Autonomous Observing of Inshore & Coastal Waters

Opportunities in Research & Statutory Monitoring

Workshop Findings & Roadmap

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In Partnership With

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Disclaimer

1. Foreword

"On behalf of the NCCA, it was a pleasure to welcome participants from across UK academia, industry, government and our international experts to Plymouth for this FMRI Workshop on Autonomous Observing of Inshore and Coastal Waters.

This workshop was an important step in establishing a Coastal Autonomy Community of Practice, with remarkable breadth of expertise from across marine science and technology, alongside representatives from government, agencies, industry, regulators, and funders. This report reflects two days of exploring the transformative potential of emerging autonomous technologies to address the pressing challenges facing our coastal seas, challenges that span ecological, economic, and societal domains.

The need to better measure, monitor and understand coastal waters is particularly relevant and challenging. Coastal waters are among the most dynamic and complex marine environments. They host stronger currents, faster changes, richer biodiversity, and higher productivity than the deep ocean. They are also the most heavily influenced by human activity, from shipping and fishing to energy extraction, national security, and the impacts of agriculture, urbanisation, and pollution. These pressures demand more than scientific insight; they require robust, actionable evidence to guide policy, regulation, management, and investment.

The UK is best placed to address such challenges. Offering a world-leading marine science community, cutting-edge technologies, and deep cultural ties to the sea, we are uniquely positioned to lead in the development of autonomous systems for coastal monitoring. This workshop was a critical step in building a roadmap for future research and statutory monitoring, grounded in the best available knowledge, skills, and innovation.

Most importantly, this meeting fostered new collaborations, connections that will be vital as we navigate a changing research and funding landscape. With increasing emphasis on efficiency, partnership, and environmental responsibility, autonomy offers a compelling pathway to net-zero solutions. This FMRI workshop has been essential in identifying and addressing current gaps and aspirations in technology, regulation, and skills.

As you read through this report, I encourage you to reflect on the ideas, discussions, and partnerships that emerged during the workshop. Let them inspire continued collaboration and help shape the future of autonomous coastal observation for the benefit of our communities, our environment, and our shared marine future."

Prof. Matthew Palmer, Co-Director National Centre for Coastal Autonomy

2. Introduction

The purpose of this document is to report the outcomes of the *Autonomous Observing of Inshore and Coastal Waters: Opportunities in Research & Statutory Monitoring* workshop (25^{th}-26^{th} June 2025) convened by the FMRI programme in partnership with: the National Centre for Coastal Autonomy (NCCA), Department for Environment, Food & Rural Affairs (Defra), UKRI Natural Environment Research Council (NERC), National Oceanography Centre (NOC), National Physical Laboratory (NPL) and Scottish Government Marine Directorate.

Combining keynote presentations from research, government and industry leaders, breakout working groups and networking opportunities, the workshop brought together a diverse community of 64 stakeholders from across science users/operators, industry and other Government organisations.

The outcomes are mapped to a high-level action plan or 'roadmap' for the implementation of coastal autonomy in research and statutory monitoring applications.

Workshop Objectives

This workshop sought to provide understanding of:

- The aspirations and opportunities to use coastal[1] autonomy for scientific research and regulatory monitoring and how those sectors can mutually benefit from current capacity and future investment and developments.
- How to overcome the challenges that prevent adoption and upscaling of autonomy in coastal and inshore waters: including community acceptance, skills and infrastructure capacity, regulation and assurance.
- The opportunities to exploit overlaps in requirements, capabilities and funding for deep-water and coastal applications: including shared benefits from similar technical requirements or specifications, shared physical and digital infrastructure, skills bases and training opportunities.
- Common interests and opportunities for cross-sector investment, funding and development of autonomous systems and networks.
- How cross-sector and multi-discipline requirements and aspirations can be best fostered to help shape and strengthen the case for long-term investment in marine and maritime autonomous infrastructure.

3. What are the Requirements for Coastal Autonomy?

Inshore, coastal and shelf sea waters present a multitude of risks, requirements and considerations that are unique to their shallower depths, often harsh conditions, proximity to land and other maritime infrastructure & people, and their potential for conflicted use of space

[1] This report defines **coastal** as covering the Exclusive Economic Zone (EEZ) while noting that technical challenges are predominantly in the inshore operating environment.

from transport, marine protected areas, militarised and secure areas and commercial activity. Nations also face greater scrutiny of these waters, and are typically bound under law to protect and sustainably manage coastal regions, as legislated in the UK Marine Strategy. For autonomous systems to be effective in these regions therefore requires specific consideration of this broad range of challenges and legal requirements, alongside the priority observations and monitoring requirements that stakeholders require from observing networks. Workshop attendees proposed the following opportunities, challenges and next steps for the following areas.

3.1 Environmental Monitoring

Environmental monitoring of marine physical, chemical, and biogeochemical states of coastal waters sits at the core of UK marine research and monitoring activity and provides an essential evidence base in supporting understanding of systems, improving future prediction of ocean health, changes and potential risks, and guiding sustainable management of our marine resources.

- **Opportunities for autonomy:** Improved spatial and temporal coverage; reduced cost; improved integration and connection of monitoring networks; improved coverage during hazardous conditions, increased opportunities for citizen science.
- **Challenges:** Misaligned investment; gaps in assurance and community trust; slow infrastructure uptake; regulatory limitations; data embargos; skills capacity and retention.
- **Next Steps:** Centralised data repository to improve standardisation, data access and distribution. Improve collaboration across organizations. Increase the number of useful autonomy use cases to increase confidence.

3.2 Species Monitoring

Monitoring of species abundance and distribution is essential to ensure that biodiversity is maintained that species populations and health remain within safe biological limits and to understand the impact of human activities and natural changes on ecologically and commercially important stocks. It includes various methods to assess and track the health and biodiversity of marine life, including fish, mammals, birds and plankton.

- **Requirements:** Reliability; Delivery of data & meta data within a time frame that meets scientists' requirements; often high-resolution (time and/or space) sampling; long-term monitoring at seasonally important periods; strategic planning with legislators; Data collected from sea organisms needs to meet scientists' requirements whilst also considering data telemetry constraints.
- **Opportunities for autonomy:** Cost efficiencies; enhanced spatial and/or temporal resolution; longer sustained monitoring; greater abilities for big data (inc. image) analysis; improved collaboration with legislators; improved coverage during hazardous conditions.
- **Challenges:** Big data processing; lack of standardisation; skills and training; limited operational or sustained funding; biofouling on long deployments; data sharing limitations; regulatory barriers.

- **Next Steps:** Develop better protocols; develop and formalise standard operating (SOP) procedures; foster agency/industry exchanges for staff and studentships; establish technology correlation projects.

3.3 Habitat Monitoring

Habitat monitoring is essential for assessments of Good Environmental Status (GES), which is at the core of the UK marine Strategy. It provides data on the structure and function of marine ecosystems and is required to enable identification of trends and to assess the impact and effectiveness of management interventions and marine policy, contributing to UK commitments and obligations under OSPAR and the Convention on Biological Diversity. It involves monitoring the integrity of a range of marine habitats, including seafloor, pelagic, inshore and offshore environments.

- **Requirements:** Geolocatable benthic mapping; acoustic sensors; biodiversity metrics; tractable methodologies that can adapted to future offshore renewable energy monitoring.

- **Opportunities for autonomy:** Wider spatial coverage; ecosystem-based monitoring; non-invasive seabed monitoring.

- **Challenges:** Standardisation of data across technologies; data sharing; regulatory compliance; commercial data sensitivities; data management costs; dependency on physical sampling collection; automated piloting frameworks for driving autonomous technology.

- **Next Steps:** Create a UK directory of marine observation stations to increase awareness of what work is being, where it is being done and by who to reduce duplication of effort and encourage collaboration. Gather peer-reviewed evidence to drive regulatory change.

3.4 Discovery Science

Discovery science is essential to advance fundamental understanding of marine systems and to address emerging challenges that cannot be solved by applied research alone. It shares motivations with statutory monitoring to understand complex natural processes, and better predict future change and risk, but it also seeks to drive innovation and discovery of the unknown, and plays an important connection to broader, including international partnerships and thinking.

- **Requirements**: Trustworthy and robust sensors and platforms that match or improve upon traditional, internationally accepted methodologies.

- **Opportunities for autonomy:** Flexible opportunistic research; improved safety over human operation; multi-disciplinary platforms; improved anomaly detection.

- **Challenges:** Definition of ‘Discovery Science’ needs some clarification. Hardware trustworthiness; modelling uncertainties; differing interdisciplinary requirements. Lack of available recognised standards. Cost of adoption of new technologies and methods.

- **Next Steps:** Enhance onboard processing of data; improve reliability; reduce adoption costs; standardise platforms, data formats and methods; foster greater cross sector and interdisciplinary collaboration; investigate opportunities from AI including use of semantic technologies to improve findability of data, reorganising data, Smart Observing (e.g. digital twins and adaptive sampling)

4. Developing the Roadmap

4.1 Technical and Enabling Requirements

To develop the roadmap for coastal autonomy, the delegates were asked to identify the technical and other enabling requirements, opportunities and challenges in different areas of capability, including: platforms (vehicles), command-control (C2) and navigation, digital and data, capacity building (upscaling, governance, regulation *etc*), and knowledge and skills.

Delegates were then asked for their opinion on how far we are away from the regular use of coastal autonomy for marine monitoring. A majority (57%) of respondents assessed this as being achieved in the 5-10 year timeframe and 100% of respondents thought it would be achieved within 10 years.

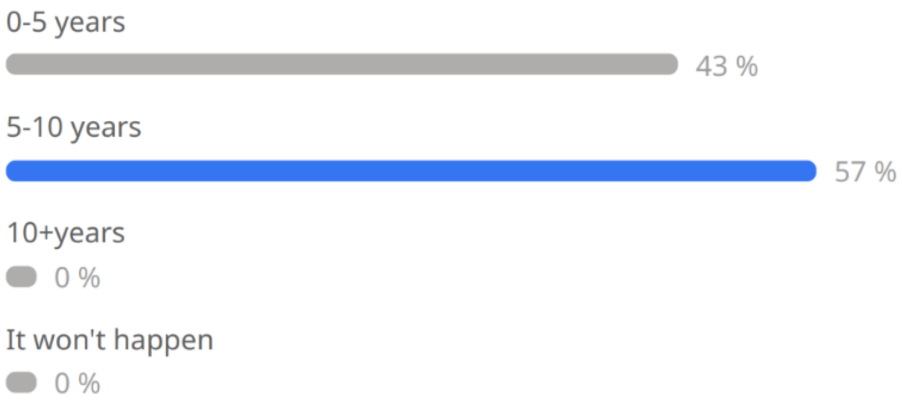

Figure 1. Responses to the question: How far are we away from the regular use of coastal autonomy for marine monitoring?

4.1.1 Platform Technologies

- **Requirements:** Fit-for-purpose designs for coastal operations, with a focus on user needs.
- **Opportunities:** Cross-industry applications, low-cost nearshore AUVs, carbon reduction drivers.
- **Challenges:** Biofouling, high traffic zones, maintenance issues, interoperability gaps, insurance, regulator testing restrictions.

  Engineering specific challenges include: Power draw of having multiple different sensors. Necessity for lower power-draw sensors/more battery packs/solar panels to increase deployment time. Development of low maintenance systems that don't require frequent visits and has low overhead costs is critical to adoption   Project design requires clear specification of where the vessel will be deployed.

- **Next Steps:** Develop global engagement, a series of technology appropriate testbeds, proportionate regulation (particularly around training), risk-managed deployment.

4.1.2 Command-Control and Navigation

- **Opportunities:** Mission rehearsal simulators, transparent decision-making, on-vehicle autonomy.
- **Challenges:** Situational awareness, complex topography and high currents, battery demand, hazardous areas, GPS denied navigation.
- **Next Steps:** Standardise decision-logging, improve reliability, enhance interoperability, improve situational awareness.

4.1.3 Digital and Data Technologies.

- **Requirements**: Capacity for future data volume increases (particularly from image data) including archiving, storage, access; make data/metadata/information FAIR
- **Opportunities:** AI-assisted analysis, quality control and interpretation; federated archives and tools (e.g. reference libraries, software packages); decentralised access; machine-to-machine systems.
- **Challenges:** Current large, fragmented data ecosystems; relatively slow FAIR adoption in marine autonomy; current lack of standards; security risks with autonomous systems.
- **Next Steps:** Fund secure federated archives; promote compliance QA/QC for data collected by autonomous platforms; establish best practices including adoption from other sectors.

4.1.4 Capacity Building

- **Requirements:** Functioning regulatory frameworks; greater assurance of marine autonomy; open accessible knowledge and tools; coordinated (cross-sectoral) growth.
- **Opportunities:** Defining key research and statutory questions to improve upon currently parallel monitoring practices; adoption of autonomous methods targeted at identified high-win areas; cross-sector collaboration; alignment of broad sector training programmes e.g. technical colleges, university, PhDs and industry initiatives.
- **Challenges:** Geographic skill distribution, lack of cross-sector/dual purpose funding opportunities; lack of transferability of technology and people to areas of greatest need; skills shortage in compliance/regulatory knowledge for operating in conflicted spaces. Need real world experience and oceanographic knowledge to work in highly dynamic shallow waters, i.e. balance of soft and hard skills.
- **Next Steps:** Localised trials, hands-on demonstrators, standardisation of operational procedures, establishing communities of practice to foster common incentives for investment, development and delivery.

4.1.5 Knowledge and Skills

- **Requirements:** Transferable people skills for adopting new and emerging technologies at low TRLs; regulatory and compliance knowledge; open, accessible knowledge of best practice and SOPs.
- **Opportunities:** internships, apprenticeships and secondments; broad sector relevant CPD programs; inclusive training providing accessible and engaging skills development to all career stages; promoting transferable skills opportunities and pathways (e.g. partnering defence sector and military).
- **Challenges:** Keeping pace with rapid technology evolution; retention of skills; creating viable career pathways e.g. limited pools of employers and roles; lack of sustained or stable funding opportunities.
- **Next Steps:** Gather cross-sector requires to inform training and CPD requirements; explore current relevant training programmes and recruitment pathways; publicise autonomy skills as an attractive career pathway for the next generation.

4.2 Realising the Benefits of Coastal Autonomy

The delegates were then asked to use free text responses to capture what they regarded as the most important inputs, activities and conditions required to realise the benefits of coastal autonomy.

The consolidated[2] responses were:

- Communicate with the community to understand requirements and co-design and develop the solutions.
- Be open and accepting of change.
- Have a wide, powerful and national governance structure; centralising management to federate capabilities at national level and facilitate interfacing with EU and global partners.
- Experience sharing.
- The realisation that we can't measure everything all at once, everywhere and all the time. We need to think of informative proxies and not like for like replacements to scale autonomy and start covering the many blind spots around our coastlines, which are not covered by ships and monitoring stations.
- Appropriate levels of funding for R&D as well as regular demonstrator deployments.
- Prescriptive database / data repositories with tagged 'FMRI' data streams for traceability of how the data are used.
- Improve sharing of where resources and skills are.
- Improve infrastructure for data sharing and access.

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[2] Equivalent points have been merged into single statements.

- Focus and prioritise investment on where it is most impactful, most needed, cost effective, received happily.
- Enhance collaboration, synergy and integration.
- Clearly identify and monitor benefits and impacts, including both fiscal and knowledge benefits.
- Increase equipment availability.
- Match assured delivery to identified requirements.
- Draw a visual roadmap pathway.
- Fit-for-purpose regulation.
- Develop new operating models.

4.3 Exploiting the Overlaps Between Inshore, Coastal and Deep-Water Autonomy

To maximise impact from the roadmap, it is important to understand the opportunities to exploit the overlaps between inshore, coastal and deep-water applications. Delegates were therefore asked to identify the overlaps, the opportunities these created and how they mapped to benefits.

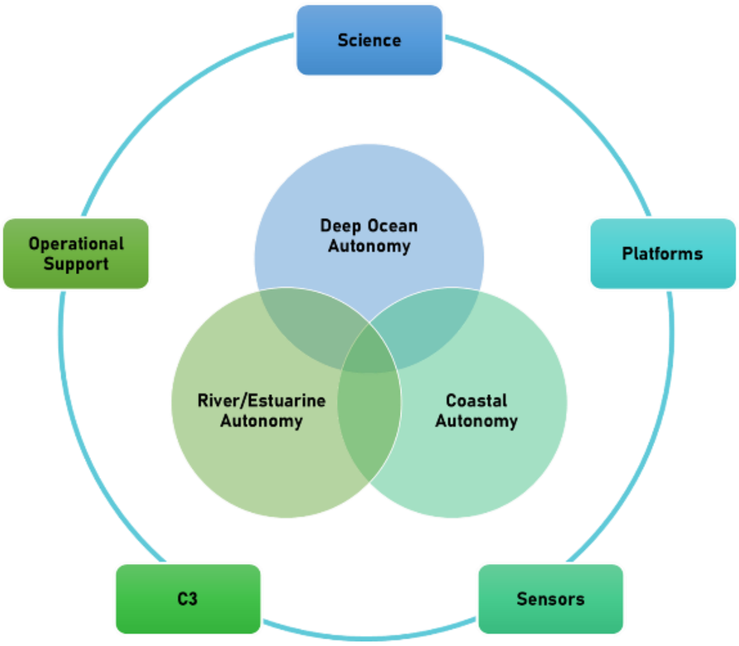


Figure 2. Representation of the overlaps between inshore (river/estuarine), coastal and deep-water autonomy enabled by the 5 themes of: science requirements, platforms (vehicles), sensors, command-control and comms (C3) and platform navigation, and operational support.

4.3.1 Identifying the Overlaps

- **Technologies & platforms**: Both use a range of autonomous underwater vehicles (AUVs) including gliders and propellor driven AUVs, uncrewed surface vessels (USVs), aerial drones, autonomous sampling moorings and buoys, Smart sensors and fixed stand-alone monitoring systems. There are also common utilities for consumables, software, digital infrastructure and people & skills, including engineering and support staff. Deployment and recovery may also at times, be able to utilise the same ships.

- **Parameters measured**: Common environmental variables include physical (temperature, salinity, currents, bathymetry), biogeochemical (nutrients, pollutants, plankton, microbial, dissolved oxygen) and biological (fish, mammals, birds, benthic species). The requirements and typical ranges of detection or identification between deep and shallow water however may be, at times, significant.
- **Skills & operations**: Overlaps exist in the need and provision of operational skills, planning and logistics, communications, and edge processing to reduce data transmission, although significant differences may exist in licenses, bandwidths and specific technologies.
- **Data architecture**: Overlaps exist in data management and archiving; data pipelines; FAIR principles; vocabularies, ontologies and citation practices; and challenges related to slow update processes of remote/autonomous systems.

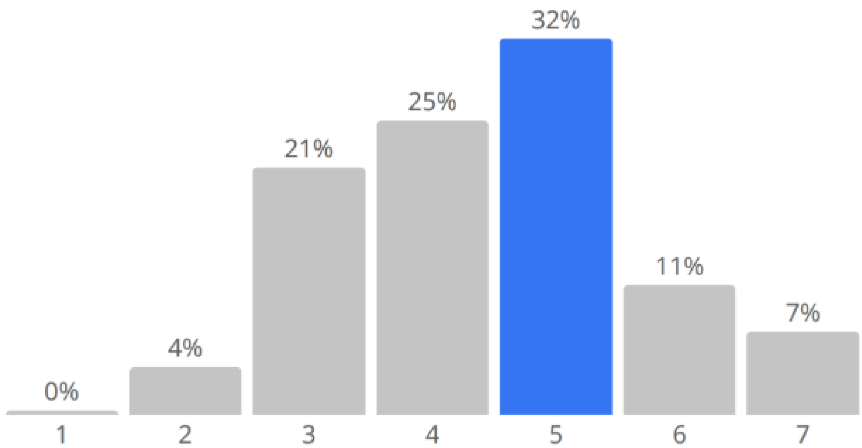


Figure 3. Responses to question: How much overlap do you think there is between coastal and deep-water autonomy for research applications. 1 = No overlap, 7 = Fully overlapping.

4.3.2 Identifying the Opportunities

- **Data & infrastructure integration**: Standardised management practices to better facilitate federated sharing of data; harmonised vessel tracking; shared monitoring schedules, which could benefit both statutory monitoring and research.
- **Cross-domain learning**: Rapid development and testing in coastal environments, which could be applied to deep-water contexts.
- **Resource optimisation**: Shared assets, mixed service models (government, academia, commercial), and cross-disciplinary standard setting.
- **Better decision-making**: Higher spatial and temporal resolution, improved habitat/species management, and faster response to events (e.g., HABs, oil spills).

- **Ecosystem modelling**: Use of coastal observations as proxies for deep-ocean processes to inform long-term predictions.

4.3.3 Identifying the Benefits

Benefits for society include:

- Cost and carbon savings from reduced ship use, dual and multi-purpose applications and shared infrastructure & skills.
- More responsive, accessible and comprehensive monitoring of national waters.
- Enhanced national security, supporting energy, defence and environmental sectors.
- Greater public policy impact through better-informed decisions and a culture of open collaboration.
- Economic growth through creation of new supply chains, customers and skills enhancement.

4.4. Other Considerations

Other considerations for a roadmap identified in the breakout discussions are summarised below.

- **Operating model**: Decide within a year on the preferred model, exploring options for integrating existing regionally located expertise and infrastructure into a national spoke-and-hub system for coastal marine autonomy, with quality control and shared deployment models, including but not limited to using commercial or 3rd party "platforms of opportunity".
- **Governance & funding**: Establish governance in the first 2–5 years to coordinate organisations and manage mixed funding streams, such as capital from FMRI, operational from NERC or Defra, commercial surveys and regulatory monitoring.
- **Skills & training**: Prevent skill loss by establishing best practice for continuous training, CPD, redundancy in technical capability, and shared access to trained personnel.
- **Infrastructure**: Link national technology, skills, and data handling. Improve biological data management, adopt FAIR standards, and tag FMRI-generated data for tracking impact.
- **Mandate & coordination**: Use the FMRI & NCCA mandates to promote and coordinate funding priorities, learning from international models and recommendations (e.g., Jerico, GROOMII). Create a visible and proactive point of access for UK for coastal marine research and monitoring collaboration using autonomous systems.
- Provide clear alignment with **net-zero 2040** goals and integrate autonomy into standard practice.

- Develop **common and transferable management architectures**, co-develop complementary technologies, and shift outcome indicators toward autonomy-enabled monitoring.
- Create and maintain a **community of practice**, expand internationally, supporting multi-sector growth.
- Streamline supply chains and balance sustained versus agile operations.
- Launch **flagship development areas**, build stepping-stone testbeds and demonstrators, and adopt a TRL accelerator framework to speed technology maturity and adoption.
- **Regulation**: Use the proposed programme to provide actionable evidence to support regulatory innovation.
- **Assurance:** Engagement with UK and international assurance activities to verify, validate and demonstrate performance against national and international expectations.

5. A Roadmap for Coastal Autonomy

This section sets out a possible high-level roadmap for the development of coastal autonomy for research and statutory monitoring applications.

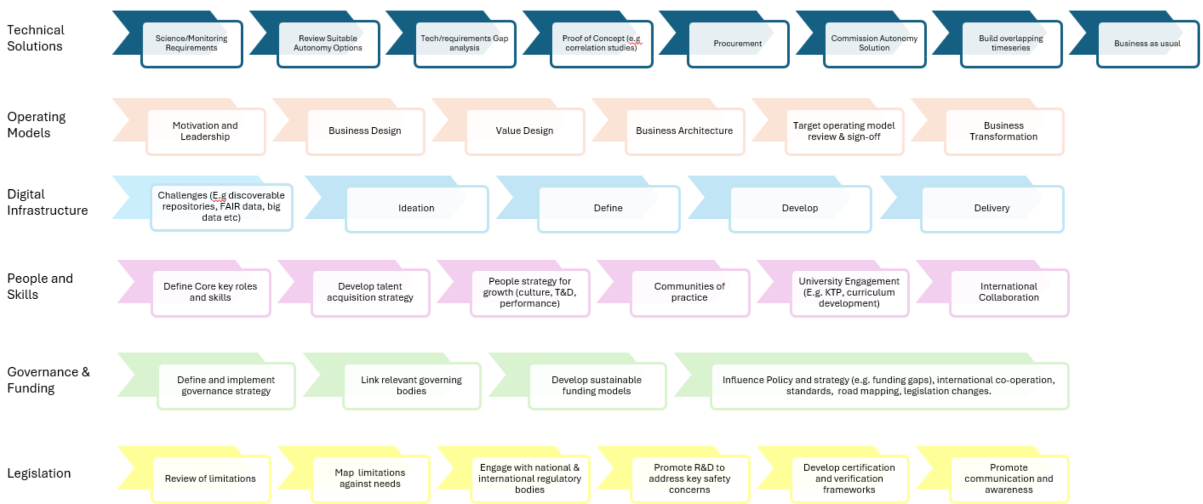


Figure 4. High-level coastal autonomy roadmap [see Appendix A].

1. Establish the foundation (0–1 year)

- Gather and record coastal research and monitoring requirements, recognising regional specific and shared (e.g. With deep ocean) components.
- Define the demonstrable beneficial impact expected from coastal autonomy and produce primary key performance indicators to measure success against.

- Decide on a preferred **operating and governance model**, such as using centralised coordination with regional "spokes" or more federated/decentralised structure.
- Map existing **capabilities, infrastructure, and skills**.
- Perform gap analysis task.
- Identify technical solutions and formulate change plans.
- Begin integrating autonomy into statutory monitoring and research plans.

2. Build governance and capability (1–5 years)

- Create **governance structures** linking FMRI, NCCA, government agencies, academia, and industry.
- Identify and gather evidence to support regulatory innovation.
- Secure **sustainable funding models** for governance, capital and operational costs.
- Establish **national data infrastructures** compliant with FAIR principles, standardised metadata, methods and repositories.
- Implement continuous **training and skills-sharing** to secure capacity and skills retention.

3. Integrate operations and assets (3–7 years)

- Harmonise **platform deployment** (government, academic, commercial).
- Use "platforms of opportunity" to maximise asset utilisation.
- Coordinate monitoring schedules and vessel movements for shared missions.
- Pilot **common architectures** for data, communications, and platform interoperability.

4. Mature and expand (5–10 years)

- Roll out **flagship capabilities** (e.g., automated eDNA, AI-driven route optimisation).
- Expand internationally through **communities of practice** and partnerships.
- Embed autonomy in **business-as-usual operations** for both research and statutory monitoring.
- Align with **net-zero targets** and use autonomy to reduce cost and carbon footprint.

5. Deliver long-term impact (10+ years)

- Maintain continuous **long-term observation series** for climate, ecosystem, and security needs.
- Enable **adaptive policy and management** based on higher-resolution, faster accessible data.
- Foster a **culture of open collaboration** and shared stewardship of marine environments.

6. Key Conclusions

Unlocking the full potential of coastal autonomy requires a collaborative, adaptive, and well-governed approach. At the heart of this effort is engagement and regular communication with communities and end-users, ensuring solutions are co-designed to meet real-world needs. This means assessing user requirements early, maintaining open dialogue, and sharing experiences across sectors to build trust and accelerate adoption.

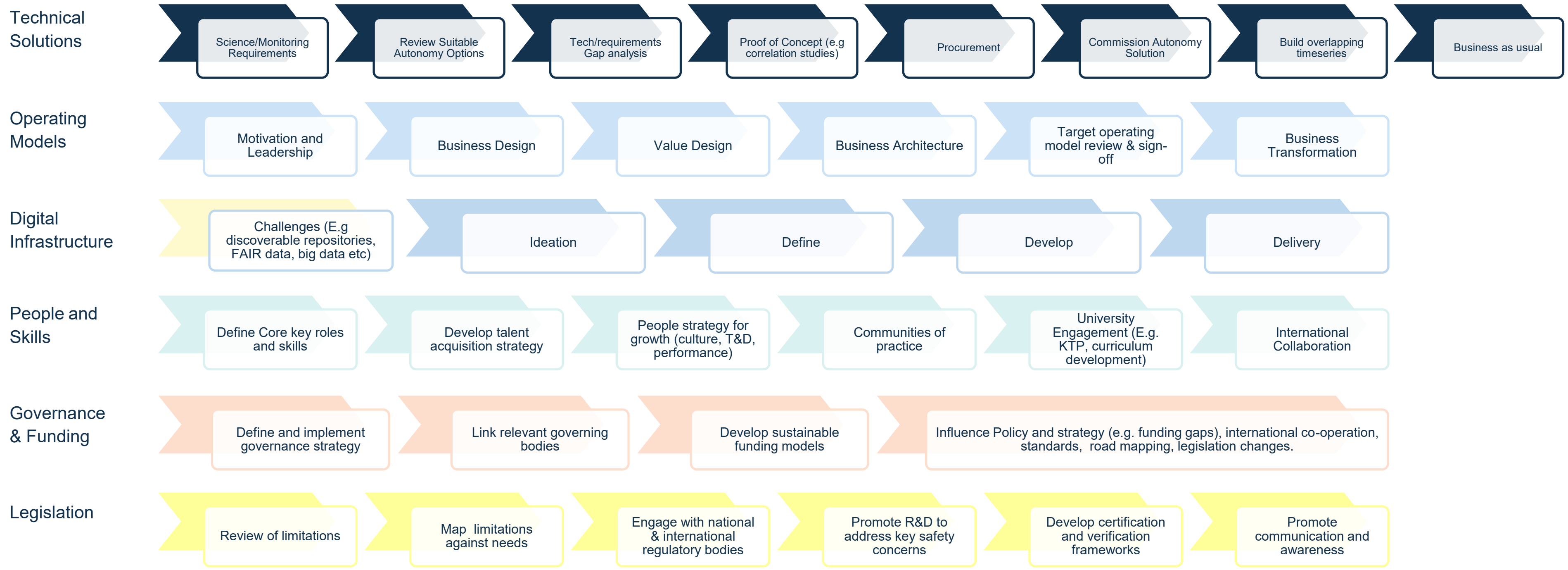
Success also depends on embracing change. Recognizing that autonomy will not replicate traditional monitoring like-for-like. Instead, we must prioritise where autonomy delivers the greatest impact, using informative proxies to fill critical data gaps and extend coverage beyond the reach of ships and fixed observational stations.

To scale effectively, we need robust governance and coordination, from national-level management and regulation to frameworks that enable integration with EU and other international and global initiatives. This includes clear operating models, effective benefits management, and visual roadmaps to guide progress.

Investment is essential: sustained funding for R&D, demonstrators, accessible equipment and infrastructure and regular deployments, will ensure continuity and innovation while helping the community adopt a ‘fail fast, scale what works’ mentality. Equally important is the digital infrastructure that supports autonomy. It must be prescriptive, have traceable repositories and establish data architectures that better facilitate data sharing and resource visibility.

Finally, achieving these goals requires collaboration and synergy across the coastal research and monitoring ecosystem, from researchers and industry to regulators and wider stakeholders. Working together, focusing on the most impactful opportunities that coastal autonomy presents, and clearly articulating the fiscal and knowledge-based benefits coastal autonomy can rapidly transform from a concept to reality.

Appendix A: High level autonomy reference roadmap



Appendix B: Engagement Statistics

64 delegates participated in Day 1 of the workshop with 33 delegates invited to be part of Day 2. These delegates represented 35 organisations covering 3 key groups: science users and operators (36 delegates, 14 organisations), industry (13 delegates, 10 organisations) and Government (24 delegates, 11 organisations).

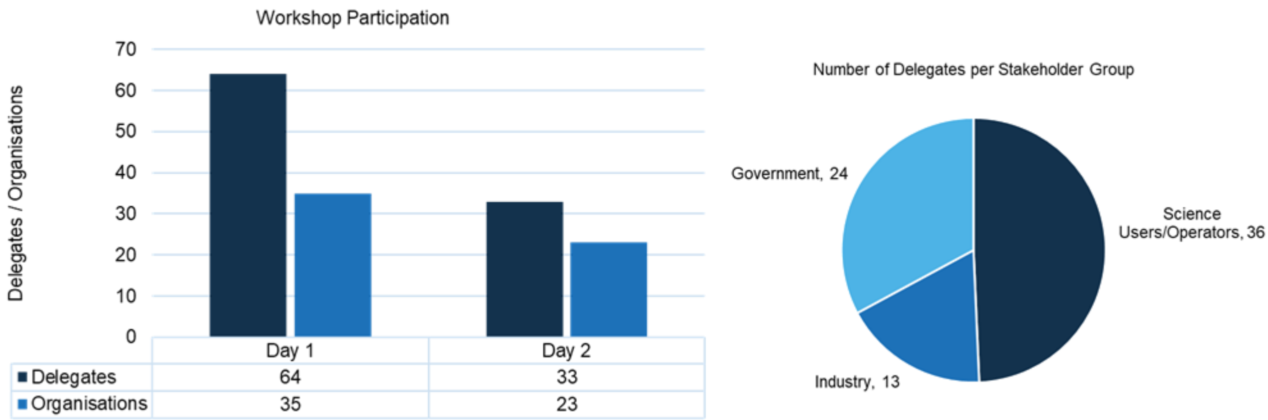


Figure 5. Participation Statistics

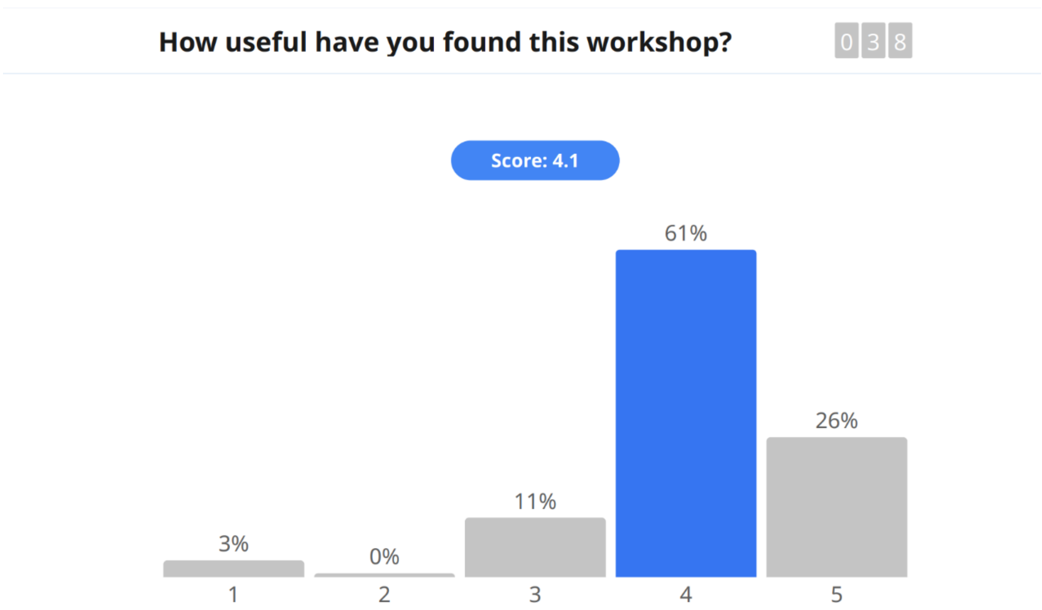


Figure 6. Participant Feedback Poll

Figure 7. Participant Feedback Word Cloud