
# UPSCALING MARINE AUTONOMY IN THE UK

## A REPORT BY THE UPSCALING AUTONOMY WORKING GROUP OF THE NOC ASSOCIATION AND THE CHALLENGER SOCIETY FOR MARINE SCIENCE

FUTURE MARINE RESEARCH INFRASTRUCTURE

UKRI Natural Environment Research Council

The Challenger Society for Marine Science

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# EXECUTIVE SUMMARY

A community consultation on upscaling of Marine Autonomous Systems (MAS) for future marine research undertaken during the spring of 2023 by the National Oceanography Centre Association, the Challenger Society for Marine Science and the Marine Facilities Advisory Board concludes in this report with three key findings and four key recommendations.

The three findings highlight the potential of MAS to significantly accelerate our understanding of the oceans, which are essential to life on Earth but remain largely unexplored.

The four recommendations chart a path for the UK to realise these ambitions and avoid pitfalls of fragmentation or unintended loss of the UK's present world-class capability.

It is anticipated that the findings and recommendations will inform UKRI-NERC in shaping Future Marine Research Infrastructures and their aspiration for that to include a massive upscaling of MAS.

# BACKGROUND AND RATIONALE

The rise of autonomy looms large in public discourse. One or more of the five 'Ds' of automation - Dirty, Dull, Dangerous, Difficult, Dear - are prime motivators for many of their applications. One 'D' that is absent from this list is 'Decarbonisation'. Approximately 70% of UKRI-NERC greenhouse gas emissions come from their fleet of three global-class research ships. The landmark publication in 2022 "Net Zero Oceanographic Capability: Summary Report"[1] listed a series of key findings (KF) and key recommendations (KR), including: KF1.1 - "Scientists are increasingly using Marine Autonomous Systems (MAS) to collect data"; KR4.6 "NERC should expect to double the size of the autonomous fleet it supports every five years". This implies an order of magnitude upscaling from a few tens of autonomous systems currently available in the NMEP (National Marine Equipment Pool) to many hundreds of systems by 2035.

Decarbonisation may act as a short-term accelerator of increased use of autonomy in marine research, but should not be seen as a long-term driver, the rationale being that all shipping will necessarily move to lower carbon fuels over time. At the same time vessel design will change to accommodate more bulky, lower carbon fuels, and this too should be reflected in our design of a parallel, but linked MAS fleet infrastructure. The strongest scientific driver behind upscaling of marine autonomy is, however, linked to carbon: the basis of life, the cornerstone of the global economy and

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[1] https://noc.ac.uk/files/documents/nzoc_summary_report.pdf

at the heart of the climate crisis. For these reasons it is increasingly important to better understand the oceans, however the global ocean is and will remain severely under sampled unless we change the way we interact with it. Autonomy offers a realistic route to alter and enhance our approach.

A slow shift towards autonomy in ocean observing is already underway, but to accelerate the transition, major investment is required. Technological advances and the carbon and heat imperatives make an accelerated transition to greater autonomous observing both possible and urgent.

UKRI-NERC has stated a clear intent to seek major infrastructure funding to upscale the use of autonomous systems for marine research. This followed the publication of the “Net Zero Oceanographic Capability: Summary Report” and establishment by UKRI-NERC of the NZOC project (Net Zero Oceanographic Capability), now reconfigured as FMRI (Future Marine Research Infrastructures).

The current shape of UK marine research infrastructure is heterogeneous. We operate a centralised system of Large Research Infrastructure (LRI) for ocean research, comprising three global class research vessels, a large equipment pool (the NMEP) and associated staffing. Equal in reach to this centralised structure is world-leading capability (staff and equipment) distributed around a diverse range of institutes and HEI departments. The shape of FMRI is a topic of active debate addressed by this report.

# COMMUNITY APPROACH TO CONSULTATION

This report is an independent assessment of a community consultation on the role of Marine Autonomous Systems (MAS) as a Large Research Infrastructure, both now and in the future. The exercise was conducted by an expert working group (Upscaling Autonomy Working Group (UAWG)) formed through an open application process jointly by the National Oceanography Centre Association (NOCA), the Marine Facilities Advisory Board (MFAB) and the Challenger Society for Marine Science (CSMS). Membership and terms of reference for the UAWG are in Annex 1.

The consultation exercise comprised a series of webinars, a community on-line survey, and a virtual round table discussion with delegates from across the UK's marine science and technology community.

This report provides insight and foresight for UKRI-NERC on how they might optimise the implementation of upscaling of marine autonomy in the UK, with due regard to existing activities and infrastructures.

## DEFINING CONSULTATION FOCUS AREAS

With its focus on future implementation of upscaling, the consultation exercise was guided to consider in detail three particular areas of interest. These areas were firstly formulated by the UAWG and secondly tested for utility during the initial Webinar Q&A sessions. The three areas are:

a. Current MAS provision. Crucially an understanding on how it presently operates in the UK as a necessary starting point to inform how upscaling might best be implemented.

b. Future development of MAS provision. Whilst this has strong external drivers, for example ship fuel technology and geopolitical trends, the views from a highly informed community of research and engineering practitioners offers considerable value to the shaping of future provision.

c. Implications of differing implementation models for UK marine researchers. This consideration also has a strong external drive and recognises UKRI-NERC's proposed shift from a "Ship+" model to a "+Ship". In the former, the ship is the dominant ocean observing platform; in the latter, the balance has transitioned towards MAS ascendency.

These three areas proved to be appropriate and were used to formulate a series of five questions which formed the basis for the online questionnaire and a virtual roundtable discussion - both fully open and accessible fora.

Taking all evidence into account, three key findings and four recommendations emerged, given in full below. Full evidence gathered through the consultation exercises is provided in the annexes 2 & 3.

## CONSULTATION EXERCISE METHODS

The consultation exercise began with a series of three repeated Webinars (for maximum coverage), chaired by UAWG Chair (Prof Mark Inall) and delivered by the UKRI-NERC Lead of NZOC (FMRI) Project (Leigh Storey). The objectives for holding webinars were twofold: 1) to set a baseline understanding of UKRI-NERC's position and aspirations on upscaling marine autonomy; and 2) to test for key areas of interest/concern. Webinars took place during February to April 2023 and were followed by an on-line survey, constructed using expert knowledge of the UAWG and feedback from the webinars. The survey comprised a series of five questions (Annex 2), a meta-analysis of which is presented below. To explore the five questions in greater detail, a virtual "round table" event was convened by NOCA on 24th April 2023, comprising 49 delegates from across the UK's marine science and technology community (Annex 3). Round table delegates were split into four groups each discussing all five questions, and then reporting back to the plenary with full note recording (reproduced in Annex 3). Group Chairs: Professor Mike Meredith (CSMS), Professor Kerry Howell (U.Plymouth), Dr Tim Smyth (PML) and Dr Matthew Palmer (PML). Group rapporteurs: Dr Maaten Furlong (NOC), Mr Alex Murphy (BAS), Dr Alex Phillips (NOC) and Dr Gillian Damerell (UEA).

The event was Chaired by Professor Mark Inall (SAMS, NOCA Chair and UAWG Chair). Leigh Storey (UKRI-NERC) and Dr Eleanor Darlington (National Marine Facilities) were observers. The event was coordinated and supported by Dr Kristian Thaller, Programme Director (FMRI), the NOC Events team and Jackie Pearson, NOCA Secretary.

## QUESTIONS POSED, MAPPING TO FOCUS AREAS

The three areas (A, B and C, listed above) were unpacked into four questions. Questions 1 and 2 map onto Area A; Questions 4 and 5 map to Areas B and C, respectively. An additional question concerning carbon footprint was included (Question 3). The following section gives an overview of the expert analysis of evidence gathered via the on-line survey (Annex 2) and round table discussion (Annex 3). The views of individuals are necessarily subjective, and the attendee group was self-selecting, though we consider our reach into the UK marine research community to be high (75 webinar attendees, 27 survey respondents, 49 roundtable participants). Responses were cross-referenced, interconnected, and grouped thematically using "Obsidian" software.

## 1. CURRENT ROLE OF MAS IN MARINE RESEARCH

Survey Q1: MAS already plays a role in marine research, but current MAS capability (not provision) poorly serves all the disciplines of marine research.

If you agree with this statement, which areas are well served and which are poorly served, and what steps should be taken to alleviate this? If you disagree with this statement, please explain why.

### SUMMARY ANALYSIS OF THE EVIDENCE

It was generally felt that upper, open ocean (0 - 1000m) basic Essential Ocean Variables (EOVs) (namely, temperature and salinity) are reasonably well served by MAS. For platforms it is endurance and depth range that are limiting; for EOVs it is energy consumption, accuracy and actual sensor existence that are limiters. Infrastructure limiters are number/availability of platforms (evident particularly in the more recent past, and considerably more so with surface and seabed vehicles), cost model (ships, unlike MAS, are essentially subsidised to the scientists), data QC handling, and machine-to-machine interoperability. Regulation is beginning to become an issue (particularly for surface vehicles) and may be a limiter in future.

## 2. DEMAND FOR MAS IN MARINE RESEARCH

Survey Q2: Demand for and uptake of MAS has been lower than anticipated by the scientific community.

Do you agree with this statement? If so, what are the specific barriers or bottlenecks to uptake? If not, what could be done, if anything, to increase uptake.

### SUMMARY ANALYSIS OF THE EVIDENCE

With the initial caveat that about half of all respondents questioned how one gauges “anticipated”, the broad view was that uptake, whilst growing, has been hindered by a number of issues: User confidence in platform and sensor reliability has deterred many from opting/seeking a MAS solution - as has data access, particularly speed and QC of data, and data flow to familiar analysis suites or lack of pipeline of new analysis software. Gliders and the AUV (Autosub family) are priced to include a higher proportion of the underlying capability costs compared to UK research vessels - making MAS less favourable to UKRI-NERC funded science projects (with some Directed Programme exceptions).

Regulatory frameworks can be ambiguous, unlike the very clearly defined Diplomatic Clearance process for vessels. There remains a novelty aspect to MAS with insufficient detailed information in the public domain, which can deter.

## 3. ROLE FOR MAS IN DECARBONISING MARINE RESEARCH

Survey Q3: Large upscaling of MAS is an essential element to decarbonising marine research.

Do you agree with this statement? If you do agree, will this impact the quality of UK marine research, if so, in what ways? If not, how can UKRI-NERC reduce the carbon footprint of marine research over the necessary timescale (NetZero by 2040)?

### SUMMARY ANALYSIS OF THE EVIDENCE

There was a strong sense that MAS and UKRI-NERC / marine science carbon footprint needed to be decoupled, and then quantitatively itemised. All current activities have carbon footprints (including weather/climate prediction, high-end computational processing inc. some forms of AI), all are seeking a range of differing solutions that have different imperatives and timescales. Research vessels are a tiny component of a vast shipping industry - fuel and vessel design will change at the pace of that industry. Due to endurance and remoteness considerations, many MAS systems require ship deployment/recovery. Many research questions are solved, increasingly, using multi-systems approaches (satellites, models, ships, MAS, HPC (inc. AI) etc), all have individual carbon footprints, the outcomes rely on all systems to contribute. To conserve high-quality scientific outcomes, significant technological development and investment in MAS are needed to change the balance of this mix and move the dial on overall carbon footprint.

## 4. SHAPE OF UPSCALING IMPLEMENTATION

Survey Q4: A centrally funded hub-and-spoke model for providing access to MAS for oceanographic observing is an appropriate way to serve the UK. (hub-and-spoke is taken to mean one main centre with multiple satellites).

Do you agree with this statement? If so, are there any improvements that might be made? If not, what other model should be implemented?

### SUMMARY ANALYSIS OF THE EVIDENCE

This question elicited the greatest volume of response. Implementing a “hub and spoke” model in the UK had many interpretations. However, underlying the varied interpretations, a strong voice emerged for a mixed economy of MAS upscaling.

An historical perspective is given, in which the size and reach (and therefore cost) of ships led over decades to more centralisation of research vessel operations in the UK. MAS may allow that to be partially unwound, with the benefits that diversity of access and know-how bring to innovation and wide-spread education. Nevertheless, the challenges and disadvantages of a totally dispersed model are considerable. Equitable access may be harder to achieve, adherence to good operational practices and common data standards (FAIR principles) similarly. Large fleet programming is far from trivial and cannot be a distributed function. Likewise, connectivity to third parties (e.g., other agencies, commercial and philanthropic bodies) is facilitated more reliably and consistently through a single coordination point.

## 5. MAS + SHIP MODEL FOR UK MARINE RESEARCH

Survey Q5: The UKRI-NERC NZOC programme is proposing a transition from the current Ship+ Model to a +Ship Model (see https://nzoc.ac.uk/theme/ship-technologies).

Is the model of few ~60m hydrogen-powered ships, hundreds of MAS, and data/model integration a good aspiration for UK marine research? Please consider the pros, cons, and alternatives.

### SUMMARY ANALYSIS OF THE EVIDENCE

The vast majority of responses recognise that this would be a fundamental cultural shift from the current direction of travel of ever-increasing vessel capacity. It was felt that a shift to smaller vessels may be driven by carbon emissions considerations, but that is currently not clear; there are also cost drivers at play. However, we cannot upscale MAS without upscaling the associated human resources. Whether those people are at sea or not, data bandwidth and seamless accessibility to MAS platform for mission control, data QC and near real-time processing is a vital part of a new MAS infrastructure.

The same number of research vessels, each with fewer berths inevitably would reduce access to these centrally managed research vessels. It was noted that a discipline-based asymmetry in seagoing opportunity may emerge (arguably, one already exists). This may change the traditional attractors into marine science. But robots need people to prepare, deploy, command, recover and develop. Upscaled MAS could easily democratise access to the ocean, if the new opportunities are geographically diverse and have emphasis placed on lowering some of the current barriers to participation imposed, necessarily, by long-endurance ocean missions.

# KEY FINDINGS AND RECOMMENDATIONS

The rationale for this consultation was to inform UKRI-NERC's aspirational significant (£100sM) future investment in MAS. Investment at this scale was taken as the underlying assumption and therefore does not appear as an explicit recommendation.

## FINDING 1

The ocean is massively under-observed compared with any other part of the Earth's biosphere / climate system, and the primary value of upscaling MAS is to significantly increase ocean observing capacity without the need to increase global-class research vessel provision (and its associated cost and carbon footprint). The mantra that MAS will replace ships is misplaced: ships will always be needed, but alone they cannot provide the observational coverage we require. MAS will not in any foreseeable future be able to replace all people at sea, their future is to greatly extend ocean coverage beyond that of ships, and to reach into areas inaccessible by ship.

## FINDING 2

Improving MAS range and EOV sensor development is required to fulfil the aspiration of significantly upscaled MAS contributions to the Global Ocean Observing System (GOOS) and global ocean research more broadly. MAS currently determine only a small fraction of Essential Ocean Variables (EOVs) to an acceptable degree of accuracy, and the UK is a global leader in ocean observing and discovery primarily from our global class research vessels. An absence of MAS range and sensor development and a simultaneous reduction in research vessel provision would be disastrous for UK and international marine research and our contributions to global ocean research.

## FINDING 3

A high level of nationally coordinated community engagement is needed over the next decade to avoid adverse unintended consequences of MAS upscaling. This must include balancing merits of bespoke MAS platform innovation and commercial procurement; sensor development to Technology Readiness Level (TRL) 8/9; FAIR data delivery mechanisms. National coordination does not however imply centralisation of capital, resource, and activity. A great strength of the UK marine science community is its diversity of viewpoints, sites, expertise, reach and scope which promotes an ecosystem of innovation and new ways of working. Utilising and nationally coordinating this ecosystem is vital to the success of MAS upscaling that delivers optimal gains for ocean observing and marine science.

## RECOMMENDATION 1

Investment in upscaling of UK MAS must support three pillars: sensor development (to expand the range of EOVs); platform endurance, depth range and environmental reach (air/sea, seabed, cryosphere, deployment methods); and accessibility (data flow, user costs, equitable access). No investment can ignore any one of these pillars, and to achieve the scale required they must be accompanied by a large capital investment in fleet size.

## RECOMMENDATION 2

A baseline assessment of current UK MAS provision and coordination - including attendant deployment vessels and methods - is a strong foundation on which to build an upscaled infrastructure. UKRI-NERC should commission and publish an assessment that includes number and type of platforms, operational and capital costs, full carbon inventory (including offshored carbon) by platform in terms of “hours-at-sea” and data collected. This baseline cost assessment must be tempered against the challenges of different operating environments (remoteness, hazards), and the scientific uniqueness and value of the data produced, which cannot be monetised.

## RECOMMENDATION 3

UKRI-NERC to fund stepwise MAS upscale “demonstrator” projects. These to include optimal design work for centralised FAIR data access for currently operational UK MAS platforms, machine-to-machine data handling, and decentralised MAS operations with central coordination. These design elements, once optimised, are needed to inform the shape of upscaled MAS in FMRI and should materially support the involvement and inclusion of all UK MAS research operators and actively facilitate their engagement and those of aspiring operators. MAS hardware should be centrally coordinated and equitably accessible, with housing and operations distributed across the community.

## RECOMMENDATION 4

Due to their diverse nature, size, and distribution, upscaling of MAS offers an opportunity to increase and diversify ocean education and ocean access. If future low-carbon marine fuels lead to a reduction in global-class vessel carrying capacity, a distributed network of MAS deployment and recovery centres (assets and personnel) can more than offset any reduction in deep ocean opportunity. An optimally designed (Recommendation 2) and geographically distributed MAS FMRI is the favoured model to emerge from this consultation exercise for UK implementation, and UKRI-NERC is encouraged to embrace the opportunity.

# ACRONYMS

**CSMS:** Challenger Society for Marine Science.

**FAIR:** Findability, Accessibility, Interoperability, and Reusability. The four foundational principles that serve to guide data producers and publishers.

**FMRI:** Future Marine Research Infrastructure.

**LRI:** Large scale Research Infrastructure.

**NMEP:** National Marine Equipment Pool.

**NOCA**: National Oceanography Centre Association.

**NZOC:** Net Zero for Oceanographic Capability.

**MFAB:** Marine Facilities Advisory Board.

**UAWG:** Upscaling Autonomy Working Group

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