Centre for Environment Fisheries & Aquaculture Science

Cefas

The Future of the UK National Monitoring Fleet Capability

Author(s): James Parker

Date: June 2021

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Cefas Document Control

Submitted to:	National Oceanography Centre
Date submitted:	9th June 2021
Project Manager:	Charlotte Jessop
Report compiled by:	James Parker
Quality control by:	David Limpenny
Approved by and date:	Mark Kirby
Version:	3.0 - FINAL
Recommended citation for this report:	Parker, J. (2021). The Future of the UK National Monitoring Fleet Capability. Cefas Project Report for National Oceanography Centre, 35 pp.

Version control history

Version	Author	Date	Comment
0.1	James Parker	29th March 2021	Draft
0.2	James Parker	30th March 2021	Revised Draft
1.0	James Parker	31st March 2021	Approved Draft for Submission
1.1	James Parker	20th May 2021	Update of document to address customer feedback
1.2	James Parker	21st May 2021	Update of document to address internal review feedback
1.3	James Parker	24th May 2021	Submission for internal approval
1.4	James Parker	26th May 2021	Updated submission for internal approval
2.0	James Parker	26th May 2021	Approved Revised Draft for Submission
3.0 - FINAL	James Parker	09th June 2021	Issued as Final

Executive Summary

The UK Government Fleet is made up of vessels with various capabilities and of varying sizes, ranging from small inshore compliance vessels to large icebreaking polar research platforms. For the purposes of this report, the UK Research Fleet shall be defined (in alignment with the Marine Science Co-ordination Committee (MSCC) Research Vessel Working Group) to be the collection of vessels with a minimum overall length (LOA) of 50 meters, and those which are at the direct disposal of the UK Government and its Devolved Administrations for the purposes of scientific research and monitoring. This UK Research Fleet is therefore made up of:

- British Antarctic Survey (BAS) vessels *RRS James Clarke Ross* and *RRS Sir David Attenborough*.
- National Oceanography Centre (NOC) vessels *RRS Discovery* and *RRS James Cook*.
- The UK National Monitoring Fleet:
    - *RV Corystes*, owned by Northern Ireland's Agri-Food and Biosciences Institute (AFBI)
    - *RV Cefas Endeavour*, owned by the Centre for Environment, Fisheries and Aquaculture Science (Cefas)
    - *RV Scotia*, owned by Marine Scotland.

Due to the aging nature of the UK Research Fleet, it is appropriate to consider what the future requirements and applications might be (for both the delivery of scientific research / monitoring and wider UK Government requirements), and how these may be achieved.

With due consideration of the anticipated continuation of the UK's statutory and Ministerial signatory obligations surrounding fisheries, environment, and biodiversity, there is a continued requirement for scientific research and monitoring.

Whilst there have been developments in autonomous and semi-autonomous technologies, there are limited examples of where such technologies have been accepted by the scientific community (as being suitable to replicate work from research vessels), and there are fewer examples of where they have replaced the role of a research vessel entirely. There is therefore an expectation that research vessels will continue to be required to deliver elements of the UK's scientific research and monitoring for the foreseeable future.

There is, however, an opportunity for the UK to augment vessel delivery with autonomous and semi-autonomous solution and 'green' technologies, and to better integrate / collaborate UK Research Fleet operations / operators in a manner similar to other European nations who operate a fleet.

Contents

Glossary of Acronyms

AFBI	Agri-Food and Biosciences Institute – a non-departmental public body in Northern Ireland
BAS	British Antarctic Survey
BEIS	UK Government Department for Business, Energy and Industrial Strategy
Cefas	Centre for Environment, Fisheries and Aquaculture Science – an Executive Agency of Defra
DCF	Data Collection Framework
Defra	UK Government Department for Environment, Food & Rural Affairs
EU	European Union
GGC	Greening Government Commitments
ICES	International Council for the Exploration of the Sea
LOA	Overall Length (of a vessel)
MSCC	UK Government Marine Science Co-ordination Committee
MSS	Marine Scotland Science
NERC	Natural Environment Research Council – a research council within UKRI
NOC	National Oceanography Centre
NZOC	Net Zero Oceanographic Capability
OFEG	Ocean Facilities Exchange Group
PSRE	Public Sector Research Establishment
RV	Research Vessel
RRS	Royal Research Ship
UKNMF	UK National Monitoring Fleet
UKRF	UK Research Fleet
UKRI	UK Research and Innovation (UKRI) – a non-departmental public body sponsored by BEIS,

1. Introduction

Due to the age profile of the current vessels making up the UK National Monitoring Fleet (AFBI's *RV Corystes*, Cefas' *RV Cefas Endeavour*, and Marine Scotland's *RV Scotia*) and the wider UK Research Fleet (consisting of the UK Monitoring Fleet, BAS' *RRS James Clarke Ross* and *RRS Sir David Attenborough*, and NOC's *RRS Discovery* and *RRS James Cook,*), there is a need to address the future of this fleet with due consideration of:

- the current and anticipated future capability of the UK Research Fleet (out to 2035) and its applications to the UK's monitoring obligations.
- the current and anticipated future capability of autonomous and semi-autonomous solutions (out to 2035) which could complement the fleet.
- how the UK's net zero carbon emissions (by 2050) may influence development and/or adoption of technologies in support of the UK's monitoring obligations and wider climate commitments.
- what fleet integration might be needed to deliver the UK's monitoring requirements collaboratively by 2035, how would transition take place, and what may be the consequences for the associated organisations.
- what new skills and training would be required to deliver the vessel and scientific delivery aspects of a wider delivery model (in relation to autonomy, semi-autonomy, and/or traditional crewed vessels).

This report presents a high-level review of the consideration items above, making a number of high-level recommendations to further develop understanding and progress.

2. Future Requirements and Capability

2.1. Monitoring Requirements

The UK is committed to securing clean, healthy, productive and biodiverse seas and oceans, and is a signatory to national and international commitments to do so. The range of national and international statutory and Ministerial signatory drivers that require survey effort to provide the necessary scientific evidence to demonstrate compliance is provided in summary in Table 1.

Objective	Drivers
Managed Fisheries	• The Common Fisheries Policy (Amendment etc.) (EU Exit) Regulations 2019
An ecologically coherent and well managed network of marine protected areas (MPA)	• The Marine Environment (Amendment) (EU Exit) Regulations 2018
Seas with good environmental, ecological and chemical status	• The Marine Environment (Amendment) (EU Exit) Regulations 2018 • Water Environment (WFD) (England and Wales) Regulations 2017 • The Convention for the Protection of the Marine Environment of the North-East Atlantic (the 'OSPAR Convention')
Levels of contamination and pollution in the marine environment	• The Marine Environment (Amendment) (EU Exit) Regulations 2018 • IMO Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention) • The Convention for the Protection of the Marine Environment of the North-East Atlantic (the 'OSPAR Convention')
Levels of contamination and pollution in harvested seafood from it	• The Marine Environment (Amendment) (EU Exit) Regulations 2018 • UK Food Standards Agency

Table 1: UK statutory or Ministerial signatory drivers which require survey effort to fulfil obligations.

2.1.1. Fisheries

The sustainable management of fisheries relies on data collected, managed and supplied by EU countries under the Data Collection Framework (DCF). These data are used within the international stock assessment and advisory process (under the auspices of ICES) that feeds into the annual European fisheries negotiations. Prior to exit from the EU, most of the UK's fisheries monitoring was coordinated under the DCF, and national plans were evaluated and approved by the Scientific, Technical and Economic Committee for Fisheries (STECF).

Whilst the UK is now an independent coastal state under the UN Convention on the Law of the Sea, statutory instruments (including *The Common Fisheries Policy (Amendment etc.) (EU Exit) Regulations 2019*) have been put in place to effectively transcribe the European Commission's Common Fisheries Policy requirements into domestic legislation. Additionally, the UK-EU Trade and Cooperation Agreement (signed in December 2020) continues the joint commitment to sustainable fisheries management, and it enables the UK to conduct annual fisheries negotiations (regarding the Total Allowable Catch for shared stocks) with the EU, other coastal states, and international organisations.

Consequently, there continues to be a critical requirement for fisheries data to be collected by the UK (under standardised protocols to provide confidence in stock size estimates and continuity of method) to ensure sustainable management of both domestic UK stocks and shared fisheries, and the associated determination of sustainable quotas allocated to national fishing industries, including the UK. Furthermore, unless alternative methods of fisheries data collection are accepted by the scientific community, it is assumed that the fisheries data collection will be achieved via fisheries independent monitoring using dedicated research vessels, with some contribution from commercial vessels commissioned specifically for scientific monitoring data collection.

2.1.2. Environment and Biodiversity

Following the establishment of the UK as an independent coastal state, the UK's commitments for monitoring the marine environment and biodiversity (within EU legislation) have been transferred into domestic legislation through statutory instruments including *The Marine Environment (Amendment) (EU Exit) Regulations 2018*. As a result, it is anticipated that there will continue to be a requirement for data and evidence to understand the condition of the marine environment and biodiversity, and to demonstrate ongoing compliance with legislation.

In addition to this, the *Benyon Review Into Highly Protected Marine Areas* recommended that UK Government should introduce Highly Protected Marine Areas (HPMAs) in conjunction with the existing Marine Protected Area (MPA) network (GOV.UK, 2020). The report also recommended that, to establish comparative baselines, the monitoring and evaluation of biological, social and economic processes and effects of HPMAs must begin before designation and continue long term; with the caveat that UK Government should not allow the lack of perfect evidence to delay HPMA designation (GOV.UK, 2020).

It is therefore possible, and indeed likely, that the designation of some HPMAs may require additional data and evidence collection from targeted survey activity. As also set out in the *Benyon Review Into Highly Protected Marine Areas* (GOV.UK, 2020), it is also likely that vessels, along with other technological advancements, will be needed to ease the burden of enforcement and monitoring of HPMAs, and thus increase utilisation further.

2.2. UK Research Fleet

2.2.1. Current UK Research Fleet

The UK Government Fleet is made up of vessels with various capabilities and of varying sizes, ranging from small inshore crafts to large icebreaking polar research platforms.

For the purposes of this report, the UK Research Fleet shall be defined to be the collection of vessels with a minimum overall length (LOA) of 50 meters, and those which are at the direct disposal of the UK Government and its Devolved Administrations for the purposes of scientific research and monitoring. This definition of the UK Research Fleet aligns to the defined extent of the UK Government Marine Science Co-ordination Committee (MSCC) Research Vessel Working Group (GOV.UK, 2021).

Focus on this sub-set of UK Government vessels in no way detracts from the valuable role that the wider UK Government fleet (including the following) contributes to the delivery of the UK's obligations:

- research and monitoring vessels with LOA of less than 50m operated by organisations including Marine Scotland, the Marine Management Organisation, the Inshore Fisheries and Conservation Authorities, etc.), and
- compliance vessels (operated by organisations including Marine Scotland, the Environment Agency, the Inshore Fisheries and Conservation Authorities, etc.).

Focus on this sub-set of UK Government vessels also does not detract from the valuable role that the wider UK Government fleet (as above) may play in the delivery of the UK's future requirements (see Section 2.6).

Table 2 (below) captures details of the UK Research Fleet which are pertinent to this report.

The UK Research Fleet is utilised to deliver domestic and international scientific research and monitoring, with platforms allocated to operations based on the remit of their owners.

For UK Research and Innovation (UKRI), a non-departmental public body sponsored by the UK Government Department for Business, Energy and Industrial Strategy (BEIS), BAS and NOC operate their 'global' vessels to deliver scientific research and logistical support from the polar regions, down to temperate mid-latitudes and tropical oceans.

In contrast, AFBI, Cefas and Marine Scotland Science operate their respective vessels to undertake scientific research and monitoring activities in support of the UK and Devolved Administration's statutory and ministerial signatory obligations. For the purposes of this report, such vessels are considered to make up the UK National Monitoring Fleet.

		RV / RRS	Operator	Vessel Class[1]	LOA (m)	Year Delivered	Anticipated Decommissioning
UKRF	UKNMF	Cefas Endeavour	Cefas	Ocean	73.9	2003	2033
UKRF	UKNMF	Corystes	AFBI	Regional	52.2	1988	2018[2]
UKRF	UKNMF	Scotia	MSS	Ocean	68.6	1998	2028
UKRF		Discovery	NOC	Global	99.7	2013	2038
UKRF		James Clarke Ross	BAS	Global	99.0	1990	2015[3]
UKRF		James Cook	NOC	Global	89.2	2006	2031
UKRF		Sir David Attenborough[4]	BAS	Global	129	2019	2044[5]

Table 2: Current UK Research Fleet (>50m LOA)

In addition to delivering the national monitoring obligations, vessels within the UK National Monitoring (and the wider UK Research) Fleet are available for (and regularly undertake) work under a 3rd party charter. Examples include:

- UK National Monitoring Fleet vessels are deployed on wider UK Government projects (i.e. beyond the parent Government Department), both domestically and overseas.
- UK Research Fleet vessels being chartered to other UK Research Fleet partners (Cefas has chartered UKRI vessels for the delivery marine science in the South Atlantic).
- UK Research Fleet vessels are chartered to domestic and overseas commercial and Government customers.
- UK Research Fleet vessels are chartered (via barter system) to international Government-based vessel operators (from France, Germany, Netherlands, Spain and Norway) within the Ocean Facilities Exchange Group (OFEG).

The key benefit of such 3rd party work is that through financial contribution to the operational costs through a contractual charge out mechanism, the assets remain affordable for the UK Government. Additionally, where scientific research is delivered

[1] As defined in (Nieuwejaar, et al., 2019)
[2] The working life of *RV Corystes* has been extended to meet delivery of a replacement research vessel.
[3] The working life of *RRS James Clarke Ross* has been extended to meet the commencement of operations by *RRS Sir David Attenborough*.
[4] *RRS Sir David Attenborough* is expected to commence polar operations in 2021.
[5] Assumes 25-year nominal life expectancy.

under OFEG barter arrangements, it can allow to the scientific research to be undertaken more time and cost efficiently, and with a reduced impact on the environment (as typically such works are undertaken by international partner vessels local to the area of operation, thus reducing transit times, associated costs, and the creation of greenhouse gas emissions).

2.2.2. Current European Research Fleet

The assessment of the European research vessel fleet by Nieuwejaar, et al. (2019) indicates a strong improvement in the fleet's capability to undertake science over the past decade, with newer vessels typically being equipped with advanced systems and capabilities as standard (e.g. the consideration and accommodation of autonomous and semi-autonomous technologies), and with mid-life vessel upgrades further increasing capabilities in other areas (e.g. satellite communication capacity).

2.2.3. Planned Development of UK Research Fleet

Due to the age profile of the UK Research Fleet, with the majority of the operational fleet beyond the expected mid-point of life expectancy, several vessels are either moving towards or have already exceeded their nominal working life. As the design, procurement and delivery of a new vessel can take between 3 and 10 years, with the actual duration subject to the nature of the design and build process, operators need to consider such timeframes, along with budget availability and their anticipated future needs, when planning for vessel replacement.

Replacing the aging *RRS James Clarke Ross*, and the chartered *RRS Ernest Shackleton*, the commissioning of *RRS Sir David Attenborough* was part of a major UK Government investment in polar infrastructure which is intended to keep Britain at the forefront of world-leading research in Antarctica and the Arctic (British Antarctic Survey, 2021).

As highlighted within Section 2.1, due to the transposition of the requirements into UK legislation, the requirement for monitoring of marine environment, biodiversity and fisheries is expected to continue following the establishment of the UK as an independent coastal state. Whilst there is a growing number of areas in which automation (or semi-automation are becoming accepted – see Section 2.3), there continues to be a requirement for research vessels to undertake aspects of scientific research required under statute and ministerial signatory obligations.

In recognition of this, Marine Scotland and AFBI have commenced activities to replace their research vessels. In February 2021, Houlder Ltd. were awarded a contract from Marine Scotland to assist Marine Scotland in developing a tendering technical specification, and its associated plans, for a new 80m research vessel (to replace *RV Scotia*) as well as a smaller compliance vessel (Public Contracts Scotland, 2021). Similarly, in February 2021, Skipsteknisk AS were awarded a contract from AFBI to provide design, procurement, and project management support for the construction of a new research vessel to replace *RV Corystes* (Tenders Electronic Daily, 2021).

Furthermore, plans have now been initiated for the strategic replacement of RV Cefas Endeavour and/or other means of collecting marine data and evidence in support of Cefas' delivery as a world leader in marine science and technology.

It is anticipated that, given the expected development and increasing acceptance of the autonomous and semi-autonomous technologies complementing research vessels, any new research vessels will be designed and built with the capability to deploy, recover and service such autonomous and semi-autonomous platforms.

2.2.4. Possible Development of UK Research Fleet

For the foreseeable future, research vessels will continue to deploy, service and recover stationary autonomous instruments on the ocean floor, in the water column or on the surface, in addition to deploying and recovering autonomous vehicles which are drifting or being self-propelled on the surface and/or in the water column (Nieuwejaar, et al., 2019). Nieuwejaar, et al., (2019) continues that research vessels will therefore remain a vital component of the Earth and ocean observation and monitoring system.

With *RRS James Cook* and *RV Cefas Endeavour* reaching their projected end of life in 2031 and 2033 respectively, and considering the lengthy timeline for design, procurement and delivery of replacement vessels, it is evident that these vessels will be next to undergo replacement consideration. As part of this, there will need to be a consideration of the historic, present and anticipated future utilisation of the vessels, along with their associated historic, present and anticipated future impact on scientific research and policy development/implementation, particularly in light of the UK's position as an independent coastal state. There will also need to be a consideration of the what the wider UK Government fleet (of all vessel sizes) is and may be comprised of, and the capability and the capacity of such a fleet to successfully deliver the UK's designated obligations.

Whilst the reporting of carbon emissions from research vessel / ship activity is not currently covered by the Greening Government Commitments (GGC), it is understood that such platforms make up a significant proportion of their Owners emissions. Consequently, with the UK Government's target to bring all of the UK's greenhouse gas emissions to net zero by 2050, a key aspect of any new vessel commissioned in the next 10-15 years will be how the new vessels will contribute to this targeted reduction.

With UKRI's enhanced objective of becoming a net zero organisation by 2040, NERC has funded the establishment of the Net Zero Oceanographic Capability (NZOC) scoping project to inform planning for the future low carbon oceanographic research capability (National Oceanography Centre, 2021). Within the NZOC project, NOC are considering how marine scientific research may be conducted beyond 2035, what role vessels and alternative technologies (e.g. autonomous and semi-autonomous systems) may play in this delivery, and how will this work towards UKRI's net zero objectives.

Similarly, having recently procured a new vessel management contractor for *RV Cefas Endeavour*, Cefas is continuing to deliver the necessary statutory monitoring and scientific research from this asset. However, there may be opportunities in the short- to medium-term to drive through efficiencies in the platform operations, which may include consideration of alternative power sources (e.g. battery fuel cells) to satisfy the peak loading (currently accommodated by increasing the use of the onboard diesel-electric generators). Alongside this, Cefas is also developing an understanding of how aspects of the necessary statutory monitoring and scientific research could be delivered through the use of complementary autonomous and/or semi-autonomous solutions.

Notwithstanding the above, there may also be opportunities for integration and/or collaboration of UK Research Fleet operators, or wider within Europe (see Section 2.6).

2.3. Autonomous and Semi-Autonomous Solutions

2.3.1. Development of Autonomous and Semi-Autonomous Solutions

In recent years and decades, global autonomous and semi-autonomous technology development has enhanced the ways in which organisations can undertake aspects of scientific research and monitoring, with the consequential ability to complement (and in some cases reduce reliance on) the UK Research Fleet.

This is evidenced by the UK's National Marine Equipment Pool (NMEP), which has been developed and invested in to become Europe's largest centralised marine scientific equipment pool holding more than 10,000 instruments and technologies capable of sampling from the sea surface to the deep ocean (National Oceanography Centre, 2021).

In addition to this, PSREs within the UK can utilise earth observation (satellite) data and combine this with the operation of autonomous and semi-autonomous technologies, including:

- Cefas SmartBuoy, which has been developed to host a range of sensors, nutrient analyser, and water sampler, to collect and communicate water quality data over 3-month deployment periods in support of the UK's OSPAR obligations.
- Uncrewed surface vehicle (USV) which has been developed with the manufacturers (Liquid Robotics) to host the Cefas SmartBuoy payload with additional interactivity allowing remote triggering of the onboard water sampler (see Figure 1).

There is also an increasing number of commercial organisations offering the provision of autonomous and semi-autonomous assets (under turnkey solutions) for the delivery of marine scientific research and monitoring.

However, despite the development of such platforms, there remain concerns and limitations surrounding their effective operation in certain environmental conditions. Examples include where platforms are reliant upon solar power, which can be limited by the low light conditions of winter, or large amounts of cloud cover, both of which affect the UK for a large part of the year.

Other limitations relate to the extent of biofouling. In shallow water environments, at higher temperatures, it takes just three weeks for biofilm to form and then attract larger colonisers, which in turn attract much larger organisms causing macrofouling (Sonardyne, 2020). Such fouling may not just affect sensor performance but may also impact the manoeuvrability and seakeeping of the platforms themselves. As a result, the environmental conditions in which the platforms will be deployed will also be a consideration in determining their suitability for the intended task.

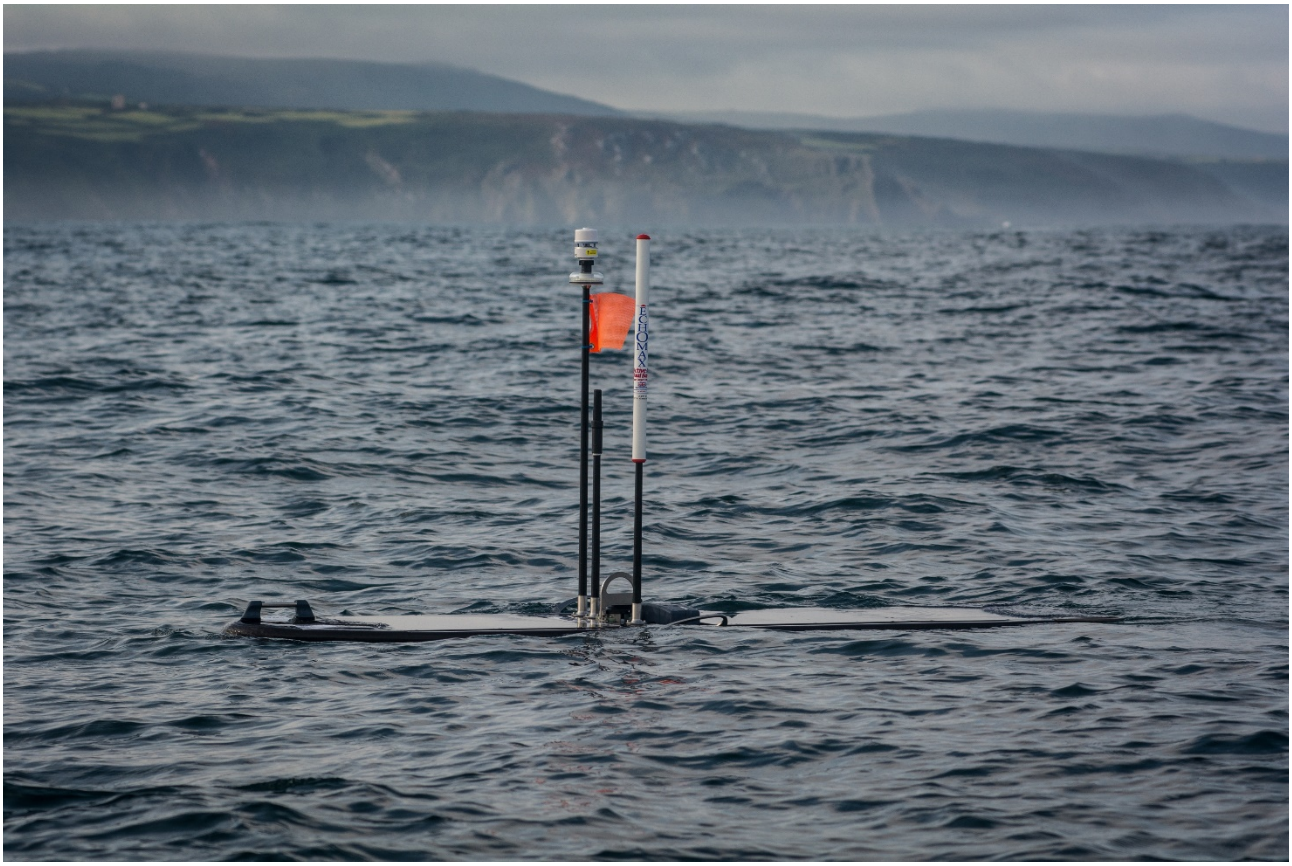

Figure 1: Cefas' Liquid Robotics SV3 Wave Glider deployed for environmental monitoring (Credit: Chris Read (Cefas))

There are also regulation and risk management considerations relating to the safe navigation and operation of such autonomous and semi-autonomous technologies within the marine environment, and in particular, in areas of high marine traffic and/or fishing activity (static or dynamic).

Looking to the future, the UK Government vision for marine autonomy is for the UK to be at the heart of a global maritime autonomy industry, leading in the design, manufacture, uptake and use of maritime autonomous systems and the associated regulatory framework (Department for Transport, 2019). It is therefore anticipated that there will be technological advancements, developed in both domestically and internationally, that will enable routine sensor-based data collection to be automated and affordable.

This is supported by the various scientific research projects commissioned by UK Government to look at the application of alternative technologies, including:

- CAMPUS – a three-year project working to combine autonomous observations with computer models for predicting and understanding shelf seas (www.campus-marine.org).
- MASSMO – Marine Autonomous Systems in Support of Marine Observations is a pioneering multi-partner series of trials and demonstrator missions that aim to explore the UK seas using a fleet of innovative marine robots (https://projects.noc.ac.uk/massmo/).
- AlterEco – a project to develop a novel monitoring framework to deliver improved spatial and temporal understanding of key shelf sea drivers for the investigation of the shelf sea ecosystem functioning (https://altereco.ac.uk/).
- CMEMS – the Copernicus Marine Environment Monitoring Service provides free and open marine data and services to enable marine policy implementation, support Blue growth and scientific innovation (https://marine.copernicus.eu/).

2.3.2. Acceptance of Autonomous and Semi-Autonomous Solutions

The challenge of implementing such technologies is the scientific community perception of them, and the associated confidence and acceptance of the acquired data in support of scientific disciplines which have historically relied upon vessel-based survey activity (e.g. safe navigation and fish stock assessments).

For the collection of data to support safe navigation, which has transitioned from historical lead-line surveys through to the modern-day multibeam bathymetry, the UK's Civil Hydrography Programme (CHP) is an example of where such technology has been adopted and accepted with good effect. In 2018, for the first time, autonomous survey vessels (ASVs) were deemed appropriate for the high-quality data expectations employed by the CHP, and thus accepted for multibeam bathymetry data acquisition used for nautical charting (Maritime & Coastguard Agency, 2019). Through employing ASVs for this work, it consequently reduced the requirement for vessels, with vessels only required to perform wreck investigations, the collection of physical seabed samples, and acquisition of navigational photographs specified under the CHP requirements. Into the future, it may also be possible to automate some of these aspects (e.g. acquiring photographs using uncrewed aerial vehicles), particularly if underlying specifications are adjusted in recognition of such technologies.

For the collection of data to support fish stock assessments, autonomous platforms have demonstrated that they can be used to collect acoustic fisheries data for use in stock assessment of Celtic Sea Herring (Carlisle & O'Donnell, 2018). However, whilst the autonomous platform can measure acoustic abundance without a research vessel, it is acknowledged that such data also requires ground truthing via scientifically accepted fishing methods from research vessels (Carlisle & O'Donnell, 2018).

Despite this, acceptance of such data doesn't appear to be a current or future consideration within the associated scientific community. In January 2020, a Workshop on Unavoidable Survey Effort Reduction (WKUSER), initiated by the ICES Working Group on Improving Use of Survey Data for Assessment and Advice (WGISDAA), challenged survey and stock assessment scientists from Europe, Canada, and the United States to investigate the nature, knowledge, and responses to unavoidable reductions of survey effort (ICES, 2020). WKUSER participants examined methods that can minimise the amount of information lost and identified appropriate methods to accommodate the survey design and objectives, however the use of stand-alone autonomous or semi-autonomous platforms was not factored in, with only the use of modelling and/or technology onboard the vessel considered to increase the volume and/or accuracy of the data (ICES, 2020). It is therefore recommended that there is greater alignment between PSREs, the scientific communities, and technology groups/developers in order to better understand how autonomous and semi-autonomous solutions could be applied to achieve current and future scientific research and monitoring requirements.

Consequently, whilst autonomous and semi-autonomous solutions can deliver elements of the scientific requirements, due to the requirement to ground-truth such sensor-based data collection with physical samples, and the current inability for autonomous or semi-autonomous platforms to perform such tasks, there is expected to remain (for at least the short-term) a requirement for vessel platforms to both undertake the physical sampling and servicing the limited application of complementary autonomous / semi-autonomous platforms.

2.3.3. Marine Autonomy and Smart Shipping

Today, vessels are primarily operated by human crews, however advances in technologies such as sensors, data analytics, and machine learning mean that in the future, vessels could operate with fewer crew onboard, be completely uncrewed (virtually 'crewed' from shore-based control centres), or operate entirely independently of any human operator with decisions made entirely by the machine (Department for Transport, 2019). With such advances in artificial intelligence (AI) and machine learning, and their increased application in more and more ship systems, it is inevitable that a subset of tasks currently performed at sea will move to land and be carried out from shore-based facilities, and the role of seafarers and their tasks, responsibilities and required skills will change (IMarEST, 2019). See Table 3 for further details.

Maritime autonomy is therefore part of a broader technological shift in the maritime sector referred to as 'Smart Shipping': a technological pathway for the entire maritime sector encompassing the automated, partly-digitised equipment of today, the remote operation of equipment, and the development of autonomous maritime systems, both at sea and onshore (Department for Transport, 2019). Such developments will determine how and where research vessels may be used, having the potential to decrease crewing levels, and allow the greater accommodation of onboard infrastructure, either to power the platform (see Section 2.4 for further information on alternative fuels), or to deploy, recover and maintain an increasing fleet of autonomous and semi-autonomous technologies (as detailed earlier in this section).

Operational Areas	2030	2050
Propulsion	Around 75%[6] believe that an onboard presence would still be required, however the onboard role may increasingly move to a person making decisions based on solutions and recommendations proposed by automated systems.	Over 90%[6] of shipping industry representatives believe that functions related to propulsion would be moved on land by 2050, with it being possible that a ship could be left alone for a certain amount time with some level of learning capability, and supervision of such systems as required on land.
Ship Supporting Systems[7]	There is likely to be a low reliance on human skills, however 66%[6] believe that a human would still be required to perform a range of tasks.	100%[6] believe that the management of such systems would be moved off a vessel, with majority feeling that the function would be watched over by a supervisor who could intervene when necessary.
Performance and Efficiency Monitoring	66%[6] believe that much, if not all, of the function of monitoring ship performance could be moved off a vessel by 2030 with a supervisor in the loop who would step in to make decisions when necessary.	93%[6] believe that vessels would have full functional performance with decisions being made through marine learning capability and no need for any person at any stage.

[6] Percentage values relate to the proportion of shipping industry representatives responding within a survey
[7] Any infrastructure, components or subsystem used on a generic ship as operated and maintained by the engineering department

Operational Areas	2030	2050
Safe Evacuation of Personnel	62%[6] believe that there will still be a high reliance on human skills (e.g for adjustment or intervention), with little adoption of autonomy.	Nearly 80%[6] believe that technology would progress sufficiently enough so that the safe evacuation of any personnel onboard a vessel could be undertaken through offshore supervision and by using automated technologies onboard.
Administration (i.e. paperwork and documentation)	More than 50%[6] believe that the vessel could take care of the majority of the onboard admin functions, however 38% still felt that there would need to be a human onboard to undertake admin tasks.	100%[6] believe that technology would progress sufficiently enough so that that the administration workload associated with shipping would be semi- to fully-autonomous delivered entirely off a vessel.
Physical Maintenance	Whilst technology will continue to progress steadily through innovation in maintenance trending and condition-based monitoring through (the use of AI and sensors), 40%[6] believe that there would be a medium reliance on human skills with regards to physical maintenance tasks.	100%[6] believe that technology would progress sufficiently enough so that any requirements for physical maintenance on a generic ship would become a monitoring function off a vessel, and that the vessels would see much more significant gaps in the need for recurring physical maintenance.

Table 3: The likely future status of reliance on human skills versus reliance on machines in performing operational tasks (IMarEST, 2019)**.**

Whilst the above positions from Department for Transport (2019) and IMarEST (2019) relate to vessel operations only, the potential reduction in personnel onboard can also be associated with the delivery of scientific research and monitoring activities. Other implications of marine autonomy will be:

- the skillsets required for those personnel remaining onboard (see Section 2.5).
- the extent of equipment and system redundancy (to address the enhanced reliance on autonomous systems with their associated back-ups and fail-safes).
- the associated introduction of, and subsequent compliance with set of agreed standards for the safe operation of equipment, at the both domestic and international level – Figure 2 shows the regulation map capturing the broader regulatory environment, including the organisations and activities operating within it, and the associated interdependencies (Department for Transport, 2019).

- the impact on the scientific organisations who operate and currently place scientific personnel onboard such vessels (see Section 2.6.3).

Due to the development of industries working on a push-pull basis, one of the possible factors on the progress made in this area is the outlook of people working within the maritime sector, and their views on how realistic development of autonomy will progress. For example, only 15.5% of the shipping industry believe that the industry is ‘geared up’ to support the implementation of remotely operated or autonomous vessels, and approximately 42% of the shipping industry believe that there are too many barriers to see the full adoption of remote or autonomous operations within the shipping sector (IMarEST, 2018). It is therefore important that, when considering future developments for the maritime sector, there is a balance of opinion, where each party understands the requirements and desired outcomes of the other.

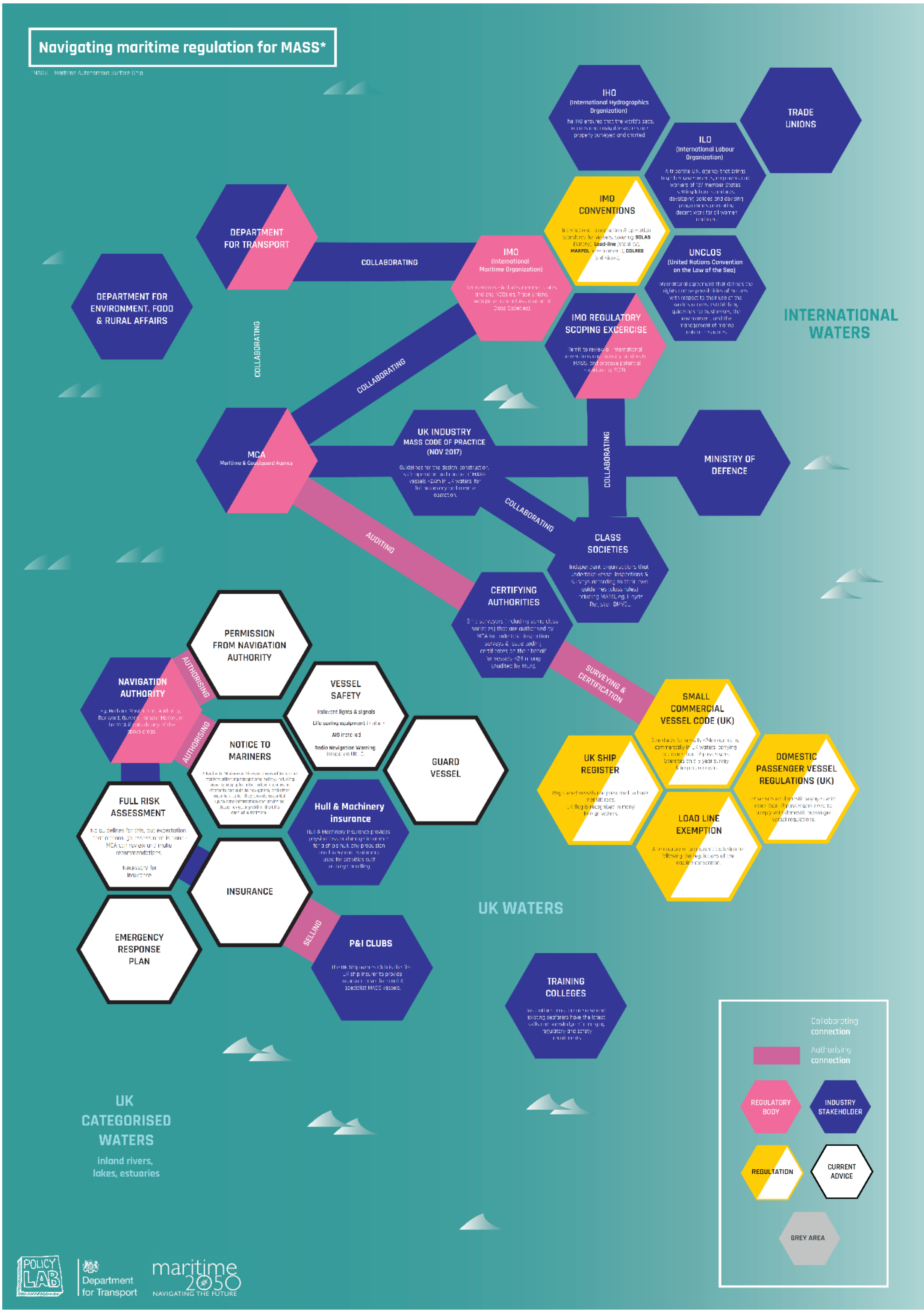

Figure 2: Navigating Maritime Regulations for Maritime Autonomous Surface Ships (MASS) (Department for Transport, 2019)

2.4. Climate Change and Green Technologies

2.4.1. Net Zero

In 2019, the UK became the first major economy in the world to pass laws requiring the UK to bring all greenhouse gas emissions to net zero by 2050, compared with the previous target of at least 80% reduction from 1990 levels (GOV.UK, 2019).

Following this, the UKRI Environmental Sustainability Strategy came into force in April 2020, with the objective achieve ‘net-zero’ for UKRI carbon emissions by 2040 (UKRI, 2020). To assist the realisation of this strategy, NERC funded the establishment of the Net Zero Oceanographic Capability (NZOC) scoping project to inform planning for the future low carbon oceanographic research capability (National Oceanography Centre, 2021). Within the NZOC project, NOC are considering how marine scientific research may be conducted beyond 2035, what role vessels and alternative technologies (e.g. autonomous and semi-autonomous systems) may play in this delivery, and how will this work towards UKRI’s net zero objectives (National Oceanography Centre, 2021).

2.4.2. Green Technologies

Most modern research vessels currently in service, and almost all new builds, are designed and built with requirements to be as environmentally friendly as possible with regards to emissions to air (nitrogen oxides, sulphur oxides, and particles), discharge to water (e.g. oil spills), fuel consumption, antifouling measures and radiated noise to air and water (Nieuwejaar, et al., 2019).

A small number of recently built research vessels within Europe have adopted fuels with lower carbon emissions than diesel. An example is Germany’s latest research vessel, *RV Atair*, which is the first research vessel powered by LNG (BSH, 2020). The benefits of operating LNG, when compared to a diesel-fuelled ship, are that the carbon dioxide emissions are reduced by around 20%, the emission of sulphur dioxide is reduced by 90%, and the emission of nitrogen oxides by around 80%, with particulate matter virtually non-existent. It should however be noted that the vessel has a diesel-gas-electric propulsion concept, meaning that electricity generation for the electric propulsion and manoeuvrability equipment is carried out by two dual-fuel engines, one of which is powered exclusively by LNG (10 day fuel capacity), and the other is a diesel engine intended as redundancy if the gas supply has failed or the LNG bunker supply is not guaranteed (Fassmer, 2020).

Similarly, in recognition of the need to embrace new fuels, and have the flexibility to transition to other fuel sources over time, the work surrounding the replacement of Marine Scotland’s *RV Scotia* will have a feasibility study performed regarding the use of liquefied natural gas (LNG) as a fuel, and an indication of a long-term aspiration of ammonia acting as the fuel source (Public Contracts Scotland, 2021).

Whilst ‘greener’ fuels are being introduced in the research community, and are becoming more widespread in the maritime sector, consideration must be given to the availability of infrastructure to support operational requirements. For example, such ‘greener’ fuels may be ideal as a sole source of fuel for vessels that operate in limited geographical areas who are frequently in the same port and can rely upon the establishment of supporting infrastructure, however these fuels may not be appropriate for vessels operating over vast geographical areas and only visiting ports every three-four weeks (Nieuwejaar, et al., 2019). In such instances, where reliance on diesel may remain due to the limited supporting infrastructure available, or the associated energy density (see below), it may be possible to consider alternative technologies (e.g. onboard batteries banks to take peak loading requirements) to reduce fuel use (and associated emissions).

However, it is inevitable that, in future years and decades, there will be a paradigm shift relating to ‘greener’ technologies and fuel sources in the marine sector, led by the moral and legal obligations imposed to address the UN defined “climate crisis”. The UK is observing a similar transition within the car industry, with legislation introduced by UK Government to end the sale of new petrol and diesel cars by 2030, and the investment of over £1.8 billion in infrastructure and grants to increase access to zero-emission vehicles and promote a green economic recovery (GOV.UK, 2020). A similar stimulus may therefore be required, either at a national or international level, to stimulate a similar transition between fuels within the maritime sector.

Considering alternative fuels, and future possible scenarios for their uptake, **Figure 3**, Figure 4 and Figure 5 present the estimates of the fuel utilisation (fuel mix) for UK shipping development under different scenarios, each of which involve a target of greenhouse gas reductions by set milestones dates (Frontier Economics, 2019). These scenarios are estimated to have broadly similar transitions, with all scenarios showing a competitive advantage of ammonia (over other fuel sources including hydrogen and methanol) from the 2030s onwards, and an estimation that ammonia will be the most prevalent fuel for shipping by 2051 (Frontier Economics, 2019).

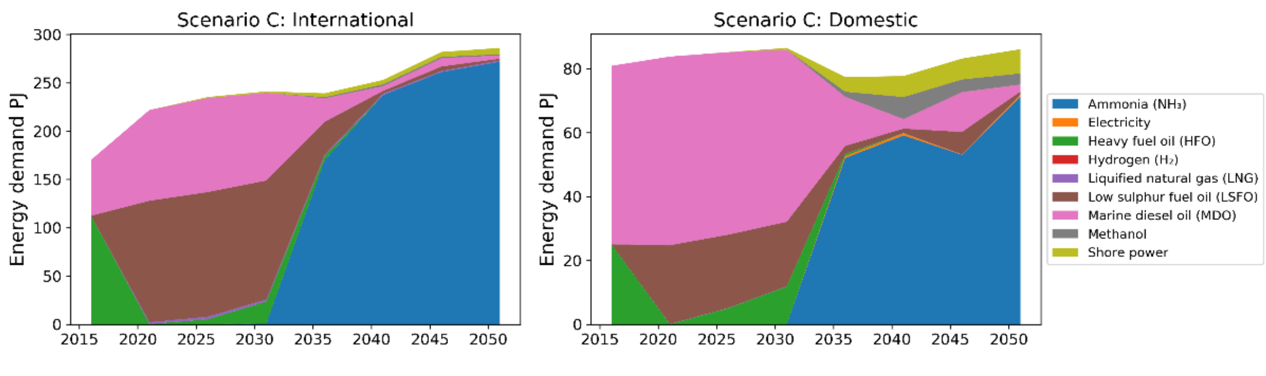

Figure 3: Projected fuel mix for UK shipping under a scenario (Scenario C) with a target of zero (operational) shipping greenhouse gas emissions globally by 2040 (Frontier Economics, 2019)**.**

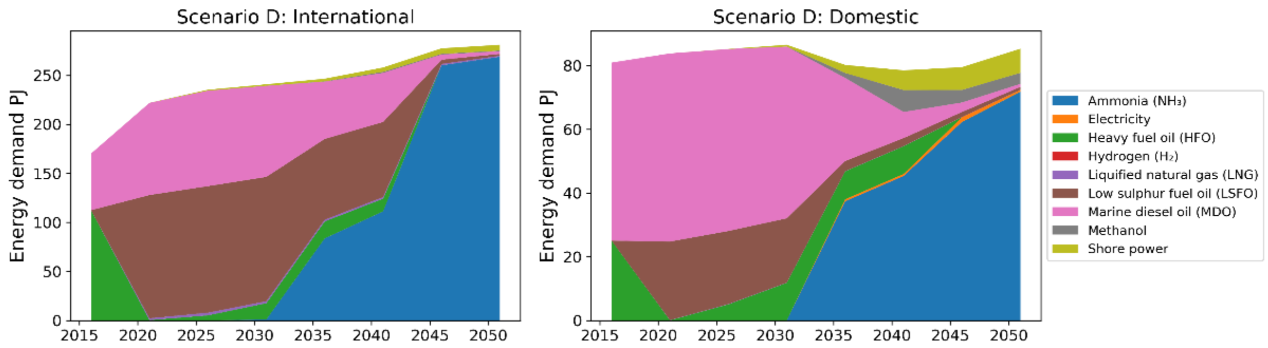

Figure 4: Projected fuel mix for UK shipping under a scenario (Scenario D) with a target of zero (operational) shipping greenhouse gas emissions globally by 2050 (Frontier Economics, 2019)

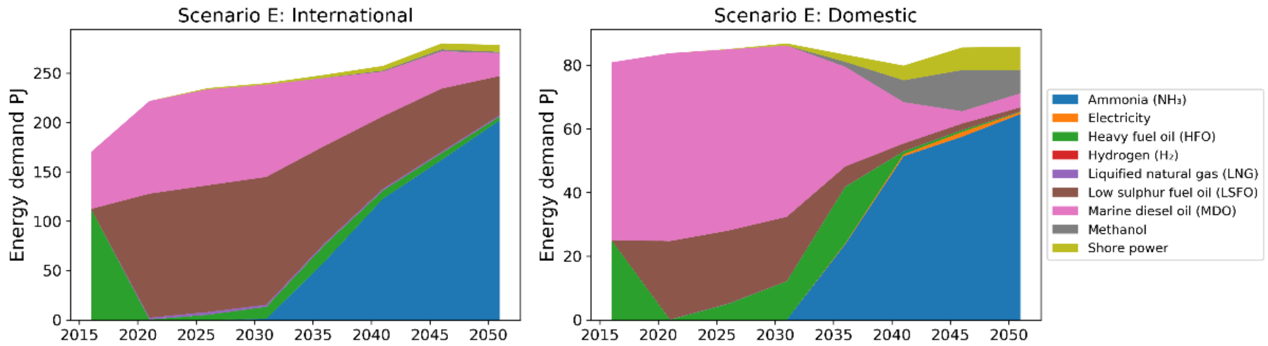

Figure 5: Projected fuel mix for UK shipping under a scenario (Scenario E) with a target of 50% absolute reduction in (operational) shipping greenhouse gas emissions globally by 2050 (compared to 2008); and zero (operational) shipping greenhouse gas emissions globally by 2070 (Frontier Economics, 2019).

Noting the changing mix of the alternative fuels over time in Figure 3, Figure 4 and Figure 5, when considering the infrastructure required to safely store them onboard, Figure 6 shows that fuels such as liquefied natural gas (LNG), liquefied petroleum gas (LPG), ammonia, methanol and bioethanol all require more space and are heavier than diesel.

Consequently, the energy density characteristics of fuels, determined by output by volume (volumetric) and/or output by mass (gravimetric), and their storage requirements (e.g. refrigerated/cryogenic or pressurized storage), can subsequently impact the design and use of a vessel, whether being refitted, or at new-build.

For refitting, it may be necessary to automate aspects of the vessel (see Section 2.3.3) to create space for the additional storage requirements for alternative fuels. Similarly, whilst it may be possible to automate certain processes for new build vessels to reduce the crewing level requirements (as per Section 2.3.3), the additional space requirements of alternative fuels may force new build vessels to maintain the size and capacity (relative to their predecessors).

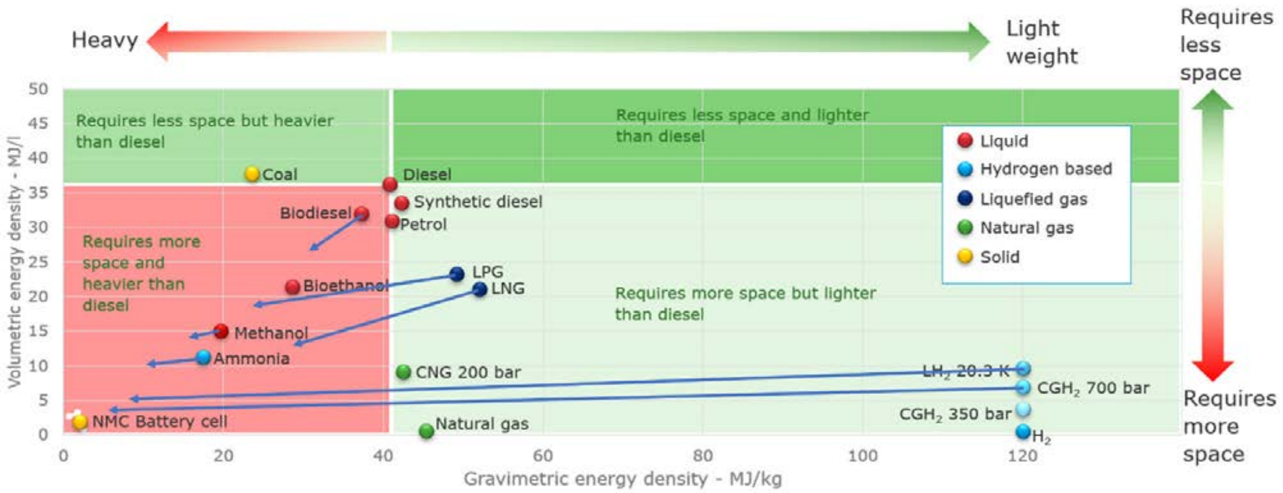

Figure 6: Energy densities for different fuels, with arrows representing the impact on density when taking into account the storage systems for the different types of fuel (DNV GL AS Maritime, 2019).

2.5. Skills Requirements

The shipping industry has embraced significant technological change before, with many tasks (which used to be carried out manually, including fire control and navigation) having been automated to some degree for decades (Department for Transport, 2019), and whilst majority of shipping industry representatives feel that many onboard roles could be relocated to shore (either now or into the future, others believe that it will be difficult (and therefore unlikely) to see fleets remove their deck and engineering officers and ratings (IMarEST, 2018).

2.5.1. Skills for a Wider Delivery Model

Whilst the majority of seafarers are concerned about the impact of autonomous shipping, threats to employment primarily stem from the failure to adapt, through retraining and the assimilation of new skills to perform new functions through continuing professional development (IMarEST, 2018).

As identified by IMarEST (2019), there is going to be an inevitable enhancement in automation onboard vessels, which in turn is likely to force traditional roles to be re-examined, and where appropriate, for traditional roles to be merged. Whilst this may indicate a reduction in the number of people required, there is also likely to be an increasing need for people to supervise and manage such systems, with such roles being delivered in increasingly diverse locations.

The skills required to operate a vessel, along with those required to deliver scientific research and monitoring, under this new operating model will be entirely dependent upon the technologies taken up by vessel operators and scientific organisations, along with their associated modes (and locations) of delivery. Due to the embryonic nature of some of these technologies, with the high likelihood that new technologies are developed over the coming years (for which training cannot be anticipated), it is not possible at this stage to define the skills that will be required by 2035 and beyond. However, it is likely that there will be a need to ensure that people in the maritime sector possess skills (and thus receive appropriate training) for:

- Alternative fuels (e.g. safe bunkering, onboard management, legislative/regulatory compliance, etc.).
- Computer and/or technology literacy.
- Electrical maintenance and repair (e.g. there may be an enhanced requirement for one of more of the vessel crew to be an Electro-Technical Officer – ETO).

2.5.2. Outlook

The introduction and adoption of autonomous and semi-autonomous technologies introduces new ways of organising work, meaning that it is possible for jobs to be less physically hazardous, and having the ability to provide a better work environment and 'normal' working hours, particularly with an anticipated increase in the proportion of roles delivered on land (IMarEST, 2020). With such improvements to accessibility and inclusivity, it subsequently becomes possible to attract different people to vessel related jobs, including women or those with reduced mobility, who are currently under-represented within the sector (IMarEST, 2020).

Recognising the support required for the sector to facilitate such improvements, (Department for Transport, 2019) recommend the following:

- In the short-term, a single industry body should be tasked with a responsibility for overseeing a more coordinated cross-sector in-school awareness and ambassador programme, and to bring greater coherence and coordination to the promotion of maritime careers sector wide.
- In the long-term, and to inform the maritime training curriculum and keep it up to date with the evolving needs of the sector, the UK Government will need to establish a Maritime Skills Commission (made up of existing leading maritime skills experts) to report on the existing and future skills needs of the industry on a 5-yearly cycle.

2.6. Integration, Collaboration and Transition

2.6.1. Integration and Collaboration

Nieuwejaar, et al. (2019) found that European research vessels are generally owned by a public body and that the management processes differs by country, ranging from a centralised management of almost all research vessels in countries such as France and

Germany, to nations with a range of different operators (e.g. the UK Research Fleet is operated by AFBI, BAS, Cefas, Marine Scotland, and NOC). Nieuwejaar, et al. (2019) consequently recommended that whilst the European research vessel fleet as a whole has huge potential to be more cost-effective if countries would be more willing to pool resources, even the sharing of resources (by creating national pools of equipment, marine technicians, and trained vessel crew) at a national level would introduce efficiencies. With increasing financial pressures on Government funds, enhanced by the COVID-19 global pandemic, efficiencies are likely to become a larger driving force in the future.

The consideration of improved coordination is not something new for the UK – the Marine Science Coordination Committee (MSCC) formed a group to develop and assess a range of practical and innovative proposals for managing and operating research vessels across the UK more effectively and efficiently, and subsequently issued a Report (MSCC, 2013).

It was proposed by MSCC (2013) that a UK public sector operated fleet could offer a considerable advantage (in terms of efficiencies), and whilst there is less opportunity to coordinate the work of the ‘global’ research vessels operated by BAS and NOC with the UK National Monitoring Fleet (due to the different areas of operation) improved coordination and sharing vessel programmes may provide the best opportunity to maximise the active days at sea for each ship.

Despite efforts within the MSCC Research Vessel Working Group to continue such discussions around integration and/or collaboration, no real progress has been made in this area for reasons including (but not limited to):

- a continuation of statutory and Ministerial signatory obligations during the intervening period, and the associated delivery by the relevant Government Departments and Devolved Administrations utilising majority of the UK National Monitoring Fleet capacity.
- the spare capacity of the UK National Monitoring Fleet being sold to UK and international Government customers, and commercial 3rd parties.

2.6.2. Anticipated Transition

Whilst a UK public sector operated fleet has not materialised as a result of the MSCC (2013) report for the above reasons, and it may not be possible to integrate vessel management processes between the UK Research Fleet operators into the future, the UK may benefit from findings by Nieuwejaar, et al. (2019) which highlighted that extensive recent networking activities have allowed international research vessel operators to integrate interoperability of equipment into the design of their research vessels. Consequently, with the new vessels being designed and built by AFBI and Marine Scotland, the ability for Cefas to contribute into the design process may enable greater future interoperability within the UK National Monitoring Fleet.

Furthermore, Nieuwejaar, et al. (2019) highlighted that the key to a successful future will be to work together and be ready to adapt to change in order to ensure that the European research vessel fleet remains capable and fit-for-purpose for addressing the scientific and societal challenges to come, while continuing to strive for efficiency. This can equally be applied at a national level, and UK Research Fleet operators should be encouraged to share experiences and best practices to inform others within the national community. With a finite budget available for vessel operators, it may also be appropriate for vessel operators to focus on identified strategic areas of development, with the potential for these to be employed across the domestic boundaries to drive efficiencies. In doing so, it may subsequently change the look of the UK Research (or National Monitoring) Fleet (and its scheduling of activities), moving from a fleet made up of numerous multi-disciplinary research vessel, to a fleet where some vessels become specialist platforms for the delivery of certain ‘automated’ scientific activities for the whole of the UK.

It may also be appropriate to consider the wider UK Government vessels (i.e. the vessel of LOA less than 50m which fall outside of the scope of this report) to ascertain whether synergies between the respective organisations and their future operating models can introduce efficiencies, and the role(s) that smaller vessels (with LOA <50m) will play in the delivery of the UK’s future requirements.

2.6.3. Consequences of Integration and Transition

From a vessel operator perspective, the development and operation of a UK public sector operated fleet (as proposed by MSCC (2013)), or the development of specialist national vessels, can introduce economies of scale, allowing the opportunity for financial savings (associated with a decreased workforce requirement and associated increased efficiency) to be made for the benefit of public value. This may not just be associated with the consolidation of shore management teams for the current operators of the UK Research (or National Monitoring) Fleet, and may also relate to the transition of roles from onboard to onshore (with the potential for deck and engineering officers overseeing the operation of multiple vessels). The removal of roles from onboard delivery will also decrease the amount of vessel space required for accommodation, and potentially the overall size of future vessels, which in turn could lead to reductions in ‘safe crewing’ levels and associated crewing costs.

Whilst such integration may offer benefits (as set out above), there are also potential barriers, including (but not limited to) the operational delivery mechanisms employed by the various organisations, the political landscape (with defined boundaries and responsibilities), etc. There may also be real and/or perceived risks associated with integration, including (but not limited to) the dilution of decision making responsibility and authority (for survey prioritisation and investment), and reputational impacts for organisations associated with the loss of iconic assets.

From a scientific research and monitoring perspective, there is a fine balance to strike. On one hand, a lack of investment in (and the development and acceptance of) autonomous and/or semi-autonomous solutions could be interpreted by current and prospective employees (or customers) as an organisation that is resistive to change, with a lack of vision and consciousness (for the impact to the environment caused by such platforms). On the other hand, the proactive investment in (and the development and acceptance of) autonomous and/or semi-autonomous solutions could be interpreted by current and prospective employees (or customers) as an organisation being efficiency focused, losing touch with the data collection methods underpinning current accepted scientific output, and providing a much-reduced career development path.

The outlook, and presentation to stakeholders, needs to be balanced, with lessons learned from similar organisations going through the identical process (for example those nations highlighted by Nieuwejaar, et al. (2019)). Organisations should also consider other industrial settings where the delivery of work has been successfully transitioned from an established workplace, to a more remote one. In support of this, organisations can reflect on the lessons learned when operating under the COVID-19 global pandemic, which saw large proportions of the workforce delivering work from home. Whilst technology may have been sufficiently developed to facilitate this overnight transition, the vision for future working includes a 'hybrid' scenario, with work delivered both in the workplace and at home (where possible to do so), with the ration between the two locations determined by the role (and work) being delivered. This recent and stark experience for organisations and individuals alike, and a generally optimistic vision of the 'hybrid working' future (that few could have anticipated in late 2019), allows organisations to showcase what can be gained (as opposed to what could be lost), and promote a conversation about how the organisation acknowledges it's history, whilst taking the necessary step of embracing the leading edge of marine scientific research.

3. Conclusions

There continues to be a requirement for scientific research and monitoring in support of the UK's statutory and Ministerial signatory obligations surrounding fisheries, environment, and biodiversity. Whilst there have been developments in autonomous and semi-autonomous technologies, there are limited examples of where such technologies have been accepted by the scientific community (as being suitable to replicate work from research vessels), and there are fewer examples of where they have entirely replaced the role of a research vessel.

There is an increasing global consciousness surrounding the 'climate crisis', and the role that industries, organisations, and individuals play in taking the appropriate steps to protect the global environment for successive generations. Such steps will enhance the role of vessels and/or autonomous and semi-autonomous technologies in their delivery of scientific research and monitoring at sea, and there will be a need to understand and address the balance of achieving desired climate outcomes with the requirement for scientific data (quality and quantity) to further enhance the detailed understanding of the global environment.

There is therefore an expectation that research vessels will continue to be required to deliver elements of the UK's scientific research and monitoring for the foreseeable future. Alongside this, the UK has an opportunity to:

- augment vessel delivery with autonomous and semi-autonomous technologies, in which there will need to be due consideration of the training requirements for the personnel supporting such technologies and vessels (either onboard or ashore), and the timeline associated with developing competency and confidence in the management of such systems.
- reconsider the established delivery model of scientists and technicians delivering desk-based roles onboard a vessel (in light of improving communication networks and remote access capability).
- better integrate / collaborate its vessel operations in a manner similar to other European nations (who operate a fleet). Such integration could be limited to the vessels within the UK National Monitoring Fleet, be extend further to the larger UK Research Fleet, or wider still to the UK Government fleet of all sizes. There is also the potential for vessels within the future UK Government fleet to become specialised for the delivery of defined/bespoke elements of the UK's statutory or Ministerial signatory obligations (where it is appropriate for them to do so).

4. Recommendations

There are a range of opportunities available for the UK, both in terms of leading and stimulating industrial growth, and in terms of being scientifically progressive.

It is therefore recommended that:

1. UK PSREs (operating the UK National Monitoring Fleet) explore and develop opportunities to apply autonomous and semi-autonomous technologies (e.g. uncrewed surface vehicles) for the collection of (aspects of) data and evidence in support of the UK's statutory and Ministerial signatory obligations, with a view to having such technologies employed in support of the UK National Monitoring Fleet (where affordable, offering public value, and without impacting scientific delivery) by 2025.
2. There is greater engagement between PSREs, scientific communities, regulators, and technology groups/developers to better understand the strengths, weaknesses, opportunities, and threats associated with the application of autonomous and semi-autonomous solutions to achieve current and future scientific research and monitoring requirements.
3. AFBI, Cefas, and Marine Scotland invite the other members of the UK National Monitoring Fleet to contribute into the design process for any new vessels (replacing *RV Corystes*, *RV Cefas Endeavour*, and *RV Scotia* respectively), with the desired outcome to integrate the interoperability of equipment into the design of the research vessels. Given the timing of any new builds, such design integration should be commenced at the earliest opportunity and be concluded by 2025.
4. Owners (collectively or individually) explore the use of alternative technologies (e.g. alternative and/or complementary power sources) over the remaining life of their vessels, with an aim to implement such technologies (where it is appropriate do so, whilst maintaining affordability of the platforms and continue to offer public value) and reduce the impact of the current delivery model to the environment (through greenhouse gas emissions). Due to the remaining life expectancies of both vessels, such exploration (and implementation where appropriate) should be undertaken at the earliest opportunity.
5. Cefas and NOC consider how scientific research and monitoring will be delivered by their respective organisations (and the rest of the fleet) into the future, with strategic roadmaps for the replacement of *RV Cefas Endeavour* and *RRS James Cook* (with due consideration of autonomous, semi-autonomous, and 'green' technologies) developed by the respective organisations.
6. The UK, through the MSCC RV Working Group or a suitable alternative body, investigate greater formal integration and/or collaboration at a national and/or international scale (considering the possibilities identified in Section 2.6), to realise efficiencies in the operating model, and the delivery of UK's future requirements.
7. The UK Research Fleet considers the application of their vessels to support wider UK Government delivery and initiatives.

5. Bibliography

Agreements reached between the United Kingdom of Great Britain and Northern Ireland and the European Union. (2020). Retrieved from GOV.UK: https://www.gov.uk/government/publications/agreements-reached-between-the-united-kingdom-of-great-britain-and-northern-ireland-and-the-european-union

British Antarctic Survey. (2021). *RRS Sir David Attenborough*. Retrieved from British Antarctic Survey: https://www.bas.ac.uk/polar-operations/sites-and-facilities/facility/rrs-sir-david-attenborough/

BSH. (2020). *The new ATAIR.* Retrieved from Bundesamt für Seeschifffahrt und Hydrographie (BSH): https://www.bsh.de/EN/The_BSH/Our_ships/New_Atair/new_atair_node.html

Carlisle, A., & O'Donnell, C. (2018). *Fisheries (White Paper).* Retrieved from XOCEAN: https://xocean.com/services/fisheries/

Cefas. (2020). *Centre for Environment, Fisheries & Aquaculture Science Annual Report and Accounts 2019-20.* GOV.UK. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/901098/Cefas_Annual_Report_and_Accounts_2019_2020.pdf

Department for Transport. (2019). *Technology and Innovation in UK Maritime: The case of Autonomy.*

DNV GL AS Maritime. (2019). *Comparison of Alternative Marine Fuels.* Retrieved from https://safety4sea.com/wp-content/uploads/2019/09/SEA-LNG-DNV-GL-Comparison-of-Alternative-Marine-Fuels-2019_09.pdf

Fassmer. (2020). *BSH acquires new surveying, wreck search and research vessel ATAIR.* Retrieved from Fassmer: https://www.fassmer.de/en/news/2020/bsh-uebernimmt-atair

Frontier Economics. (2019). *Reducing the maritime sector's contribution to climate change and air pollution.* London: Department for Transport. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816018/scenario-analysis-take-up-of-emissions-reduction-options-impacts-on-emissions-costs.pdf

GOV.UK. (2019, June 27). *UK becomes first major economy to pass net zero emissions law*. Retrieved from GOV.UK: https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law

GOV.UK. (2020). *Benyon Review Into Highly Protected Marine Areas | Final Report.* Retrieved from https://www.gov.uk/government/publications/highly-protected-marine-areas-hpmas-review-2019

GOV.UK. (2020, November 18). *Government takes historic step towards net-zero with end of sale of new petrol and diesel cars by 2030*. Retrieved from GOV.UKJ: https://www.gov.uk/government/news/government-takes-historic-step-towards-net-zero-with-end-of-sale-of-new-petrol-and-diesel-cars-by-2030

GOV.UK. (2021). *Marine Science Co-ordination Committee (MSCC)*. Retrieved from GOV.UK: https://www.gov.uk/government/groups/marine-science-co-ordination-committee#working-groups

Houlder. (2019, September 23). *Sir David Attenborough Celebrations*. Retrieved from Houlder: https://houlderltd.com/sir-david-attenborough-naming-celebrations/

ICES. (2020). ICES Workshop on unavoidable survey effort reduction (WKUSER). *ICES Scientific Reports, 2*(72), 92. doi:http://doi.org/10.17895/ices.pub.7453

IMarEST. (2018). *Autonomous Shipping: Putting the human back in the headlines.* Singapore: Institute of Marine Engineering, Science and Technology (IMarEST). Retrieved from https://www.imarest.org/reports/1009-autonomous-shipping/file

IMarEST. (2019). *Auonomous Shipping: Putting the human back in the headlines II.* Institute of Marine Engineering, Science and Technology (IMarEST). Retrieved from https://www.imarest.org/reports/1055-autonomous-shipping-putting-the-human-back-in-the-headlines-ii/file

IMarEST. (2020, March 19). *Marine Professional Special Report: Autonomous Shipping*. Retrieved from Institute of Marine Engineering, Science and Technology (IMarEST): https://www.imarest.org/themarineprofessional/item/5497-marine-professional-special-report-autonomous-shipping

Maritime & Coastguard Agency. (2019). *UK Civil Hydrography Programme: 2019 Edition.* Maritime & Coastguard Agency.

MSCC. (2013, April 2). *UK Marine Research Vessels: proposals for improved co-ordination.* Retrieved from GOV.UK: https://www.gov.uk/government/publications/uk-marine-research-vessels-proposals-for-improved-co-ordination

National Oceanography Centre. (2021). *National Marine Equipment Pool*. Retrieved from National Oceanography Centre: https://noc.ac.uk/facilities/national-marine-equipment-pool

National Oceanography Centre. (2021). *Net Zero Oceanographic Capability*. Retrieved from Net Zero Oceanographic Capability: https://projects.noc.ac.uk/nzoc/

Nieuwejaar, P., Mazauric, V., Betzler, C., Carapuço, M., Cattrijsse, A., Coren, F., . . . Naudts, L. (2019). *Next Generation European Research Vessels: Current Status and Foreseeable Evolution.* (J. K. Heymans, Ed.) Ostend, Belgium: European Marine Board. doi:10.5281/zenodo.3477893

Parliament.uk. (2016, December 17). *Summary of conclusions and recommendations.* Retrieved from Parliament.uk: https://publications.parliament.uk/pa/ld201617/ldselect/ldeucom/78/7814.htm

Public Contracts Scotland. (2021). *Notice*. Retrieved from Public Contracts Scotland: https://www.publiccontractsscotland.gov.uk/search/show/search_view.aspx?ID=FEB406248

Sonardyne. (2020, December 1). *Unattended Sensors, Easier Said Than Done*. Retrieved from Sonardyne: https://www.sonardyne.com/unattended-sensors-easier-said-than-done/

Tenders Electronic Daily. (2021). *Contract Award Notice*. Retrieved from Ted - Tenders Electronic Daily: https://ted.europa.eu/udl?uri=TED:NOTICE:62959-2021:TEXT:EN:HTML&tabId=1

UKRI. (2020, December 3). *Environmental sustainability.* Retrieved from UKRI: https://www.ukri.org/about-us/policies-standards-and-data/environmental-sustainability/

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We are the government's marine and freshwater science experts. We help keep our seas, oceans and rivers healthy and productive and our seafood safe and sustainable by providing data and advice to the UK Government and our overseas partners. We are passionate about what we do because our work helps tackle the serious global problems of climate change, marine litter, over-fishing and pollution in support of the UK's commitments to a better future (for example the UN Sustainable Development Goals and Defra's 25 year Environment Plan).

We work in partnership with our colleagues in Defra and across UK government, and with international governments, business, maritime and fishing industry, non-governmental organisations, research institutes, universities, civil society and schools to collate and share knowledge. Together we can understand and value our seas to secure a sustainable blue future for us all, and help create a greater place for living.

Pakefield Road, Lowestoft, Suffolk, NR33 0HT

The Nothe, Barrack Road, Weymouth DT4 8UB

www.cefas.co.uk | +44 (0) 1502 562244