile Communication (GSM), AIS, Satellite Service Providers), and the continued use of Global Maritime Distress and Safety Systems (GMDSS) (for Vessels over 300 gross tonnage) as per SOLAS international requirements (International Convention for the Safety of Life at Sea (SOLAS 1974)) with their aligned requirements as set out in national regulations.

And further for all, including smaller vessels, we can expect to see the continued use of ship to ship and ship to shore communications using radio (e.g. marine VHS radio). A key challenge for fisheries management and MCS going forward is how to enable communications and support location tracking of small fishing vessel (artisanal fishers). The UK Space Agency IPP Programme has supported a number of fisheries programmes to exploit satellite communications, in support of small fishers, e.g. Indonesia - Satellites for Sustainable Fishing (Inmarsat consortium project); and South Africa - Tracking small boats to increase their safety in South Africa and Madagascar (exactEarth Europe Limited (eEE) consortium). These case studies are explored further below and in the PNT section of this paper, where the wider topic of AIS is addressed.

Cybersecurity

Through considering data infrastructure we have seen the need for ever more data sharing and exchange in support of fisheries management and MCS and above that future marine communications will be driven by the increasing need for data transfer between vessels and onshore bases for optimal operational efficiency, safety, and security. This brings with it a requirement to ensure the security of infrastructure (equipment, hardware and software), end points, bearers and data content exchanged thereon as well as the security vetting of people at appropriate levels of security clearance commensurate with their role and responsibility.

> *"Lloyds reports on the emergence of cyber warfare impacting Naval actors and that with an increasing dependence on the internet for essential communications and operations, the resilience of systems to cyber-attack will be continually tested by criminals, terrorists, malicious individuals, and rogue states. A digital arms race (between competing Naval powers) will be fuelled by a significant increase in computing power and increasingly intelligent software with the capability to learn, spoof and evade detection within a computer network."*

Whilst this is primarily of concern for Defence and Naval entities; Coast Guards and Fisheries Authorities, should be aware that they may be considered more vulnerable points of entry by cybercriminals. Further, as systems become more connected, ports and commercial vessel operators and owners' threats, vulnerabilities and risks will also increase.

Commercially available GNSS signals are vulnerable to jamming and spoofing. Interference monitoring systems are being developed that can be deployed in critical or sensitive areas in response. This is explored further using the European GNSS Agency case study.

GNSS User Technology Report Issue 2, European Global Navigation Satellite Systems Agency, 201891 reports:

'Jamming remains a challenge'. At source, transmitted GNSS satellite signal power is equivalent to a 40-watt light bulb. 20,000 km later, the signal arriving on Earth is very weak and extremely sensitive to interference and jamming. Even mW level interference in GNSS bands can disrupt GNSS reception up to several hundred metres, and cheap jammer devices available for a few euros on eBay aim to do this. Therefore, defeating jamming impacts remains a key challenge. More sophisticated jammers do not only affect all GNSS frequencies but also jam mobile phone and Wi-Fi frequencies, thus denying almost all radio communications within range and making contingency measures more difficult.

To handle the growth in use of such illegal jamming devices, many governments, together with research and academic institutes, are developing interference monitoring systems that could be deployed in critical or sensitive areas. Their purpose is to locate and identify jammer types as well as several other parameters (jamming duration, power, etc.). These systems help map and log jamming events, useful to the authorities, as well as being a potential value-added service for operators. Moreover, in order to enhance GNSS receiver robustness, the EU's GNSS Radio Equipment Directive (RED -2014/53/EU) mandates that all receivers sold in the EU have a certain level of resistance to out-of-band interference.

The emerging threat Spoofing uses GNSS-like signals to trick GNSS receivers into computing false positions, velocities and/or times. Even though GNSS signal specifications are open, spoofing has long been considered as difficult to implement and only possible for governmental organisations because considerable resources are needed to generate credible false signals. The relatively recent availability of low cost USRP (Universal Software Radio Peripheral) allows GNSS-like signals to be generated in software and then transmitted in GNSS bands. A simple €5 USB to VGA adapter can spoof L1 GPS signals using open source software available on the Internet.

Cybersecurity response overall requires an International and National led approach. Common with other sectors such as aviation and utilities, it is Governments that set policies with an aligned regulatory framework and from there both public and private sectors can respond.

In their Maritime 2050 Strategy[92], the UK Government acknowledges cybersecurity threats in the maritime domain and sets out their policy and support to maritime industry as follows:

"The rate of technological change is likely to make critical national infrastructure increasingly vulnerable to cyber-attack. The UK has committed to lead development of appropriate standards, regulations, and guidance in these fields. The onus is on industry to protect themselves and ensure resilience to cyber threats across the supply chain. However, this will be in lockstep with government, who will provide threat and risk assessments, regulation, and guidance to ensure that collectively, the UK is a centre of excellence for the provision of maritime cyber security solutions.

Short Term 1-5 years: It is unlikely that every maritime organisation will have the resources to employ dedicated cyber security specialists so industry should consider exploring models that could provide the maritime industry with cyber support services more effectively. Government will continue its approach to assessing cyber threats through the National Cyber Security Centre and closely liaise with industry to warn, inform, and advise of such threats.

Medium Term 5-15 years: The UK will lead in the development of regulation for the security of automated vessels and connected systems. In a future where the use of autonomous vessels and connected systems are progressively used, government will provide cyber security advice to industry to warn, inform, and advise on threats."

91 GNSS User Technology Report Issue 2, European Global Navigation Satellite Systems Agency, 2018 https://www.gsa.europa.eu/newsroom/news/gnss-user-technology-report-2018-available-download-now

92 HMG Maritime 2050 – Navigating the Future; https://www.gov.uk/government/publications/maritime-2050-navigating-the-future

Once overarching cybersecurity policies and regulations are in place then both public and private sectors can respond and implement through their internal security instruments, e.g. information security management policy and planning.

As digitalisation progresses, and our operations become more data-driven, more automated, and more connected with a deeper integration of technology, we should expect cybersecurity to become higher profile and ever more important to our day to day operation.

Technology in Action: Fisheries Use Cases

Satellite communications provide a lifeline to the fishing community[93 94]

Low-cost satcomms capabilities provided by UK company Inmarsat have been deployed in Southeast Asian fisheries to protect human life at sea. Working with the Indonesian government's Department of Fisheries, the project used low-cost, solar-powered satellite technology on smaller fishing vessels, with the aim of enhancing safety, efficiency, ship-to-shore contact and offering potential fish stock sustainability improvements.

Independent analysis by consultancy Poseidon Aquatic Resource Management Limited (a partner in the Verumar programme), showed that applying modern, satellite-based technology to smaller boats below 30 gross tonnage (30GT), not currently legally required, supported the local industry's move towards safer, more sustainable and profitable operations.

Crucially, the technology enabled participating fishers to call for help during times of acute distress. Poseidon estimates that 39 lives were saved during the project.

Globally, the Food and Agriculture Organisation of the United Nations claims fishing at sea to be the most dangerous occupation in the world, with over 32,000 fishermen perishing at work every year, so any new solutions to help provide greater safety at sea is to be welcomed.

The project was made possible via support from the UK Space Agency's International Partnership Programme.

> ***"Technology, training and respect for the expertise of fishers can together deliver enhanced safety, economic growth and environmental sustainability."***

93 https://www.inmarsat.com/news/satellite-technology-saves-lives-in-indonesia/
94 https://www.inmarsat.com/wp-content/uploads/2019/09/DI330-7_Endline_ME_Evaluation.pdf

Technology in Action: Fisheries Use Cases

5G enables innovation in fishing port[95 96 97]

The Port of Vigo – the biggest fishing port in Europe – has invested in satellite-enabled communications infrastructure, as part of its drive towards being a truly digital port.

In particular, telecoms operators Orange and Vodafone are introducing 5G at the port to enable a wide range of additional services.

The port, on the Spanish Atlantic coast, has promoted a strong digitalisation agenda for many years, so the culture is ripe for further innovation enabled by enhanced communications capabilities. Initiatives currently in trial include:

- A security system based on employees' 5G smartphones will control access to the company's corporate facilities.
- A drone surveillance system equipped with very high resolution cameras.
- A network-based facial recognition system in the main office to reduce surface contact.
- An automated valet parking system to see how well vehicles can communicate with their environment in a complex urban environment.

A June 2020 report commissioned by Vodafone U.K estimated that upgrading to 5G could add as much as £158 billion to the national economy to 2030.

> ***"5G will play a vital role as the economy recovers from the COVID-19 pandemic".***

Technology in Action: Fisheries Use Cases

Fishing sector vulnerable to cyber attack[98 99 100]

The maritime industry's major cyber security wake-up call came in the summer of 2017. Global container shipping company A.P. Moeller Maersk estimated that a cyber-attack it had endured – part of the NotPetya ransomware series - would cost it $300 million in lost revenue. For two days, Maersk Line was reportedly unable to take bookings from customers, though the company stressed that no third-party data was lost as a result of the attack.

The fact that the fishing sector is not immune to this threat was underlined in May 2020 when the Northwest Atlantic Fisheries Organization (NAFO) reported that it been affected by a ransomware attack. The Canada-based firm's website was down for over a week, though they have not commented in detail on the damage suffered.

The maritime industry has been criticised for being slow to react to the new wave of cyber security threats, though some marine-specific cyber security products are beginning to come to market. By only allowing pre-approved systems to operate on a company's network, the Abatis Marine product reduces the amount of computing resource required to maintain security.

95 https://www.rcrwireless.com/20200630/5g/5g-could-add-almost-200-billion-uk-economy-10-years-vodafone
96 https://thespainjournal.com/eight-new-5g-technology-pilot-projects-awarded/
97 https://www.businesswire.com/news/home/20190716005806/en/CTAG-Groupe-PSA-Spanish-City-Vigo-Test
98 https://safety4sea.com/cm-maersk-line-surviving-from-a-cyber-attack/
99 https://www.cbc.ca/news/canada/nova-scotia/ransomware-attack-at-fisheries-organization-in-halifax-1.5585701
100 https://www.abatismarine.com/wp-content/uploads/2020/04/Abatis-Marine-brochure.pdf

12 MARITIME DOMAIN AWARENESS SYSTEMS

While the majority of this paper focuses on individual technology domains, there are many cross-cutting themes where a range of technologies converge to bring new opportunities within a particular sector. As the Verumar programme is focused primarily on the use of technology to counter IUU fishing, we end our look at technologies with a closer look at maritime domain awareness and applications.

This builds out from earlier sections on platforms, sensor and analytics technologies to address fisheries management and MCS aspects, and look at key systems that are enabling cooperation and joint operations between fisheries authorities and their mission partners in the maritime domain. Through this we consider fisheries monitoring centres, maritime security centres, and vessel traffic systems (for ports and maritime corridor vessel traffic management).

Rear Admiral Nick Lambert, NLA International co-founder and mariner states:

> *We have gone from a position of Sea Blindness to Sea Vision, and we are now in a world of Sea Vision in real-time. We have the technology to have 100% maritime domain awareness in as many and as complex sea basins as you like.*

Maritime Domain Awareness Systems Technologies

Maritime Domain Awareness emerging technology trends, many of which are relevant to MCS, include:

- The ability to have national coastal radar coverage.
- Emergence of satellite, high altitude and aerial, UAV and USV platforms and sensors providing remote monitoring and surveillance capabilities. Between these capabilities we have near persistent coverage and coverage over areas where we were previously blind (i.e. we can now monitor the sea area beyond the reach of coastal radar systems). Further, we have the ability to task these systems to meet our operational requirements.
- Vessel detection using AIS is becoming standard and we are now seeing the emergence of more advanced analysis using data fusion, that enables the detection of vessel activity, the identification of candidate dark vessels, and vessels that pose a potential IUU fishing, law enforcement and/or wider maritime security threat.
- The emergence of data-driven and the provision of actionable intelligence for use by maritime law enforcement actors, including for use in targeted maritime patrols, and evidence for investigation and judiciary case work. We are also seeing a general movement towards intelligence-led law enforcement in the maritime domain.
- Dedicated MCS and maritime monitoring information centres are being established at National and case by case in sub-national (regional) locations. We are seeing the emergence of systems integration and continuity of operations between different centre locations providing a common operating picture, and levels of operational resilience not seen before.
- Nominated port monitoring centres are expanding their monitoring coverage to include port, approach to port and in some cases the monitoring of traffic throughout adjacent channels, e.g. Dover Straits, Malacca Straits and Singapore.
- With the expanding use of standards and defined data, systems and operating protocols, we are moving towards a position where an integrated 'system of systems' approach is feasible with the ability to rapidly enable joint operations between mission partners based on a single common operating picture and shared levels of situational awareness as needed.
- Dedicated training facilities are emerging, where fisheries authority and mission partner officers can come together for a range of training and exercising.

Fisheries Management Monitoring, Control and Surveillance systems

The UK's Maritime Monitoring Organisation (MMO)[101] states that

> *MCS approaches ultimately all lead towards compliance to fishery management measures: monitoring gathers information on the fishery that is used to assist in developing and accessing control through appropriate management measures, while surveillance uses this information to ensure that these controls are complied with. This approach is as relevant for the management of activities within Marine Protected Areas (MPA) as it is for the management of fisheries as a stand-alone activity. The Food and Agriculture Organization of the United States (FAO) describe these aspects as:*
>
> - *monitoring - the continuous requirement for the measurement of fishing effort characteristics and resource yields;*
> - *control - the regulatory conditions under which the exploitation of the resource may be conducted; and*
> - *surveillance - the degree and types of observations required to maintain compliance with the regulatory controls imposed on fishing activities.*
>
> *The options available for an MCS system and the various combinations of these options are almost limitless. They include a range of separate or interlinked components of hardware in varying degrees of sophistication, various levels and types of human resources (both linked and separate to the hardware), a whole host of approaches to implementation ranging from military type enforcement to community driven compliance programmes and then finally, once the system is developed, to even more choices of how to manage the MCS system and organisation.*

As described in detail in other paper sections and summarised here, MCS emerging technologies and innovations include:

- Ongoing use of fixed wing aircraft for patrol – this is a well-established technology used for MCS. A number of authorities are extending the use of patrol aircraft, while leveraging other intelligence sources such as satellite-based analysis to target patrol areas.
- Unmanned Aerial Systems (UAS) including UAVs – UAVs are increasingly deployed for monitoring, compliance, and enforcement purposes. There are a range of UAV options based on payload, communications capabilities, operational coverage, endurance, and wider performance features. These may be deployed from land to monitor inshore areas, from vessel at sea to support the gathering of evidence, and/or provide forward patrol capabilities.
- Unmanned Surface Vessels (USV) – USVs are emerging as a useful MCS capability to complement wider patrol activities and potentially fulfil designated area monitoring (e.g. longer range and duration monitoring at the extent of an EEZ or for other specified areas of interest such as a Marine Protected Area (MPA) or a closed fishing area), gathering evidence on vessel activity as well as providing forward observation (via digital imaging and video systems).
- Satellite based surveillance – Satellite provides a unique perspective wide area coverage view and is a covert monitoring and surveillance capability. Satellites can be tasked to focus on a specific area of interest or through multiple scenes an entire EEZ. Through the range of sensors, their associated sensing modes and advanced analysis, satellites provide enhanced capabilities for MCS, such as automated vessel detection, vessel activity detection, the identification of candidate dark vessels (vessels not transmitting on AIS) and provide tailored intelligence for MCS officers to inform their wider patrol tasking or port state measures reviews.
- Patrol Vessels – Patrol Vessels are continuing to be the main operational resource for MCS enforcement. There are some simple

101 UK HMG Maritime Monitoring Organisation Blue Belt Programme (MMO), https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/804653/BB_High-Level_Technology_Review_FINAL__002_.pdf

enhancements that can be made to an existing patrol vessel, such as the installation of more powerful binocular, through to the more complex use of patrol vessel mounted imaging sensors with computer vision technologies applied to provide automatic horizon-scanning.

- Floating Buoy-mounted sensing – including imaging, radar and potentially passive acoustic sensors using hydrophone; floating buoys provide a useful ongoing monitoring and deterrent option for specific operating settings such as protected areas of interest and calmer water environments.
- Vessel CCTV combined with self-reporting community fisheries approaches are being encouraged. Good success has been achieved in the use of CCTV systems mounted onboard fishing vessels in Canada by the British Columbia groundfish fishery[102], where logbooks are audited against video as part of a wider community led electronic monitoring community fisheries programme.

For monitoring, reconnaissance and surveillance purposes a blended capability of the above provides an optimal approach. Satellite Data and wider intelligence can be used to focus patrol operations. In some instances, a patrol vessel will be deployed supported by UAV and in others a patrol aircraft will be mobilised. For longer term deployments and deployment in selected operational settings, monitoring and surveillance using fleets of USVs / floating buoys may be deployed. With flexibility to support a range of strategic and tactical operational enforcement requirements, a robust monitoring and surveillance capability is emerging available for fisheries authorities' use.

Systems supporting cooperation and joint operations between fisheries authorities and their mission partners in the maritime domain.

National and Regional Fisheries Monitoring Centres: a range of systems components come together to provide a national and regional fisheries monitoring systems capability. These can include VMS, with AIS transceiver equipment on vessels, use of satellite connectivity, port and coastal monitoring radar, floating buoys with meteorological and environmental sensors, commercial fishers electronic reporting applications, a national and linked regional fisheries monitoring centres all working through a National Data Centre.

The Philippine IMEMS Phase II Project (DA-BFAR supported by SRT Marine (UK)) is providing a National VMS System for the Philippines. Upon roll out completion this will become one of the most up to date fisheries monitoring capabilities globally. This is detailed further by dedicated case study.

102 British Columbia Groundfish Fisheries; https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/fisheries-and-aquaculture/seafood/sustainable_groundfish.pdf

National Maritime Security Centres: Many countries have implemented National Centre Capabilities to coordinate and respond to Maritime Security threats. These centres typically provide a facility where various agencies involved in maritime security can come together to exchange data and undertake joint maritime security intelligence operations. Cooperating agencies may include Navy, Coast Guard, Maritime Police, Border Force (Customs), Immigration, and others. These centres primary areas of interest will concern maritime security pertaining to national security, terrorism, and international crime.

In the UK, the National Maritime Information Centre (NMIC) was established in 2010 and has key responsibilities towards intelligence behind the delivery of UK Government National Maritime Security Strategy. The NMIC brings together maritime information and intelligence from across government departments and agencies and acts as a national focal point for international partners. It provides real time information on maritime activity around the UK and areas of national interest. It supports government and industry decision-making in times of need. Today the NMIC is involved in a number of UK maritime security priorities, e.g.:

- the risk of terrorist strikes against cargo or passenger ships.
- attacks on UK maritime infrastructure, from ports to offshore assets, including cyber-attack.
- transportation by sea of threats into the UK - including weapons of mass destruction, drugs, and guns.
- people smuggling and human trafficking.

Essentially the centre contributes to the task of understanding by collecting and sharing information, but also providing a space for the joint interpretation of what happens at sea. This involves an underlying data infrastructure with systems enabling event and incident tracking in the maritime environment with intelligence analysis capabilities.

The technologies behind Maritime Security Centres, are typically brought together and integrated by defence and security sector lead systems integrators. Example technology systems and integrator providers include: Airbus, BAE Systems, L3 Harris, Raytheon, Thales, among others. Intelligence workflows may be provided by specialist advanced analytics companies, typically coming from an intelligence background, examples being: Geollect (Geospatial Intelligence and Analysis), Windward, among others.

In Philippines, Raytheon has provided 2 phases of development of the National Coast Watch Center, including systems, technologies and training. These are detailed further by dedicated case study.

Vessel Traffic Services (VTS)

IMO[103] define Vessel Traffic Services (VTS) as

> *“shore-side systems which range from the provision of simple information messages to ships, such as position of other traffic or meteorological hazard warnings, to extensive management of traffic within a port or waterway.”*

Generally, ships entering a VTS area report to the authorities, usually by radio, and may be tracked by the VTS control centre.

Ships must keep watch on a specific frequency for navigational or other warnings, while they may be contacted directly by the VTS operator if there is risk of an incident or, in areas where traffic flow is regulated, to be given advice on when to proceed.

> *“SOLAS Chapter V (Safety of Navigation) states that governments may establish VTS when, in their opinion, the volume of traffic or the degree of risk justifies such services.”*

There are many VTS instances globally. Example implementations providing monitoring and management of vessel traffic for some of the business maritime corridors and ports, include: Straits of Dover / Dover Port, Malacca Straits, Singapore Straits, Port of Hamburg, Port of Rotterdam. Example VTS technology providers include: Airbus, Japan Radio Company (JRC), Kongsberg Gruppen ASA, Leonardo, SAAB, among others.

VTS implementations involve a range of key technologies, typically including: radar and radar tracking systems, VHF radio communication system, transmission, and communication links, AIS, CCTV systems, VTS data systems, and meteorological sensors. Current technology innovations for VTS include:

- Ensuring availability of real-time maritime information.
- Enabling interoperability for data and systems interfaces.
- Maintaining pace with radar innovations for future enhancements.
- Predictive support to inform navigation decisions.
- Innovation support to support analysis of vessel routes, traffic hotspot prediction, and the detection of potential collision situations.

Below we case study a recent project to enhance the VTS in Malacca and Singapore straits in Indonesia, delivered to Indonesian Government. This was implemented by a Japanese grant aid project.

103 IMO Vessel Traffic Services http://www.imo.org/en/OurWork/Safety/Navigation/Pages/VesselTrafficServices.aspx

Technology in Action: Fisheries Use Cases

IMEMS project protects, conserves and manages the Philippines' marine resource [104]

The DA-BFAR Integrated Marine Environment Monitoring System (IMEMS) Phase II systems are currently being implemented in Philippine by DA-BFAR supported by SRT Marine (UK). This programme will provide a National VMS Systems for the Philippines. IMEMS Phase II has 3 key objectives:

1. Protect, conserve, and manage the country's marine and aquatic resources in a sustainable manner.
2. Intensify the implementation of BFARs monitoring, control, and surveillance (MCS) to combat Illegal, Unreported and Unregulated Fishing (IUU Fishing).
3. Strengthen the existing Vessel Monitoring System of Phase 1 to create an integrated and operational fisheries and marine environment monitoring centre to comply with the implementation of various conservation and management measures (CMMs) in the Coastal States and Regional Fisheries Management Organizations (RFMOs).

IMEMS Phase II will provide an architecture of national (No. 1) and a series of regional (No. 15) fisheries monitoring centres across Philippines, underpinned by a national marine data centre and the following systems capabilities:

- Vessel Monitoring System Transceivers - 5,000 VMS Transceivers for Commercial Fishing Vessels
- Port and Coastal Monitoring System – 15 Type 1 Sensor Stations and 117 Type 2 Sensor Stations to regional and local ports
- Electronic Reporting System - 5,000 Terminals for Commercial Fishing vessels to enable electronic catch reporting and 500 terminals for Fisheries ObserversSatellite Maritime Domain Awareness – 300 satellite radar images and a continuous feed of VMS and AIS data
- Meteorological Environmental and Production System – 20 sets of sensor system to provide real time monitoring of the sea environment
- National Marine Data Center (NMDC) – Central database and network control and monitoring system
- Fisheries Monitoring Centers (FMC) – 1 National Fisheries Monitoring Center and 15 Regional Fisheries Monitoring Centers
- Ocean Resource Information System – analysis of ocean environment and stock assessment modelling

Fishing vessels (Domestic flagged vessels operating inside the EEZ) will be equipped with transponders that will continuously transmit location and status over satellite communications channels. Fishing vessels within the range of the ports/coast stations will be monitored in real-time (every minute). Outside the range, satellites will relay vessel tracks to the FMC. All information streams into a central data centre which connects and supports multiple system operators to manage the fleet.

104 Philippines DA-BFAR Integrated Marine Environment Monitoring System (IMEMS) – PHASE II: Verumar Project Data

Technology in Action: Fisheries Use Cases

The Philippines' National Coast Watch Center brings a unified approach

The National Coast Watch Center was established under Executive Order 57 (s.2011) as the central inter-agency mechanism for a coordinated and coherent approach on maritime issues and maritime security operations toward enhancing governance in the country's maritime domain.

The purpose of the National Coast Watch Center (NCWC) is to implement and coordinate maritime security operations, and includes the following functions:

- Gather, consolidate, synthesize, and disseminate information relevant to maritime security.
- Develop and maintain effective communications and information systems to enhance inter-agency coordination in maritime security operations.
- Coordinate the conduct of maritime surveillance or response operations upon the request of a member agency or when an exigency arises.
- Plan, coordinate, monitor, evaluate, document and report on the conduct of maritime security operations.
- When so authorised by the Council, coordinate cross-border and multinational maritime security cooperation.
- Coordinate support for the prosecution of apprehended violators.
- Develop a common operating picture to enhance maritime situational awareness.
- Conduct periodic assessments on maritime security.
- When so authorised by the Council, and in coordination with the Department of Foreign Affairs, initiate cross-border and multinational maritime security cooperation.
- Perform such other functions as may be directed by the Council.
- Raytheon105 states that the 1st phase of work (Value: $US 19m): The NCWC is the hub of the Philippines' National Coast Watch System for maritime security. The system vastly improves the ability of the country's maritime forces to detect, prevent and deter threats and security risks across its territorial waters. The Raytheon team also provided communication and surveillance solutions for the islands of Palawan and Cebu with associated training and sustainment for the Filipino operators.

Raytheon[106] states that the 2nd phase of work (Value: $US25m): Raytheon will deliver sensing, command and control, and communications systems along with the training and sustainment services necessary to operationalize maritime border security capabilities. Specific work planned under the increment II contract includes:

- Installation of a common operating picture platform in the National Coast Watch Control (NCWC) and National Coast Watch Stations in two different Philippine provinces.
- Design, installation, and testing of electro/optical infrared cameras.
- Continued integration of command, control, and communications equipment and infrastructure.
- Construction of a training centre.
- Communications and surveillance upgrades to Philippine Coast Guard vessels.
- Sustainment, training, and transition of capabilities to the government of the Philippines.

Under this latest contract award, Raytheon will enable the government of the Philippines to stand up a fully-operational security capability that detects, deters, and prevents threats along its coastal borders.

105 Raytheon; https://raytheon.mediaroom.com/2015-05-18-Raytheon-designed-Coastal-Watch-Center-opens-in-Philippines
106 Raytheon; https://raytheon.mediaroom.com/2015-06-02-Raytheon-awarded-second-phase-of-DTRA-Philippines-maritime-border-security-contract

Technology in Action: Fisheries Use Cases

Vessel Traffic Systems in Southeast Asia strengthen inter-continental links[107]

The Project for Enhancement of Vessel Traffic System in Malacca and Singapore straits in Indonesia (2017) - The Republic of Indonesia.

Directorate General of Sea Transportation (DGST) – a Japanese Grant Aid Project delivered by Japan Radio Company (JRC).

The Straits of Malacca and Singapore bordered by Malaysia, Indonesia and Singapore, measure about 250 nautical miles and are one of the most important strategic maritime passages serving as a vital inter-continental and intra-Asia link. More than 90,000 ships per annum pass through the Strait, making it one of the busiest maritime stretches of water globally.

Prior to the VTS implementation, there was no suitable sea surveillance system in operation to monitor the approaches and access channels of a port in areas having high traffic density, movements of noxious or dangerous cargos, navigational difficulties, narrow channels, or environmental sensitivity.

JRC provide the VTS implementation, including radar system with GPS, radar tracking system, multi-function console, VHF radio communication system, transmission and communication links, AIS, CCTV camera system, VTS data system and web server, recording and playback unit, meteorological sensor, power generator, and air conditioner. The project was successfully handed over to the Indonesian government in June 2017.

There is a main VTS Centre is located at Batu Ampar with a sub centre at Dumai.

107 The Project for Enhancement of Vessel Traffic System in Malacca and Singapore straits in Indonesia (2017) - The Republic of Indonesia Directorate General of Sea Transportation (DGST) – a Japanese Grant Aid Project delivered by Japan Radio Company (JRC); https://www.jrc.co.jp/eng/casestudy/case0005/index.html#anc01

13 CONCLUSION

This white paper identifies a wealth of emerging technology that together represent a compelling opportunity for exploitation for fisheries management and MCS, and by both Public and Private sectors entities. We have focussed on nine technology groups, namely:

- Space-Based Earth Observation and Meteorology
- Unmanned Aerial Systems (UAS) and High Altitude Pseudo Satellites (HAPS)
- Marine Autonomous Systems (MAS)
- Position, Navigation and Time (PNT)
- Sensors and Internet of Things (IoT)
- Data Infrastructure
- Big Data
- Communications Technology and Cybersecurity
- Maritime Domain Awareness Systems

For each technology group we have provided a detailed explanation of the technologies and their key features; and explained how they are beginning to be applied to have a positive impact within fisheries management. Example fisheries management use cases are identified, and international case studies shared.

An overview or horizon scanning graphic is presented in section 3 'Emerging technologies overview: Key features and areas of potential disruption'. Whilst the paper identifies more, this graphic usefully identifies some one hundred and fifty emerging technology features, of which in the order of thirty features are potentially disruptive or have significant positive fisheries management impact going forward.

> ***"Fisheries management and MCS benefit from the experience of others' EmTech investments and actions"***

It became clear throughout the research, that the fisheries management sector can learn and benefit from first mover rollout of emerging technologies elsewhere. A number of the technologies, for example Maritime Autonomous Systems (USV, UUV) are at a high level of maturity, already proven or already being exploited extensively in wider maritime domain areas such as oil and gas, underwater infrastructure engineering and exploration. Similarly, other technologies, for example IoT, are proven in land, urban, and infrastructure asset management settings; and these lend themselves to rapid exploitation in the context of static fisheries, i.e. for use in ports, aquaculture, etc. Fisheries management is in a good position to look towards wider maritime domains in particular, and we include here the Navy, as well as energy, infrastructure engineering and maritime transport – looking to where others have taken a first move, learn from their experience and then progress informed, with a tailored exploitation for fisheries applications.

> ***"Some EmTech are Transversal and Others are Fisheries Application Specialised"***

Some of the emerging technologies considered are transversal or cross-cutting, notably 'data infrastructure' and 'communications and cybersecurity'. These are also foundational technologies and are typically addressed at an organisation level, underpinning a diverse range of business applications and operational activities. For instance, communication networks and connectivity will be centrally managed, e.g. through an ICT Division, and/or provided by a partner government agency. Communications technologies are critical for the successful exploitation of a number of other emerging technologies e.g. network IoT and associated Big Data analysis among others. The wider rollout of fibre wide area networks (WAN) in land-based infrastructure locations (e.g. ports and processing plants), mobile 4G and 5G as well as the emergence of 5G by satellite communications means that within a few years we will have global coverage broadband at a more affordable price. This would provide a good step forward toward the 'always on' goal, with the resulting benefits this would bring. Cybersecurity policy cascades from national to local level and into both public and private sector organisations. We see emerging cybersecurity technologies, such as wider use of encryption and the emergence of new counter cyber threat solutions coming through, e.g. counter GNSS jamming, anti-spoofing, drone monitoring and counter drone systems, among others.

Other emerging technology groups contain fisheries specific application use and benefit. For example, the use of Unmanned Under Water (UUV) and Remotely Operated Vehicles (ROV) to assess and repair aquaculture nets, or a network of sensors that ubiquitously monitor, measure and report water chemistry and other variables across all phases of an aquaculture operation.

For MCS, we are seeing a wealth of technology innovations coming through. Many Nations are expanding radar networks to ensure complete coastal coverage and expanding fishing vessel coverage through transceiver equipment investment. Some nations are rolling out Drone / Unmanned Aerial System (UAS) capabilities and some early adoption work is underway for the use of Unmanned Surface Vessels (USV) and floating buoy-mounted specialist imaging sensors for MCS support. Further, through a blend of Satellite and Terrestrial AIS we now have global monitoring capabilities with the ability to track and model the movement of all vessels equipped with appropriate transceivers. Whilst a huge benefit for safety at sea, this also comes with an unintended consequence with the emergence of the use of AIS for the monitoring of fishing vessels and supporting counter IUU fishing authority action. We are seeing this being progressed through implementation projects like the Verumar project in the Philippines, where AIS data is being analysed with VIIRS, Synthetic Aperture Radar and Electro-Optical satellite imagery; AI and machine learning is used to identify vessel types, dark vessels, detect fishing activity and analysis of at-sea behaviours to collate capture and report instances of potential IUU fishing within the EEZ, municipal waters and other protected areas.

As we look forward, we can see the emergence of new space sensors and constellation options. These will provide additional sources of data and MCS actionable intelligence, and further through High Altitude Pseudo Satellites (HAPS), we see a potential game-changing capability with the proven ability to provide persistent monitoring at imagery resolutions below 10cm, with real-time imagery streaming over a wide area of interest and for months at a time.

"Emerging technology adoption and implementation does come with challenges"

Throughout the research it became evident there are challenges associated with new technology adoption and rollout across the fisheries management domain. Example challenges include:

- Pace of Adoption: whilst open to innovation and new technologies, the fisheries management domain tends to be slower in adoption compared to other maritime domains (Navy, Energy, Infrastructure Engineering and Maritime Transport).
- Private sector (Large scale Commercial Fishers) tends to be faster in adoption compared to lower-scale commercial fishers or public sector, especially where there are well-defined health and safety, welfare, or operational efficiency benefits and outcomes.
- Commercial fishers (private sector) have a willingness to invest and will typically start their investment with relatively small amounts to test concepts and feasibility. As this moves forward into scale-up, commercial entities appear to have a preference to develop their own technologies to retain their competitive advantage.
- Small-scale fishers can mainly only adopt new technologies where they are supported through public sector action, typically requiring outreach and community-based educational support, bolstering regulatory efforts with targeted financial assistance and support.
- We identified a good number of small-scale feasibility type projects, but it was difficult and not common to source projects that were designed to focus on the scale-up and full rollout of new technologies. This appears to be a gap in the public sector where unless build-out

is undertaken by in-house teams or through donor grant funding enablement, limited progress is made to scale up new technology rollout.

- Technology is viewed by some parts of the fishing community as being punitive – providing overwatch and intrusive monitoring, which can foster resistance and potentially be a barrier to adoption. The lesson here is to present technology as a cooperation, bringing more opportunity for all partners, with technology benefits framed more positively as a joint, industry-orientated outcome.
- There may be a fear factor over how much change an emerging or new technology will bring For example, will the technology rollout lead to a loss of people, changing current ways of working potentially leading to loss of jobs, redeployment of existing roles, etc.
- Prerequisite foundations may need to be in place for new technology implementation and rollout. This may be wider technology-related, e.g. the availability of ICT networks and connectivity or availability of cloud; or data-related, e.g. the ability to link available operational data digitally; or people-related, e.g. where a range of foundational skills as well as specialist expertise may be needed to build out from.
- Technology enablement also requires capacity building action in tandem, providing know how and skills transfer, and ensuring the ability for users to manage and operate technology solutions beyond an implementation phase and for the long term.

> ***"With so much emerging technology, where do we start and how do we move forward towards implementing and exploiting these technologies?"***

In this research we have identified some key steps to consider following:

<u>Build awareness and socialise on emerging technology benefits to the user</u> - This white paper is an example of collateral supporting the building of awareness of emerging technology in the fisheries management domain. Further industrial organisations and initiatives such as, Seafood and Fisheries Emerging Technology (SAFET) provide excellent outreach channels and support effective awareness-building directly to the fisheries management community.

<u>Seek a Technology Solution provider / User Community Partnership Approach to investigate and trial new technology approaches</u> - Internal to Fisheries authorities, specialist groups such as Scientific Advisory Groups will convene to address thematic action domains such as fisheries management areas. Such groups provide effective channels to investigate technologies and how they can be applied directly and in partnership with users and at a pace users are comfortable with.

<u>Feasibility Projects and small-scale pre-operational trials</u> – Generally, feasibility projects and small-scale technology trials can be funded through a range of public sector research and development, and innovation funding sources. These typically require match funding by technology solution providers. Ideally feasibility projects should begin to look at sustainability, capturing the business value and defining a set of technical requirements, timeline and budget to implement, roll out and operationalise a technology solution, with a goal to enable a smooth transition into future implementation should partners wish to proceed thereafter.

<u>Implementation Projects</u> – These may be funded by authorities through their internal business process or draw down grant funding support. The Verumar project is a good example of the latter and has been enabled through the UK Space Agency's International Partnership Programme (IPP).

EXPLAINER:

The UK Space Agency's International Partnership Programme (IPP) is a five-year, £30 million per year initiative designed to utilise the UK space sector's research and innovation strengths to deliver measurable and sustainable economic, societal and/or environmental benefits to developing countries.

IPP is funded from the Department for Business, Energy and Industrial Strategy's (BEIS) Global Challenges Research Fund (GCRF). This £1.5 billion Official Development Assistance (ODA) fund supports cutting-edge research and innovation on global issues affecting developing countries.

Generally speaking, the IPP delivery mechanism supports technology solutions implementation by:

- Proposal requirements with associated expert review, ensuring a conceptual fit to purpose and that the solution will deliver defined user value. Further a partnership approach between technology solution provider and user is adopted and evidenced at the proposal stage.
- In delivery, there is a need to engage with users to tailor a solution to local requirements, ultimately to demonstrate a solution's reliability, provide capacity building, ensuring users are confident in their use of the technology, and looking to the long-term ensuring cost-effectiveness in service.
- Rigorous monitoring and evaluation review throughout and beyond the project provide a formal gate process through which progress and impact is captured and reviewed, supporting project flexibility, and enabling change in support of project success.
- Finally, the IPP mechanism ensures that long-term sustainability is socialised across the project partnership, enabling continuity in service and that project benefits continue long after the grant-funded period draws to a close.

The objective is to implement a technology solution that is tailored to user requirements, delivers tangible operational benefit, with capacity building, training, know-how and skills transfer so that the solution can become self-sustaining and deliver legacy value long after the grant funding period has drawn to a close.

"Next steps – how can you assist us going forward?"

The Verumar consortium has developed a rich understanding of the adoption – real and potential of emerging technologies in the fisheries management domain.

NLAI, and its Verumar partners OceanMind, Poseidon and MDA, collectively draw on many years' blue economy innovation solution experience including technology advisory and solution delivery projects for public and private sector customers in the UK, Europe, South Americas, and SE Asia. We believe passionately in the potential of modern technology to support the blue economy, including fisheries management, and are very keen to promote sustainable ocean activity through:

- Sharing our knowledge and awareness on technologies emerging in the short, medium, and long term.
- Bringing strategic and operational level practical experience to business case and project development and delivery.
- Extensive experience of developing business cases, funding and investment propositions for grant donor bodies, innovation and research support, and investors.
- Leveraging a diverse network of leading international technology OEMs to address specialist fisheries management requirements.
- Prime contracting innovation technology solution delivery projects, ensuring robust systems integration, implementation and rollout, operationalisation, capacity building and training.

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International Partnership Programme (IPP), a UK Government initiative led by the UK Space Agency which is part of the Department for Business, Energy and Industrial Strategy's Global Challenges Research Fund

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Glossary

(4IR or Industry 4.0) Fourth Industrial Revolution

(AI) Artificial Intelligence

(AIS) Automatic Identification Systems

(AIS-SART) (AIS-MOB) AIS-Search and Rescue Transponder and AIS Man Overboard

(API) Application Programming Interface

(ARD) Analysis Ready Data

(AUVSI) Association for Unmanned Vehicle Systems International

(AWS) Amazon Web Service

(BRLOS) Beyond Radio Line of Sight

(CMMs) Conservation and Management Measures

(COTS) Commercial off-the-shelf

(CSTDMA) Carrier Sense Time-Division Multiple Access

(DA-BFAR) Philippines' Bureau of Fisheries and Aquatic Resources

(DG MARE) European Commission Directorate-General for Maritime Affairs and Fisheries

(DGST) Directorate General of Sea Transportation

(DOST-ASTI) Philippine Department of Science and Technology's Advanced Science and Technology Institute

(EarthCARE/CPR) Earth Cloud, Aerosol and Radiation Explorer / Cloud Profiling Radar

(eCDT) Electronic Catch Documentation and Traceability

(eEE) exactEarth Europe Limited

(EEZ) Exclusive Economic Zone

(EFCA) European Fisheries Control Agency

(ELT) Emergency Locator Transmitter

(EMODnet) European Marine Observation and Data Network

(EMSA) European Maritime Safety Agency

(EO) Earth Observation

(EPIRB) Emergency Position Indicating Radio Beacon

(ESA) European Space Agency

(EU) European Union

(EUMETSAT) European Organisation for the Exploitation of Meteorological Satellites

(FAO) Food and Agriculture Organization

(FMC) Fisheries Monitoring Centers

(GBAS) Ground-Based Augmentation

(GIS) Geographic Information System

(GNSS) Global Navigation Satellite System

(GOES) Geostationary Operational Environmental Satellites

(GOSAT-GW) Global Observing Satellite for Greenhouse gases and Water cycle

(GPS) Global Positioning System

(HAPS) High Altitude Pseudo Satellites

(IBM GRAF) IBM Global High-Resolution Atmospheric Forecasting System

(ICT) Information and Communications Technology

(IMEMS) Integrated Marine Environment Monitoring System

(IMINT) Imagery Intelligence

(IMO) International Maritime Organisation

(IoT) Internet of Things

(IPP) International Partnership Programme, a UK Government initiative led by the UK Space Agency which is part of the Department for Business, Energy and Industrial Strategy's Global Challenges Research Fund

(IR) Infrared

(ISE) Ion-Selective Electrode

(ISR) Intelligence, Surveillance and Reconnaissance

(IUU Fishing) Illegal, Unreported and Unregulated Fishing

(JAXA) Japan Aerospace Exploration Agency

(JRC) Japan Radio Company

(LEO) Low Earth Orbit

(LiDAR) Light Detection and Ranging

(LRIT) Long-Range Identification and Tracking

(M2M) Machine to Machine

(MARD) Vietnam's Ministry of Agriculture and Rural Development

(Marine SDI) Marine Spatial Data Infrastructure

(MCS) Monitoring, Control and Surveillance

(MEOSAR) Medium Earth Orbiting Satellites

(ML) Machine Learning

(MOAV) Multi Operation Aerial Vehicle

(MODIS) Moderate Resolution Imaging Spectroradiometer

(MOU) / Agreement (MOA) Memoranda of Understanding

(MSI) MultiSpectral Instrument

(MSS) Mobile satellite service

(NAFO) Northwest Atlantic Fisheries Organization

(NASA) National Aeronautics and Space Administration

(NCWC) National Coast Watch Center

(NGO) Non-Governmental Organisation

(NMDC) National Marine Data Center

(NMIC) National Maritime Information Centre

(NOAA) National Oceanic and Atmospheric Administration

(OEMs) Original Equipment Manufacturer

(Optical) Electro-optical

(OVI) Ocean Voyages Institute

(PLB) Personal Locator Beacon

(PNT) Position, Navigation and Time

(PPP) Precise Point Positioning

(PSMA) Port State Measure Agreement

(QR) Quick Response (QR) Code

(RFID) Radio-frequency identification

(RFMOs) Regional Fisheries Management Organizations

(RGB) Red/Green/Blue

(RLOS) Radio Line of Sight

(RPA) Robotic Process Automation

(RPAS) Remotely Piloted Aircraft Systems

(RTAF) Royal Thai Air Force

(RTK) Real Time Kinematics

(RTN) Royal Thai Navy

(S-AIS) Satellite-based AIS

(SARSAT) Search and Rescue Satellite Aided Tracking

(SAR) Synthetic Aperture Radar

(SatComms) Satellite Communications

(SBAS) Satellite-Based Augmentation

(SDB) Satellite Derived Bathymetry

(SOLAS) Safety of Life at Sea

(SOTDMA) Self-Organized Time-Division Multiple Access

(SSTL) Surrey Satellite Technology Limited

(STANAG 4586) NATO Standardization Agreement No. 4586

(STUAS) Small Tactical UAS

(SUSTUNTECH) Sustainable Tuna Fisheries Through Advanced Earth Observation Tools

(T-AIS) Terrestrial AIS

(TDMA) or (FATDMA) Fixed Access Time-Division Multiple Access

(TDS) Total Dissolved Solids

(TTFF) Time To First Fix

(UAS) Unmanned Aerial Systems

(UAV) Unmanned Aerial Vehicles

(UN) United Nations

(USAID) United States Agency for International Development

(USRP) Universal Software Radio Peripheral

(USVs) Unmanned Surface Vehicles

(UUV) / (AUV) are Unmanned Underwater Vehicles interchangeable with Autonomous Underwater Vehicle

(UUVs) Unmanned Underwater Vehicles

(UUV) we also include (ROV) Remotely Operated Underwater Vehicles

(UV) Ultraviolet

(VHF) Very High Frequency

(VIIRS) Visible Infrared Imaging Radiometer Suite

(VLOS) Visual Line of Sight

(VMS) Vessel Monitoring Systems

(VMS / VTS) Vessel Management and Vessel Traffic Management Services

(VSAT) Very Small Aperture Terminal

(VTS) Vessel Traffic Services

(WARTK) Wide Area RTK

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