Next generation

European Research Vessels

Current status and Foreseeable Evolution

Position Paper 25

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Next Generation European Research Vessels

Current Status and Foreseeable Evolution

European Marine Board IVZW Position Paper 25

This Position Paper is a result of the work of the European Marine Board Expert Working Group on Next Generation European Research Vessels (WG Research Vessels, see Annex 1), co-organized with the European Research Vessel Operators (ERVO – see Box 1.1 for more information).

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Foreword

Many of the global challenges facing the world today – climate change, food and water security, health and well-being, and economic development – are driving the ever-greater need for science to help understand and ultimately address these challenges. The natural, and in particular the marine sciences, have a significant role to play, and the research vessel fleet is called upon to deliver data and support globally important scientific research. Science has used ships as instruments for research since at least the 1700s, and the evolution of usage from instrument to laboratory can be traced through history. Today's research vessels have been shaped to become complete research support platforms by the demand for scientific knowledge, fast-paced technological development and the increasing need for new ocean observations.

Given the context in which Europe's research vessel fleet is now operating, and the rapid developments in technology such as smart sensors and autonomy seen in recent years, it was timely to review the current status of the fleet and its ability to deliver the data that is needed. It is more than 10 years since the first EMB Position Paper on research vessels was published, and a lot has changed in that time. In particular, new research frontiers have arisen, especially in the deep sea and Polar regions, placing a new set of demands on the capabilities of vessels.

This Position Paper provides a review of the current European research vessel fleet, its capabilities and equipment, assessing its ability to support science across the globe now and into the future. It also takes a wider vision, assessing the importance of these vessels in the ocean and earth observing landscape. This review includes not only technological but also human capabilities, looking at training needs for crew and technicians to ensure they can continue to deliver on critical science needs. It also considers the ways in which the current European fleet is managed.

This Position Paper sets out recommendations for how the fleet will need to develop in the future to ensure that it will continue to provide the same high level of support to science globally, as well as highlighting ways in which management could be made more efficient. It is aimed at national- and European-level policy makers and funders, as well as the marine science community and the research vessel operator community.

On behalf of the EMB membership, I would like to sincerely thank the members of the EMB Research Vessels expert working group (Annex 1) for their enthusiasm and drive in producing this publication. I would particularly like to thank working group Chair Per Nieuwejaar and co-Chair Valérie Mazauric for their dedication to delivering this excellent document, as well as the chapter leaders Lieven Naudts, Olivier Lefort, André Cattrijsse, Erica Koning and Giuseppe Magnifico. I would also like to thank ERVO for proposing to revisit this topic and for their collaboration in producing this document. Finally, I note with thanks the efforts of the EMB Secretariat in ensuring that this publication was delivered successfully, in particular Paula Kellett, Sheila JJ Heymans and Cláudia Viegas. I hope that this publication will help carry the European research vessel fleet into a new and exciting era of exploration, which will inspire interest in science across wider society.

Gilles Lericolais

Chair, European Marine Board IVZW

October 2019

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Executive Summary

The European research vessel fleet plays a vital role in supporting scientific research and development not just in Europe but also across the globe. This document explores how the fleet has developed since the publication of the European Marine Board Position Paper 10 (EMB PP 10) "European Ocean Research Fleets – Towards a Common Strategy and Enhanced Use" (Binot *et al.*, 2007). It looks at the current fleet and its equipment and capabilities (Chapter 2), the deep sea (Chapter 3) and Polar regions (Chapter 4) as study areas of ever-increasing importance for science and for the vessels that explore them, the role that research vessels play in the wider ocean observing landscape (Chapter 5), the importance of training personnel for research vessels (Chapter 6), and considers management of the European research vessel fleet (Chapter 7). This Position Paper considers what has changed since 2007, what the status is in 2019, and future directions for the European fleet, with a 10-year horizon to 2030.

This Position Paper finds that the current European research vessel fleet is highly capable, and is able to provide excellent support to European marine science and wider scientific research and can lead on the world stage. However, with a typical life expectancy of a research vessel of 30 years, the fleet is ageing and urgently requires further investment and reinvestment to continue to be as efficient and capable as the scientific community expects and requires. The capabilities of the fleet have increased considerably since 2007, and vessels have kept up with fast-paced technological developments. The demand for complex and highly capable vessels will continue, and research vessel designs and the fleet as a whole will need to keep pace in order to remain fit-for-purpose and continue to be a key player globally.

There is huge diversity in vessel types and designs in terms of capabilities and equipment, management structures and processes, and training possibilities. While it would not be possible or appropriate to highlight any one approach as the only one to use, a growing trend in collaboration through community groups, agreements, legal entities and funded projects now enables more strategic thinking in the development of these vital infrastructures. However, some issues remain in enabling equal access to research vessel time for all researchers across Europe regardless of country, and regardless of whether or not that country owns a suitable research vessel for their scientific needs.

THE FLEET IN FIGURES

99
VESSELS

Operated by 62 operators
in 23 different European countries.
6 countries own more
than 5 vessels

25
YEARS

Average age of the fleet is 25 years.
The fleet is split equally into 1/3 Local
and Coastal Class, Regional Class, and
Ocean and Global Class

Detailed recommendations arising from this Position Paper are outlined at the start of each chapter; however, the overarching recommendations are that:

- Information and data on the capabilities and equipment of the European research vessel fleet should be kept up to date and continue to be made available through the EurOcean Research Infrastructure Database[1] (EurOcean_RID, see Box 2.1). This data should be periodically reviewed by the infrastructure owners with support from the European Research Vessel Operators (ERVO) group (see Box 1.1) in order to remain able to support science needs, and to keep users, decision makers and funding agencies informed about status and trends;
- For the European research vessel fleet to remain capable and fit-for-purpose, both the fleet and its scientific equipment and instruments should be renewed and developed as a matter of urgency. Given the time-frames involved, this will require ongoing strategic planning through communication with all relevant stakeholders;
- The research vessel community should continue on its path towards greater collaboration in order to aim for equal access to research vessel time based on excellent science not (constrained by) the country of origin of the scientist, for more effective use of resources, for appropriate training for all parties, and for strategic planning of the research;
- Funding agencies should engage in discussions with the research vessel and marine science communities as well as other relevant stakeholders to identify key funding needs. This could for example be achieved through formal invitation of relevant agencies to future International Research Ship Operators (IRSO) (see Box 7.2) and ERVO (see Box 1.1) meetings. These needs will cover fleet renewal and development, training, transnational access for ship-time, and joint research programmes;
- The research vessel operators community should continue to look forward to the emerging science and technological developments (e.g. towards real-time data delivery, new autonomous systems, new science frontiers) and work together with relevant parties to ensure that the fleet is ready to support these.

8

DEEP-SEA VESSELS

that can deploy a full set of deep-sea equipment and a total of 16 vessels that can conduct some research in the deep sea

9

POLAR VESSELS

with ice-breaking capability and a total of 24 vessels that have some ice-going capability

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[1] www.rid.eurocean.org

1

Introduction

Credit: Artevelde Hogeschool

Ocean science is ‘big science’, involving sophisticated and costly equipment ranging across all shapes and sizes of research vessels (RV), some with the ability to deploy remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs) and gliders, to deploy and recover fixed platforms such as observatories and moorings (UNESCO, 2017). Research vessels are a key research infrastructure offering vital access to our seas and ocean for conducting marine science and ocean observing (European Marine Board, 2013).

The Marine Board – ESF[2] Position Paper (PP) 10 "European Ocean Research Fleets – Towards a Common Strategy and Enhanced Use" (Binot *et al.,* 2007) was published in March 2007. This Position Paper included an inventory and description of the existing fleet, and recommendations on their enhanced use and management at a pan-European level. Now, more than ten years on, the research landscape has evolved significantly.

Driven by the need to understand the inevitable and often far-reaching impacts of changing global systems (e.g. climate, population, resource use) (European Marine Board, 2019; IPCC, 2019), the demand for ocean data is higher than ever. The focus for marine research is increasingly moving into remote areas, such as Polar and deep-sea regions, placing specific demands on the research vessels that are called on to procure this data.

Scientific research generally requires large budgets, usually resourced from the public. This often leads to the question ‘why is it important to go to sea and spend all this money?’. Consequently, scientists and policy makers are keen to be able to demonstrate results. The focus in marine science traditionally has been on the scientific outcome, publication of results in scientific journals and new discoveries such as species and/or processes. However, with the growing interest in the blue economy and the resources that the ocean can provide, the focus will increasingly shift towards more exploration to increase knowledge and understanding within the context of human and societal relevance. This will change the paradigm of marine scientific research away from a pure focus on scientific knowledge and understanding and will make the importance of marine scientific research more visible.

This paradigm shift is also aligned to several political drivers that demand data collection for the creation of science-informed policies. These political drivers include:

- European Union directives such as the Marine Strategy Framework Directive[3] (MSFD) and the Water Framework Directive[4] (WFD) requiring EU Member States to conduct regular monitoring in their own waters to demonstrate compliance against clearly prescribed indicators;
- Various types of national legislation requiring similar measures, such as the Norwegian Marine Resources Act[5];
- The Sustainable Development Goals[6] (SDG’s), and especially SDG14 (Life below water), which places added political pressure on countries to understand the status of ocean health, pressures and impacts on their national waters; and
- Legal and political activities where coastal nations wish to define their Exclusive Economic Zones (EEZ) under the UN Convention on the Law of the Sea (UNCLOS), which increases demand for physical and biological ocean research worldwide.

Credit: Karen Hissmann, GEOMAR (CC BY 4.0)

The German research vessel *Maria S. Merian*

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[2] On 1 January 2017 the organization became a separate legal entity called the European Marine Board IVZW, www.marineboard.eu

[3] http://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive/index_en.htm

[4] http://ec.europa.eu/environment/water/water-framework/index_en.html

[5] https://www.fiskeridir.no/English/Fisheries/Regulations/The-marine-resources-act

[6] https://www.un.org/sustainabledevelopment/sustainable-development-goals/

The demands from many stakeholder groups for data and information provided by research vessels will only continue to grow, as deduced from the increasing number of geographical- and scientific research areas in which ocean data is of importance. As an example, most of the scientific priorities of the UN Decade of Ocean Science for Sustainable Development[7] (2021-2030) will not be achievable without significant support from research vessels (see Table 1.1). Research vessels will also be vital in delivering the data to support future marine science requirements, such as those outlined in EMB's PP 24 *Navigating the Future V* (European Marine Board, 2019). This same prediction of increasing demand for data from various stakeholders including science, applied science and industry is echoed in a similar report from the US (National Research Council of the National Academies, 2009). While this report is now 10 years old, the messages it contains remain very relevant and further demonstrate not just the European but also the global need for more data.

SCIENTIFIC PRIORITY	RESEARCH VESSEL RELEVANCE
1. Comprehensive digital atlas of the ocean	Provision of the means to aquire the data which will underpin the atlas
2. Comprehensive ocean observing system for all major basins	Enabling installation, maintenance and calibration of ocean observation infrastructures, and delivering the monitoring needed for a fully comprehensive ocean observing system
3. Quantitative understanding of ocean ecosystems and their functioning as the basis for their management and adaptation	Key provision of data to enable understanding and analysis
4. Data and information portal	Provision of data, including in real- and near-real time
5. Integrated multi-hazard warning system	Data collection and observation infrastructure support, especially in critical deep-sea and Polar regions
6. Ocean in earth-system observation, research and prediction, supported by social and human sciences and economic valuation	Providing observations but also providing a research vessel operators perspective on social, human and economic valuation of fleet, equipment and infrastructures
7. Capacity-building and accelerated technology transfer, training and education, ocean literacy	Technological innovation to enable new science and research vessels as a great tool for outreach and ocean literacy promotion
8. Provide ocean science, data and information to inform policies for a well-functioning ocean in support of all sustainable development goals of 2030 Agenda	Provision of data conducted in a sustainable manner to the science community, in order to support policy- and decision-making

Table 1.1 Research vessel relevance to the scientific priorities of the UN Decade of Ocean Science for Sustainable Development

The EUROFLEETS+ project (see Box 2.3) will conduct a mapping exercise to understand the current European landscape of research vessel stakeholders and their needs[8] better.

The evolution of marine science has driven a technological revolution. This has come in the form of autonomous systems, improved interfaces with existing earth and ocean observing systems, more capable and environmentally sensitive vessels, and a move towards greater digitalization. This revolution has significantly increased the support that research vessels can provide to the scientific and political communities, and will continue to be a significant factor in future. At the same time, such innovations will in turn have significant influence on the design of future research vessels.

Taking these developments into account, the European Marine Board (EMB) and the European Research Vessel Operators (ERVO, see Box 1.1) communities agreed to build on EMB Positon Paper 10 and to assess the capabilities within the European research vessel fleet and its community once more. It is also important to identify where the fleet and the community will need to adjust their strategy to ensure that European research vessels continue to provide excellent support to the scientific and political communities in the future.

The Position Paper does not discuss the costs and economics associated with research vessels, which is a very complicated and nuanced topic. As a general rule for research vessels, the crew accounts for 40-60% of the costs depending on the crew size, which can vary significantly between different nations due to national legislation and union agreements. Some nations allow a two-watch system (12 hours work per day) while others use a three-watch system (8 hours work per day) which can lead to a 33% difference in crew size for deck, bridge and engine room staff. Fuel cost is 15-20% of the total operating budget for open water vessels and as much as 40% for Polar vessels. Other costs (maintenance, insurance, consumables, harbour fees, food, travel cost for crew changes etc.)

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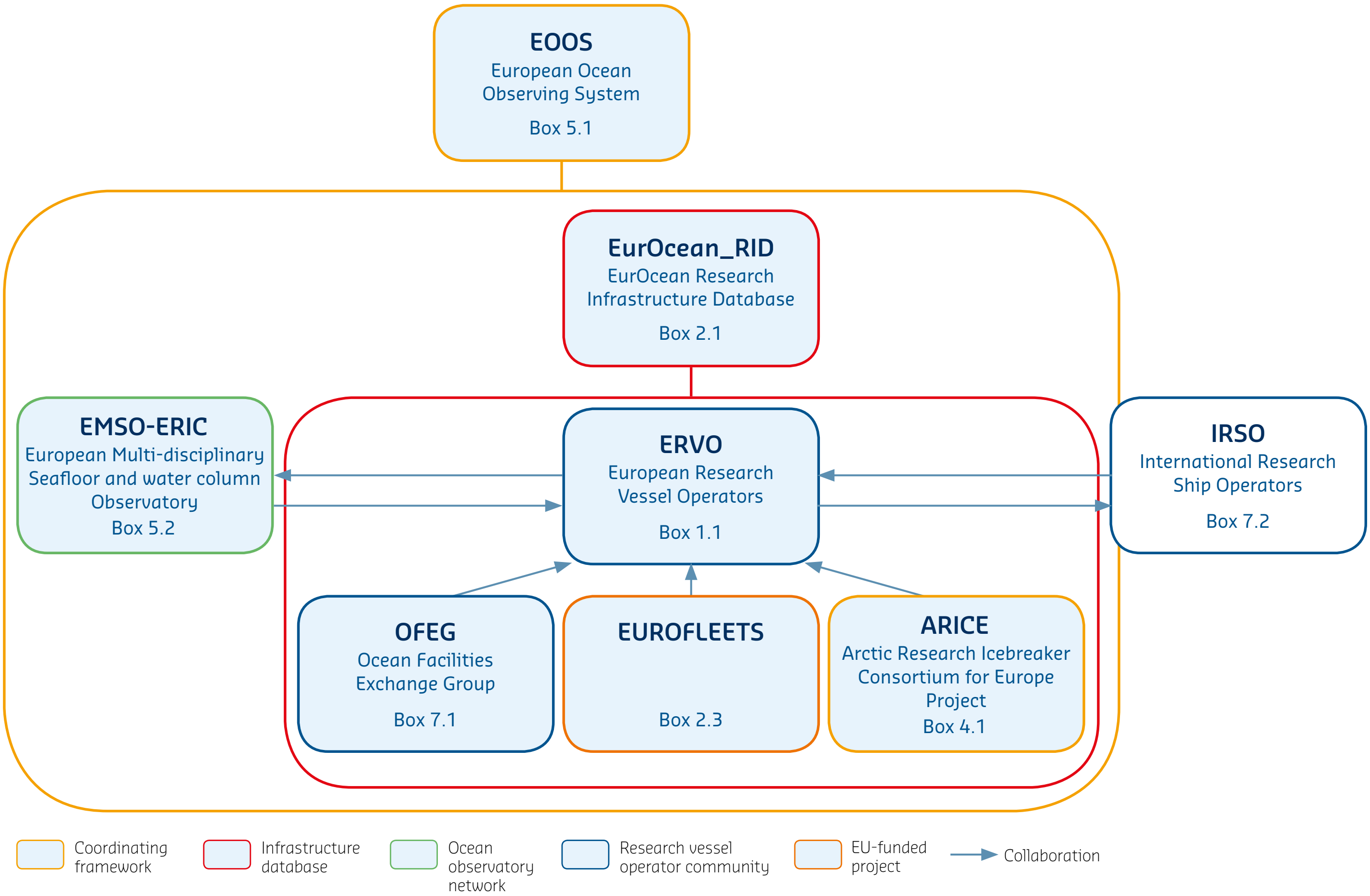
[7] https://oceandecade.org/

[8] https://www.eurofleets.eu/project-information/work-packages/wp5/

account for around 25%. Further discussion on the costs associated with research vessel operations can be found in the report from the US National Research Council of the National Academies (2009).

This document presents the current status of the European research vessel fleet with a comparison to the status in 2007, focusing in particular on the capabilities of the fleet to support current and future Polar and deep-sea research needs. It considers the role of research vessels within the wider scope of ocean observation systems, in particular the European Ocean Observing System (EOOS – see Box 5.1). It also considers the research vessel community; the management of the fleet and the people behind the vessels, looking at training options and needs, and considering how the fleet is and could be managed in the future within Europe. Finally, the publication provides recommendations for the fleet and for the community going forward.



Credit: European Marine Board

Figure 1.1 Overview of key networks and projects related to European research vessels

BOX 1.1 EUROPEAN RESEARCH VESSEL OPERATORS (ERVO)

http://www.ervo-group.eu

The European Research Vessel Operators (ERVO) group started in 1999 as a panel under the auspices of the ESF-Marine Board (now European Marine Board), to serve as a flexible forum to share common experiences, and to explore co-operation between research vessel managers. A formal Terms of Reference (ToR) for the group was adopted in 2011, and in 2014, ERVO signed a service agreement with the EurOcean Foundation[9]. The group has grown from seven regular participating countries, to over 18. ERVO meetings allow research vessel managers and operators to share information on national fleets and identify new requirements and solutions to enable research vessels to continue to serve the scientific community, and share best practice.

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[9] http://www.eurocean.org, see Box 2.1

2

Research vessels as a platform and interface for ocean technology

Credit: SOCIB, Tomeu Cañellas Moragues

Background

The size and capabilities of the European research vessel fleet and associated scientific equipment and instruments must be adapted to the current and foreseeable demands for marine data collection and sampling in national, European and international waters. This chapter describes the major changes in the European research vessel fleet and Large EXchangeable Instruments (LEXI) since the EMB Position Paper (PP) 10 (Binot *et al.*, 2007) and some predictions of future trends.

Conclusions

Based on the analysis of information on 99 European research vessels operated by 62 research vessel operators in 23 countries, the following conclusions were made:

- The size of the European research vessel fleet is relatively stable, but the average age of the vessels is increasing and now stands at 25 years;
- In comparison with older research vessels, the newly built European research vessels are more multipurpose and equipped with more capable scientific instruments and equipment, with increased data handling and data transfer capacity, have lower underwater noise signatures and increased ability to deploy and recover large instruments and vehicles;
- The European research vessels are operated for both research and monitoring activities. A vessel operating a single crew will typically operate on average 180 days per year, and a vessel with two crews will deliver on average 250-270 science days per year;
- The size of the European LEXI pool has seen a major increase since 2007, in particular the number of autonomous underwater vehicles (AUVs) and remotely operated vehicles (ROVs) etc., in addition to the introduction of autonomous gliders. Currently 88 underwater- and surface-vehicles (e.g. AUVs, ASVs and ROVs) are available for research in Europe;
- Over the coming 15 years, no substantial increase of the European research vessel fleet size and a moderate number of replacements of existing vessels is expected, and so research and monitoring activities will be performed with a continuously ageing research vessel fleet if no action is taken.

Recommendations

- The size and composition of the European research vessel fleet, its capabilities, and the available equipment (both LEXI and a new proposed category of Medium-sized EXchangeable Instruments (MEXI)) need to be monitored and described at regular intervals to keep the scientific community, funding agencies and decision makers informed about status and trends. This information should be available on the EurOcean Research Infrastructure Database (EurOcean_RID), and appropriate support should be provided to ensure its continuation and accuracy;
- The European research vessel fleet is ageing and needs to be modernized and renewed at a faster pace than done currently to meet not only the current demands, but also the foreseeable demands of the future, in terms of both quantity and capability;
- Since the present study mainly focuses on Global, Ocean and Regional Class research vessels, a separate study on the full Local and Coastal Class European research vessel fleet should be undertaken to understand their status, trends, management approaches, challenges and future development opportunities.

2.1 Current status and foreseeable evolution of the European research vessel fleet

Research vessels and their associated capabilities and instruments are required to study and understand the ocean and seas. European research vessels are mainly deployed for fundamental marine research as well as to monitor the influences of human activities on the marine environment. In recent years with the introduction of European Union framework directives (e.g. Marine Strategy Framework Directive (MSFD), Water Framework Directive (WFD), etc.) and other regional and national regulations, the boundary between marine research and monitoring is less clear since budgets and infrastructure need to be shared. In the European context, the importance of the marine environment is becoming more significant (see for example the blue economy[10] concept, the next European Framework Programme's Mission on Healthy Oceans, Seas, Coastal and Inland Waters and other blue initiatives). This results in higher demand for marine data and knowledge, and hence marine research infrastructures (research vessels, ocean instruments, etc.). A strategy is therefore required for understanding the status and foreseeable evolution of the European research vessel fleet, its capabilities and associated LEXI, and how this relates to trends in demand.

In order to understand the status of the fleet and its equipment, a comprehensive and centralized record of this information is needed. EurOcean's Research Infrastructures Database (EurOcean_RID, Box 2.1) currently fulfils this purpose, and should continue to be the place for recording and presenting this information. EurOcean_RID is a searchable database of the European marine infrastructures in Europe. It is managed by the EurOcean Foundation Secretariat and financed via membership fees paid by EurOcean members (FRCT, VLIZ, FCT, Ifremer, IMR, IO-PAN, MI, GeoEcoMar, CNR, Nausicaa, IEO, Submariner and CESAM). Infrastructure owners and operators are encouraged to update their own information on a regular basis. However, it is clear from a number of inaccuracies in the database that this is cannot always be done. While the authors of this Position Paper commend the work that is done to maintain and host this database on a voluntary basis, it is apparent that the current system cannot always provide a comprehensive and up-to-date database. This database of marine research infrastructures is the only one of its kind in Europe and represents an invaluable resource to the scientific community, funders and decision makers alike. In order to make it fit-for-purpose and to ensure that it is not lost, dedicated European level funding is required. This would enable dedicated staff time to work with the research vessel operators community in a continuous strategic and efficient way to ensure the information remains up to date, is validated and fulfils user requirements.

In order to ensure that relevant information and views from the whole community of research vessel stakeholders were considered within this Position Paper, the working group interacted with stakeholders in a number of different ways including through surveys, consultations and presentations. More details can be found in Annex 3.


Credit: SOCIB

Spanish research vessel RV *SOCIB*

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[10] http://www.worldbank.org/en/news/infographic/2017/06/06/blue-economy

BOX 2.1 EUROCEAN RESEARCH INFRASTRUCTURES DATABASE (EUROCEAN_RID)

http://www.eurocean.org
EurOcean, the European Centre for Information on Marine Science and Technology, is an independent scientific non-governmental organization established in 2002, whose membership comprises leading European marine research, funding and science communication organizations. Its aim is to facilitate information exchange and generate value-added products in the field of marine science and technology between a wide range of governmental and non-governmental bodies.

http://rid.eurocean.org/
The EurOcean_RID (Research Infrastructures Database) is the largest of its kind in Europe, and offers a list of all existing facilities in Europe that are dedicated to marine sciences' broad range of activities.

This Position Paper used information from two EurOcean databases: EurOcean_RV and EurOcean_LEXI. Meanwhile, those two databases were merged with two others (the Aquaculture Experimental and Research Facilities Infobase (AF), and the Research Infrastructures Database (RID)) into a new database launched on 16 May 2019; EurOcean's Research Infrastructures Database (EurOcean_RID). This new database was updated, harmonized and standardized with the support of relevant stakeholders such as ERVO and EUROFLEETS, and will now also benefit from the results of this Position Paper.

2.1.1 The research vessels of the present European research vessel fleet

The number of research vessels considered as part of the European research vessel fleet is highly variable when consulting different sources, ranging from 46 to 302 vessels. This variability is due to differences in selection criteria (ship's class, type of activity, type of owner, etc.) for these different datasets. This complicated the current and future fleet evolution assessment, the methodology of which is summarized below. This was overcome through the development of four criteria, described below, to define which vessels should be included in the assessment.

2.1.1.1 Selection criteria

For the current assessment, an initial listing was made of all research vessels included in the EUROFLEETS2 Fleet Evolution Group (FEG) report (EUROFLEETS2 Consortium, 2017a), the EurOcean European Research Vessel Infobase and the EurOcean Marine Research Infrastructure database. After the initial integration of the different databases, 278 research vessels were listed.

The list of 278 research vessels was then reviewed by the ERVO community (see Box 1.1) and further categorized using the three criteria listed below:

- **Criterion n° 1:** The research vessel should be openly available for, and known to perform, research. Research vessels performing monitoring, stock assessments, hydrography, naval research, etc. were only included if part of their activity is allocated for public research[11];
- **Criterion n° 2:** A research vessel should operate at least on a regional scale. Research vessels only operating on a daily basis (i.e. locally) should be excluded;
- **Criterion n° 3:** A research vessel belonging to a private company and not operating for public research was excluded.

The list was then sent to all responsible research vessel operators and managers to gather any further information. This filtering process led to a refined list of 119 research vessels. The majority of the vessels that were removed from the initial list list of 278 vessels corresponded to research vessels operated only on a daily basis (Criterion n° 2), followed by research vessels not involved in public research (Criterion n° 1), or operated by and for the private sector (Criterion n° 3).

To ensure that all listed research vessels have at least the minimum expected capabilities for a multi-disciplinary research vessel operating on at least a regional scale, an additional criterion was added. This differed from the selection methodology used in EMB PP 10, where the ship's length (taken as a minimum length of 35m) was chosen as an indication of the ship's capability. The approach adopted in this assessment was based on the definition of a minimum set of capabilities that together form a final selection criterion (Criterion n° 4):

Criterion n° 4:

- Ability to deploy a CTD (Conductivity, Temperature and Depth)-rosette and a small towed body;
- Ability to deploy a small-sized sediment/fauna sampling device;
- Ability to deploy a plankton net, a small trawl, and a sledge, etc.; and
- Having at least one kind of scientific acoustic sensor (e.g. scientific/fisheries single beam, multibeam, Acoustic Doppler Current Profiler (ADCP), etc.).

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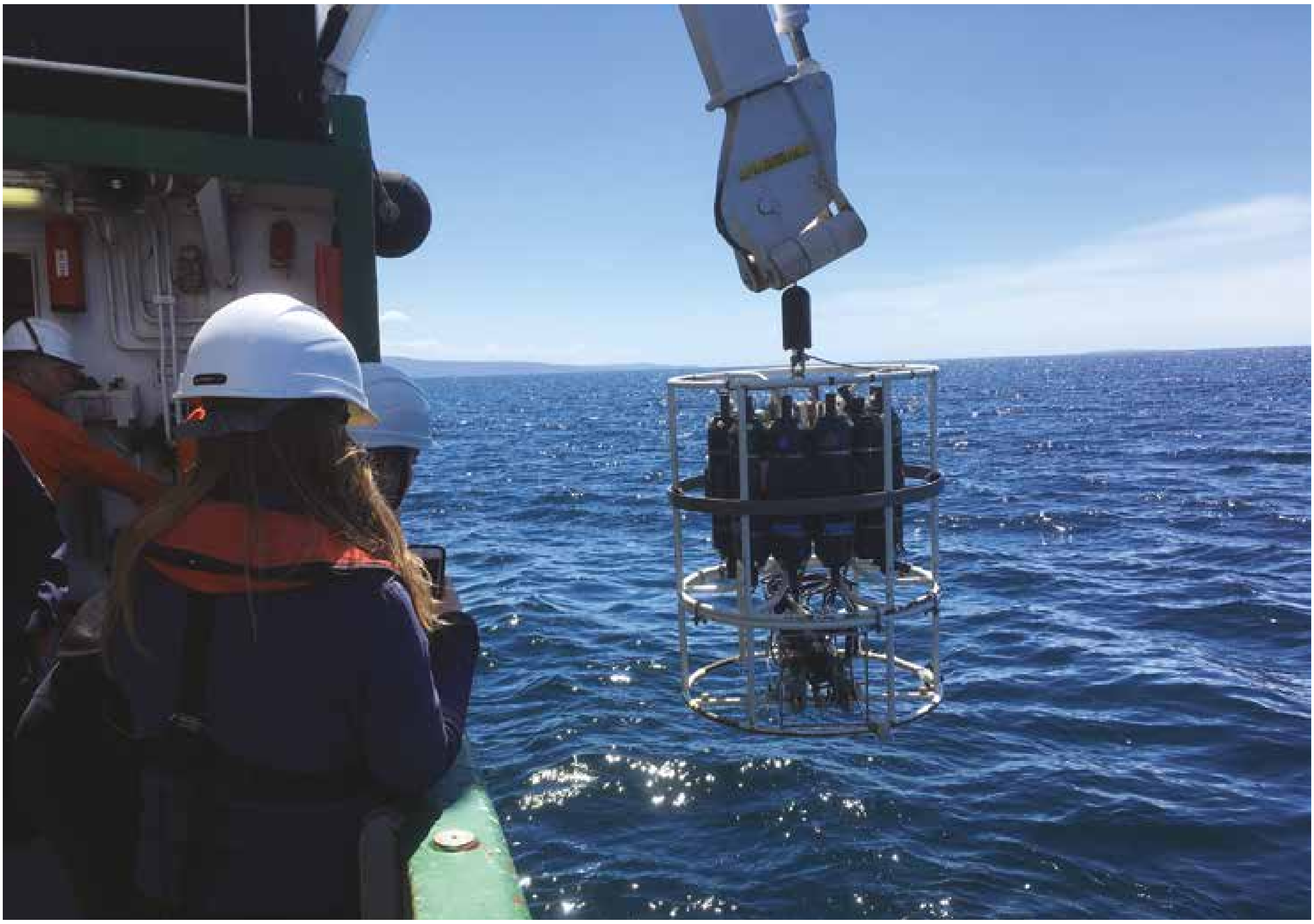
[11] Public research is here defined as research that is conducted in the public domain, and is funded through public funding sources and not conducted in a commercial context, e.g. a commercial seismic survey in oil and gas exploration



Credit: Louise Allcock

Deploying a CTD rosette from RV *Celtic Voyager* during Ocean Sampling Day 2019

Based on these criteria the final list contained 99 research vessels (see Annex 4.1) originating from 23 countries (see Figure 2.1) and managed by 62 research vessel operators. Three countries each operate 11 of the 99 listed research vessels (France, Germany and Norway), the UK operates nine research vessels, Spain operates eight research vessels and Portugal operates seven. The remaining countries operate five or fewer of the 99 listed research vessels (for further analyses see Chapter 7). It is noted that the number of vessels alone is not a good indication of the research-conducting capability of a country.

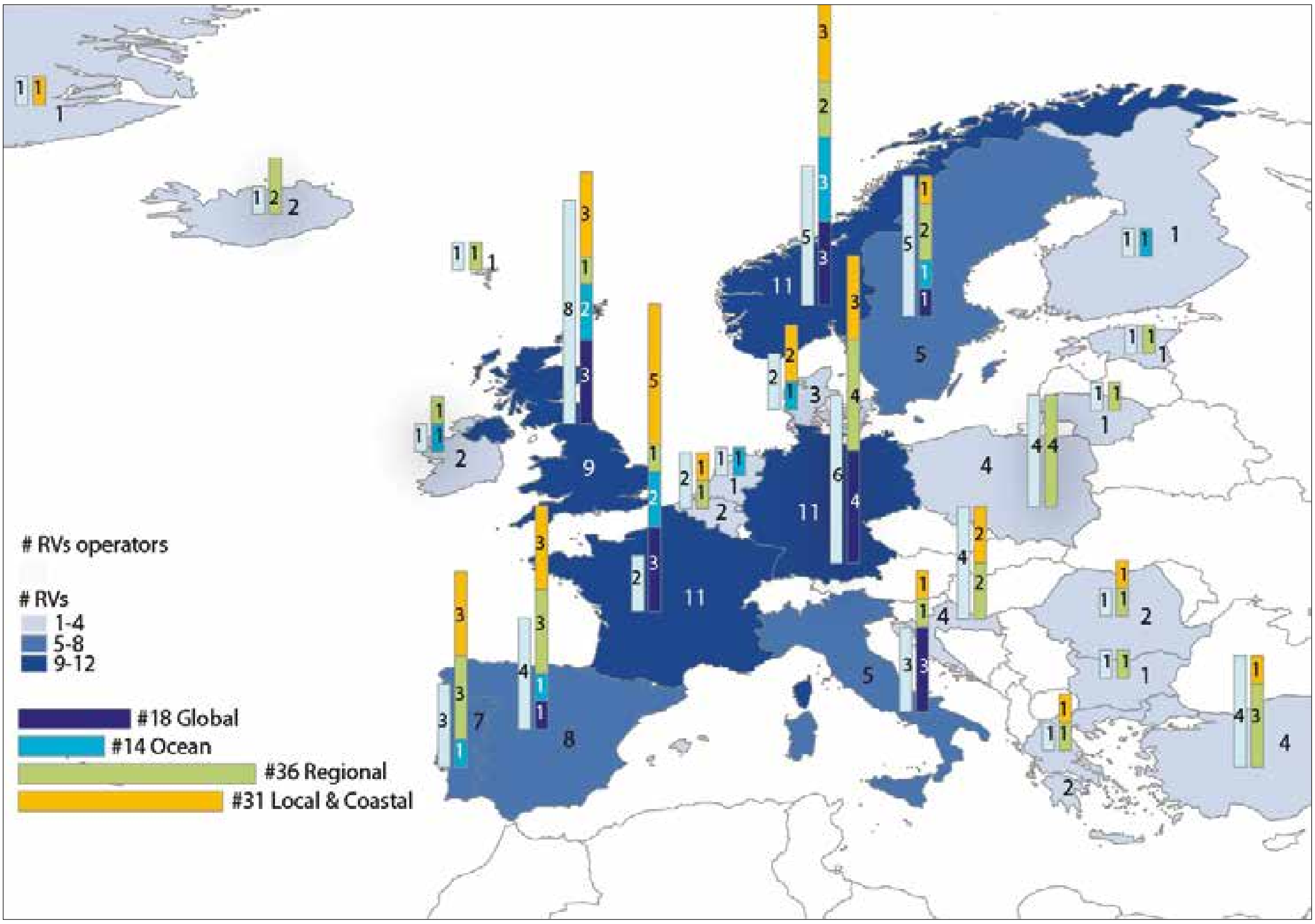
While the fleet of smaller vessels operating on a daily basis has not been considered in this Position Paper, they nevertheless play a critical role in marine scientific research, often driven by local and regional data and sampling needs, and in training and educating the next generation of marine scientists. These vessels are operated in a very different way to the larger vessel, and are likely to have different needs and opportunities for future development. It is therefore recommended that a separate study focusing on these vessels is conducted.

2.1.1.2 Research vessel classes

To get a better insight into research vessel size, capabilities and areas of operation, the 99 research vessels were divided into four different classes – Global (G), Ocean (O), Regional (R), and Coastal & Local (C & L) – based on the classification defined by the EUROFLEETS Fleet Evolution Group (FEG, see Box 2.2). As indicated before, for this assessment, the size of the research vessel was not a criterion, and this is in contrast to EMB PP 10 (see Annex 4.2 for the list included in EMB PP 10 and information on their current status). This explains why Coastal Class research vessels and even some Local Class research vessels have been included in this study, where they previously would not have been considered. As a result, for this study they have been combined into a separate class: Local & Coastal Class.

Based on the above research vessel classification, the 99 European research vessels (see Figure 2.1) are divided as follows:

- 31 Local & Coastal Class research vessels – 31% of the European research vessel fleet
- 36 Regional Class research vessels – 36% of the European research vessel fleet
- 14 Ocean Class research vessels – 15% of the European research vessel fleet
- 18 Global Class research vessels – 18% of the European research vessel fleet



Credit: European Marine Board

Figure 2.1 Geographical overview of the number and classes of European research vessels per country. The left-hand bar shows the number of vessel operators (#RVs operators) for each country, and the right-hand stack shows the number of research vessels in each class. The number on the country itself shows the total number of research vessels (#RVs) owned by that country. All values are based on the 99 research vessels included in this Position Paper

BOX 2.2 ADAPTED EUROFLEETS RESEARCH VESSEL CLASSIFICATION

Ship Class	Global	Ocean	Regional	Coastal	Local
Areas of operation	Minimum 2 oceans	Minimum one ocean	Minimum one area	-	-
Range of operation from principal harbour base (nautical miles)	-	-	-	>50nm	<50nm
Length (metres)	>80m	80m≥ L >60m	70m≥ L >30m	45m≥ L >20m	40m≥ L >15m
Science berths (including scientists and non-permanent marine technicians)	>25	>20	>10	>5	<5

Credit: Gilles Ferrand, Genavir, Ifremer

Global Class: RV *Pourquoi pas?*

Global Class

These large research vessels operate globally and are not limited to one ocean. They can typically house over 25 scientists and marine technicians. With their extensive deck space, equipment, and a broad and diverse complement of laboratory space and outfitting, they are equipped to handle a wide array of instruments and to deploy suites of moorings, autonomous vehicles, large and complex sampling tools, and sophisticated acoustical equipment. These vessels are also capable of changing their role according to their mission. Some vessels in this class support specialized services, including the operation of deep-submergence vehicles or multi-channel seismic survey equipment. Some are ice-strengthened (e.g. ship's hull is reinforced) for operations in Polar regions.

Credit: Marine Institute

Ocean Class: RV *Celtic Explorer*

Ocean Class

These vessels are designed to support integrated, interdisciplinary research and survey cruises with many similar capabilities as seen in the Global Class. The Ocean Class research vessels are generally operated in only one ocean.

Credit: IEO

Regional Class: RV *Ramón Margalef*

Regional Class

These vessels operate on the continental shelf and in the open ocean of a specific geographic region. Regional Class vessels are designed for specific regional conditions, such as the capability to work in shallower areas like estuaries and bays, and under seasonally harsh weather conditions.

Credit: Bangor University

Coastal Class: RV *Prince Madog*

Coastal Class

These vessels serve a crucial role in supporting science throughout coastal zones where the human impacts of development and resource use are greatest. The science cruises are largely driven by local and regional needs. Vessels are capable of conducting night operations.

Credit: IMR

Local Class: RV *Hans Brattstrøm*

Local Class

These vessels operate locally with a very small scientific team and, in most cases, return to port on a daily basis because they do not have the facilities to accommodate the whole science party overnight. For this assessment, only vessels not operating on a daily basis are included (see criterion 2).

The distribution of European research vessels in the classes defined above shows that the Regional Class is the largest, followed by the Local & Coastal Class, Global and Ocean Class (see Figure 2.2). In reality, the Local & Coastal class is even larger but was limited by the selection criteria applied.

The average age of each class of European research vessels falls between 20-27 years (Figure 2.3). Regional Class vessels have the highest average age (27 years) followed by the Local & Coastal Class (24 years) and the Ocean Class vessels (23 years). The Global Class vessels have the lowest average age (20 years). The average age of the European research vessel fleet as a whole is currently 25 years. The average length of each vessel class is shown in Figure 2.4.

The expected functional lifetime of a research vessel is 30 years, however in reality most research vessels are in service for 40 years or more, and hence often the vessels are no longer fit-for-purpose towards the end of their working lives. Considering this, it is clear that the European research vessel fleet on average is already relatively old, with 36 vessels (i.e. almost 36% of the European research vessel fleet) more than 30 years old. Furthermore, the European research vessel fleet is also getting older in comparison to the data presented in the EMB PP 10 (see Figure 2.5). Since the last survey conducted in 2007, it is clear that the age distribution of the Regional, Ocean and Global Class vessels has increased dramatically, notwithstanding a recent input of some new Regional and Global Class research vessels (Figure 2.5). It should be noted that the data shown in Figure 2.5 are based on different lists of European research vessels, where the current 2019 research vessel list includes more Regional, Ocean and Global Class vessels of a greater age. Furthermore, no Local & Coastal Class vessels were included in EMB PP 10. For all research vessel classes, except for the Ocean Class, the greatest number of European research vessels fall into the +30-year category (see Figure 2.5), nearing their life expectancy of 30 years. There are even 14 research vessels that are 40 years or older (9 Regional, 4 Local & Coastal and 1 Global Class research vessels). Based on these numbers, it is evident that the replacement and building of new research vessels is lagging behind. This is mainly due to the relatively high building costs of research vessels that lead to postponed investments and hence the delayed modernization of the European research vessel fleet. Delaying new investment disregards the likely consequences of significantly higher maintenance costs of older vessels.

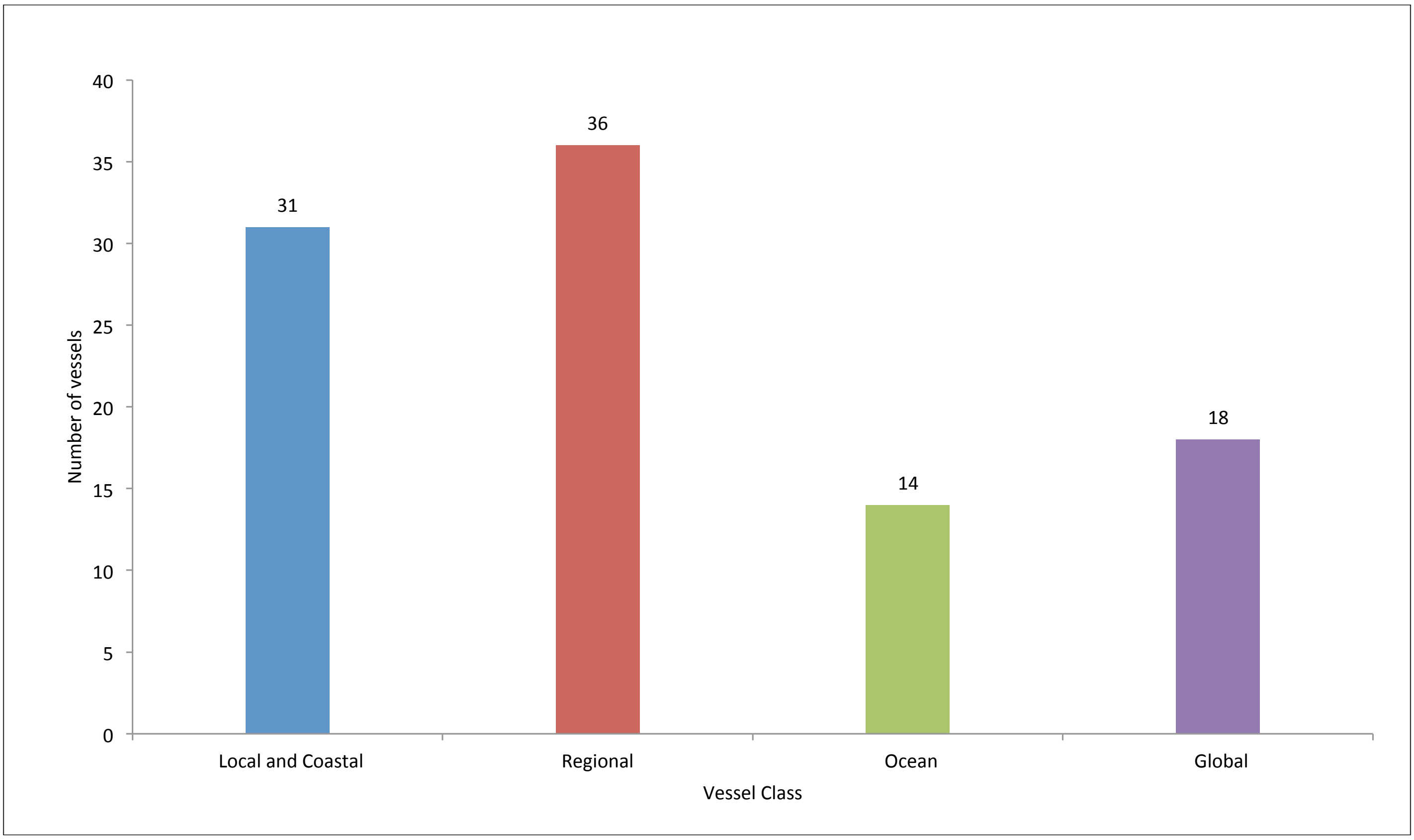


Figure 2.2 Number of research vessels per class for the 99 vessels included in this Position Paper

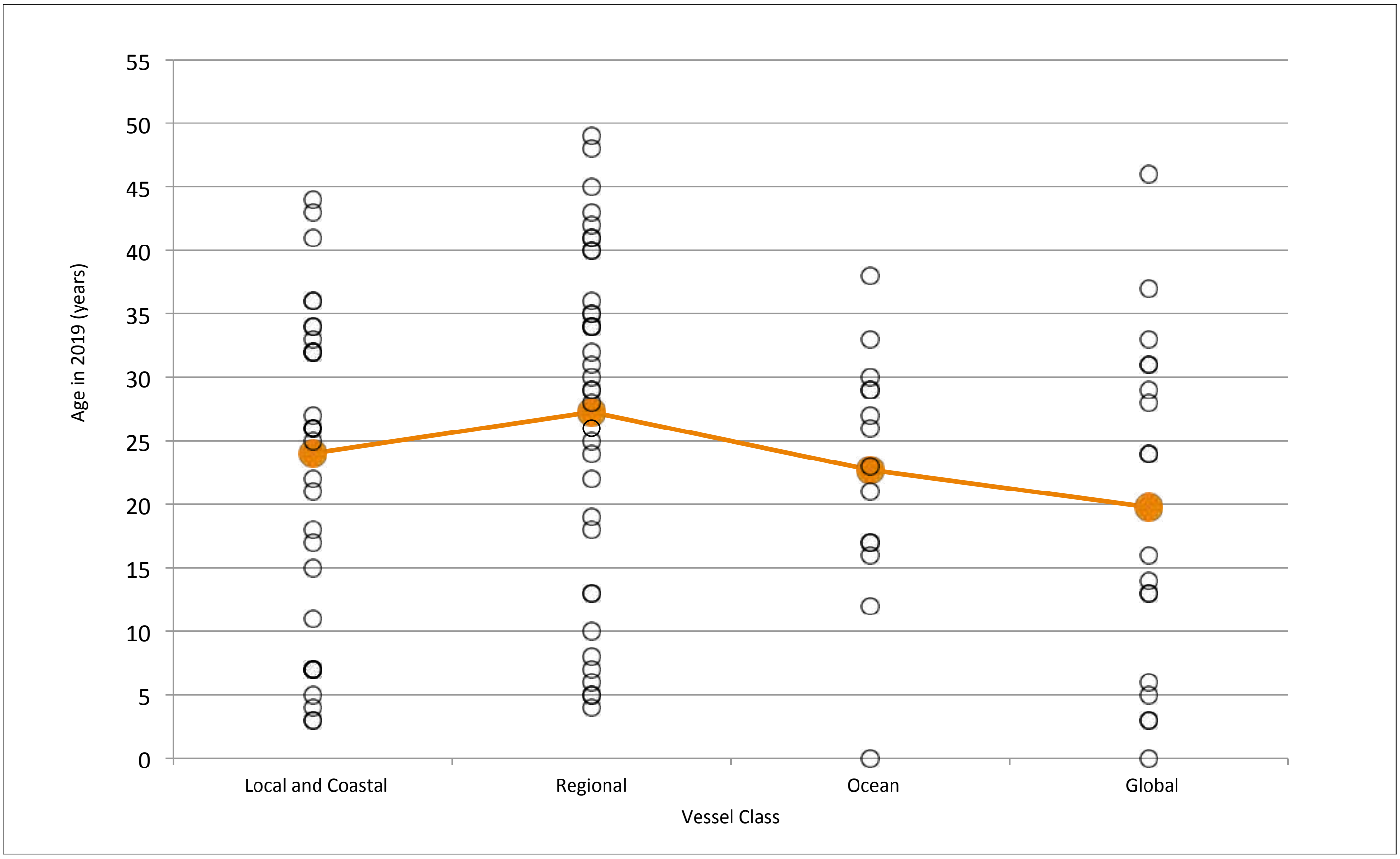


Figure 2.3 Distribution of vessel age per class for 98 vessels (excluding 71-year-old RV *Vila Velebita*) included in this Position Paper

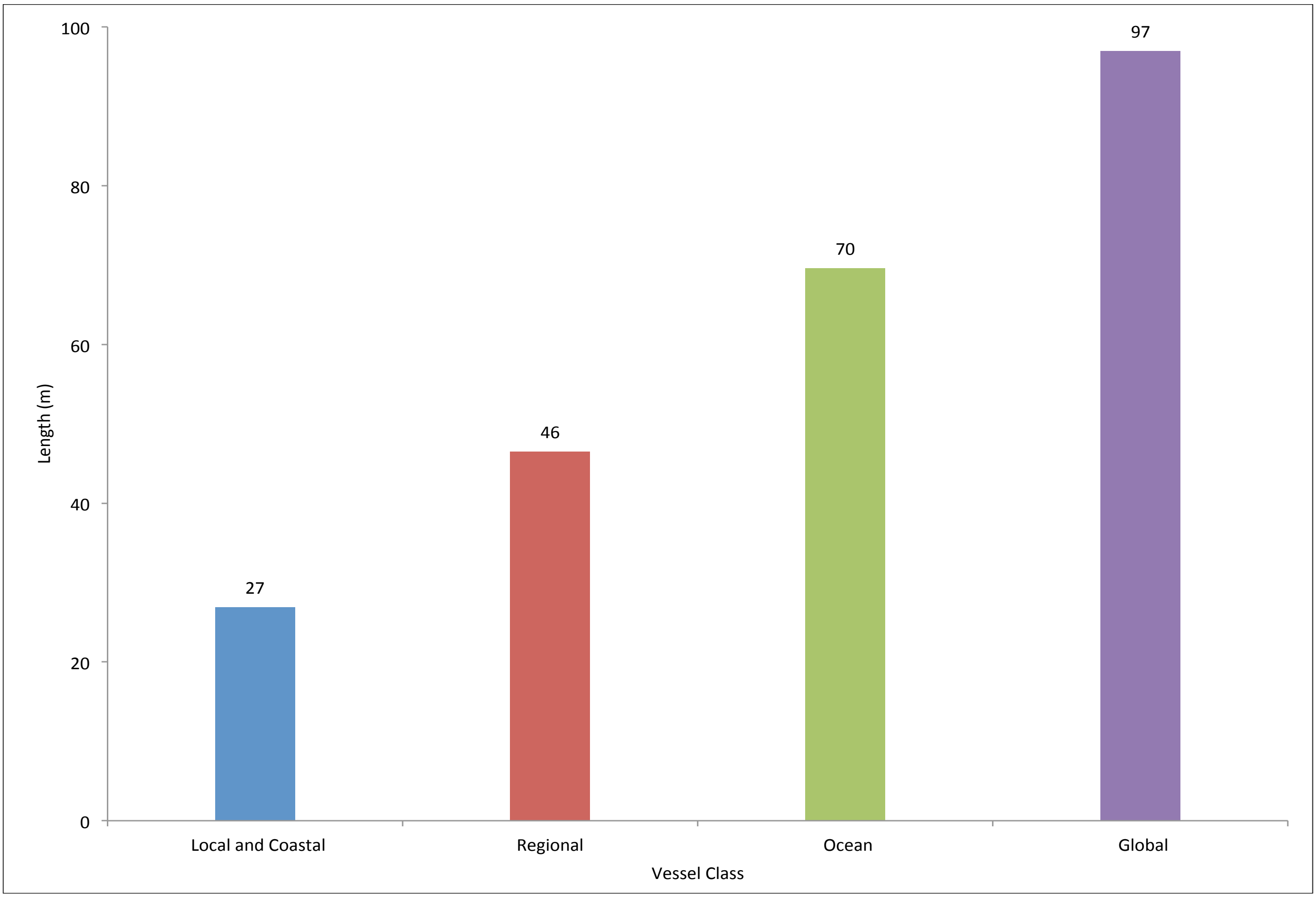


Figure 2.4 Average vessel length per class for 99 vessels included in this Position Paper

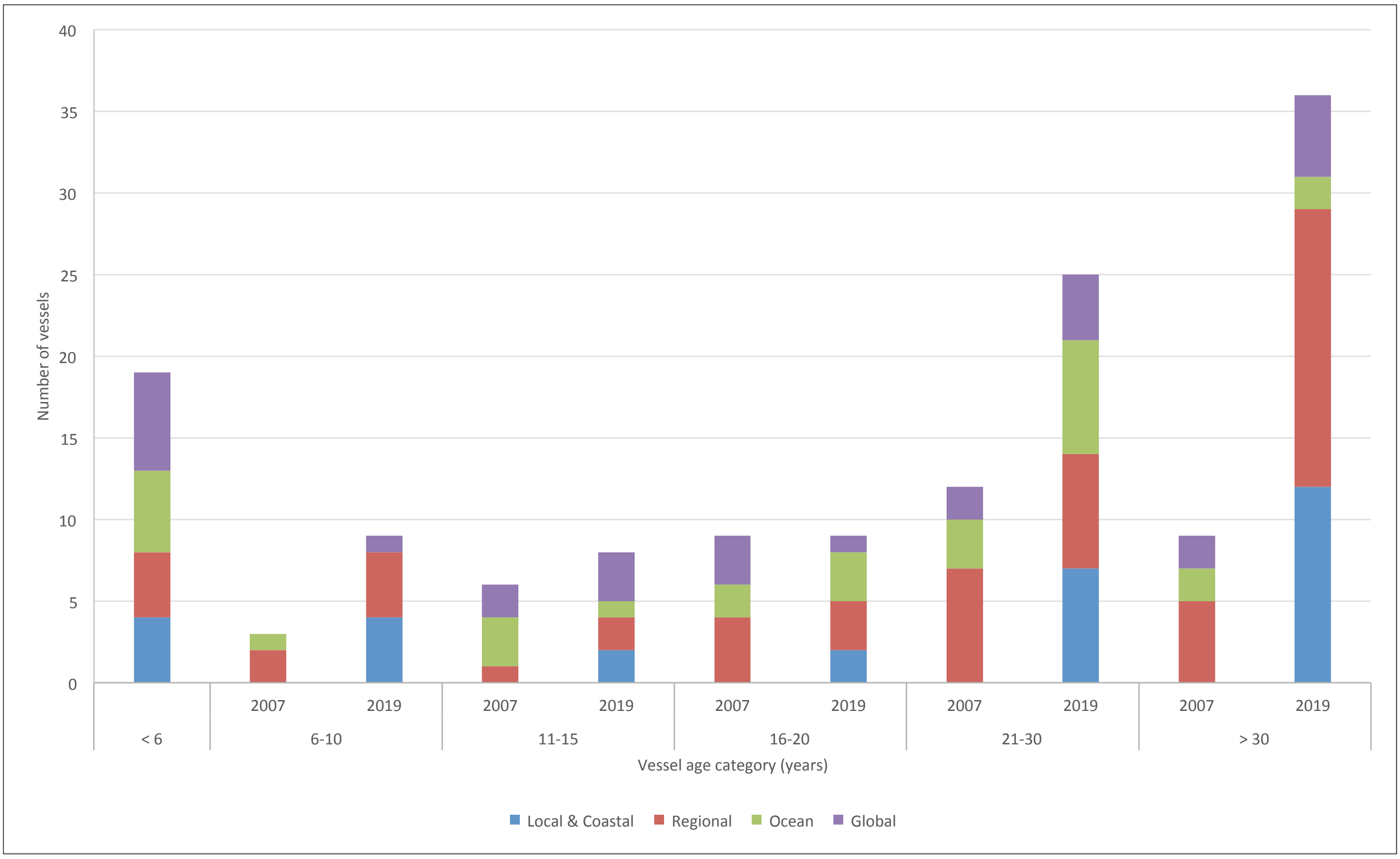


Figure 2.5 Comparison between European research vessel age distribution (in years) per class in 2007 and 2019

2.1.1.3 Type of activity and areas of operations

The operators of the European research vessels were asked to provide information on the type of activities their research vessels conduct, and they were also asked to distinguish time spent on typical activities, including: research, monitoring or survey, logistics, chartering, transit or passage time, maintenance or lay-up.

Information was received for 69 of the 99 research vessels and provided in the form of annual average days for each of the activities listed above, representing a combined number of around 23,500 days (238 days total per vessel on average). For all classes of research vessels, on average 32% or 116 days per year are dedicated to research activities. Another 25% (or 91 days) per year are used for monitoring activities (see Figure 2.6). Broken down further, the research activity ranges from less than 10 days to 308 days per year per vessel, and for monitoring this ranges from 0 days to 290 days per year per vessel. The split between time spent on research and monitoring activities therefore varies hugely across the fleet. A reason for this variation may be that research vessels can be purpose-built specifically for either research or monitoring, and operating budgets may also be specifically allocated to one of these tasks. Conversely, some operators indicated one combined number of days for research and monitoring since both activities are strongly intertwined and no clear distinction could be made between days spent on research or monitoring.

Around 19%, or 69 days per year on average, are considered available days, although it can be seen that this figure varies with vessel class (Figure 2.6). Available days in this context are defined as days on which the vessel is not being used for any other activity, and could in theory be used for research. However in practice, there are generally other circumstances in play that mean this cannot be done. Local & Coastal Class research vessels have the higher number of available days (34%, see Figure 2.6). This may be because the activities of these vessels, due to their smaller size, are often preferably scheduled out of the winter season, for better working conditions at sea. A lot of the Regional Class and certainly the Local & Coastal Class research vessels are also operated by only one crew, which allows them to sail for a maximum of around 180 days per year. It is then logical that some ship-time remains available in theory, and this can be exacerbated by a lack of projects or a lack of funding for variable costs. In many cases, making use of this available ship-time would only be possible through investing in a second crew, but uncertainty about ongoing funding to cover this significant additional cost means it is not a viable option. In other cases, when vessels are rarely available for other activities, initiatives such as Transnational Access[12] (TNA) funded through projects is one way to efficiently make greater use of available days.

Maintenance and lay-up days (where the vessel is taken temporarily out of service) are estimated at 14%, or 50 days per year on average. The average days for logistics, chartering and transit are low and account for 3-4%, or 12-14 days. However, transit days naturally tend to be lower for Local Class compared to Global and Ocean Class vessels, purely due to the nature of the different areas in which they operate.

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[12] Transnational Access (TNA) is where research teams have the opportunity to use research infrastructures, in this case research vessels and equipment, owned by other research institutes or countries. In EU-funded EUROFLEETS (see Box 2.3) and ARICE (see Box 4.1) projects, TNA calls for proposals have been successfully issued and access granted based on scientific excellence. In these projects, funding enables this access to be provided free of charge to the research team.

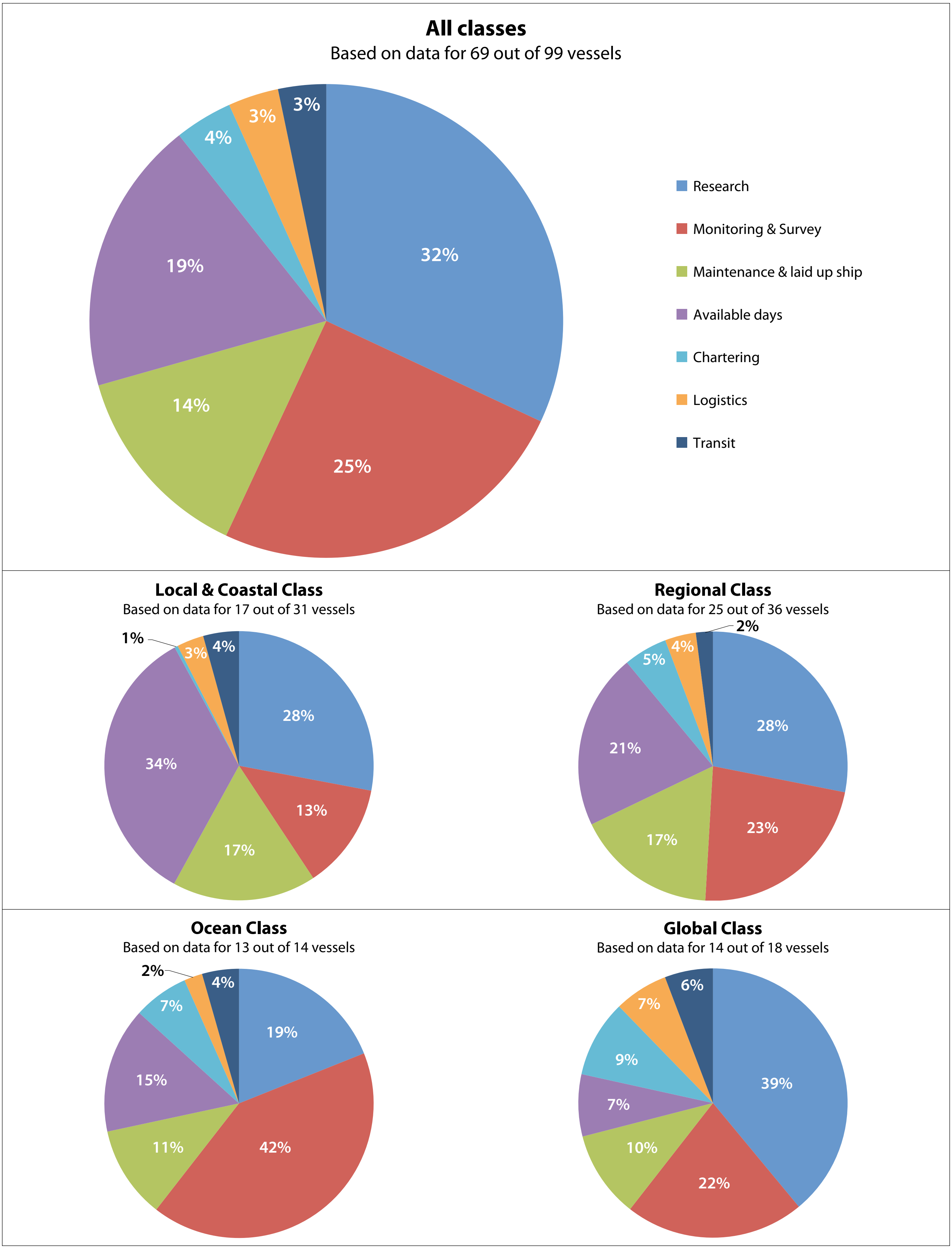


Figure 2.6 Average annual activities of European research vessels per class and overall

BOX 2.3 EUROFLEETS PROJECTS

http://www.eurofleets.eu

EUROFLEETS is a series of EU-funded projects, including EUROFLEETS and EUROFLEETS2 that were funded through the 7th Framework Programme (FP7), and the new EUROFLEETS+ project funded through the Horizon 2020 Framework Programme.

EUROFLEETS *(Towards an alliance of European research fleets - Grant number 228344)* ran from 2009 to 2013 with 24 institutions from 16 European countries. EUROFLEETS was based on the recommendations of EMB PP 10, and aimed at bringing together the European research vessel fleet operators to enhance their coordination and promote the cost-effective use of their facilities. The Fleet Evolution Group (FEG) fulfilled this requirement, allowing the project's research fleet operators to share their strategic views and develop a common vision. Providing open access (for the first time) to European research vessels was also a central aim of the project, with 16 vessels: 5 Global/Ocean Class and 11 Regional Class research vessels from 11 countries opened to access in its Transnational Access activity.

EUROFLEETS2 *(New operational steps towards an alliance of European research fleets – Grant number 312762)*, 2013-2017, further consolidated the alliance built in EUROFLEETS and extended the scope to include the Polar research vessel community. EUROFLEETS2, with partners from 31 institutions in 20 countries, aimed to contribute to the development of a new pan-European distributed infrastructure and coordinated access to research vessels and their equipment. The programme further increased Transnational Access to 22 vessels: 8 Global/Ocean Class and 14 Regional Class research vessels from 15 countries were made accessible through innovative calls.

EUROFLEETS+ was launched in 2019 and will run until 2023. It is a further expansion of the scope and scale of the preceding projects, now with 42 partners from 24 countries in Europe and internationally. The project provides access to 27 vessels. The project will facilitate open, free-of-charge access to an integrated and advanced research vessel fleet, designed to meet the evolving and challenging needs of the user community. In addition to comprehensive Transnational Access activities, the project will undertake joint research in challenging and highly relevant areas, including deep-sea research and exploration, data management, and enabling future virtual access. To maximize the impact of the project, EUROFLEETS+ will implement diverse training and education activities, strong management of innovation in collaboration with industry, and widespread dissemination and communication actions.

Credit: Marine Institute

Participants at the EUROFLEETS+ kick-off meeting held at the Marine Institute, Galway, Ireland on 5th – 7th March 2019

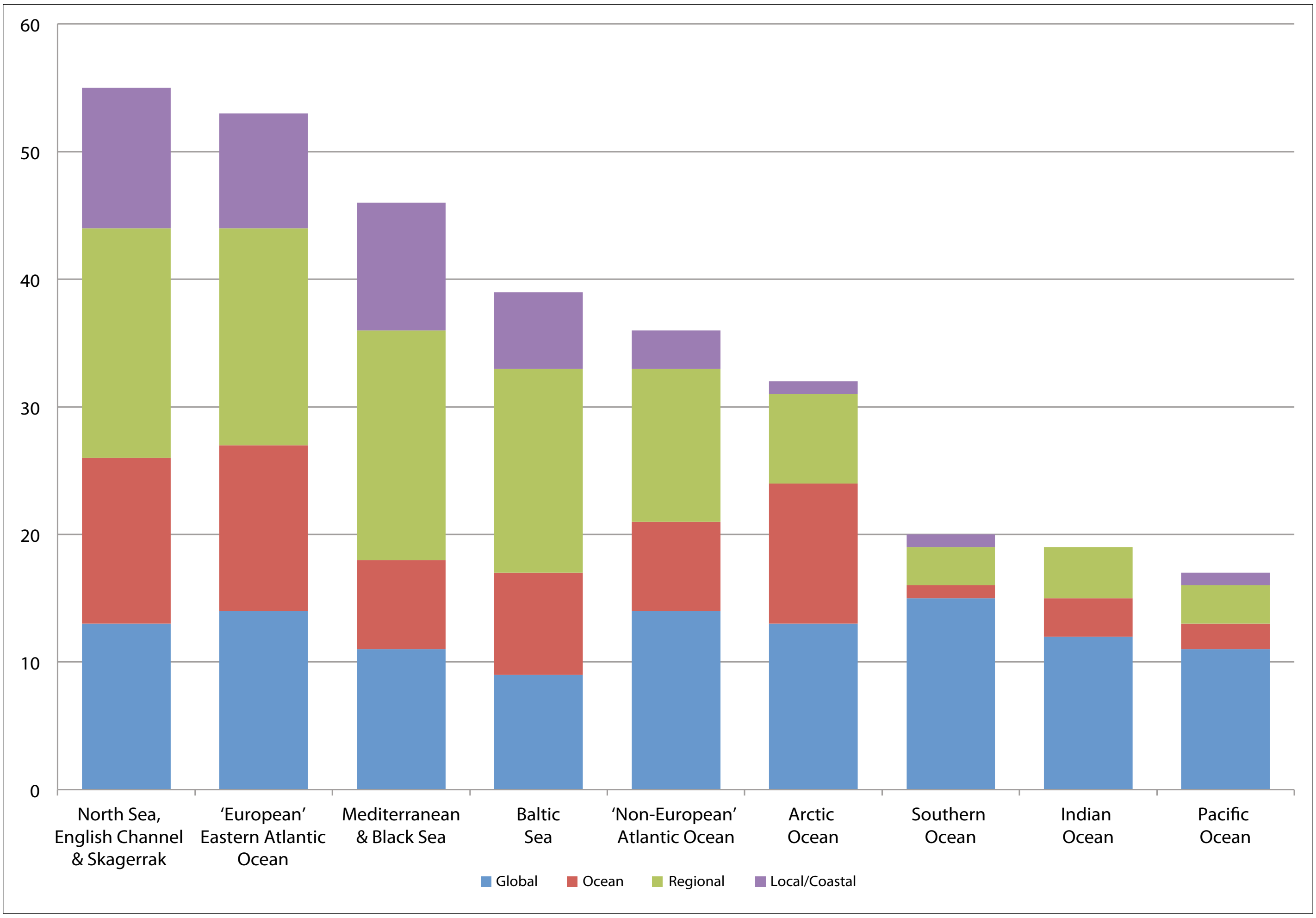


Figure 2.7 Overview of the areas of current and potential operation of European research vessels, based on data for 92 of the 99 vessels included in this Position Paper

The operators of the European research vessel fleet were asked to provide information on the geographical areas of operation of their research vessels. Based on the feedback received for 92 of the 99 vessels, an overview of where the different classes of European research vessels operate has been generated (see Figure 2.7). It should be noted however that the responses received did not differentiate between the area in which their vessel could be operated and where it has operated in recent years.

Generally, all classes of research vessels have approximately equal capabilities of operating in the different European locations. This is also the case for the "non-European" part of the Atlantic Ocean. For the areas of operation further from Europe (i.e. Arctic, Southern, Indian and Pacific Ocean), the Global Class is the largest active class. The majority of the Global Class vessels operating in these areas have specific capabilities as described in Chapter 3 for deep-sea science and Chapter 4 for Polar operations. Fewer Ocean Class vessels appear to be sent to these remote ocean areas, but some Regional and even Local and Coastal Class research vessels operate in these distant locations, typically because these European research vessels have their homeports there.

NUMBER OF ACADEMIC RESEARCH VESSELS PER CLASS

Year	Global	Ocean	Regional	Total	Average age (years)
2007	11	15	20	46	17
2019	12	12	18	41	25

Table 2.1 Comparison between the number and the average age of the European research vessels in 2007 and 2019 based only on the academic research vessels included in EMB PP 10

2.1.2 Evolution of the European academic research vessels since the EMB Position Paper 10 (PP 10)

In 2007, EMB PP 10 predicted that of the 46 vessels (11 Global, 15 Ocean and 20 Regional Class) considered in that study (see Annex 4.2), a reduction of 21 vessels (3 Global, 3 Ocean and 15 Regional Class) would occur if no replacements were made. In reality, in 2019, only five of these 46 vessels (three Ocean and two Regional Class) have been taken out of service without replacement. This evolution has resulted in an increase in the average age of European research vessels from 17 years to 25 years (see Table 2.1). Academic marine research is being performed on increasingly ageing research vessels that are rapidly approaching or even exceeding their maximum functional life expectancy of 30 years.

Two research vessels will be replaced in 2019 and five vessels will be built/replaced in the near future (2020-2022), indicating some activity in funding and building new research vessels. However, this will only have very limited influence of the average age of the European research vessel fleet, which will be reduced to 22 years in 2022.

2.1.3 Overall evolution of European research vessels

Based on a survey sent to research vessel operators during 2018 (see Chapter 6 and 7, and Annex 3), we report that 28 new research vessels have been built in the period 2005-2019 (see Figure 2.8) and 12 countries expect to replace 28 research vessels in the period 2020-2035, pending the approval of the required funding. Based on the feedback from the research vessel operators, it can be concluded that almost no research vessels will be taken out of service without replacement in the coming 15-year period, with only the RV *Poseidon* going out of service at the end of 2019 without replacement.

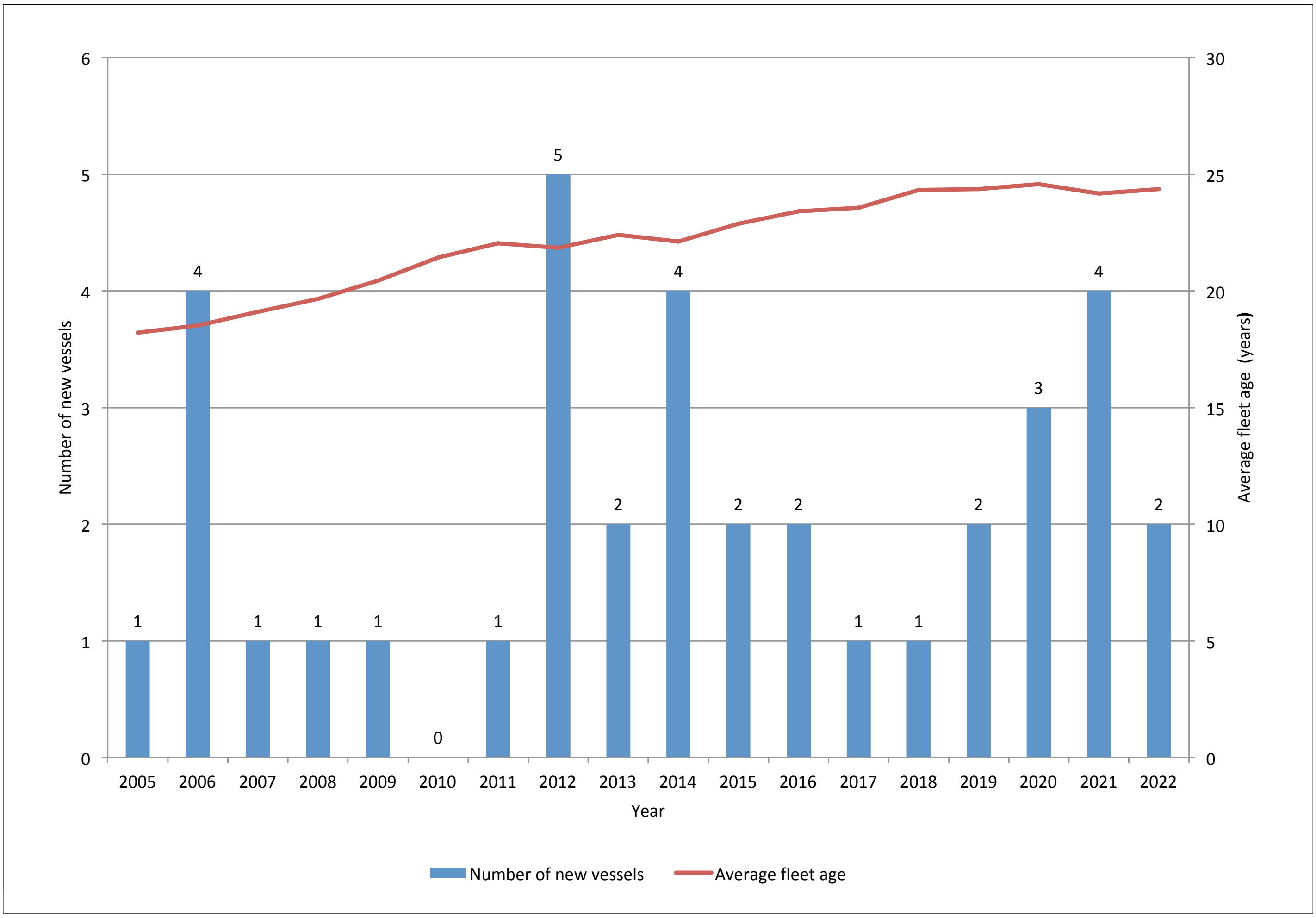


Figure 2.8 Evolution of the fleet based on new builds and average fleet age in the period 2005-2022

Focusing only on the research vessels for which funding is already (at least partially) in place, eight replacements (1 Global, 2 Ocean, 3 Regional and 2 Coastal Class) are expected in the next three years (2020 - 2022) for which funding is already at least partially in place (see Table 2.2).

Country	Investments	Class	Age of vessel when replaced	Delivery
Belgium	1 Replacement – new build	Ocean (see below)	36 *(Belgica)*	2020
Faroe Island	1 Replacement – new build	Regional	42 *(Magnus Heinason)*	2020
Iceland	1 Replacement – new build	Ocean	51 *(Bjorni Saemundsson)*	2021
Greenland	1 Replacement – new build	Regional	50 *(Paamiut)*	2021
Netherlands	2 Replacements – new builds	Coastal & Global	40 *(Navicula)* & 31 *(Pelagia)*	2021 & 2022
Norway	1 New vessel (TBD)	Coastal	N/A	2021
Ireland	1 Replacement – new build	Regional	24 *(Celtic Voyager)*	2022

Table 2.2 Overview of the planned investments in the European research vessel fleet for which funding is (partially) in place

Credit: Rolls-Royce Marine; Freire Shipyard; BELSPO; RBINS-OD Nature

Replacement of RV *Belgica* to be delivered in 2020

For the other vessels that would need to be replaced in the coming 15 years no definite funding and thus no clear information is available at this time. While the eight replacements or new vessels listed in Table 2.2 are an encouraging sign, the lack of further concrete renewal plans does not alleviate concern regarding ongoing ageing of the fleet.

2.2 A wide range of portable and exchangeable associated instruments

To be able to carry out research on board a research vessel, equipment is essential. Equipment is often small and provided by the science party joining the vessel, but it can also be of significant size and value. These larger items of equipment are referred to as Large EXchangeable Instruments (LEXI), where exchangeable means that they are not typically permanently installed on the vessel but are portable and can be deployed from several different vessels as long as they have the minimum requirements with regard to handling systems, deck space and compatibility. The science party or the vessel operator may provide these LEXI.

However, an instrument that is small for a Global or Ocean Class vessel may be a LEXI for a Regional or Coastal Class research vessel. “Large” might thus have different meanings depending on the size of the vessel. A new category of equipment has therefore been included in the present study: the Medium-sized EXchangeable Instruments (MEXI).

2.2.1 Preliminary definition and description of Large EXchangeable Instruments and Medium EXchangeable Instruments

The Large EXchangeable Instruments (LEXI) can be divided into different categories:

- Unmanned surface and underwater vehicles (USV/AUV/ROV);
- Human Occupied Vehicles (HOV/manned submersibles);
- Seismic systems;
- Sediment sampling systems (coring systems/sediment drills).

Other LEXI that do not belong to any of the categories mentioned above include:

- **Biological sampling devices** such as bottom and pelagic trawls;
- **Towed instruments** such as side scan sonars, towed video systems, and towed sampling systems with various other payloads;
- **Portable winches:** (containerized) winches with synthetic cables for clean sampling, large mooring winches, streamer winches; and
- **Large containerized systems** such as specialized isotope labs, chemistry labs or containerized ultra clean CTD systems.


Credit: European Marine Board

A plankton net on board RV *Johan Hjort*

Equipment of a smaller size that is considered standard equipment on the Global and Ocean Class vessels is of considerable interest to operators of the smaller Regional or Coastal Class vessels. We therefore introduce an additional category of exchangeable equipment, the Medium-sized EXchangeable Instruments (MEXI) and recommend that this category is taken up by the community and included in the EurOcean Research Infrastructure Database (EurOcean_RID). This category could contain:

- Small autonomous vehicles (gliders, small ROVs);
- Small towed systems;
- Small coring equipment (box corers, grabs, multi-corers);
- Mooring equipment (sediment traps, moored profilers);
- Water samplers (CTD rosette samplers, with the exception of the large and heavy special CTD systems);
- Small seismic systems including Ocean Bottom Seismometers (OBS); and
- Biological sampling devices such as the vertical and horizontal multinets, plankton nets, sledges, nets for microplastics (manta trawl).

The instruments included in the MEXI list may partially overlap with the LEXI list. This current list of MEXI equipment is a first attempt to catalogue this type of smaller equipment and it only includes items that could be easily identified as being part of this category. However, to complete the MEXI list and make it accessible to users, an additional survey with questions dedicated to this type of equipment should be sent out to research vessel operators and science teams as a first step.

For the LEXI, as for the MEXI equipment, it is essential to ensure that a research vessel has enough deck space and appropriate handling systems to handle these equipment in an efficient manner. Another important aspect in the design of a research vessel, especially for the LEXI, is the ability to integrate this complex and cutting-edge scientific equipment and processes easily into the vessel's hydraulic and electrical power systems, and into the signal- and data-networks through the laboratories. These also need to be flexible enough to support equipment from different nations with diverse power and voltage requirements.

To gain a better insight into the wide variety of instruments in these categories, a short overview of the LEXI equipment and a full overview of the distribution of LEXI capabilities for different vessels are presented in Annex 5.

2.2.2 Contribution to the inventory of the present European Large EXchangeable Instrument inventory

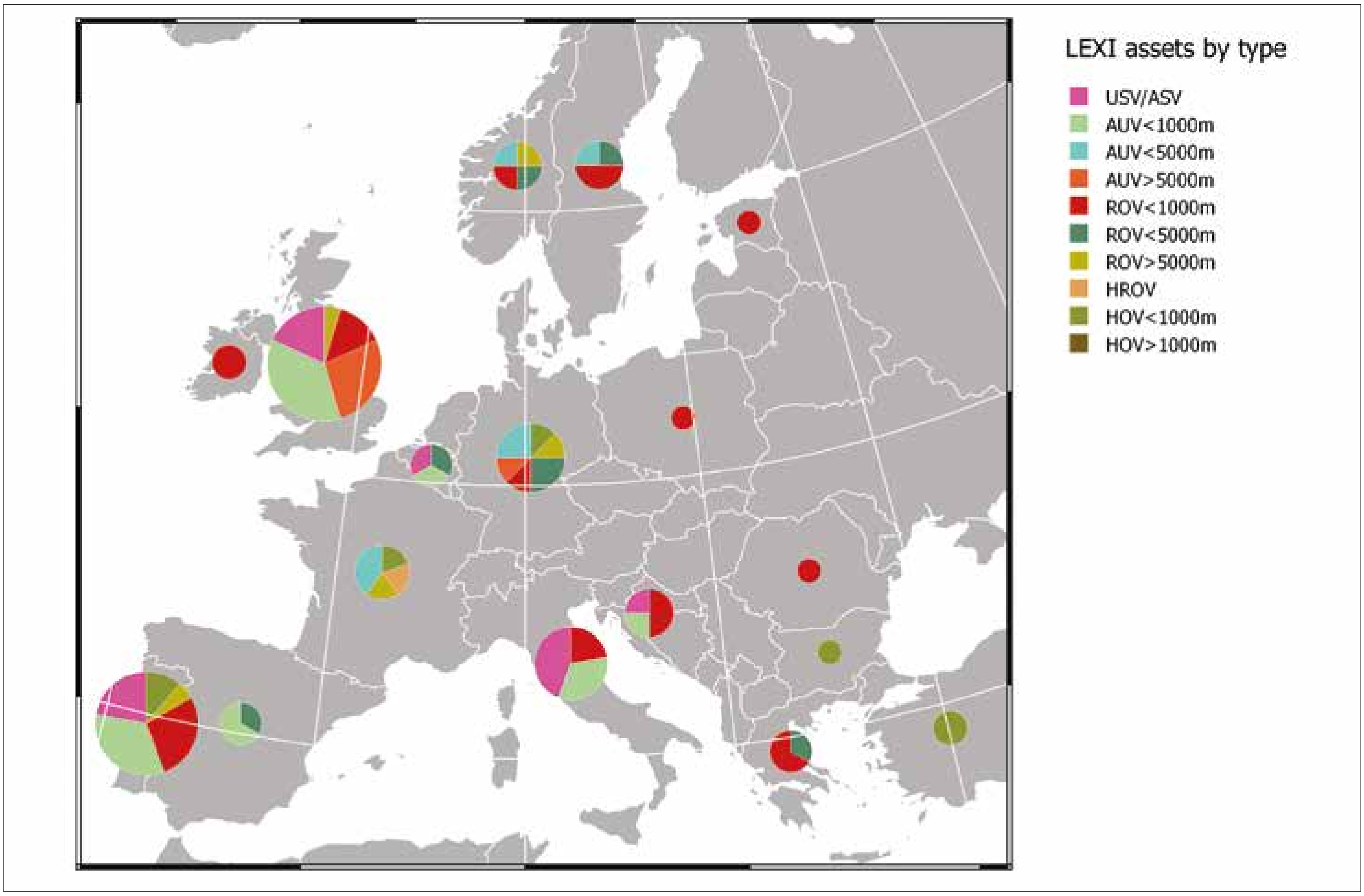
Based on the EurOcean Large EXchangeable Instruments Infobase (LEXI) and Marine Research Infrastructures Database (RID), an updated list of European LEXI was created. Initially the EurOcean LEXI list contained 156 instruments, but not all equipment on the list was available for or used for research, which was an important condition to be included in the LEXI overview. To get updated information, the operators of the known European LEXI were contacted. A table summarising the reported LEXI by type is given below, while the full overview is available in Annex 5: Annex 5.1 gives a short description of key LEXI equipment, Annex 5.2 provides a detailed breakdown of the LEXI subcategory of underwater and surface vehicle capacity in Europe and Annex 5.3 presents Large Exchangeable Instrument capability in the European research vessels fleet. However, this proved to be a challenging exercise as not all operators responded, some only provided partial information, and since not all equipment is owned by the vessel operators it is likely that some of the actual equipment owners were not contacted. These figures cannot therefore be considered comprehensive, and it is recommended that a much wider study is conducted to gain an accurate picture of LEXI ownership in Europe, and to establish an efficient and centralized management system to keep this information current.

LEXI type	Number of LEXI	Number of owner countries
Underwater and surface vehicles		
AUV	34	10
ROV	35	15
ASV/USV	14	5
HROV	1	1
HOV	7	5

Table 2.3 A summary of European underwater and surface vehicle LEXI in 2019

Many of the operators contacted only reported their underwater and surface vehicles LEXI (i.e. AUVs, ROVs, USVs and HOVs), and did not inform the working group about other equipment they own. The data presented for underwater and surface vehicles (91 items owned by 17 countries, see Annex 5.2) is therefore seen by the authors as a good representation of the size of the pool available in Europe. However, for other equipment the data does not give an accurate representation (see Annex 5.3). For this reason, the analysis below focuses only on the underwater and surface vehicles in Europe (Figure 2.9).

Figure 2.9 shows the distribution of underwater and surface vehicle assets only across Europe. When discussing the evolution of the LEXI pool since 2007 we will therefore only focus on this type of equipment. For details of the LEXI pool in 2007, refer to Appendix 2 of EMB PP 10 (Binot *et al.,* 2007). The trend towards more autonomous systems now compared to 2007 is considered accurate by the authors, with the major increases in numbers of equipment in this category. Towed equipment is expected to decline in number in the future as they are replaced by autonomous vehicles. By contrast, geological equipment (such as coring and drill rigs) are a niche group not operated by many countries and the numbers are expected to remain fairly stable. For all other equipment types, specifically for coring systems and towed instruments, data was incomplete. We recommend that further input from the operators is obtained before the information can be used to search for equipment available in Europe. The LEXI overview will remain a work-in-progress because the list will require constant updating to remain accurate. A list of MEXI in Europe should also be initiated.



Credit: GeoEcoMar

Figure 2.9 Geographical distribution of the European Underwater and Surface Vehicles. The area of the circle is proportional to the number of assets for a given country

2.2.3 Perceived trends in European Large EXchangeable Instruments since EMB Position Paper 10

Compared to the LEXI list presented in EMB PP 10, the current list presented in Annex 5.3 contains far fewer different types of LEXI. This is likely to be due to underreporting of information by the operators contacted in the current study, and a mismatch between those contacted and those owning the equipment, rather than the existence and use of fewer equipment types.

It is therefore difficult to comment on the evolution of the overall LEXI pool in Europe, but through the information gathered it is possible to indicate some trends. As predicted in EMB PP 10, the number of underwater and surface vehicles and the number of countries owning these instruments has grown substantially, especially larger ROVs and the AUVs. ROVs with depth-rating between 1000m and 5000m are now owned by seven countries (compared to five in 2007) while the number of countries owning ROVs with a depth-rating deeper than 5000m has increased from two to five. For AUVs, the increase is even larger: from four countries operating these instruments in 2007 to ten countries owning 34 AUVs at present. A completely new category since 2007 is the autonomous or unmanned surface vehicles (ASVs/ USVs), now owned by five countries.

2.2.4 Forward-looking vision on the oceanographic tools of tomorrow

Many instruments used and deployed from a research vessel are based on advanced technologies, which are permanently evolving and subject to rapid changes compared to the 30-year lifetime expectancy of a research vessel. As a result, when building a new ship, it is of utmost importance to make use of the most recent technologies, knowing that a research vessel will have to adapt and change during its lifetime to deploy and recover increasingly sophisticated and innovative tools. Research vessels should therefore be built with deck space and handling systems suitable for deploying and recovering current and foreseeable future platforms and vehicles.

Three major LEXIs will be important in the future: underwater vehicles, coring and drilling devices, and seismic systems.

2.2.4.1 New generation underwater vehicle systems and operation scenarios

While at present underwater vehicles are typically deployed sequentially (i.e. one at a time), or partially coordinated from ships, scientific and technological trends suggest the emergence of new needs in terms of underwater vehicle missions. Future operations will need to cover wide geographic (from 1 to 100km^2) and temporal (from instantaneous observation to multi-year monitoring) scales and will need to consider multiple parameters. This section discusses advances that are already market-ready and are currently or imminently being taken up by the European fleet. A further horizon scan is not presented here.

Credit: Ifremer

6000m AUV for wide scale survey and local inspection developed at Ifremer

Multiple system approaches will allow the operation of several types of mobile or permanent instruments in an interconnected way. Remotely operated vehicles (ROVs) will be designed to carry, deploy and recover light physical, chemical or biological sensor acquisition packages. ROVs will provide functionalities to dock to observatories for servicing of instruments and databases. AUVs accomplishing intelligent missions will be able to connect to ROVs in specific rendezvous manoeuvres through high bandwidth acoustic and optical links or transfer datasets collected during the dive to the observatories. Autonomous surface vehicles (ASV) will function as communication relays for AUVs, with over-the-horizon connection to the research vessel for transmitting AUV monitoring data. Reconfiguration of AUV missions will be possible remotely without recovery and without the AUV surfacing. There is also an increasing trend towards swarming AUVs, i.e. the ability to operate several AUVs together in a coordinated fleet.

Autonomous surveying of the seabed will benefit from **enhanced instrumentation, manoeuvring and processing capabilities.** AUVs will combine advanced sensor data with generic high-resolution mapping (including using simultaneous localization and mapping (SLAM) navigation technologies), geochemical sensor suites, spectroscopy, chemical analysers working with filtering devices, and automated sampling. The next generation of 6000m AUV e.g. CORAL (Ifremer), coming into operation in 2021, will provide these features (see picture above). It will have manoeuvring capabilities that will allow precise targeting of measurement locations. In addition to classic long-range navigation, it will also be able to manoeuvre at low velocity close to the seabed, and to hover in optical imaging range focusing on automatically identified targets.

Future trends for ROVs will include the availability of **high electric power** (greater than several tens of kW) for scientific equipment. The potential availability of higher power would enable the development of energy intensive rock drilling and deep probing devices, large volume filtering devices and charging interfaces for deep-sea stations (see Chapter 3). The additional capacity of deploying heavy packages directly using the ROV will allow complex installation or maintenance operations such as the installation of interconnected cables over long distances with the use of specific tools.

Even though *in situ* sensing will continue to gain importance and eventually reduce the need for actual sampling, in the near term there is still a requirement for future systems to carry samples and the associated development of systems to compensate vehicle weight balance. **'Clean' operation** approaches that avoid jettisoning steel weights for compensation will be necessary in order to face new, stricter environmental regulations.

The transfer of materials, special tools and samples from surface to seabed and back in modern ROV operations is identified as an area that requires innovation to increase operational efficiency. Current operations are dependent on elevators used for transport of materials to and from the ROV. Elevators presently use passive 'free-falling' concepts with imprecise landing and surfacing, resulting in a lack of efficiency and interruption of ROV work. In future **active 'smart' elevators** capable of reaching a precise location on the seabed or close to the vessel for recovery will be used; cable-operated elevators will provide more efficient tools down to depths of approximately 3000m to 4000m. This will save time because of greater handling accuracy, result in better use of dive time, and a better preservation of samples.

The effectiveness of unmanned operations on the seabed, and more generally the human perception of the remote environment, will benefit from the capabilities of information systems to exploit high-resolution images, real-time 3D reconstructions, measurements, and acoustic sensors. A vision for a virtual ocean, supported by real-time data delivered by sources including research vessels is outlined in detail in EMB's PP 24 *Navigating the Future V* (European Marine Board, 2019). This vision also aligns closely with the aim for a transparent and accessible ocean (whereby all nations, stakeholders and citizens have access to Ocean data and information, technologies, and have the capacities to inform themselves prior to taking decisions), one of the societal outcomes of the Decade of Ocean Science for Sustainable Development [13]. **Augmented reality technologies** will combine quantitative information with a visual representation of a wider seabed scene and introduce new interactive tools to select samples and probe targets, locating the technical tools (machine, manipulator arm, probes) in the environment model visualized on the pilot screens (see pictures on page 31). Intelligent pre-processing techniques and assistance to data exploitation will help the scientific end-user to handle big data volumes quickly and generate scientific results during a cruise.

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[13] https://en.unesco.org/ocean-decade/about

Left: real time 3D modeling from multibeam echosounder data and visualization of the vehicle (here HROV Ariane) with respect to the seabed; Centre: 3D immersive viewing and analyzing of optical terrain model; Right: classification during scientific post-processing on a 3D terrain model

Credit: Ifremer

2.2.4.2 New tools for coring and drilling

In the field of geosciences, the current work on continental margins, seismic risks and paleo-climatology suggests the need for longer cores (more than 100m) and larger diameters (12cm) which will require the development of new tools on board Global Class vessels, ideally related to the International Ocean Discovery Program[14] (IODP). This need is associated with the development of mobile drill-rig systems, such as the MARUM MeBo200 system, which can provide up to 200m cores without a ship-fitted drilling tower such as those installed on dedicated drill ships such as RV *Joides Resolution* and RV *Chikyu*.

2.2.4.3 New generation of seismic systems and operation scenarios

In the future, new seismic technology developments, such as time synchronization and streamers, and surveying methodology development will have to meet emerging needs, as outlined below.

Seismic sources need a high quality transmitted acoustic signal to reduce the total transmitted sound level in order to avoid disturbing marine life, as they are very sensitive to both underwater noise and pressure waves. This area will continue to be explored as technology advances.

Time synchronization of the individual elements of a source array optimizes the resulting acoustic signal. Improving the stability of the geometry of the source array will also contribute to a more stable acoustic signal. Precise control of the acoustic signal can reduce the total volume of the seismic source without affecting the data quality, reducing the impact on marine life. During a recent seismic survey conducted on Ifremer's RV *Pourquoi pas?*, offset distances up to 750km were recorded on Ocean Bottom Seismometers (OBS) with reduced source volume; this was unprecedented with previous generations of seismic source. With these offsets, imaging down to 70-80km to understand mantle processes better becomes a possibility.

Within the current European research vessel fleet, the **maximum streamer length** is limited to 7.2km (Ifremer seismic devices). These long streamer configurations need large research vessels, such as the RV *Pourquoi pas?*, the RV *Sonne II* or the RRS *James Cook* to operate them. A number of European research institutes are equipped with compatible streamers, so it is feasible to carry out a seismic survey with a 12-15km-long streamer by combining these separate streamers, potentially enabling imaging at sub-bottom depths over 100km.

Most seismic surveys are conducted with a single vessel deploying both the source array and the streamer. A successful two-ship seismic study was carried out in the East Pacific, with the RV *Sonne II* and the RRS *James Cook* in 2015, with the ships individually deploying seismic sources, streamers and OBS in a joint experiment. Through collaboration between European fleet operators, **new surveying methodologies** can be developed using multiple ships conducting seismic surveys with a wider range of offsets and angles. By combining ship and equipment capabilities across the communities, a variety of deployment configurations is possible, significantly enhancing the options for 2D and 3D operations for deep sub-bottom imaging, and high density and wide-angle data.

2.3 Current status of the European research vessel fleet capabilities

A review of both a vessel's key capabilities required to perform modern marine science, and the current status of these capabilities across the European research vessel fleet are presented here. Although this review is not intended to be exhaustive, it gives an overview of key performance aspects inherent to the vessel itself (such as the greening of the ship, which is a major topic for existing and future research vessels, or its underwater acoustic signature - see Section 2.3.1), key capabilities associated with the range of instruments permanently installed on board, the mobile equipment required such as the LEXIs or MEXIs described in Section 2.2, and the handling capabilities for their deployment and recovery.

The range of complementary instruments and associated capabilities are presented in Table 2.4, with an indication of their main related scientific disciplines in oceanography, geology, biology, fisheries research and meteorology. The review does not include the broad range of ship scientific laboratories (such as dry lab., temperature-controlled lab., clean lab., etc.), which of course would span all the marine scientific disciplines if they were included.

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[14] https://www.iodp.org/

		Oceano-graphy	Geology	Biology	Fisheries research	Meteo-rology
Underway sensors installed on board	Sea surface monitoring (Temp, Salinity)	X			X	
	Meteorological sensors					X
	pCO_2 sensors	X				
Hydroacoustic systems installed on board	ADCP	X				
	Multibeam echo sounder		X		X	
	Sub-bottom profiler		X			
	Fisheries single beam echo sounder	X	X		X	
	Fisheries multibeam echo sounder				X	
	Fisheries sonar				X	
Mobile equipment deployed using over-the-side handling capabilities	CTD (rosette etc.)	X	X	X		
	Trawls and nets			X	X	
	Underwater vehicles (ROV, AUV, HOV)	Depending on payloads				
	Coring		X			
	2D / 3D seismics		X			
	Moorings	Depending on payloads				

Table 2.4 Typical equipment available on a research vessel (excluding ship scientific laboratories) versus their main related scientific disciplines

The depth of operation of complementary instruments is considered a major criterion in this analysis since this is a key driver for the hydroacoustic systems installed on board as well as for the handling capabilities, and consequently for the design of the ship itself. Three different categories of water depth have been considered, depending on whether operations are carried out on the continental shelf or slope, in medium ocean depth or in full ocean depth.

Finally, the data underpinning this analysis presented in this chapter has been gathered directly from the European research vessel operators, however complete information was not received for all vessels. The values presented are therefore indicative of trends and capabilities and should not be considered comprehensive.

2.3.1 Greening of ships

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 (NO_x, SO_x and particles), discharge to water (i.e. oil spills, sewage, grey water), fuel consumption, antifouling measures and radiated noise to air and water. This is of particular importance for research vessels built and operated for marine science use, where knowledge gathering in support of protection of the environment and marine life is one of the main goals.

The dominant part of the vessel design and outfitting regarding environmental "footprint" is the propulsion plant. Most modern research vessels are built with some kind of diesel-electric power plant, where diesel generators are used to produce electricity to feed electrical propulsion motors that drive the propeller(s). This allows the most fuel-efficient operation of the machinery under different vessel operations (transit, trawling, station work using dynamic positioning (DP), in port etc.) where the engine load will vary significantly during the different operations.

New energy carriers are coming into the shipping industry, such as Liquid Natural Gas (LNG), Liquid Petroleum Gas (LPG), methanol, biofuel, hydrogen, batteries, fuel cells etc., which can be used as the main energy source or in combination with a diesel-electric propulsion system as detailed by the Royal Academy of Engineering (2013).

These new energy types are ideal as a sole source of "fuel" for vessels that operate in limited geographical areas with good shore supply, e.g. tug boats, ferries, and offshore supply vessels etc. who are frequently in the same port and can charge their batteries or fill up their LNG tanks. However, for vessels operating over vast geographical areas and only visiting ports every three-four weeks, such technologies cannot currently replace the onboard diesel generators. Instead, batteries and/or fuel cells can be used as "peak shavers" to avoid starting up extra diesel generators for short periods of time when a battery pack or fuel cell can deliver the extra power needed for a limited time (minutes). Additionally, batteries and fuel cells can be an alternative to running a diesel generator when in port if electrical shore power is not available.

As an example of what can currently be achieved on a research vessel, the Norwegian RV *Johan Hjort*, built in 1990, had the main propulsion plant replaced with a hybrid propulsion system in 2016. It now consists of a diesel main engine, two diesel auxiliary engines connected to electrical generator sets, a battery pack and a shaft generator. The shaft generator can be used both as an electrical power generator when the main engine is running, or as an electrical motor powered by the auxiliary generator sets in combination with the battery pack working as a “peak shaver” to deliver time-limited additional electrical power to the vessel. This solution has reduced the fuel consumption compared to the old diesel mechanical propulsion system by 5-10%, depending on the mission profile, weather conditions etc., and at the same time has reduced harmful air emissions.

All new research vessels must comply with all environmental standards required by national and international regulations and conventions such as the International Safety Management (ISM) code[15] and the MARPOL convention[16] that provides a stringent and continuously evolving legal framework to maintain vessel operations at sea and in ports at optimum environmental conditions. However, research vessels should also be “frontrunners” to the extent possible by minimizing their environmental footprint, since their mission is to contribute to “healthy” oceans and the welfare of all life in the marine environment. This is therefore a key topic at research vessel operator meetings in networks such as the European Research Vessel Operators (ERVO, see Box 1.1) and International Research Ship Operators (IRSO, see Box 7.2). IRSO also have a Code of Conduct that members are obliged to follow[17].

2.3.1.1 Ship Energy Efficiency Management Plan

All vessels must have a Ship Energy Efficiency Management Plan (SEEMP) in accordance with the MARPOL convention. For research vessels, it is important to focus on energy saving in the following operating modes:

- Transit;
- Cruise activities;
- In port; and
- In the shipyard during maintenance.

Generally applied options for energy saving include:

- Stopping all energy consuming machinery, pumps, winches, thrusters and other devices and installations when not in use;
- Increasing and decreasing speed gradually;
- Working with instead of against the wind, currents and waves;
- Allowing the vessel to drift off position in DP mode;
- Slowly pulling back instead of using a lot of engine power to maintain position;
- Using LED lights in the interior and on deck as much as possible;
- Using shore power when available in harbour; and
- Keeping the hull clean of marine fouling to minimize resistance.

It is also of vital importance to monitor and report improvements in fuel consumption and measures that are found to be effective to motivate the crew, and to learn from other operators locally, nationally and internationally.

2.3.2 Acoustic performance, station keeping, and high bandwidth satellite communication

Acoustic performance relates to the underwater noise generated by a vessel, which is discussed below. Station keeping relates to the ability of a vessel to remain static in the same position despite the influence of wind, waves and currents, and is typically achieved using a Dynamic Positioning (DP) system of thrusters. High bandwidth satellite communication is seen as the main means for vessels to communicate with those on land.

These three somewhat dissimilar areas have been highlighted together as they are becoming standard requirements for modern research vessels. As they are technologies that are typically installed on newer and more capable vessels, their prevalence in a given fleet can serve as a metric of the efficiency and status of the fleet.

High bandwidth satellite communication has been highlighted here, as this is most relevant system for larger research vessels, which are the focus of this document, as opposed to the shorter-range data links, which are of more importance to the Local & Coastal Class vessels. The larger vessels are also able to make use of shorter-range systems, such as 4G mobile phone networks when in range of the shore or offshore oil fields, but they are not reliant on these.

2.3.2.1 Acoustic performance and underwater radiated noise

The acoustic performance of a research vessel, i.e. how quiet it is with regards to underwater radiated noise (URN), is a key requirement for vessels engaged in fish stock assessments, seismic surveys, seabed mapping and any other scientific activity based on the use of hydroacoustic instruments. The International Council for the Exploration of the Seas (ICES) Cooperative Research Report no.209 (ICES, 1995) provides a recommended URN level for a research vessel to reduce the effect of vessel URN with regards to disturbing fish and marine mammals close to the vessel. It also considers the Signal-to-Noise (S/N) ratio of the vessel’s hydroacoustic equipment (echo sounders, sonars, towed seismic reception cable etc.).

Figure 2.10 illustrates the ICES recommended URN requirement, which is a common URN requirement and reference to compare the noise performance of modern research vessels. The figure illustrates the maximum allowed sound level that the vessel can generate over a wide range of frequencies, in order to avoid disturbing wildlife and interfering with sound-based survey equipment. As described earlier, this vessel sound is typically generated by the engines and propeller. In addition to the ICES limits, several classification societies including DNV GL[18] (see Figure 2.11) have published a variation of the URN requirements for the purposes of formal vessel URN classification in terms of a vessel class notation, e.g. the DNV GL Silent class notation described on page 35.

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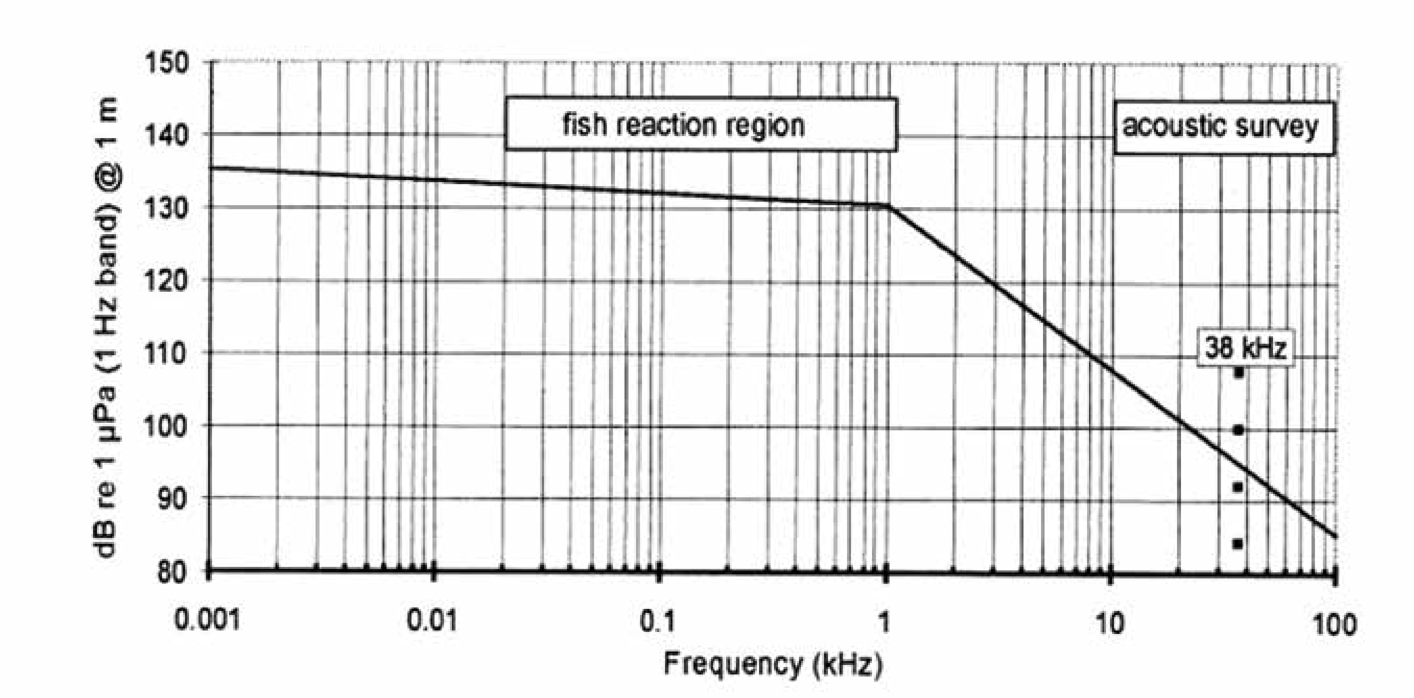
[15] http://www.imo.org/en/OurWork/humanelement/safetymanagement/pages/ismcode.aspx

[16] http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx

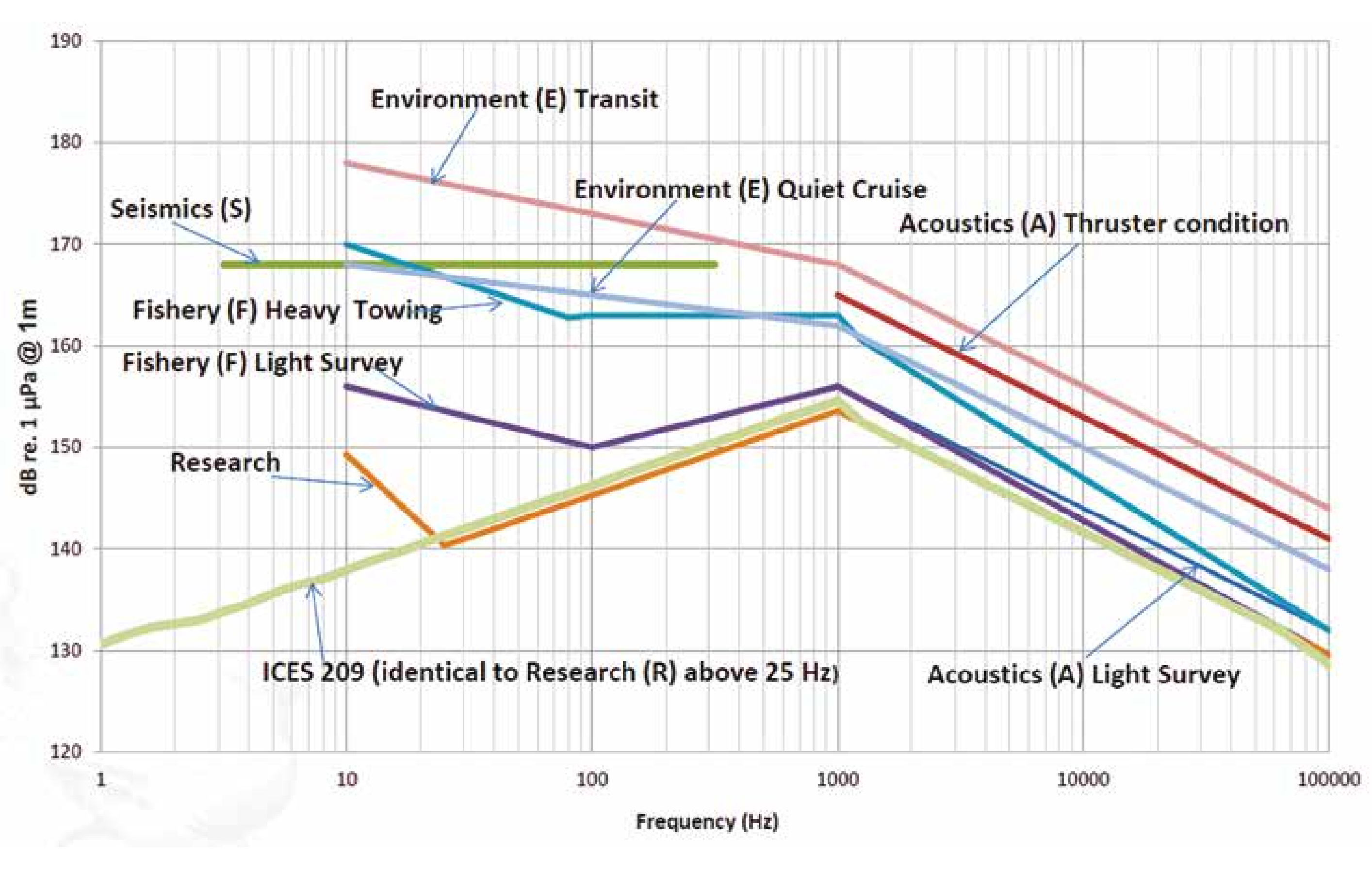
[17] https://www.irso.info/wp-content/uploads/International_RV_Code_final.pdf

[18] https://www.dnvgl.com/



Credit: (ICES, 1995)

Figure 2.10 ICES recommendation for research vessel underwater noise signature limits



Credit: IMR

Figure 2.11 DNV GL Silent Class notations (Band level)

DNV GL Silent class notations in Figure 2.11 are:

- Silent Acoustics (A) – Vessel using hydroacoustic equipment;
- Silent Seismics (S) –Vessel engaged in seismic research activities;
- Silent Fishery (F) –Vessel performing fishery activities;
- Silent Research (R) –Vessel engaged in research or other critical operation; and
- Silent Environment (E) –Any vessel wanting to demonstrate a controlled environmental noise emission.

The most stringent of these is DNV GL Silent[19] Research (R), which is a slightly modified version of the ICES curve.

It is important to note that the acoustic disturbance of fish and sea mammals is within the frequency band from approximately 20Hz to 1kHz, and this noise is usually generated by the vessel's diesel generators, pumps and pipes. Most newly built research vessels are therefore equipped with a diesel-electric propulsion system with the main components installed on dampers to reduce vibrations generating low frequency noise. The disturbance of the hydroacoustic instruments working in frequency bands higher than 1kHz is predominately due to propeller noise and cavitation (EUROFLEETS2 Consortium, 2014a). Non-cavitation propeller(s) at typical operating speeds are generally installed to avoid this. There is also intrinsic conflict between the noise generated by the side thrusters required for dynamic positioning and hydroacoustic instrument performance, particularly in the range of a few 10's of kHZ. This means that noise generated by the side thrusters to keep the vessel in position will generate unwanted noise in the same frequency range as the hydroacoustic equipment is measuring, potentially drowning out noise signals of interest.

Following a review of the European fleet, Ocean Class vessels have been found to have the highest number of 'Silent Class' vessels at 57% (8 out of 14), which is representative of the predominance of this class of vessels for acoustic fisheries stock assessment operations. Regional and Global Class vessels only have just over 20% Silent Class vessels because they are usually not fishery research vessels, but vessels geared towards physical biology, deployment of subsea systems and geoscience for which the signal-to-noise-ratio of the vessel's hydroacoustic equipment is more important. There is only one Coastal Class vessel with Silent Vessel capabilities (RV *Simon Stevin*).

2.3.2.2 Station keeping and dynamic positioning

Dynamic Positioning (DP) is essential for effective 'station-keeping' and 'survey line accuracy' for many of the activities described above, and this is desirable for all research vessel classes to enable efficient operations. Operations such as ROV deployment, seabed rock drilling, AUV deployment, seabed sediment sampling and CTD data acquisition require highly accurate positioning, particularly for deep-water operations. Additionally, activities such as trawling, towing multi-channel seismic streamers, towed sensor platforms etc. require accurate survey line keeping at low speeds and working around marine infrastructure. An overview of DP capability within the fleet is illustrated in Figure 2.12.

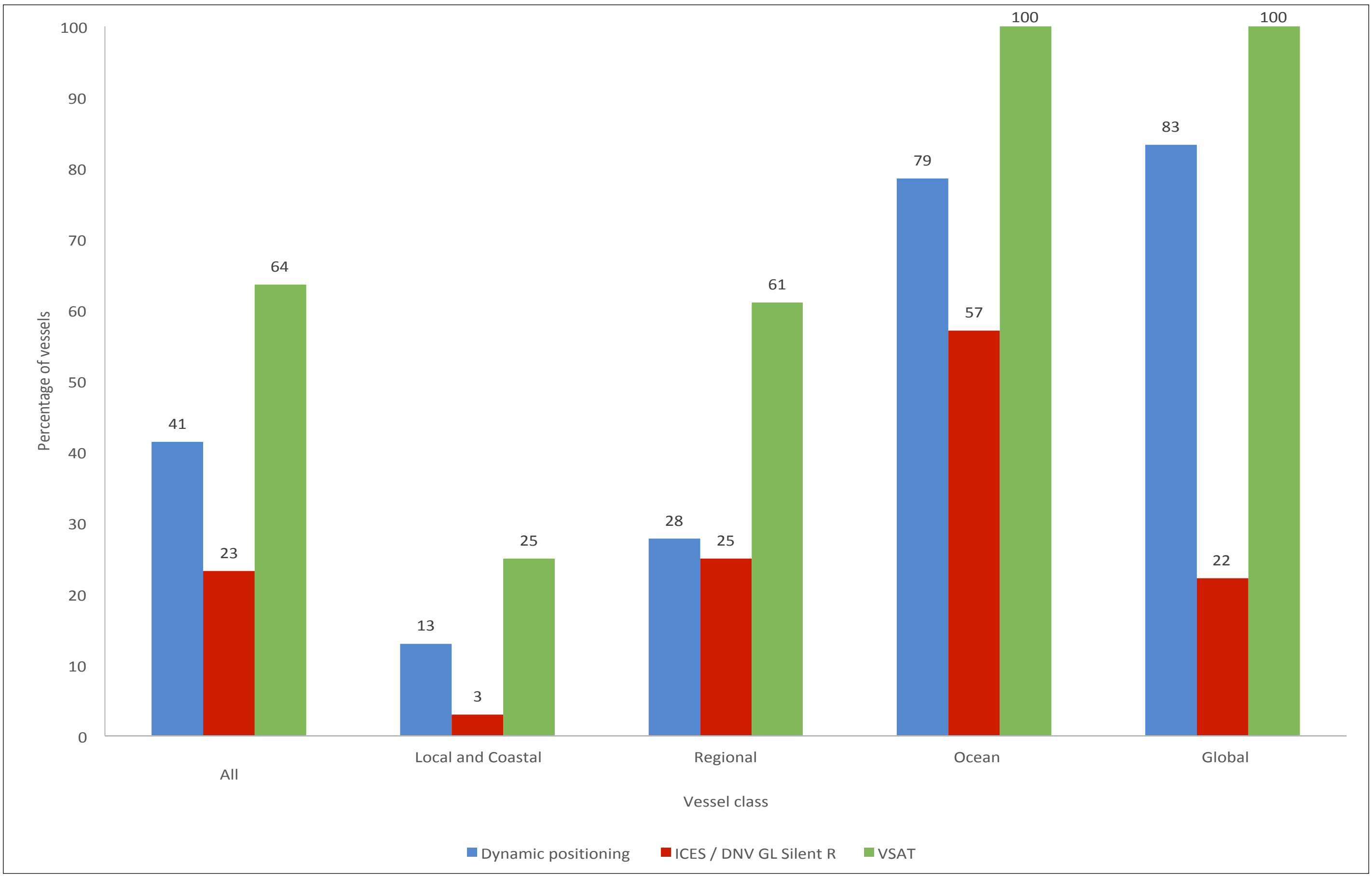


Figure 2.12 Dynamic positioning (DP), underwater radiated noise (based on International Council for the Exploration of the Sea (ICES) and DNV GL requirements), and communication capability (based on Very Small Aperture Terminal (VSAT) satellite communication availability) for the 99 vessels included in this Position Paper

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[19] http://production.presstogo.com/fileroot7/gallery/dnvgl/files/original/9cc77f1189644373b8ff7a0e0d5250b1/9cc77f1189644373b8ff7a0e0d5250b1_low.pdf

There are four different “DP classes”; DP0 – DP3, where DP0 has the lowest level of redundancy and back-up modes, while DP3 is the most “robust” system. For research vessels, DP1 is often sufficient if they are working only in “open waters” and not close to oil rigs, other offshore installations or aquaculture cages. For vessels involved in precise positioning of equipment on the ocean floor or in close vicinity to fixed or anchored installations there may be a requirement for DP2 or even DP3 to be allowed to work close to the installations. DP has emerged as a standard item for a modern research vessel with over 40% of the fleet equipped with this capability. This represents an increase from the 28% of all vessels in 2007. The figure is higher for Ocean Class vessels at around 80% (11 out of 14), and Global Class vessels at over 80% (15 out of 18). This illustrates the younger average age of these vessel types that have been designed to handle and operate larger equipment such as ROVs (see Section A5.1.1.3). The smaller Regional and Local & Coastal Class vessels have less space to accommodate this larger and heavier equipment, and hence only 30% of Regional and 13% of Coastal Class vessels have DP capability.

2.3.2.3 Shore-to-ship and ship-to-shore e-access by satellite communication

High-speed broadband (over 500Kbps download and at least 256Kbps upload) is becoming a standard requirement for modern research vessels, facilitating high-speed data connectivity to shore for data transfer, control of equipment and connection to web-based services and email. The uptake of high-speed internet capability is evident across all vessel classes with over 60% (22 out of 36) of Regional Class and 100% of Ocean and Global Class vessels having high-speed capability. This capability is now a standard fit on new vessels, and a commonly installed item during a vessel’s mid-life upgrade if not already installed. This is done to allow more efficient operation of the vessels and more efficient scientific work. It also allows crew and scientists to stay in touch with their families more reliably.

2.3.3 Oceanography and meteorology sensors

Research vessels host a range of oceanography and meteorology vessel-fitted sensors, which can acquire data as soon as the vessel is at sea. Among the most common sensors or instruments installed on board a research vessel and used for oceanography are:

- Thermosalinographs, which are instruments mounted near the water intake of ships to measure sea surface temperature and conductivity continuously while the ship is underway;
- Acoustic Doppler Current Profilers (ADCP), which are hydroacoustic systems enabling the measurement of water current velocities over a depth range below the ship;
- pCO_2 (partial pressure of carbon dioxide) sensors, which measure the partial pressure of CO_2 gas dissolved in water and are essential sensors in research on ocean acidification;
- Meteorological sensors such as anemometers, barometers, air temperature and humidity sensors, which provide weather observation data and are often operated in collaboration with the oceanographic sensors.

The analysis of the oceanographic and meteorological sampling and survey capability of the European research fleet illustrates how well equipped the Ocean Class fleet is, with all vessels equipped with ADCP, underway meteorological sensors and thermosalinographs (see Figure 2.13). Over 40% (six out of 14) vessels are also equipped with $pC0_2$ measuring systems. The Global Class fleet has almost 90% (16 out of 18) vessels equipped with ADCPs, over 90% (17 out of 18) fitted with meteorological equipment and 100% equipped with surface water sensors, while less than 30% are equipped with pCO_2 systems. The Regional and Coastal vessels are generally less well equipped with these sensors, although many still have these capabilities.

Supplementary to these on-board sensors, the ability to deploy CTD rosettes and collect water samples at a range of depths is one of the basic requirements of a research vessel. As can be seen in Figure 2.14, the vast majority of vessels in all categories (over 80% of the total) have a capacity to acquire this data in shallow continental shelf seas, or on the continental shelf slopes to less the 2000m water depth. For medium depth operations (approximately 2000m-4500m water depths), it is predominantly the Ocean and Global Class vessels that have this capability. The ability to sample full ocean depth (>4500m) is available on almost 90% (16 out of 18) Global Class vessels and approximately 45% (six out of 14) Ocean Class vessels, with only two Regional Class vessels equipped with this capability.

To allow the acquisition of increasingly accurate ‘trace metal’ measurements there is a growing requirement from the scientific community for ‘clean’ or ‘ultra-clean’ instrumented CTD systems. These systems require metal- and grease-free deployment cables (most frequently achieved using synthetic cables), and Titanium, non-steel or plastic-coated instruments and in order to reduce contamination of the water samples and sensor measurements. As seen in Figure 2.15, these systems are largely confined to Global Class vessels, with this capability on only 14% (two out of 14) Ocean Class vessels and only one Regional Class vessel in medium depths.

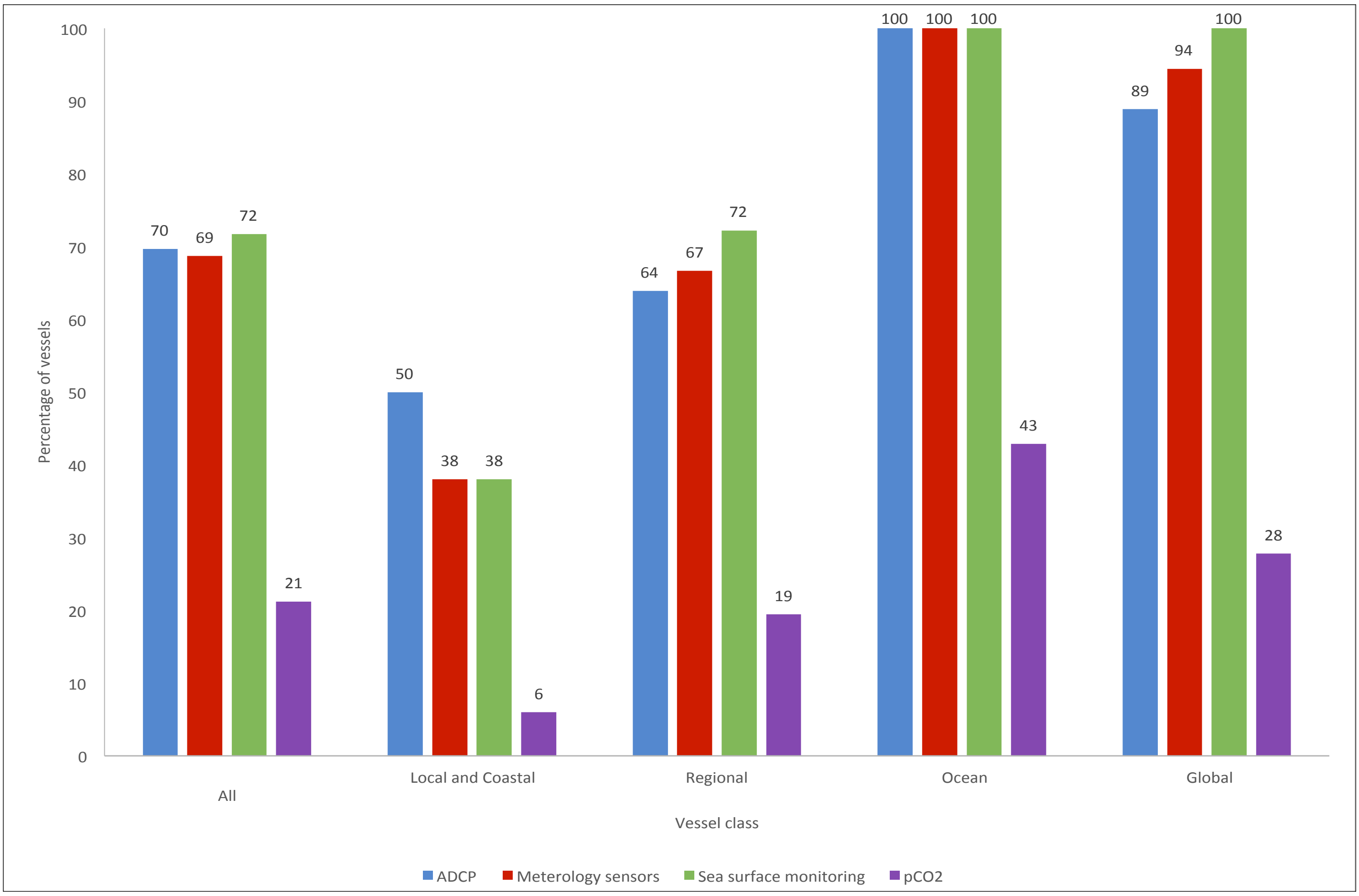

Figure 2.13 Vessel oceanography and meteorology capabilities of the 99 vessels

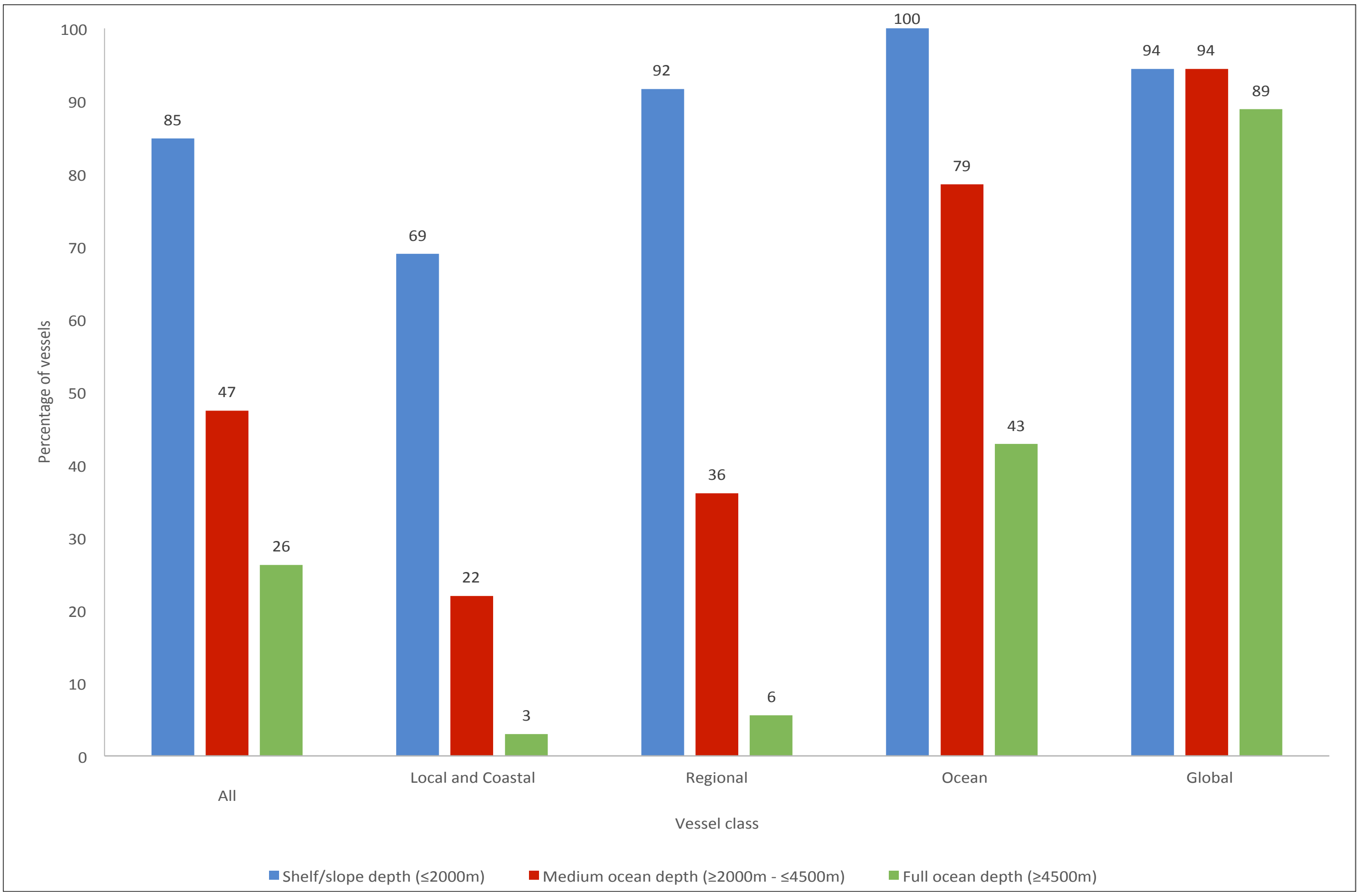

Figure 2.14 CTD capabilities of the 99 vessels

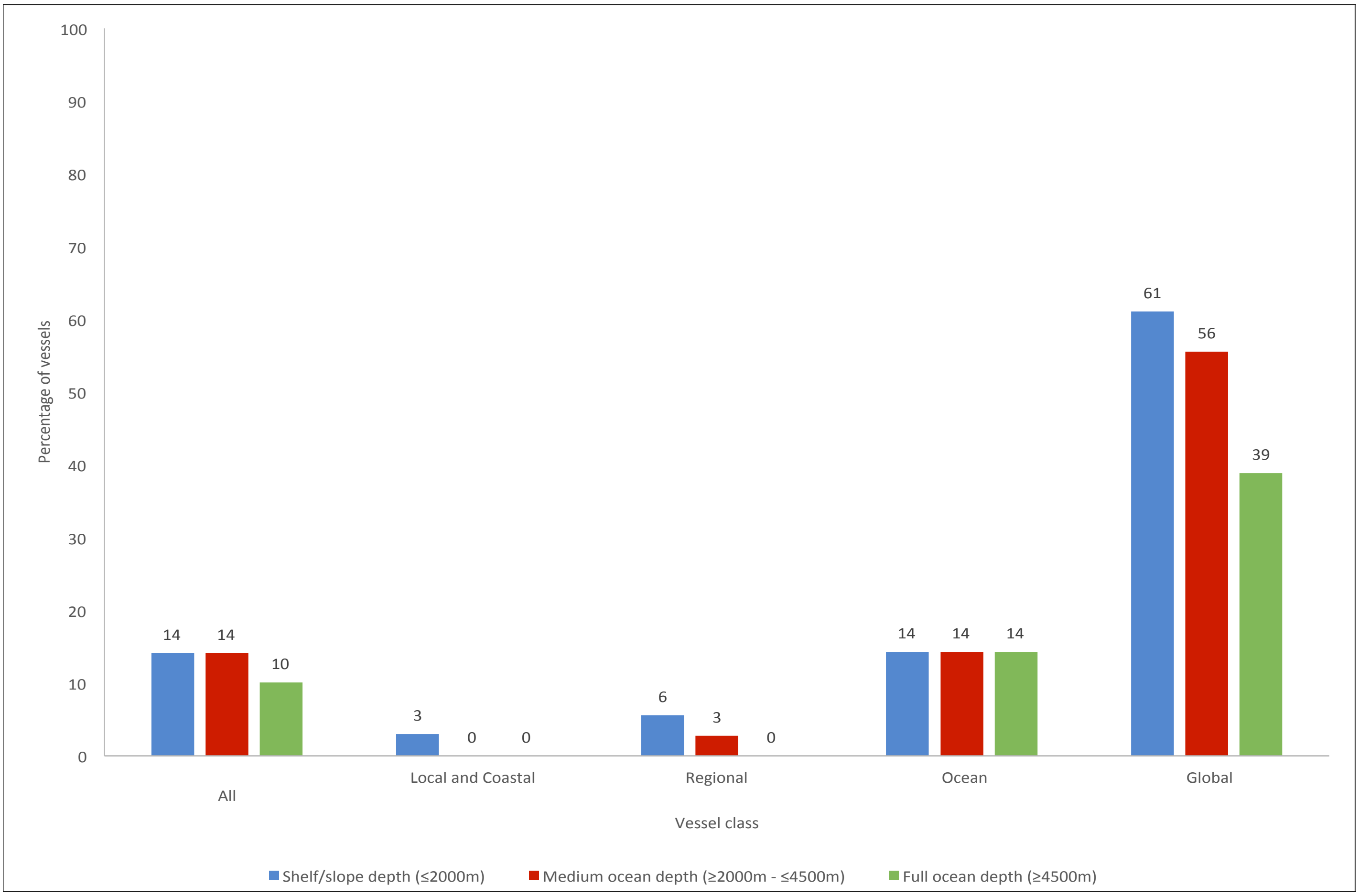

Figure 2.15 Clean CTD capabilities of the 99 vessels

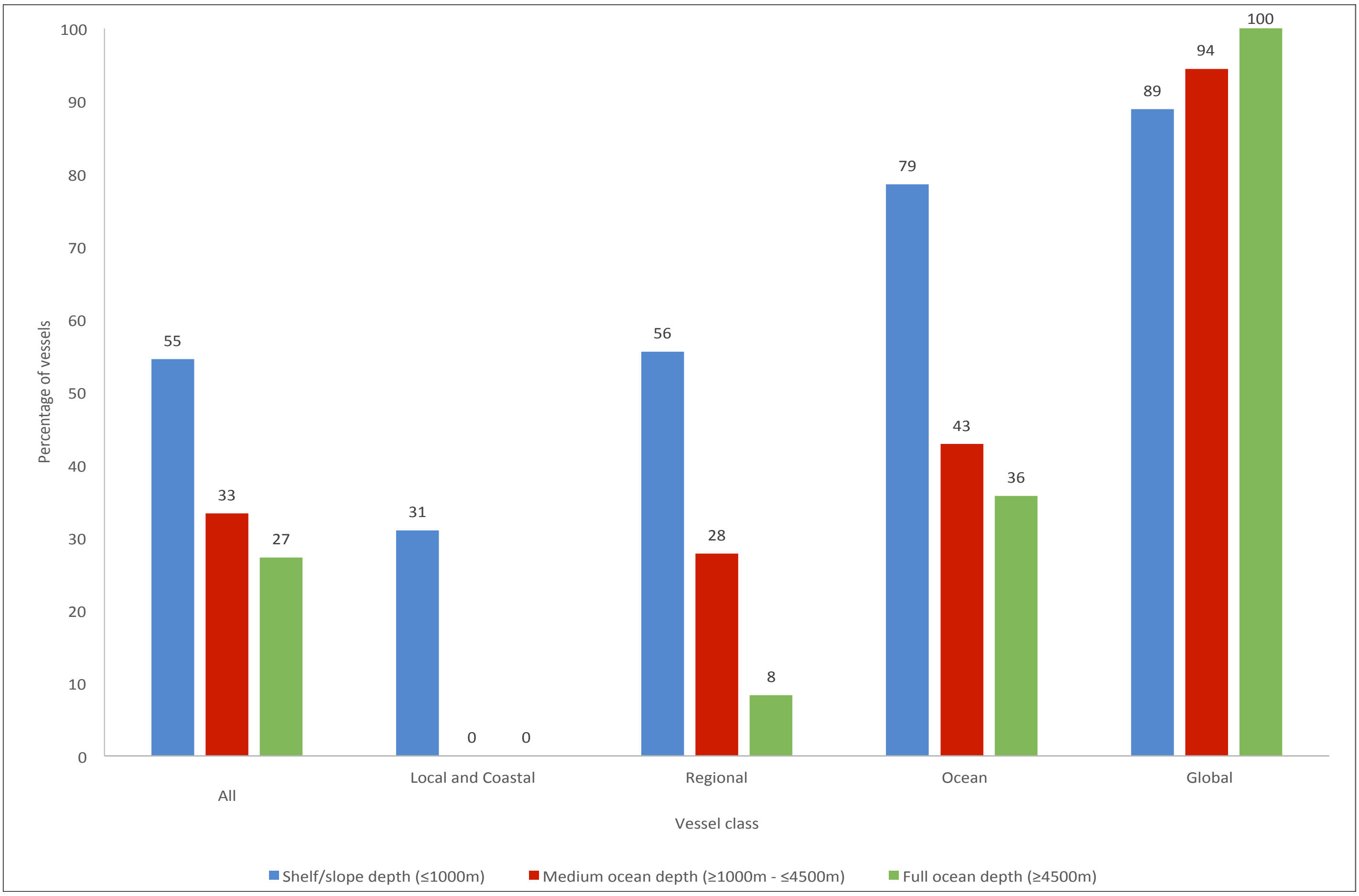

Figure 2.16 Multibeam capabilities for the 99 vessels

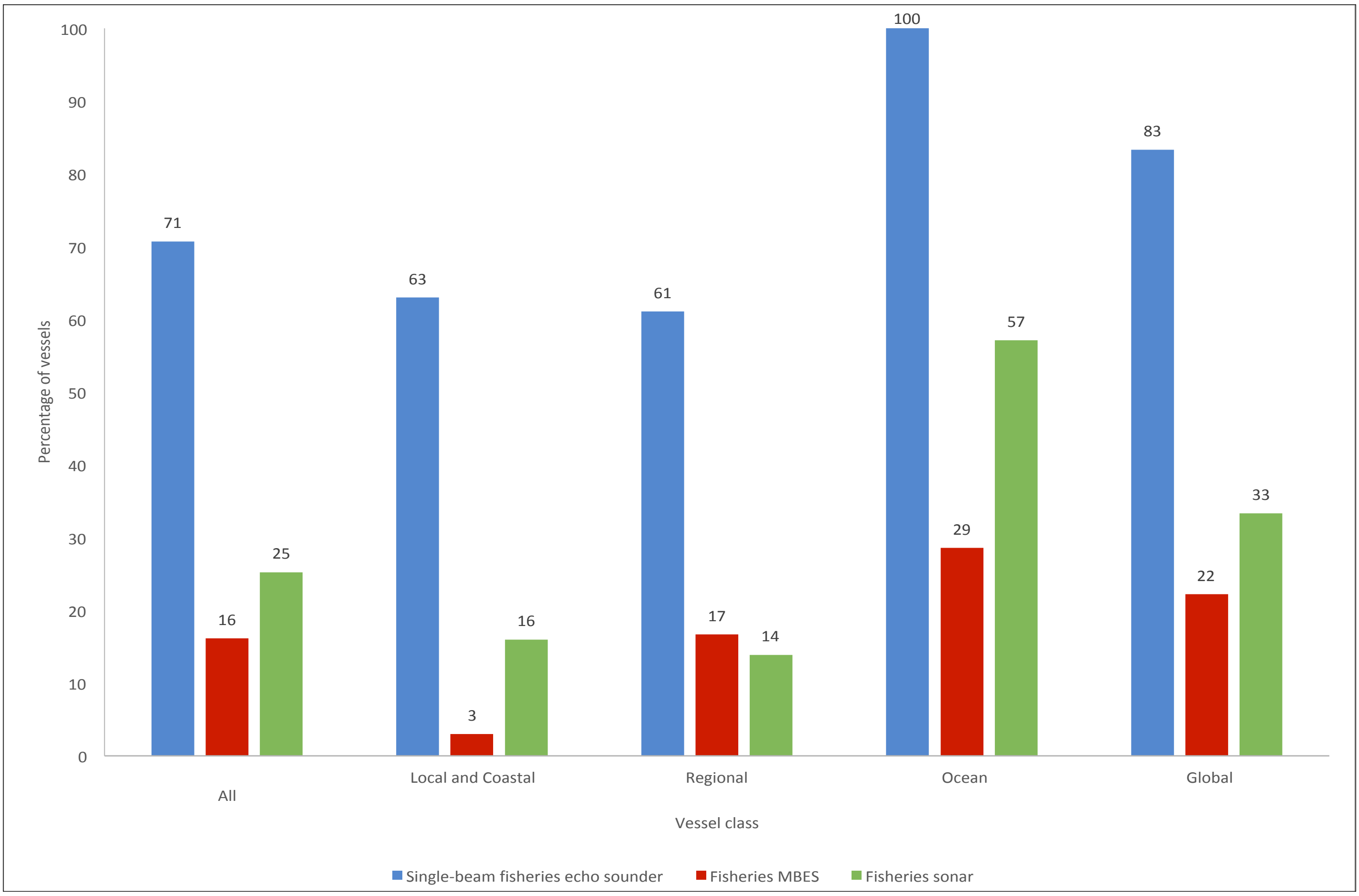

Figure 2.17 Sub-bottom profiler capabilities of the 99 vessels

2.3.4 Hydroacoustic systems for geology and geophysics

Multibeam echo sounders (MBES) are key instruments for mapping the seabed and determining its topography. These systems can also be used to collect data in the water column and have proven to be relevant tools when it comes to identifying fluid outlets in the ocean floor. They are supplemented by sub-bottom profilers (SBPs, see Section 2.3.4.2) for the exploration and mapping of the first sedimentary layers under the seabed. Depending on the size of their antennae, these systems are either integrated into the ship's hull, on the ship's hull in dedicated blisters or gondolas, or in drop keels, which enable the operator to move the arrays down in order to reduce interferences between acoustic signals and air bubbles released by the vessel's movements.

Although this analysis addresses vessel-fitted systems, MBES and SBPs can also be integrated in underwater vehicle payloads, allowing the equipment to be placed closer to the seabed to acquire data with higher resolution in small-scale working areas.

2.3.4.1 Multibeam echo sounder systems

The resolution of seabed mapping using MBES systems depends on a compromise between the operating depth and some parameters inherent to the system itself, i.e. the frequency of the transmitted signal and the size of the transducer arrays used for transmitting the acoustic signal and receiving the echoes backscattered from the seabed. The range of multibeam echo sounders therefore includes several categories, mainly depending on the water depth of operation, with high-resolution and small-size systems for shallow waters, to heavy systems with large arrays for operation in deep waters (see Chapter 3).

The analysis of MBES capabilities across the European research vessel fleet (Figure 2.16) shows that Global Class vessels are increasingly well equipped with this capability with 100% of the ships capable of full ocean depth seabed mapping. Ocean Class vessels are predominantly equipped for high-resolution continental shelf/slope mapping (<1000m), but only 36% (five out of 14) are capable of full ocean depth operations. This capability is significantly less evident in the Regional Class, which is largely restricted to working on the continental shelf with less than 10% (three out of 36) equipped for full ocean mapping. Given the design requirements of the vessels and their area of operation, this is to be expected.

2.3.4.2 Sub-bottom profilers

Sub-bottom profilers (SBP) supplement seabed mapping systems by exploring the sediment below the seabed. They are commonly used to determine the nature of the sedimentary layers over a thickness of tens of meters. European Global Class vessels are well equipped with around 80% (14 out of 18) equipped with SBP for the full ocean depth (Figure 2.17). Ocean Class vessels are predominantly equipped for continental shelf/slope studies with only around 40% (five out of 14) have capabilities for full ocean depth operations. Only around 10% (three out of 36) of Regional Class vessels have the full ocean depth capabilities and around 40% (15 out of 36) have capabilities for the continental shelf/slope water depth.

2.3.5 Trawling and acoustic capabilities for fisheries science

The monitoring of fish stocks through dedicated surveys conducted on research vessels requires the use of a range of nets, trawls and other instruments to collect biological samples and data on environmental parameters. The two key capabilities highlighted in this review are trawling, which is essential for species identification and the collection of fish samples, and hydroacoustic systems (single beam echo sounders, multibeam echo sounders and sonars) used during fisheries acoustic surveys for the estimation of fish abundance and distribution.

The analysis of the fisheries research capability indicates a very strong capacity across the fleet (see Figure 2.18), and it is again noted that vessels solely dedicated to fisheries research and not available for research are excluded from this study. This is indicative of the relatively well-funded nature of fish stock monitoring and associated research within Europe, through initiatives such as the European Marine Fisheries Fund (EMFF) and previous EU- and nationally-funded efforts. This means that many Ocean Class research vessels built over the past 20+ years have a strong fisheries' focus. Over 80% (12 out of 14) Ocean Class vessels have shelf-trawling capability, and 50% (seven out of 14) have a wire length of 4500m meaning that they are able to trawl to around 2000m. The Global Class fleet reflect their use for deep-water research rather than monitoring programs with just over 30% (six out of 18) capable of trawling (single or dual wire deployments) to depths beyond 4500m, with a similar figure for the 0-4500m range. The Regional and Coastal Class vessels also have good fisheries capacity with 75% (27 out of 36) and just under 60% (18 out of 31) respectively capable of work in the 0-2000m depth range, again reflecting the large amounts of coastal fisheries monitoring and research undertaken.

In terms of fisheries acoustic equipment, the fleet is well equipped with single beam fisheries echo sounders seen in approximately 70% of the overall fleet, and with the greatest capacity (100%) within the Ocean Class fleet (Figure 2.19). This again reflects the predominant use of Ocean Class vessels for fisheries monitoring work. The emerging technology of fisheries multi-beam survey systems, which are capable of 3D imaging of entire fish shoals, is less well represented with just under 30% (six out of 14) Ocean Class vessels being capable and fewer in other vessel classes. This is due to this technology only recently being implemented, the high costs and the requirement (in most cases) to have a drop-keel to accommodate this equipment. The Ocean Class also has almost 60% (eight out of 14) of the fleet equipped with fisheries sonar, which is largely utilized for undertaking pelagic fish surveys (an activity largely confined to Ocean Class vessels) as well as plankton/krill research and pelagic ecosystem research. More information about fisheries science capability in research vessels, elucidated by the European Fisheries and Aquaculture Research Organisations[20] (EFARO) network, is presented in Annex 6.

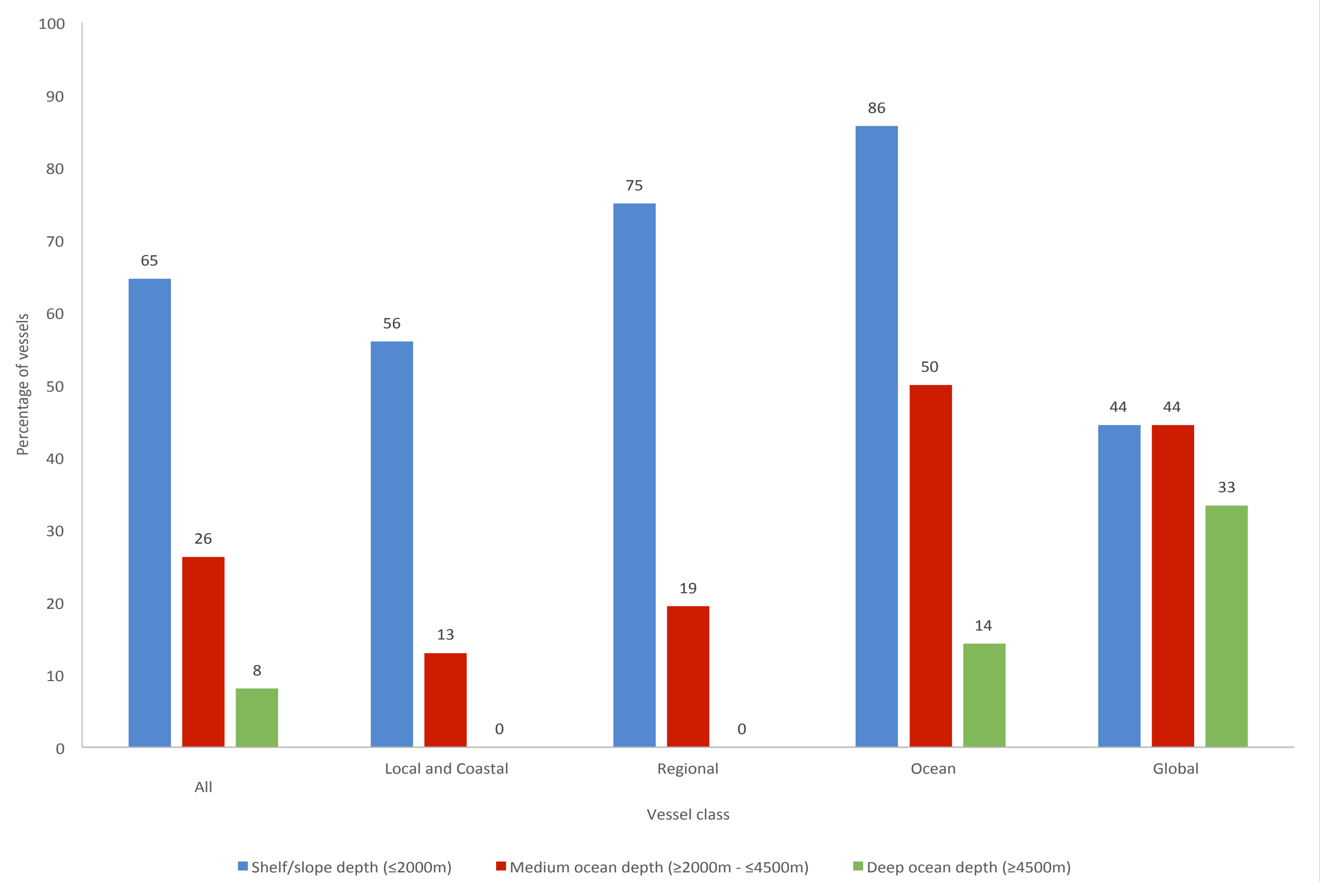

Figure 2.18 Trawling capabilities for the 99 vessels

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[20] http://www.efaro.eu/

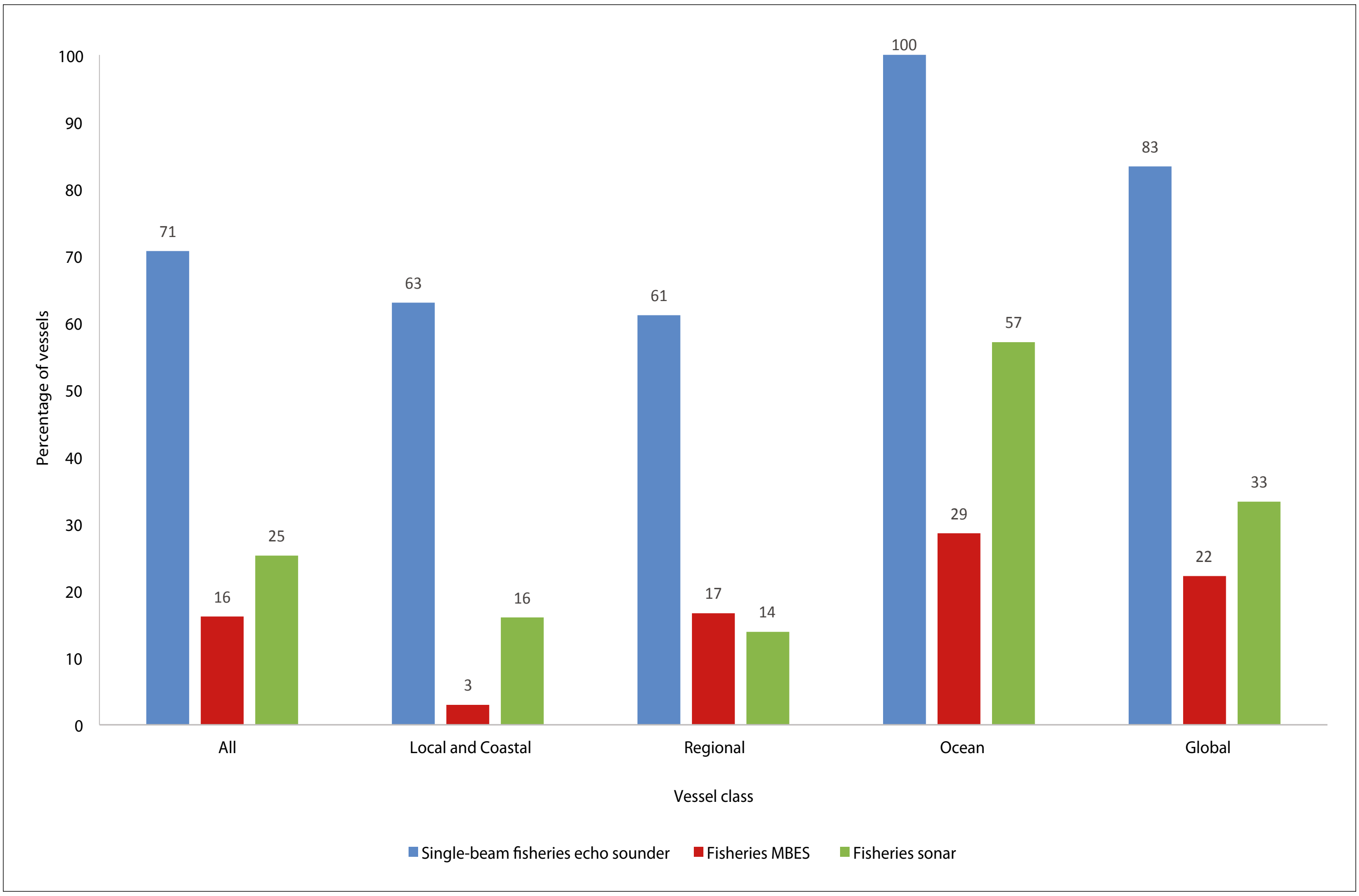


Figure 2.19 Fisheries acoustic capabilities of the 99 vessels


Mafalda Carapuço (IPMA, I.P.)

A fish trawl on RV *Mar Portugal*

Credit: Mafalda Carapuço (IPMA, I.P.)

Testing the capacity of RV *Mar Portugal's A-frame*

2.3.6 Over-the-side handling equipment

Winch and cable systems installed on multi-role research vessels are one of the main equipment suites required to deliver marine science. They are used on nearly every research cruise often 24-hours a day, with operations routinely switching between different winches and cables deploying a wide range of scientific sampling and survey equipment. These winches are matched with an array of specialized cables, wires and ropes of various lengths depending on vessel size and typical sampling depths and can vary from a few thousand metres for vessels operating on the continental shelf to 10-15000m for vessels performing deep-sea scientific operations.

The requirement for deep-sea scientific research (see Chapter 3) is a significant driver for technological development in sampling and measuring techniques, and winch and cable design needs to keep pace with these requirements. Some of the key technical challenges facing research vessel operators and equipment designers are the increasing weight of deployed equipment, the changing data gathering and data transmission requirements of the equipment, and increasing scientific requirements to measure to increasingly accurate levels. An example of this is the requirement for metal-free sampling systems to reduce contamination of samples by the handling and sampling equipment itself. These science and technology drivers will continue to develop, requiring scientific sampling and handling equipment to flexibly adapt and change to the emerging technologies and scientific requirements.

2.3.6.1 Wires, cables and synthetic ropes

Wires, cables and synthetic ropes are utilised for trawling, towing or deploying scientific equipment and instruments over the side. Winches are usually equipped with wire, electrical cable, fibre-optic cable or combined fibre-optic and electrical cable (see Figure 2.20) and utilized for their respective specialized purpose.

One of the challenges for winch and wire systems is the increasing limitation of steel wires and steel armoured cables for use during deep vertical sampling activities where the weight of the wire/cable itself can approach the wire's Safe Working Load (SWL). Powerful winch drives are also required to be able to pull the cable back on board the vessel.

In general, winches with 2000-4000m wire/cable length can use standard cables and wire, but for the largest water depths, synthetic ropes are becoming more common due to their high working load, low weight, and the metal-free materials from which they are manufactured.

Synthetic ropes are used for heavy vertical deployment activities and electro-optical synthetic ropes to deploy measuring and sampling systems. These synthetic ropes can address both the weight issue, and meet the requirements for clean, metal-free sampling and high bandwidth data transmission. An additional benefit of synthetic ropes is in deploying very light equipment such as multicorers at large depths (5000-6000m); due to the lightweight nature of the cable it is possible to detect when the equipment reaches the seabed, which is not possible with steel.

2.3.6.2 Winches

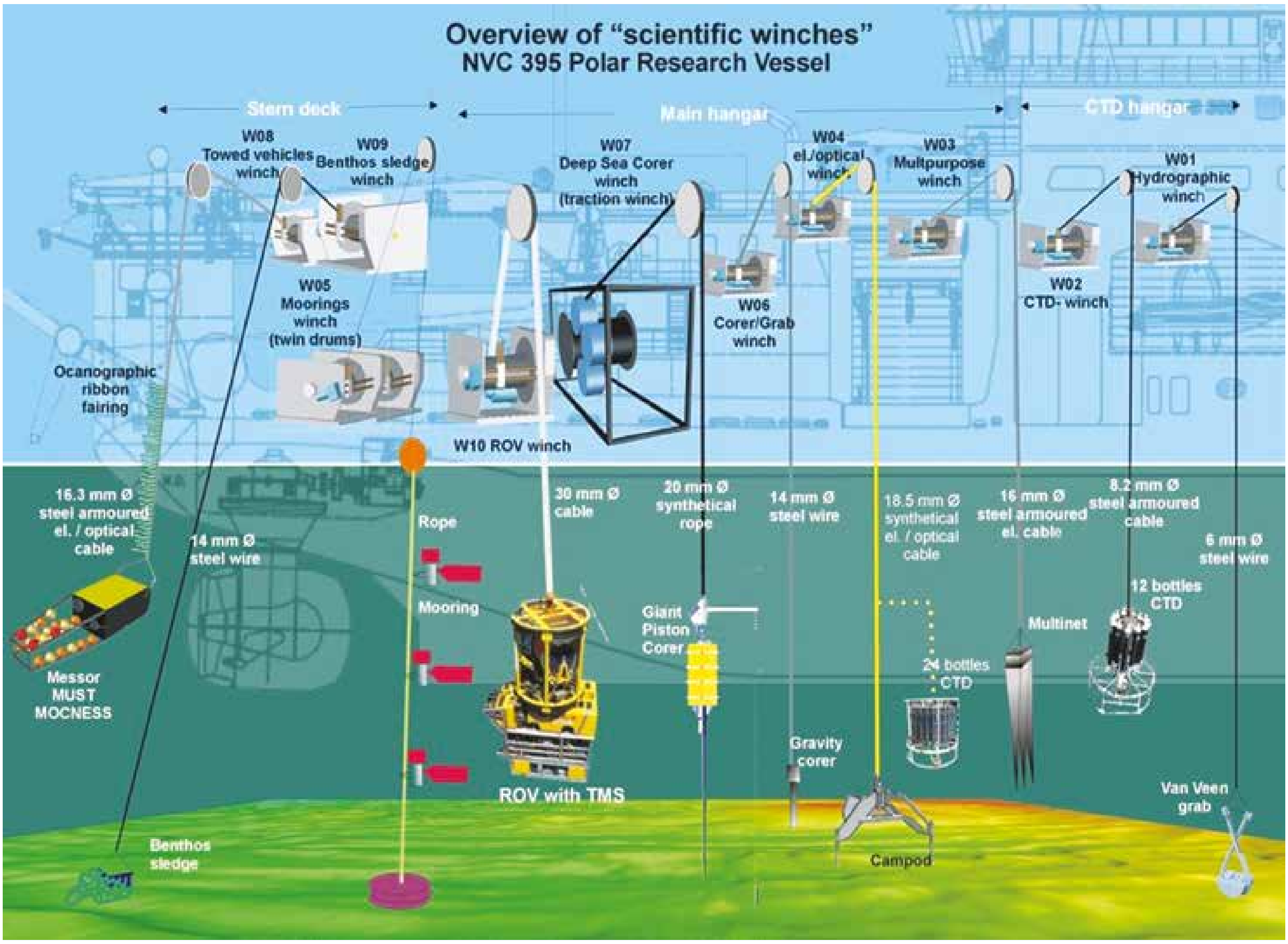
Winch design has developed significantly over the last 15 years to adapt to the changing scientific requirements. A key consideration for ship operators has been the choice of 'traction/storage' type winches, which are more appropriate for deep-sea scientific operations, or 'direct pull' type winches. The majority of European research vessels are not designed and equipped to work in deep-sea areas and therefore are usually equipped with 'direct pull' winches.

The decision on which concept of winch design is preferable for a particular research vessel or science application needs to be based on a range of operational and ship design requirements, with both traction and direct pull options being viable, depending on the operational and design criteria. This does however demonstrate the importance in considering the potential science requirements and operation types when designing vessels.

2.3.6.3 Over-the-side capabilities of the European research fleet

Figure 2.21 illustrates that the majority of vessels can handle deployment loads of < 10 tonnes over the side and over the stern of the ship. However, it is predominantly Global Class (over 85%) and around 50% (seven out of 14) of Ocean Class ships that can handle equipment deployment loads in excess of 10 tonnes. This situation will however evolve with the increasing use of synthetic cables and ropes, which are significantly lighter than steel cables whilst maintaining high load capability. This increases the operational depths to which equipment can be deployed, allows the use of heavier sampling equipment, and reduces winch and handling system loading.

Some vessels will also have other over-the-side deployment systems such as a crane or a launch and recovery system (LARS). These have all been presented together in Figure 2.21.



Credit: IMR, Hans Petter Knudsen

Figure 2.20 Overview of the range of scientific winches in use on a research vessel

2.3.7 Subsea acoustic positioning systems

The main subsea positioning systems used on board research vessels are Ultra Short Base Line (USBL) and Long Base Line (LBL) systems, which enable the accurate positioning of underwater vehicles such as AUVs and ROVs. A USBL system is mounted on the ship's hull while an LBL system consists of a network of baseline transponders deployed on the seabed (usually around the explored site) and used as reference points. In both cases, underwater vehicles are fitted with specific transponders or beacons, allowing them to be tracked and to follow their navigation.

The ability to provide high-accuracy subsea positioning for underwater equipment is essential to support the use of modern sampling and survey equipment such as ROVs and AUVs, and also to accurately position equipment such as seabed sediment corers, seabed instrument landers and deep-sea cameras. Figure 2.22 below highlights the Global and Ocean Class vessels as having the greatest capability in this area with around 80% (14 out of 18 Global and 11 out of 14 Ocean Class) of vessels equipped with this type of equipment, which, like Dynamic Positioning capability, illustrates the more recent age profile of these classes and their utilization for activities such as ROV operations. Regional Class vessels are less well equipped in this area with just over 35% (13 out of 36) having USBL and/or LBL capability. It is noted that Figure 2.22 presents the combined figures for USBL and LBL capability together.

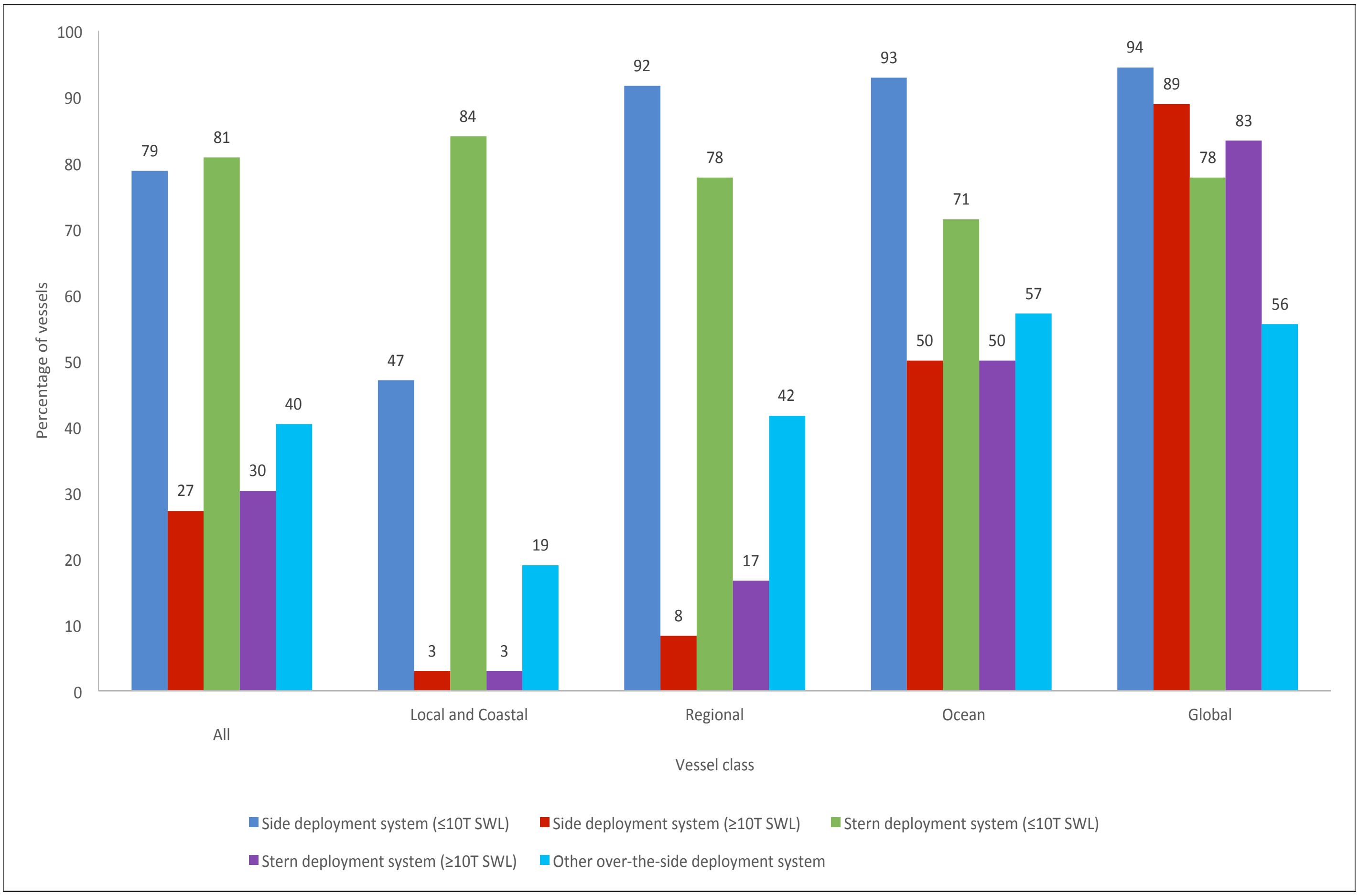


Figure 2.21 Over-the-side handling capabilities of the 99 vessels

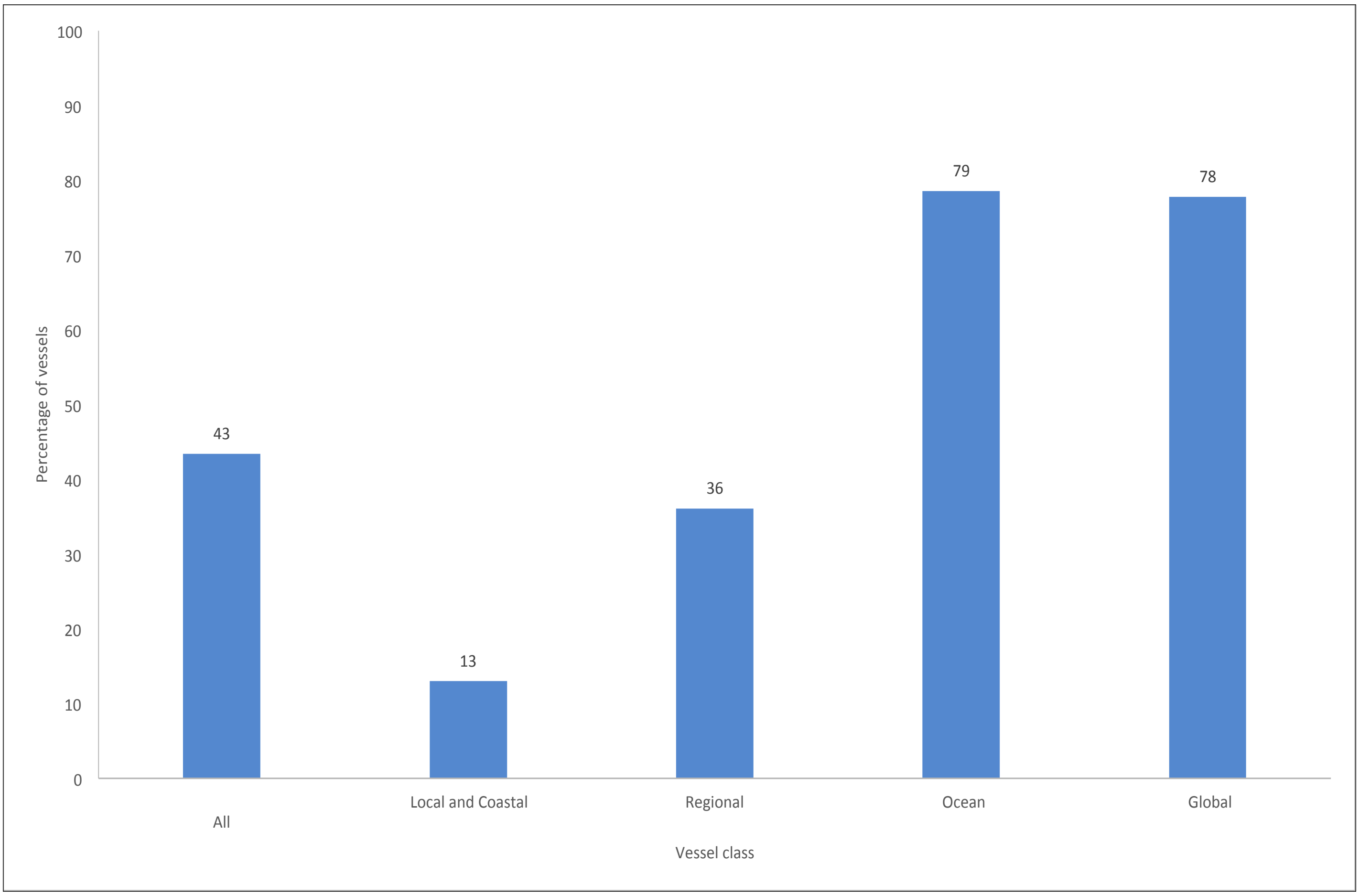


Figure 2.22 Subsea positioning capabilities of the 99 vessels

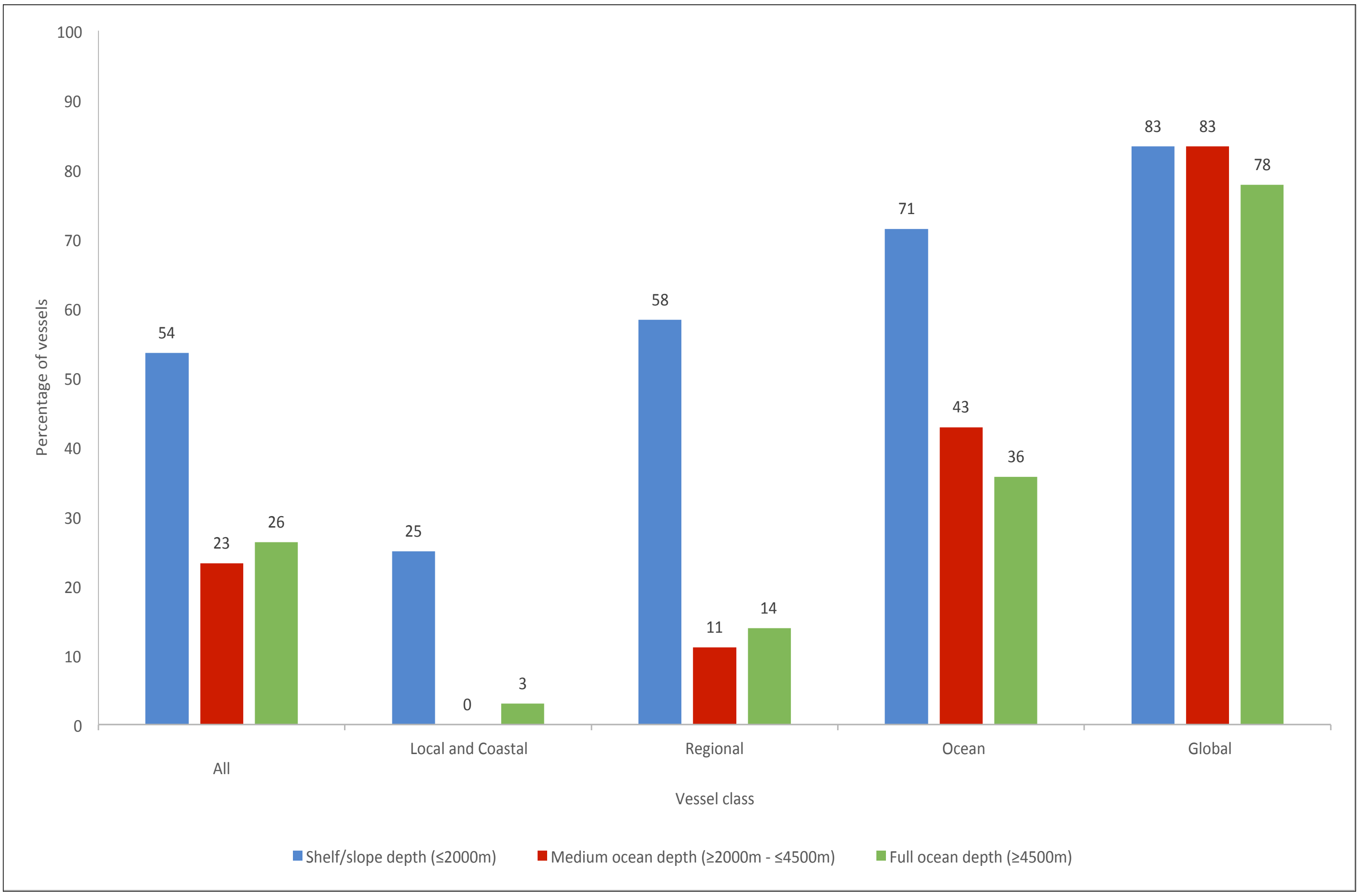


Figure 2.23 ROV hosting capabilities of the 99 vessels

2.3.8 ROV capability

Figure 2.23 illustrates the numbers of vessels that are capable of accommodating ROV systems (see Annex 5.1.1 for more information on ROVs). As expected, the Global Class vessels are capable of hosting the full ocean depth systems, which commonly require large deck space, availability of suitable electrical power, and the ability to launch and recover systems of 5-20 tonnes. However, some Global Class vessels, which are capable of hosting ROVs, are not equipped with USBL systems and are reliant on portable USBL systems provided by the ROV owners and fitted as temporary installations. Ocean Class vessels reflect the lack of deck space and/or suitable launch and recovery systems for operating the larger ROV systems with only around 30% (five out of 14) capable of accommodating the largest ROV systems. Regional Class vessels have good capacity for <2000m capable ROV systems, but are generally not able to support larger, deeper rated ROV systems with less than 20% (five out of 36) identified as capable in this area.

2.3.9 Seismic equipment

The analysis of the fleets' capability to accommodate seismic survey equipment (with the exception of small high-resolution seismic systems that can be deployed from all vessel classes) is illustrated in Figure 2.24 (see Annex 5.1.2 for more information on marine seismic equipment). The European research vessel fleet has a good capacity for this specialized work with around 45% of the Ocean Class fleet and around 70% of the Global Class fleet capable of long 2D seismic surveys. The capability of the Ocean Class fleet to accommodate 3D seismic survey systems is lower, with just under 30% having these capabilities. The ability for ships to support the upper end of the large seismic equipment (above 6km length multi-channel streamers) is limited by the requirement for very large open deck space and a very high-power source of the ship to support the equipment. This helps explain why this capability is mainly available on-board Global Class vessels where 61% (11 out of 18) of these vessels are capable of deploying this large equipment. As can be expected, the Regional and Coastal Class vessels are generally only suited to handle the smaller 2D systems.

2.3.10 Sediment coring capability

The ability to acquire sediment cores is an important requirement for many scientific disciplines, particularly for the study of past climate change effects and sediment transport. The larger and heavier seabed sediment coring systems are the gravity corers and piston corers, and can vary in sample recovery length from 1m to over 75m in the case of the Giant Calypso corer on the RV *Marion Dufresne* (see Annex 5.1.3).

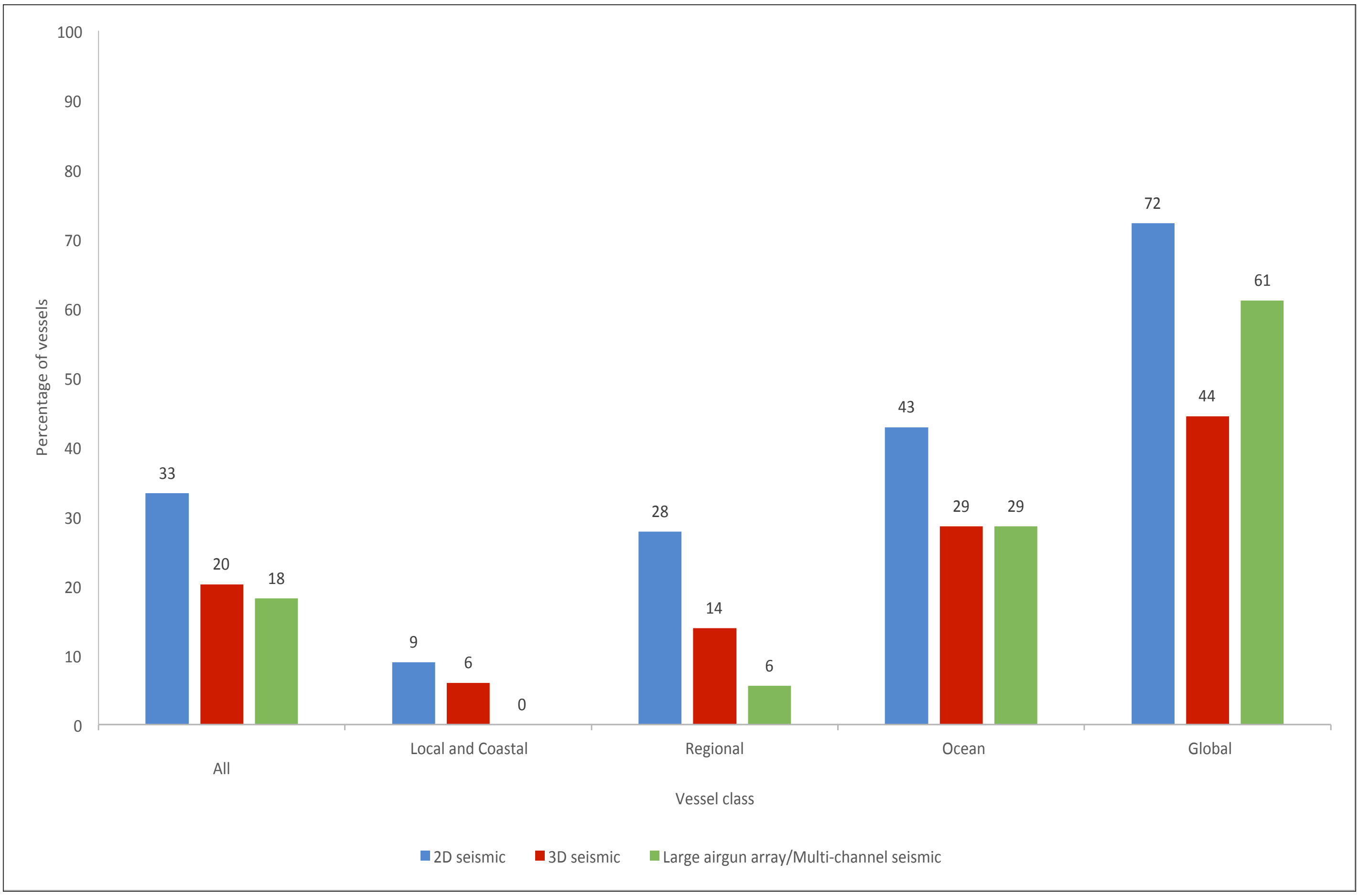


Figure 2.24 Seismic acquisition capabilities of the 99 vessel


Credit: Yvan Reaud, Ifremer/Genavir

Recovery of the Giant Calypso corer on board RV *Marion Dufresne* for the world record of the longest core MD19-3581, length: 69.73m

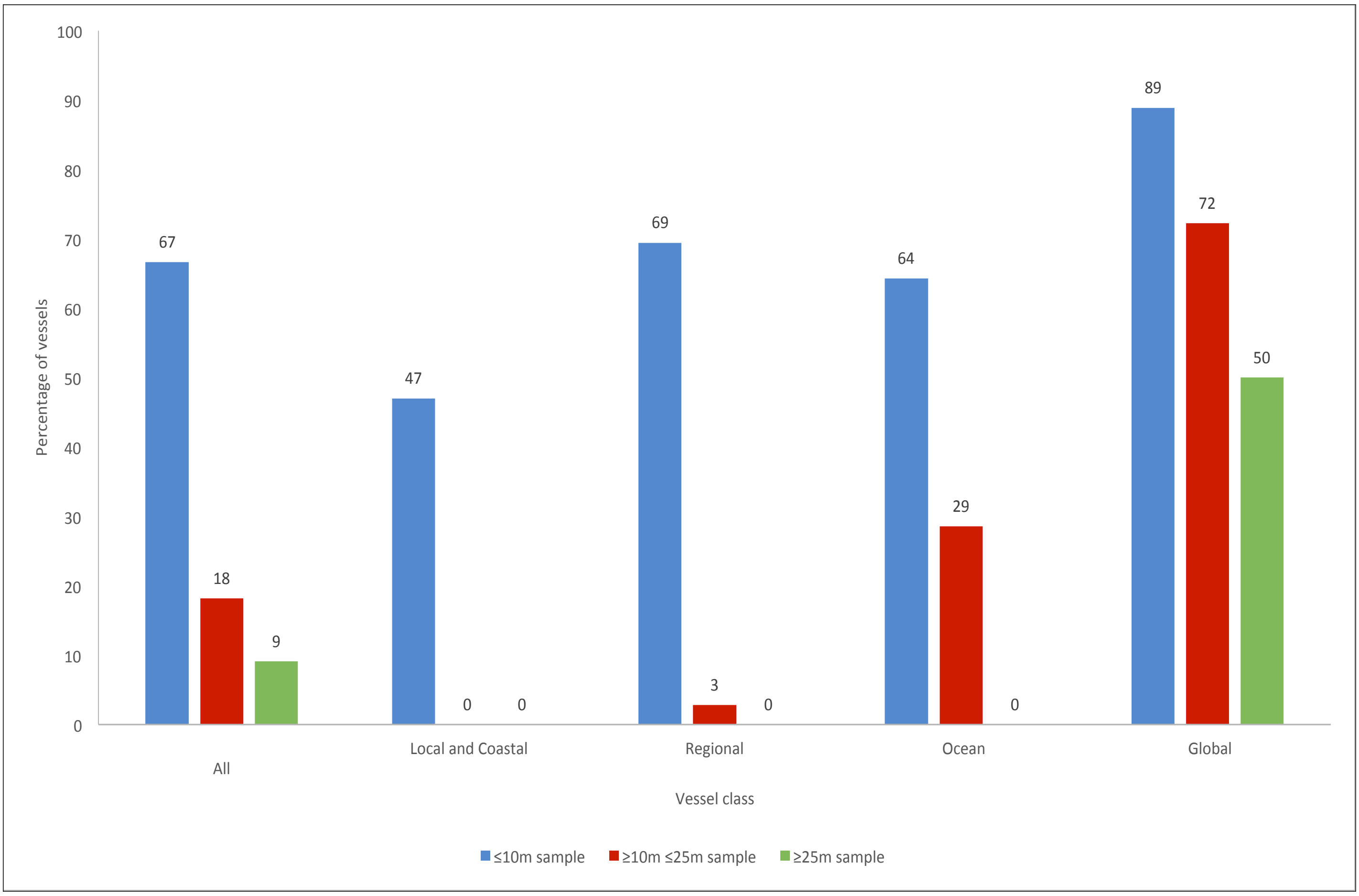


Figure 2.25 Sediment coring capability of the 99 vessels

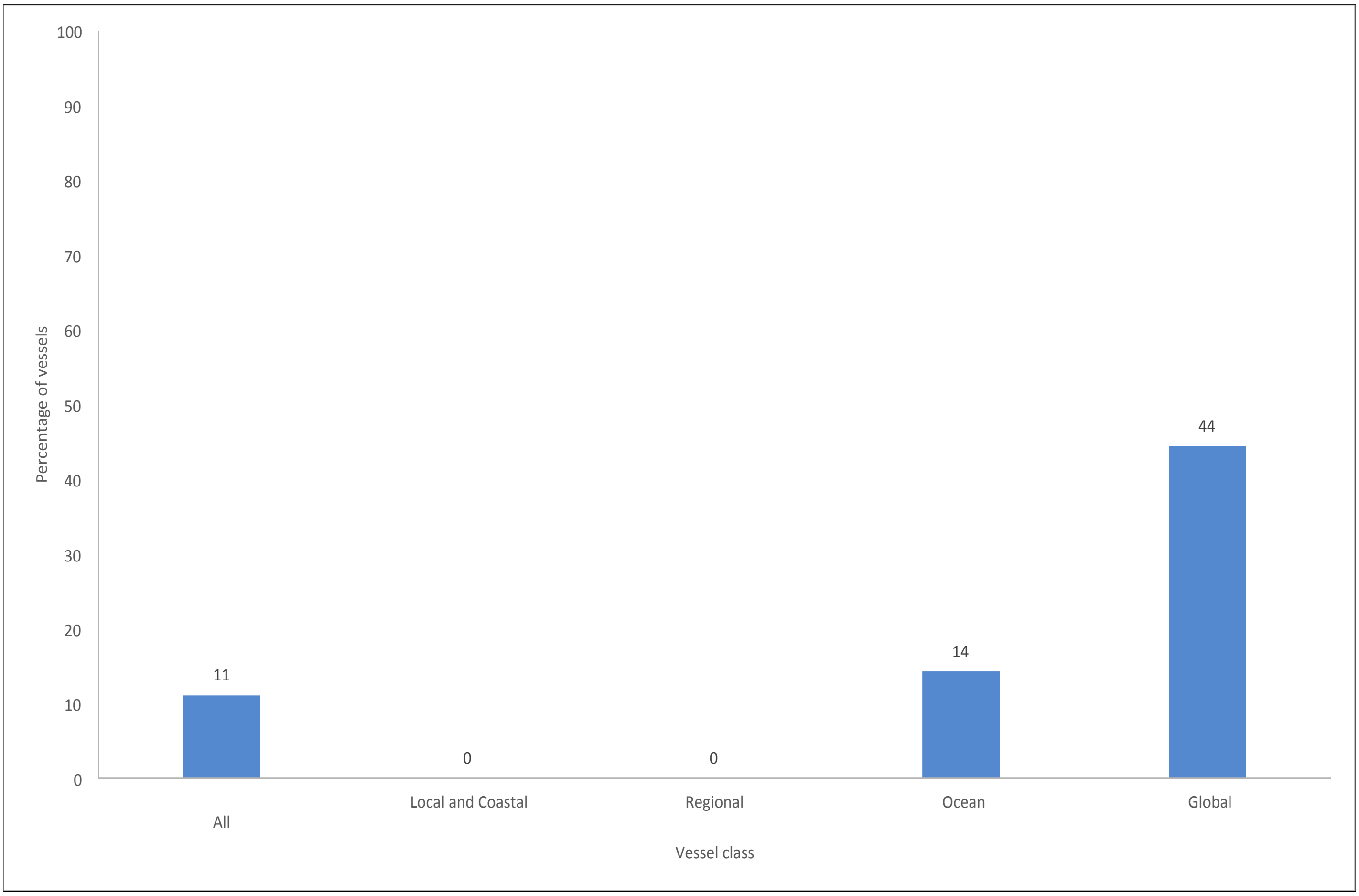


Figure 2.26 Seabed rock drill rig hosting capabilities of the 99 vessels

The larger classes of vessel (i.e. Global and Ocean) are capable of deploying longer corers (Figure 2.25). This is mainly a consequence of available deck length to handle corers and their launch and recovery systems (generally a pre-requisite when cores are longer than around 6m), and the winch and over-the-side handling capacity to manage the large weights of these corers. There is a direct relationship between vessel class/length and the size of corer that can be handled: Regional Class vessels are generally restricted to corers of less than 10m sample recovery length, whilst Ocean Class vessels have a greater capability for medium and longer length corers. Over 90% (17 out of 18) of Global Class vessels are equipped to deploy <10m corers and over 40% (eight out of 18) are capable of >25m long cores.

2.3.11 Drilling rig systems

These systems are used to drill cores from hard rock or sediment tens of meters into the seabed, and are important for geological sampling and research. Analysis of the fleet's capability to deploy the main European drill systems, the MARUM MeBo70 & MeBo200 and the BGS Rock Drill (RD2) (see Annex 5.1.3) shows that these systems are largely suited to Global Class vessels due to the deck space required and the high loads encountered (see Figure 2.26). Just over 40% (eight out of 18) of Global Class vessels can accommodate one or both of these systems with only around 15% (two out of 14) of Ocean Class vessels having that capability. This capability is largely sufficient to meet the current requirements, but there is not much additional capacity so increased demand may indicate that other vessels will have to be used in future.

2.3.12 Deep-water mooring capability

The ability to deploy and recover deep-water moorings is essential to facilitate the collection of long-term datasets. Vessels are required to handle thousands of meters of mooring line, deploy moorings to 6000m depth, embark and handle the associated anchor weights, acoustic releases, and large sub-surface and surface buoys safely without damage. This analysis indicates that half of the Ocean Class and around 75% (14 out of 18) of Global Class vessels are capable of this work, and almost 40% (14 out of 36) of Regional Class vessels have this capability (Figure 2.27).

2.3.13 Laboratory and cargo containers

The ability to accommodate specialist laboratory containers is essential to support multi-disciplinary operations on vessels, both expanding the laboratory space available and allowing specialist analysis to be conducted on board by specific research teams. Many of the larger ROV and rock drilling systems also use a large number of deck containers for control vans, and for workshop and (cold) storage containers. In particular, complex deep-sea multi-disciplinary cruises can require multiple containerized laboratories, and control and storage or cargo containers for ROVs. These containers routinely need stable and normal electrical power, connections to the ship's data and network systems, connections to the ship's fire alarm and intercom systems, telephones, water and waste systems. Containers need to be physically secured to the deck and safely accessible for scientists and marine technicians. As seen in Figure 2.28, the Global Class vessels can provide this capability with an average of ten 20ft International Organization

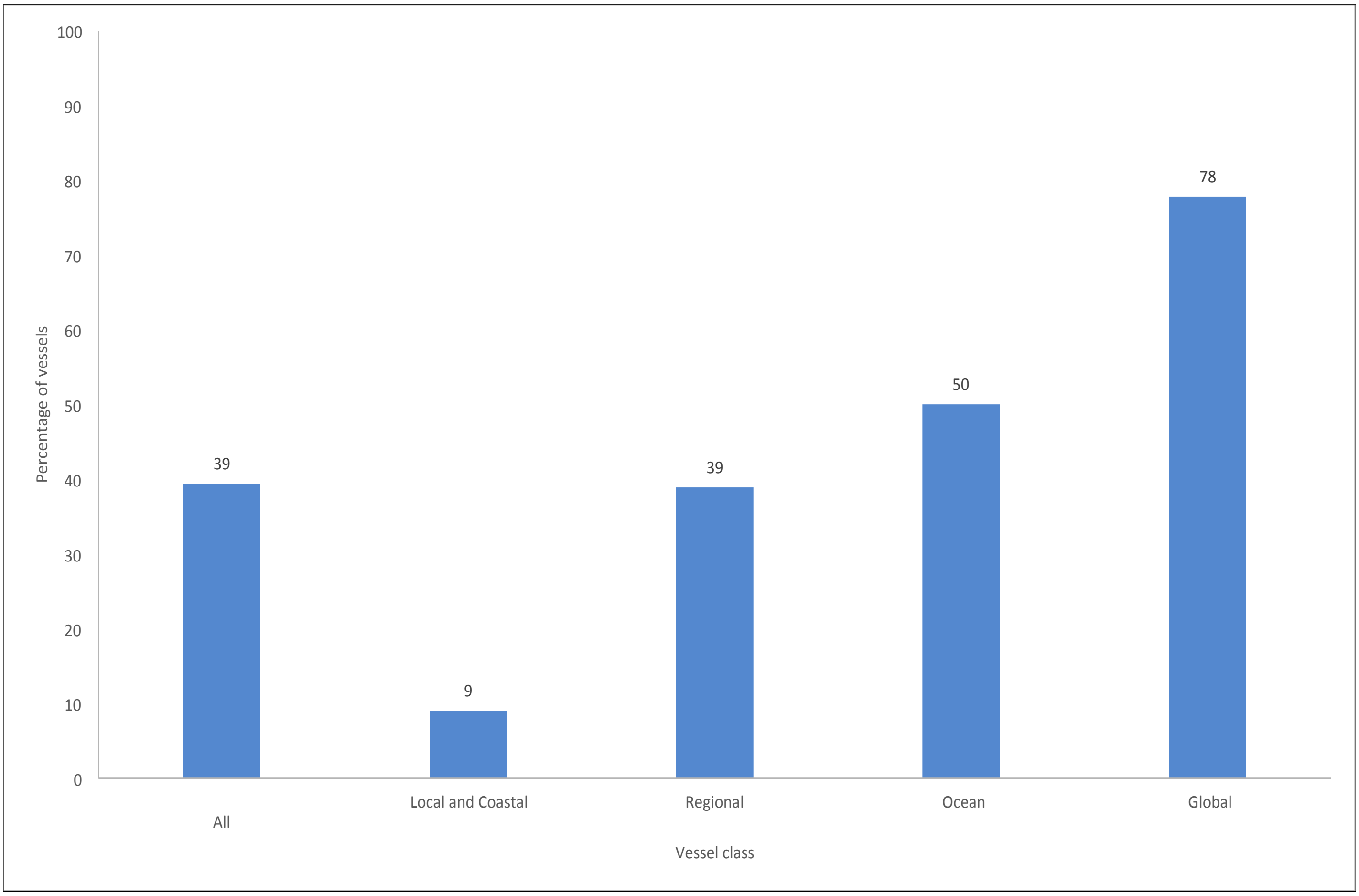


Figure 2.27 Capabilities for handling deep-water moorings at >3000m depth of the 99 vessels

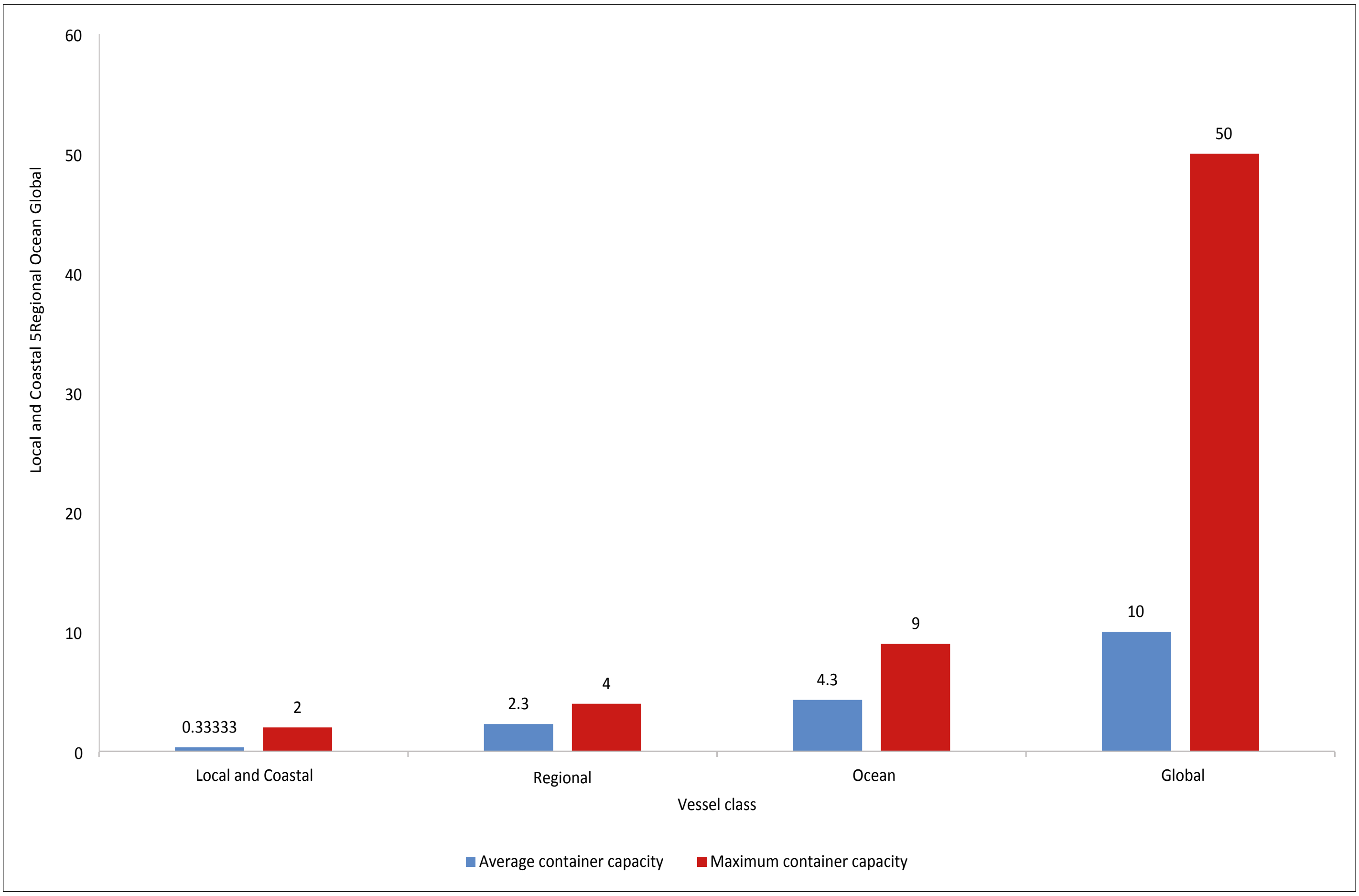


Figure 2.28 Laboratory and cargo container capacities of the 98 vessels, excluding RV *Polarstern*, which has capacity for 105 containers

for Standardization (ISO) standard containers that can be accommodated. Several Global Class vessels are able to take around 20 laboratory, storage- or cargo-containers on a single cruise, one vessel (RV *Marion Dufresne*) is able to accommodate up to 50 and one even up to 105 (RV *Polarstern*). The Ocean Class vessels have a reduced capacity due to their smaller size with an average of four 20ft containers, and up to a maximum of eight 20ft containers on specific vessels. As expected, the smaller Regional Class vessels typically accommodate only one 20ft container, but up to four in exceptional cases (e.g. NRP *Almirante Gago Coutinho*).

2.3.14 Summary

The assessment of the European research vessel fleet 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, and with mid-life vessel upgrades further increasing capabilities in other areas (e.g. satellite communication capacity). Ocean Class vessels tend to be the most capable in the areas of oceanography and fisheries research. However, Global Class vessels play an essential role in supporting large items of portable equipment such as the deployment of large ROVs, rock drills, large seismic systems and long coring systems. Global Class vessels are also capable of accommodating the large numbers of personnel, containers and equipment needed to support multi-disciplinary deep-water research. The Regional, Coastal and Local Class vessels play an essential role in supporting marine science especially on the continental shelf, and conducting research of national importance. The fleets' science capability will further improve as the latest round of vessel replacements become connected online due to the continued move towards multi-disciplinary vessels equipped with the latest technologies. Forums such as ERVO, IRSO and the Ocean Facilities Exchange Group (OFEG, see Box 7.1) and initiatives such as the EUROFLEETS projects (see Box 2.3), continue to be platforms of major relevance to share knowledge, interact and advise one another to ensure that each new build further improves on current capability. This enables lessons learned to be put into practice in terms of new hull designs, layout of systems, and uptake of new technology, resulting in a highly capable research vessels suitable for acquiring high-quality data and accommodating many interoperable pieces of equipment.

Given the long list of capabilities and equipment discussed in this document, it is not feasible or appropriate to provide a complete listing of all European research vessels and their individual capabilities. Table 3.1 provides an overview of the deep-sea research relevant capabilities of deep-sea capable vessels, and Table 4.3 gives an overview of Polar operation capabilities for ice-going research vessels. For more detailed information, readers are encouraged to view the EurOcean marine research infrastructures database[21], and to consult the individual websites of the vessels. It is however recommended that both the EurOcean database and the websites of research vessel operators are kept up to date to ensure that accurate information is always available. It may also be appropriate to establish a European-level group, e.g. ERVO to track fleet and capability evolution.

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[21] http://rid.eurocean.org/

Credit: Louise Allcock

Deploying an ROV from RV *Celtic Explorer*

3

Deep sea

Credit: Credit: Toste Tanhua, GEOMAR (CC BY 4.0)

Background

The scientific and commercial interest in the deep-sea regions of the world ocean is increasing. The scientific community have studied the deep sea for more than a century, with efforts growing in the last decades. Lately, commercial activity has also increased with interest in deep-sea mining, and the search for precious metals and new energy sources. This chapter presents various examples of research conducted in the deep sea and explains the concept of modern vessels needed for such research highlighting the current capability, state of knowledge and future challenges.

Conclusions

Deep-sea marine research usually requires multi-disciplinary research vessels designed specifically for the deployment and utilization of large amounts of scientific and acoustic equipment, accommodating large teams of scientists and a cruising range to allow for lengthy remote operations. The European deep-sea research vessel fleet is one of the most capable in the world in terms of the number and quality of ships and equipment, but it is difficult to access these vessels for researchers whose countries do not own them. If Europe is to continue to be a leader in deep-sea sciences, it must take steps at least to maintain the size of its deep-sea fleet. This fleet currently stands at eight fully deep-sea capable vessels and a further eight vessels with some ability to conduct research in deep-sea regions. They are almost all Global and Ocean Class vessels. Significant investment in the next 15-20 years is required to maintain, renew and expand this fleet. The renewal and expansion will have to be accompanied by new and innovative designs and concepts to ensure that these platforms remain able to support cutting-edge deep-sea mapping, research and monitoring whilst maintaining a low carbon impact. Close collaboration between researchers, research vessel operators and the European ship design-, shipbuilding-, and scientific equipment and instrument industries will be required.

Recommendations

- To maintain operational relevance to a fast-changing world of scientific research, the European marine research community must have continuous access to multi-disciplinary research vessels able to deploy different types of equipment and instruments in remote areas to full ocean depths;
- In 2019, the current European deep-sea vessels have an average age of 19 years. Research vessels should be modernized at mid-life and replaced after a maximum of 30 years of service. Vessel owners must therefore plan and budget for upgrading and/or replacing their vessels over the next five to 15 years to maintain and renew these vessels that are of significant importance for the European and international marine research community;
- The most capable European deep-sea research vessels are owned by only four countries: France, Germany, Norway and the UK. For scientists from other European countries to get access to these deep-sea vessels, it is recommended to establish EU-funded projects or to explore other structural solutions requiring agreement between nations that include Transnational Access (TNA) based on scientific excellence. This should be independent of the country of residence of the principal investigator and/or the science party.

Expedition M97: the oceanographic anchorage at the Cape Verde Ocean Observatory (CVOO) is deployed

3.1 The deep-sea in the context of research vessels

In this Position Paper, we define the “deep sea” based on the capabilities of research vessels themselves, with a deep-sea capable vessel defined as one which can operate at water depths up to between approximately 4000m and 6000m. The vessels that can operate to these depths are almost all from the Global and Ocean Classes.

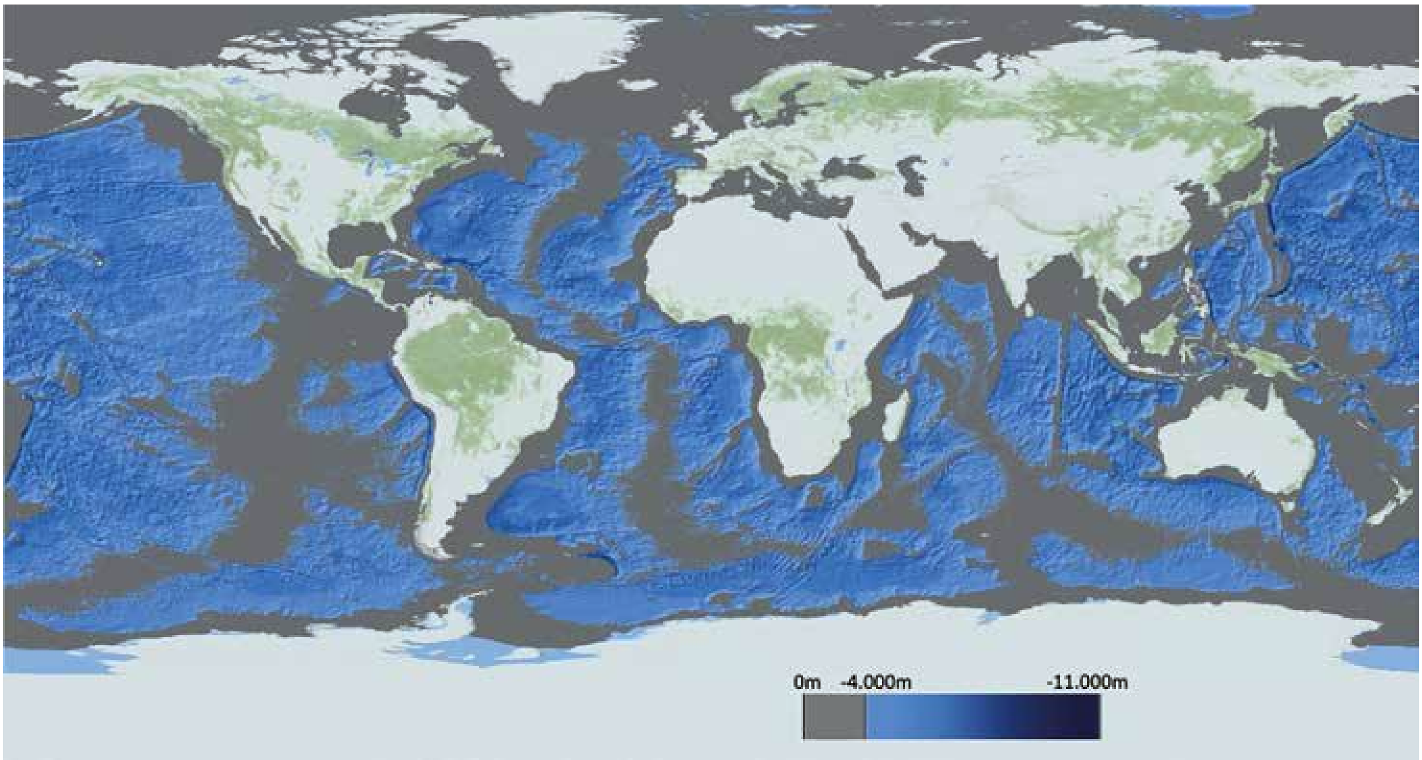
Typically, scientists requesting access to the European research vessel fleet to carry out work in deep-sea regions need vessels that are capable of deploying a range of equipment, and able to integrate different types of often highly specialized portable deck and laboratory equipment to meet scientific requirements and research cruise goals. The vessels must therefore be designed to support a wide range of marine science disciplines including physical and chemical oceanography, marine chemistry, marine biology, marine geology and geophysics, as well as to conduct deep-sea mineral surveys, and deploy and maintain deep-sea long-term observatories. A detailed discussion of observation needs in the deep ocean can be found in Levin *et al.,* (2019).

3.2 Concept of deep-sea research vessels

3.2.1 Multi-disciplinary scientific operations driving deep-sea research vessel design

The increasing requirement to carry out complex integrated sampling and surveys in deep sea areas has driven the need for research vessels to support longer, more multi-disciplinary and more remote scientific cruises.

A typical multi-purpose, multi-disciplinary research vessel configured for deep-sea operations comprises a complex array of floating scientific and engineering infrastructure operating 24 hours per day, delivering a broad range of scientific support facilities, sometimes in some of the most hostile and remote operating environments on the planet. Since multi-purpose research vessels supporting multi-disciplinary science are not dedicated to any one category of research or survey, they must be able to install and deploy a large and varied range of equipment for data collection and sampling. Deep-sea research vessels are characterized by advanced hull-mounted instrumentation and large size handling capabilities for deployment and recovery of instruments over the side and over the stern, both of which are key drivers for the vessel’s design. Much of the data gathering capability of these research vessels is based on the ability to deploy a number of water column, seabed sampling and towed equipment, both over the stern and over the side of the vessel and/or through the vessel’s moon-pool (see Section 2.3.6 for more details on handling systems). The ability of handling systems to deploy multiple types of advanced equipment, the flexibility to reconfigure the layout of the decks, and the ability to adjust laboratory spaces to the specific needs of individual science teams, all contribute to the overall effectiveness to deliver the deep-sea multi-disciplinary capability required of this type of vessels.



Credit: World Ocean Base – Esri, Delorm, GEBCO, NOAA NGDC and other contributors. Map author: Ifremer, SISMER

Figure 3.1. Global map showing global deep-sea areas. Areas with water depths up to 4000m are indicated in grey and areas deeper than 4000m are indicated in blue

Credit: Ifremer

Gondola fitted to the hull of RV *L'Atalante*

As a result, deep-sea multi-purpose research vessel design is an exercise in compromise among a wide variety of scientific vessel users. This type of vessel typically has the following properties and capabilities:

- Large size vessels (length > 60m and beam > 15m);
- Open and configurable deck, and laboratory space for scientific equipment;
- High-performance hull-mounted instrumentation suite;
- Winch and handling systems capable of deploying a wide range of equipment in deep water, including long cables;
- Long endurance (20 days plus);
- Large number of science berths (>20);
- Hold / container capacity to mobilize for multiple cruises in a campaign;
- High sea state operation capabilities with potential for high latitude operations; and
- Suitable for multi-disciplinary science projects.

In addition to the capabilities listed above, the full capability of a deep-sea research vessel is closely linked to the range of fixed and portable equipment that can be deployed and recovered from the vessel. It is therefore critical that the design of deep-sea research vessels and the major scientific equipment they are fitted with are developed with a focus on emerging technologies and the types of research likely to be required during its 30 years of operating life. The skills and continuous training of the crew and marine technicians to support the use of these technologies is also important and is discussed in Chapter 6.

3.2.2 Advanced technology vessels fitted with a range of sophisticated instruments

As previously stated, a deep-sea capable vessel is defined as one that has significant sampling and survey capabilities at depths from 4000 to 6000m. This corresponds to the maximum working depths of interest for European scientific teams (unlike e.g. Japan, which is developing equipment capable of working at depths of more than 10000m). Beyond these depths, most commercial equipment is limited by pressure ratings and cable loads, constraining deeper operations. More specialized equipment is available for deeper operations, but in general, 6000m is an operating limit for much of the equipment routinely available to researchers. Equipment capable of operating to greater depths is generally designed, integrated (e.g. where a commercial product is not depth-rated, an institution will install it in pressure housing themselves) or built in-house by science institutions and will not be highlighted in detail in this review.

The hull-mounted instrumentation can include a comprehensive suite of hydroacoustic systems integrated in the ship's hull, in dedicated "blisters", or in large gondolas in the case of long multibeam echo sounder arrays, as can be seen in the picture above.

Over-the-side handling capability of deep-sea research vessels requires a side/stern frame with a high safe working load (SWL), winches, wires and/or cables suitable for large and sophisticated equipment such as underwater systems (AUV, ROV and HOV), water sampling systems, marine seismic equipment, sediment coring systems or geotechnical tools for deep sediment drilling. A detailed description of this range of portable Large EXchangeable Instruments (LEXI) is given in Annex 5.

Credit: Emanuel Wenzlaff, GEOMAR (CC BY 4.0)

The AUV ABYSS on RV *Sonne II* during the SO242/1 expedition. The expedition was part of the JPI Oceans Project "Ecological Aspects of Deep-Sea Mining" (see section 7.2).

3.2.3 Operational and logistical requirements for deep-sea cruises

Typically, for each deep-sea research cruise a different team of scientists and marine technicians, along with a different combination of vessel-fitted and portable survey equipment (such as the AUV seen above) and sampling equipment is needed. Equipment supplied by scientists will most likely be shipped to, and loaded at, the port of mobilization, which could be anywhere in the world. Some of these ports may have limited shore infrastructure and services such as heavy lift cranes and storage facilities. Therefore, the vessel should be designed to be as self-sufficient as possible, with effective crane capability to support heavy equipment installation from quay to deck, reducing the requirement for shore cranes as much as possible. Significant provision for on board stowage of scientific equipment and hazardous materials is required within in scientific spaces or on deck. The installation of heavy/complex deck-fitted portable equipment and/or container laboratories requiring a high level of mechanical handling across the science working spaces is also to be expected.

Due to the remoteness of deep-sea regions, deep-sea research cruises can be amongst the longest in terms of duration. This generates additional requirements in terms of the consumables (food, fresh water, fuel etc.) which affect the design of the vessel. On board support capabilities such as workshops, spares and materials for repairs in case of equipment failures is also necessary, as the vessel will typically be a long way from any assistance and cutting short a research programme due to a technical failure is not ideal. The comfort and well-being of the personnel on board also needs to be considered, and thus the design of the vessel should ensure there is adequate space and facilities on board. The maximum length of a cruise is often ultimately limited by the endurance of the personnel on board (especially when scientists are inexperienced and unused to long periods at sea), with a maximum cruise duration of around 48 days considered a reasonable threshold.

3.3 Working examples of today's deep-sea cruise activities

This section provides examples of the types of deep-sea research activities that are currently undertaken by the European fleet. It aims to highlight the many complex demands placed on such vessels, and the importance of careful design and operation.

3.3.1 Multi-disciplinary research in marine sciences

Deep-sea research vessels may be required to support the preparation, deployment and operation of a wide range of different equipment sequentially during a research cruise. A multi-disciplinary and multi-scale approach enables science teams to survey and sample wide geographical regions and then use the information obtained to focus on highly targeted small-scale sites.

Typically, during long marine geology or biology cruises, a first large-scale exploration phase (>10,000km^2), including the use of multibeam echo sounders, seismic equipment and gravimeters in addition to water, sediment and/or rock sampling by the vessel will allow investigation of anomalies or subjects of interest in the water column or in the data from the seabed. The analysis of these clues will allow the selection of smaller search areas to be explored in a second phase of the cruise by autonomous underwater vehicles (AUV) or a remotely operated vehicle (ROV) carrying micro-bathymetry, seabed geophysical imaging or optical imaging tools, or by coring. Once the targets of interest have been located by this medium-scale approach (<10km^2), sampling and observation work is carried out in relatively small areas with ROVs or human occupied vehicles (HOVs).

As an example to demonstrate the overall scientific, engineering and logistical challenges routinely addressed during such a programme, this section describes the equipment deployed on the 2017 multi-disciplinary scientific research cruise DY081 on the British research ship RRS *Discovery*. This cruise studied aspects of the geology, biology, chemistry and physical oceanography in the Labrador Sea between Greenland and Newfoundland. To support the research objectives, a large amount of portable scientific equipment was embarked for the research cruise. The equipment came from a range of different sources, including the vessel operator and various scientific institutes. The key components included: a 6000m ROV; a 6000m depth-rated video guided sampling system; autonomous sea gliders; fully instrumented Conductivity, Temperature, and Depth (CTD) sampling systems; a range of seabed coring systems; seabed trawling systems; trace metal sea water sampling systems; specialist laboratory containers and sample storage containers; and deep-water sampling pumps (see Chapter 2 for more details on specific equipment). This equipment was deployed using the ship's winch and cable systems including CTD wire, synthetic core rope, steel coring wire, and electro/fibre optic wire, together with the ship's over-the-side handling systems and cranes. In addition to the portable equipment, a wide range of vessel fitted scientific equipment was employed during this cruise including: Ultra-short Baseline (USBL) acoustic positioning system; Acoustic Current Doppler Profiler (ADCP); Sub-Bottom Profiler (SBP); multibeam and single-beam echo sounders; onboard laboratories incorporating fume hoods and laminar flow cabinets; ultrapure scientific water production system; and -80°C freezers. This equipment required installation and stowage space, and knowledgeable marine technicians to maintain and operate the equipment, all demonstrating the complexity of this category of research cruises and the multiple demands placed on deep-sea research vessels.

3.3.2 At the service of climate change research

Deep-sea research vessels are essential platforms for servicing i*n situ* buoys and/or moorings deployed in remote areas and for ocean monitoring in support of climate change research.

The *Pirata program*[22] Prediction and Research Moored Array in the Tropical Atlantic) is a relevant example of these arrays of buoys and moorings deployed in remote areas. Developed in the framework of the international program CLIVAR (CLImatic VARiability and predictability), the *Pirata program* requires the cooperation between several nations (USA, France and Brazil) to address annual maintenance requirements of the deployed instruments and additional data gathering using research vessels operated by these three countries.

Large-scale ocean monitoring also requires the development of transects to measure, describe and monitor physical features and oceanographic properties, to which European vessels and research teams contribute. This naturally includes the need to obtain and maintain these transects in deep-sea regions, for which cruises are executed regularly to acquire repetitive series of measurements. The Franco-Spanish *Ovide*[23] project is one example of these research projects requiring regular cruises. This project aims to document and understand the variability of the circulation and water mass properties in the Northern North Atlantic, within the context of global change. It contributes to the CLIVAR program, the International Carbon Coordination Project (IOCCP)[24], and the CARBOCHANGE[25] international program. Since 2002, the *Ovide* project has contributed to the observation of the circulation and the water mass properties along a section from Greenland to Portugal, mainly on board the RV *Thalassa*. More recently, the program has moved to more multi-disciplinary cruises to include physical measurements and to address broader objectives (e.g. biogeochemistry, biology, geochemistry, tracers), which requires large and flexible vessels. In 2015, the *Geovide*[26] project conducted on RV *Pourquoi pas?* with a team of 40 scientists and marine technicians included the measurements of trace elements and their isotopes requiring clean winches and analysis containers. The study also made up to 150 classic rosette casts, 50 clean rosette casts, and deployed 20 floats and 12 moorings over 45 days. The above examples serve to highlight the diverse role of the large, modern deep-sea capable vessels that support ultimately needed climate change research. This is especially important now at a time when developing a better understanding of climate change is so critical.

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[22] http://www.brest.ird.fr/pirata/

[23] https://www.umr-lops.fr/en/Projects/Active-projects/OVIDE

[24] http://www.ioccp.org/

[25] https://cordis.europa.eu/project/rcn/97547/reporting/en

[26] http://www.geovide.obs-vlfr.fr/

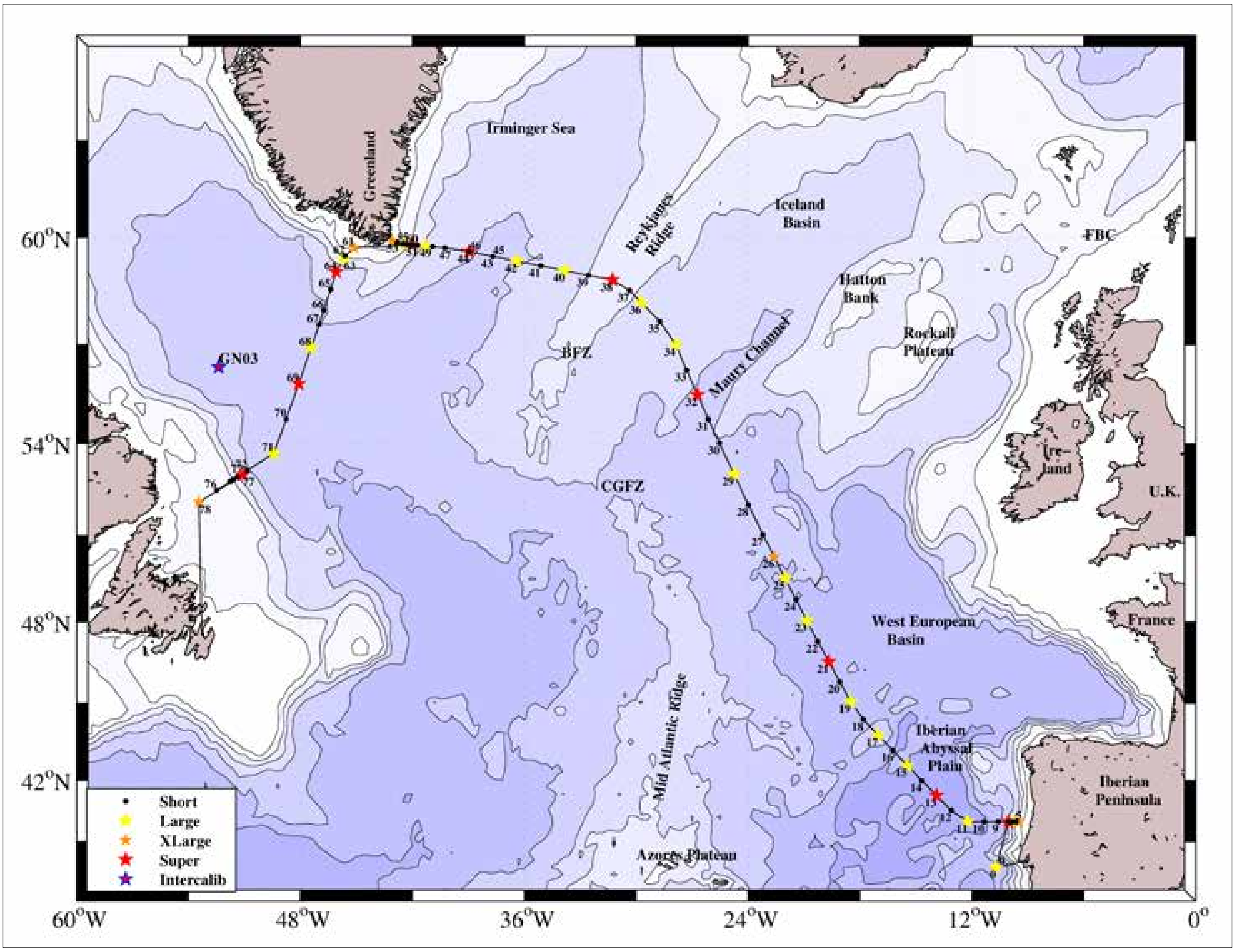


Figure 3.2 Geovide 2014: 78 stations from Portugal to St Johns (Canada)

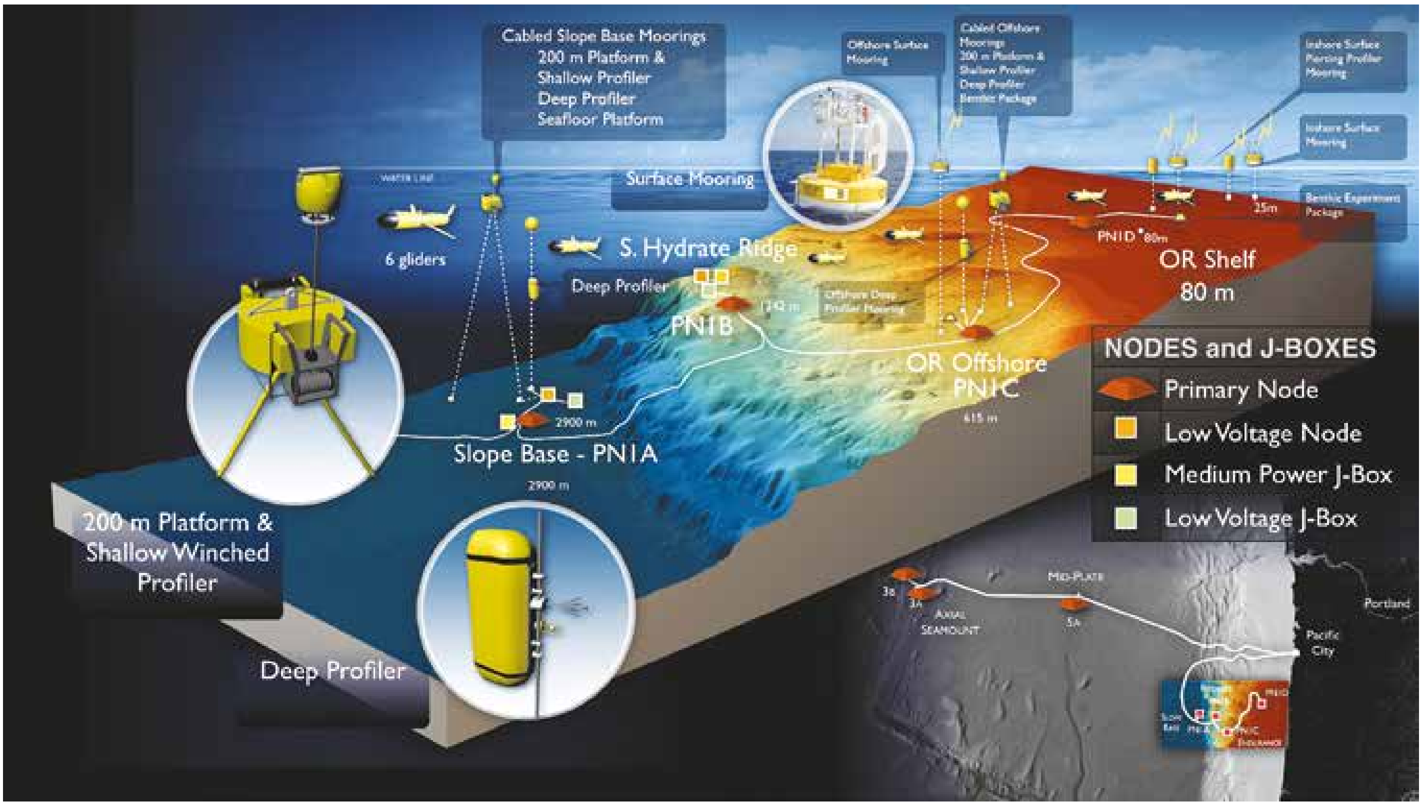
Credit: Lherminier/Ifremer

3.3.3 Deploying and servicing deep-sea observatories

The access to modern and innovative technologies has allowed significant advancement in the sampling of a variety of Essential Oceanographic Variables (EOVs) in remote and deep-sea areas, hence the gradual spread of deep seabed observatories (Figure 3.3).

The development of these seabed observatories is enhanced by the scientific demand to investigate deep-sea processes over time, from seconds, to days to years. This allows the monitoring of long-term global processes to understand deep ocean interactions between the geosphere, biosphere and hydrosphere that could explain the main sources of major global events, such as climate change and geo-hazards. These complex observation platforms can be fixed-point multi sensor cabled seabed observatories, with an unprecedented sample rate capacity and resolution. They can also be standalone mooring-based observatories linked to surface buoys and connected to satellites, which in the case of Europe are deployed across the European seas in key environmental sites such as the European Multidisciplinary Seafloor and water-column Observatory (EMSO-ERIC) configuration, see Box 5.2, part of the European Research Infrastructure Consortium (ERIC).

As discussed in more detail in Chapter 5, research vessels play a very important role in installing and maintaining these observatories. Deep-sea research vessel designs include large winch systems and spacious deck areas, which are specifically designed to handle large and heavy equipment, and are able to do so at a wide range of depths from shallower coastal waters to significant ocean depths. This means that these vessels are inherently designed to be able to support deep-sea observatories without requiring modifications or additional investments.



Credit: University of Washington

Figure 3.3 The Ocean Observatories Initiative infrastructure installed off the coast of Washington and Oregon, USA

3.4 Current capabilities of the European deep-sea research fleet and trends for its evolution

This section explores research vessel capabilities and future trends specifically looking at the deep-sea fleet.

3.4.1 Status of the European Deep Sea Research Vessel fleet

Most of the deep-sea research vessels are Ocean or Global vessels since deep-sea cruises are mainly carried out in remote areas such as the mid-Atlantic, the Pacific and the Indian Ocean with water depths greater than 4000-4500m. These vessels are typically equipped, as standard equipment, with multibeam echo sounders with an effective range beyond 6000m depth, ADCP profilers, a dynamic positioning system, winches and A-frames capable of reaching 6000m depth. Using this definition, 16 deep-sea research vessels[27] (see Table 3.1) have been identified out of the 99 vessels studied within this Position Paper (see Annex 4.1).

In addition to this standard set of equipment, deep-sea research vessels can be classified depending on some specific capabilities and therefore on their ability to carry out different types of deep-sea activities during the same cruise. The approach proposed in this Position Paper suggests considering two categories, A and B. As presented hereafter, the group of 16 deep-sea research vessels is thereby split into eight Deep Sea Category A vessels and eight Deep Sea Category B vessels.

3.4.2 Deep Sea Category A vessels

Deep-sea Category A vessels have the full range of equipment in order to carry out multi-disciplinary cruises requiring the deployment of several types of LEXI (see Annex 5) during the same cruise. They have stern and lateral deck areas equipped with A-frame(s) and/or are able to accommodate Launch and Recovery Systems (LARS) to deploy at least one ROV and one AUV, geotechnical tools, or multi-channel seismic streamers and Ocean Bottom Seismometers (OBS). These vessels also offer a minimum of 30 berths for the scientific team and marine technicians operating the embarked instruments. Eight deep-sea Category A vessels have been identified in the group of 16 European deep-sea research vessels (see Table 3.1).

3.4.3 Deep Sea Category B vessels

Deep Sea Category B vessels are equipped for deep-sea research cruises that require a lighter multi-systems approach. They are complementary to the Deep Sea Category A vessels. While equipped with the same standard equipment, Deep Sea Category B vessels are nevertheless smaller, typically carrying 20-30 scientists and marine technicians. They may lack the ability to deploy some LEXI that are indispensable for deep-sea research such as presented in Section 3.3 or may have a multibeam echo sounder with limited operating depth (i.e. lower than 4500m), or swath width (i.e. the width of the area mapped by the echo sounder). Deep Sea Category B vessels are usually not able to deploy more than one LEXI on the same cruise. Eight deep-sea Category B vessels have been identified in the group of 16 European deep-sea research vessels (see Table 3.1).

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[27] Many Polar vessels also have deep-sea capabilities that could be relevant to this chapter. In order to provide the most accurate view of European demand and capability for global deep-sea interventions in open seas, we have chosen to focus on research vessels operated in open seas only in the present chapter, and to treat Polar vessels separately in Chapter 4. Only Polar vessels, which additionally have a significant research activity in open waters, are mentioned here.

Credit: National Oceanographic Centre, UK

Deep-Sea Category A vessel RRS *Discovery*

Credit: *Pelagia* crew

Deep-Sea Category B vessel RV *Pelagia* and the Jago submarine

Open water research vessels			General					Vessel Equipment									Mobile equipment deployment capability					
		Vessel Class	Deep Sea Category	Year built	Length	Science / tech berth capacity	DP	> 4500m MBES	SBP > 4500m	ADCP	> 4500m CTD capability	> 4500m coring / sampling	< 25m coring	> 25m coring	Subsea pos. system	Broadband VSAT	1000 to 4000m ROV or HOV	ROV or HOV >4000m	AUV	Large air gun array / multi channel seismic /OBS	Portable geotech. systems	20ft lab cont.
France	L'Atalante	G	A	1989	85	30	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Marion Dufresne	G	A	1995	120	120	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Pourquoi pas?	G	A	2005	108	40	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Thalassa	O	B	1995	75	25	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Germany	Maria S. Merian	G	B	2006	95	23	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Meteor	G	B	1986	100	30	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
	Polarstern	G	A	1982	118	79	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Sonne II	G	A	2014	118	40	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ireland	Celtic Explorer	O	B	2002	66	22	Yes	Yes	Yes	Yes	Yes	No**	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Netherlands	Pelagia	O	B	1990	66	14	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No	No	Yes
Norway	Dr Fridtjof Nansen	G	B	2017	74	30	Yes	Yes	Yes	Yes	Yes	No**	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes
	G.O. Sars	G	B	2003	77	30	Yes	Yes	Yes	Yes	Yes	No**	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Kronprins Haakon	G	A	2017	100	37	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Spain	Sarmiento de Gamboa	O	B	2007	70.5	26	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
UK	Discovery	G	A	2013	100	32	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	James Cook	G	A	2006	90	30	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 3.1 European Deep Sea Category A and B vessels in 2019*.
Orange denotes the Deep Sea Category A Vessels; pale orange denotes the Deep Sea Category B vessels.
Dark blue shows the capabilities that each Deep Sea Category A vessel has while the pale blue shows the capabilities of the Category B vessels.
Dark red shows the capabilities that the Category A vessels do not have while pale red shows the capabilities that the Category B vessels do not have.

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* Table 3.1 has been drawn up based on existing vessels in 2019. If therefore does not take into account the only deep-sea vessel currently under construction, the new Belgica. This vessel will come into service in 2020 and will be a Deep-Sea Category B vessel. It will replacing the current RV *Belgica*, which is not a deep-sea capable vessel.

** Coring depth capability under 4500m

Credit: © Ifremer - Stéphane Lesbats

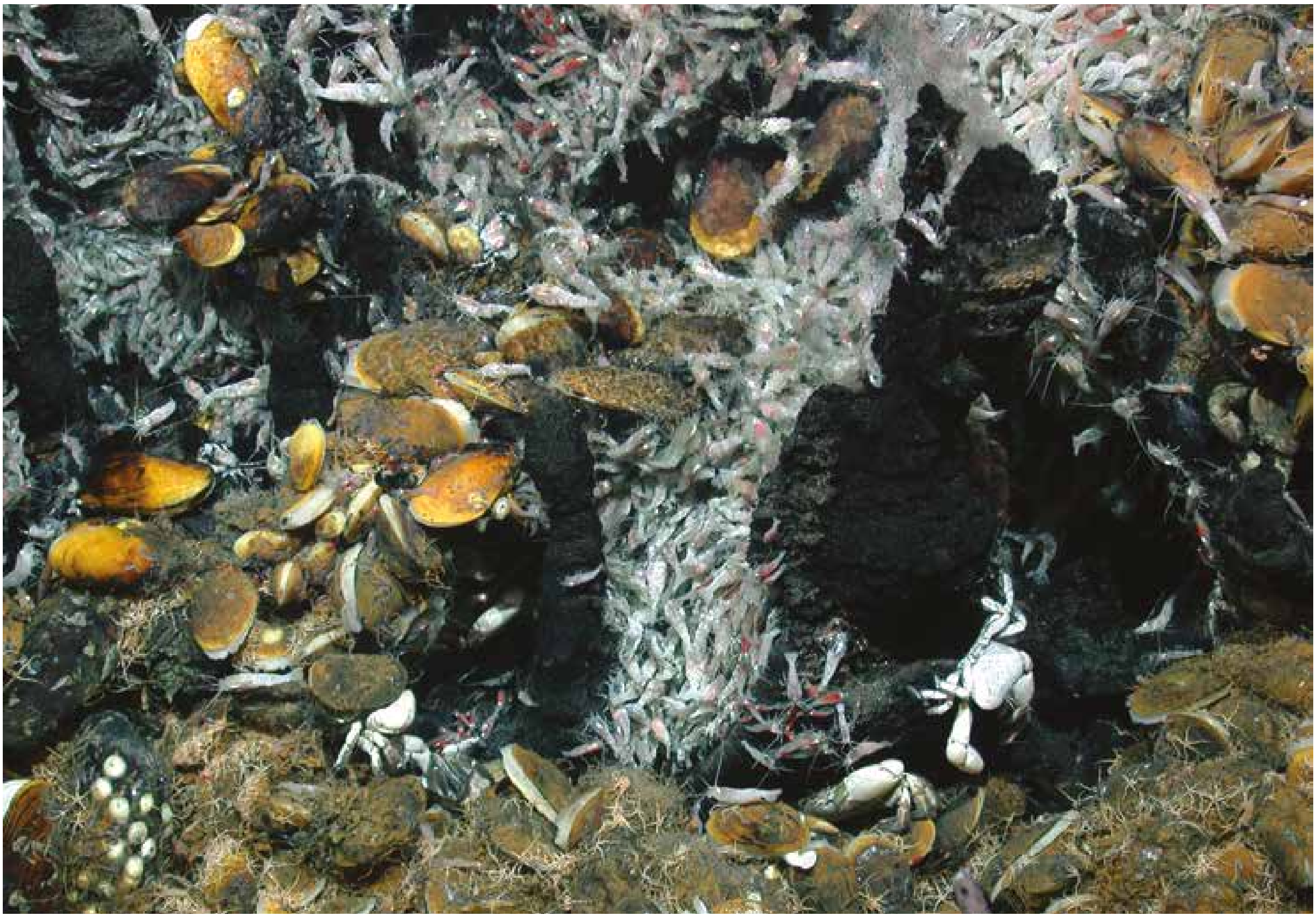
Deep-sea Category A vessel RV *L'Atalante* deploying the ROV *Victor* operating up to 6000m water depths

3.4.4 Evolution and trends for the period 2020-2050

The European deep-sea research vessel fleet is in the middle of its expected functional lifespan considering the average age (19 years) of the 16 deep-sea Category A and B vessels identified in Europe. 85% of these vessels will reach the end of their lifetime during 2020-2050. Even with a new Deep Sea Category B vessel (the new RV *Belgica*) entering service in 2020, two German vessels are expected to be replaced by only one vessel within the next five years, and there are no further known plans for the modernisation or replacement of other ageing vessels. To meet the growing demand for multi-disciplinary cruises, European countries therefore needs to plan and invest in this fleet over the next five to 15 years, in order to maintain the number of deep-sea Category A research vessels and allow the marine research community to conduct large-scale scientific cruises on all oceans. The same attention is required for deep-sea Category B vessels, which serve both as stand-alone vessels with less capability, or support and supplement the activities done by the deep-sea Category A vessels.

Science performed on board deep-sea research vessels is currently mostly driven by science teams from countries owning these vessels. To date, the Ocean Facilities Exchange Group (OFEG, see Box 7.1) is the only mechanism allowing a scientist as Principal Investigator (PI) and their science team to access a research vessel not operated by their own country. This situation is critical considering that deep-sea research vessels are owned and operated by a limited number of countries.

Enabling European science teams to study the deep sea, regardless of whether or not their country owns a deep-sea capable research vessel, requires sustainable mechanisms for funding the access to research vessels at European level. They could build on the experience of Transnational Access (TNA) successfully implemented over limited periods during the I3 (Integrating Infrastructure Initiative) European projects EUROFLEETS, EUROFLEETS2 and now EUROFLEETS+ (see Box 2.3), and the ARICE (Arctic Research Icebreaker Consortium) project (see Box 4.1). This is discussed further in Section 7.3.



Credit: MARUM – Center for Marine Environmental Sciences, University of Bremen (CC BY 4.0)

Living community at hydrothermal seeps on the Mid-Ocean Ridge at a water depth of 3030 metres

4

Polar regions

Background

The effects of climate change are becoming ever more visible in the Polar regions and changes to the environment are having a dramatic impact on food resources and habitats for birds, animals, fish and fauna. At the same time the reduction in ice coverage, in particular in the Arctic, is opening up Polar regions for more commercial activities. The European Polar research vessel (PRV) fleet used to study these regions is small compared to the scientific demand for research vessels in ice-covered parts of the Arctic and in Antarctica; however it is seen by the authors to be capable and important at a global level. This relative strength of the European Polar research vessel fleet should be maintained and preferably increased.

Conclusions

Improvements have occurred in Polar research capabilities in recent years with some new vessels built and some under construction. The introduction and adoption of the International Maritime Organization (IMO) Polar Code in 2017 across the fleet has resulted in more robust Polar research vessels that are better prepared for operations in Polar areas. Today, the European Polar research vessel fleet comprises 24 ice-strengthened vessels, but only nine of these are ice-going and/or icebreaking vessels capable of year-round operations under various ice conditions. The rate of replacement of existing Polar research vessels is too low to maintain the fleet size and a reduction in numbers seems inevitable, based on the number of replacements and/or new-builds currently planned. Most of the new ice-going vessels are combined logistics and research vessels. This means that they have to split their available time between scientific research cruises and providing logistical support to research stations in Antarctica. Modern ice-going Polar research vessels are typically equipped with a moon-pool, ice windows covering the hull-mounted antennas, large propulsion power, dynamic positioning and a stabilizing system for open water operations. They are very capable ships, both in ice-covered and open water in any ocean on the globe, and are generally Global or Ocean Class vessels.

Recommendations

- Repeat and expand the Transnational Access approach used in EU projects such as ARICE (see Box 4.1) to allow science parties from countries without their own Polar research vessels to gain access to the most remote Polar areas. This will help to increase the generation of scientific knowledge of Polar regions during such a critical time for the environment;
- Build more Polar research vessels dedicated to science avoiding where possible the combination of science and logistics. Logistical work can be carried out by different ice-strengthened commercial vessels, but science cannot be conducted by other vessels. Therefore dedicated logistics vessels to serve European Antarctic research stations are recommended;
- Improve cooperation within Europe and on a global scale between the few nations working in the niche of design and operation of Polar research vessels. For example, this could be through existing groups such as ERVO (see Box 1.1), IRSO (see Box 7.2) and OFEG (see Box 7.1), through the establishment of a Polar Research Vessel Network (PRVN) as a sub-group of IRSO, or as an independent group, to ensure that all accumulated knowledge and experience is made available to all interested parties;
- Improve infrastructure, monitoring and forecasting capability in Polar regions as weather and ice forecasting coverage and information at present is incomplete, and this can increase the risks for research vessels operating in these areas. This should ideally be done through international collaboration.

PRV *Kronprins Haakon*
during ice testing North of
Svalbard in May 2018

Credit: Credit: Øystein Mikelborg / Norsk Polarinstitutt

Credit: Øystein Mikelborg / Norsk Polarinstitutt

New Norwegian Polar research vessel PRV *Kronprins Haakon* on a cruise North of Svalbard in May 2018

4.1 Current capabilities of Polar research vessels

4.1.1 Background

The Polar regions represent a number of challenges for research vessels and associated sampling technologies and equipment. Operating in these remote and inhospitable waters requires vessels and equipment with unique specifications that are more expensive to build and operate than conventional open water research vessels. Moreover, the IMO Polar Code[28], which came into force in January 2017 sets out additional mandatory requirements for all shipping-related matters linked to navigating in Polar waters. This includes ship design, construction, equipment and training. These regulations required the Polar research vessel fleet to adapt quickly to ensure that they did not further limit the number of ice-going vessels and in turn the number of scientific cruises and consequently research, in regions where data collection and physical sampling for maintenance and improvement of global climate models is critical.

4.1.2 Challenges for conducting year-round Polar research

The Arctic and Antarctic provide the following additional challenges compared to mid-latitude waters that may lead to elevated levels of risk due to an increased probability of occurrence of hazardous incidents with more severe consequences.

- **Sea ice** may damage the hull structure, affect machinery systems, impact navigation and the outdoor working environment, increase the importance of maintenance and emergency preparedness tasks and affect operability of safety equipment and systems;
- **Topside icing** will reduce vessel stability and render deck- and safety equipment inoperable or inaccessible, as well as making decks and ladders slippery;
- **Low temperature** affects the working environment and human performance, increases the importance of maintenance and emergency preparedness tasks, and impacts material properties and equipment efficiency, survival time and performance of safety equipment and systems;
- **Extended periods of darkness or daylight** affect navigation and human performance;
- **High latitude and atmospheric disturbances** affect navigation and communication systems;
- **Remoteness**, long distances and limited readily deployable Search and Rescue (SAR) facilities makes these areas dangerous. This is often in combination with a lack of accurate and complete hydrographic data, and reduced availability of navigational aids and marks. This increases the potential for vessel groundings, delays in emergency response and limited communications capability, with the potential to affect incident response;
- Potential lack of **ship crew experience** in Polar operations could increase the risk of human errors and miscalculations, but training is intended to mitigate this; and
- **Rapidly changing and severe weather conditions** have the potential to induce or escalate incidents.

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[28] http://www.imo.org/en/mediacentre/hottopics/polar/pages/default.aspx

Despite these challenges, scientific demand for conducting research cruises in Polar regions in all seasons is growing, and recently cruises which spend a full year in the ice have taken place. For example, in January-June 2015 RV *Lance* conducted a cruise[29] in the Arctic North of Spitsbergen by being frozen in and drifting with the ice, and in September 2019, RV *Polarstern* departed to the Arctic to spend an entire year in the ice during the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC)-Expedition[30].

Weather- and ice- forecasting ability and coverage in both the Arctic and Antarctica is currently not as comprehensive as required, and this can significantly increase the risks for research vessels operating in these areas. The satellite coverage in these areas is not always sufficient to be able to provide detailed weather and ice data, and where data is available such as from vessels already in the area, this information is not always shared with others. Nations with an interest in this information should collaborate internationally and explore ways to improve the infrastructure (e.g. satellite coverage), monitoring, data transfer and forecasting capability in these areas. This would improve safety and reduce some of the risks involved in Polar operations.

4.1.3 The Polar Code

To address the risks outlined above, the IMO developed the International Code for Ships Operating in Polar Waters (Polar Code) to supplement existing IMO rules and regulations in order to increase the safety of ship operations and mitigate the impact on the people and the environment in the remote, vulnerable and potentially harsh Polar waters. The Code has to be implemented on new vessels being built but also on existing vessels that wish to operate in Polar waters.

The Code addresses the fact that Polar waters impose additional navigational demands beyond those normally encountered. In many areas, the chart coverage is not yet adequate for coastal navigation, and existing charts may even be subject to unsurveyed and uncharted shoals. The Code acknowledges that Polar ecosystems and coastal communities are vulnerable to human activities, such as ship operations. The relationship between the additional safety measures and the protection of the environment is important, as any safety measure taken to reduce the probability of an accident will also largely benefit the environment. The Polar regions are sensitive environments and are particularly vulnerable to harmful substances and other environmental impacts, and will often recover more slowly than in other regions. The Code is also designed to address these concerns.

The Code also has specific requirements for manning and training in Polar regions, to ensure that ship crew experience and knowledge is at an appropriate level.

The risk level within Polar waters may differ depending on the geographical location and time of year with respect to daylight, ice-coverage, etc. Thus, the mitigating measures required to address the hazards presented will vary and may be different in the Arctic and Antarctic.

The Code does not however address the additional requirements necessary for Polar research vessels in order to operate their equipment and conduct scientific operations safely in Polar waters (see Section 4.2). It is important to note that the Polar Code is mandatory for all sea areas above 60° latitude, with some modifications in the European Arctic, as seen in Figure 4.1 on page 68.

Credit: Alfred Wegener Institute, Stefan Hendricks

RV *Polarstern* during Antarctic winter cruise ANT XXIX/6 in June 2013 in the Antarctic Weddell Sea

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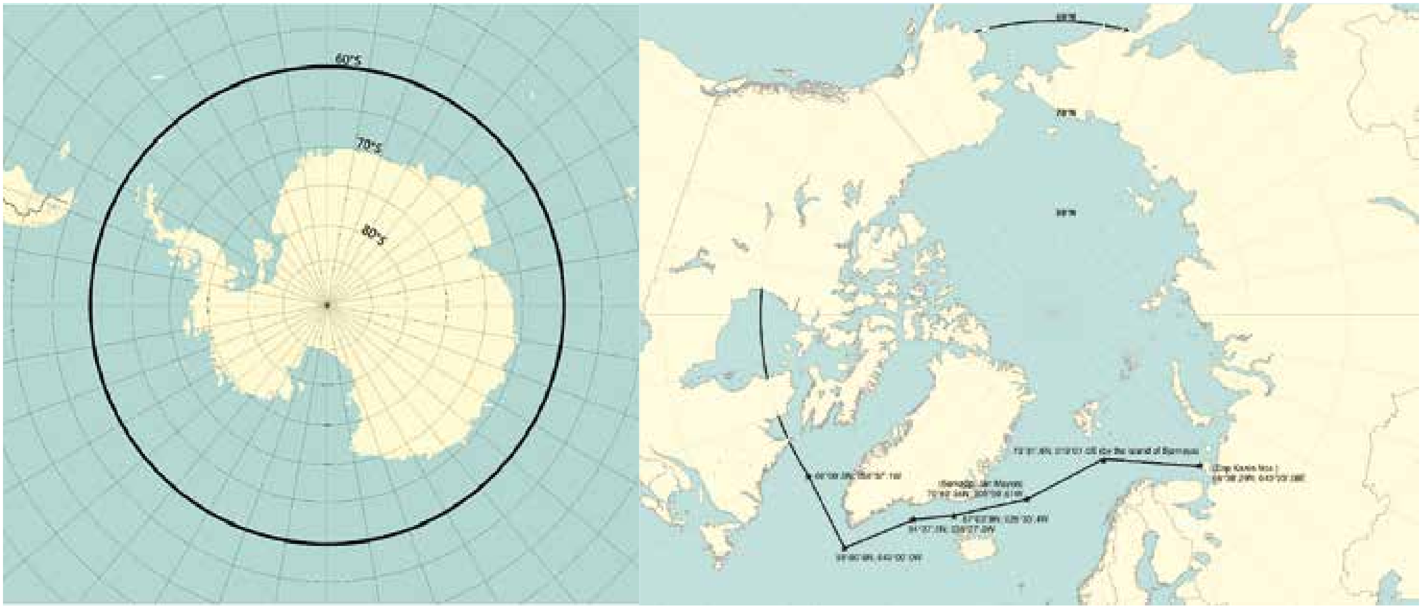
[29] https://www.npolar.no/en/projects/n-ice2015/

[30] https://www.mosaic-expedition.org/



Credit: International Maritime Organization (IMO)

Figure 4.1 Polar Code areas in the Antarctic and Arctic

Any vessel intending to operate in these areas is required to have a valid Polar Code certificate, even if it intends to operate only in ice-free areas. The Polar Code certificates are divided into three categories:

- **Polar Code Category A:** ships designed for operation in Polar waters at least in medium first-year ice, which may include old ice inclusions;
- **Polar Code Category B:** ships not included in Polar Code Category A, designed for operation in Polar waters in at least thin first-year ice, which may include old ice inclusions; and
- **Polar Code Category C:** ships designed to operate in open water or in ice conditions less severe than those included in Polar Code Categories A and B. Additionally, the certificate may contain additional limitations for each individual ship based on its capabilities, such as limitation in operating temperature, latitude and time of year for operation.

4.1.4 Polar research

The International Association of Classification Societies[32] (IACS) has taken the initiative to make global unified requirements for building ice-classed vessels to replace the company-specific rules previously used by the different ship classification societies. The first IACS Polar Class rules[33] published in 2007 apply to ships contracted for construction on or after 1 July 2007. This means that while vessels built prior to this date may have an equivalent or even higher level of ice strengthening, they are not officially assigned a Polar Class and may not fulfil all the requirements in the unified requirements. In addition, Russian ships and icebreakers in particular are only assigned ice classes according to the requirements of the Russian Maritime Register of Shipping, which maintains its own ice class rules parallel to those of the IACS Polar Class.

It is important to note that the Polar Class is not linked to the Polar Code, although there will be relative correspondence between the Polar Class and the Polar Code category. The Polar Class is divided into seven categories shown in the Table 4.1 on page 69.

4.1.5 Status of the European Polar Research Vessel fleet

The European research community had 13 ice-strengthened research vessels including two heavy icebreakers in 2007 when EMB's PP 10 was published (Binot *et al.,* 2007). The average age of the vessels was less than 16 years at the time. An overview of these vessels is shown in Table 4.2 on page 70. Since then there have been significant developments within the fleet, in particular concerning heavy icebreakers.

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[32] http://www.iacs.org.uk/

[33] https://www.webcitation.org/query?url=http%3A%2F%2Fwww.iacs.org.uk%2Fdocument%2Fpublic%2FPublications%2FUnified_requirements%2FPDF%2FUR_I_pdf410.pdf&date=2012-09-11

Polar Code Category	**Polar Class**	**Ice description** (based on World Meteorological Organization (WMO) Sea Ice Nomenclature[34])
A	PC 1	Year-round operation in all Polar waters
	PC 2	Year-round operation in moderate multi-year ice conditions
	PC 3	Year-round operation in second-year ice, which may include multi-year ice inclusions.
	PC 4	Year-round operation in thick first-year ice which may include old ice inclusions
	PC 5	Year-round operation in medium first-year ice which may include old ice inclusions
B	PC 6	Summer/autumn operation in medium first-year ice which may include old ice inclusions
	PC 7	Summer/autumn operation in thin first-year ice which may include old ice inclusions
C	No corresponding Polar Class	Open water in Polar regions as defined in the Polar Code (see Figure 4.1)

Table 4.1 IACS Polar Classes

Credit: Lars Lehnert

IB *Oden* sailing in a Polar waters containing ice floes during the Ryder 2019 expedition to the Ryder Glacier in Northwest Greenland

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[34] https://library.wmo.int/doc_num.php?explnum_id=4651

ICE-BREAKERS										
Polar Code	**Polar Class**	**Ice class**	**Ship name**	**Country**	**Length (m)**	**Year built**	**Opera-tor**	**Operating area**		**Major refit**
A	PC 1 to PC 3	DNV Polar 20	Oden	Sweden	108	1988	SMA		Arctic	
		100 A5	Polarstern	Germany	118	1982	AWI	Antarctic	Arctic	2002

ICE-STRENGTHENED VESSELS										
Polar Code	**Polar Class**	**Ice class**	**Ship name**	**Country**	**Length (m)**	**Year built**	**Opera-tor**	**Operating area**		**Major refit**
A	PC 4 to PC 5	DNV ICE 05	Ernest Shackleton*	UK	80	1995	BAS	Antarctic	Arctic	
B	PC 6 to PC 7	1A Super	Aranda	Finland	59	1989	SYKE		Arctic	
		1A Super	Dana	Denmark	78	1981	DTU AQUA		Arctic	
		Lloyds IAS	James Clark Ross**	UK	99	1990	BAS	Antarctic	Arctic	
		DNV 1A	Jan Mayen (now Helmer Hanssen)	Norway	64	1988	UiT		Arctic	1992
		DNV 1A	Lance***	Norway	61	1978	NPI	Antarctic	Arctic	1992
		PC 7	Maria S. Merian****	Germany	95	2005	LDF		Arctic	
C	No PC-class (current ice class below PC-requirement)	1B	Arni Fridriksson	Iceland	70	2000	MFRI		Arctic	
		Ice 1C	G.O. Sars	Norway	78	2003	IMR	Antarctic	Arctic	
		Ice 1C	Hesperides	Spain	83	1991	Spain Navy / CSIC	Antarctic	Arctic	2001
		1C	OGS Explora**	Italy	73	1973	OGS	Antarctic	Arctic	2002

Table 4.2 Ice-strengthened research vessels in 2007

Credit: US Coast Guard / Lt. Kellen Browne

The US Coast Guard *Cutter Healy* (WAGB-20), a Polar-class icebreaker, transits Southeast Alaskan waters on 24 November 2018

* Previously operated by BAS, UK, transferred to OGS, Italy in 2019 and renamed Laura Bassi

** To be decommissioned in 2020

*** Decommissioned in 2017

**** Ice class currently under review

The new Norwegian research icebreaker PRV *Kronprins Haakon* became operational in the summer of 2018 and replaced RV *Lance,* which was decommissioned in late 2017. RRS *Sir David Attenborough* will become operational in 2020. It will replace both RRS *Ernest Shackleton* (which has been sold to OGS in Italy and renamed *Laura Bassi*) and RRS *James Clark Ross* (which will be decommissioned) from 2020. The planning for the renewal of the PRV *Polarstern* is also underway.

With three new heavy icebreakers joining the European fleet, there is an unprecedented surge in capability in this area. They are all multi-purpose Polar research vessels with a significant increase in both icebreaking and scientific capability compared to their predecessors. In the UK however, RRS *Sir David Attenborough* will replace both RRS *James Clark Ross* and RRS *Ernest Shackleton*, which may create some challenges for covering both scientific requirements as well as logistical resupply missions to stations in Antarctica as well as the Arctic cruises scientists might plan.

Since 2017, France has operated a new PC5 class research vessel, PRV *L'Astrolabe*, for logistic support of its Antarctic station. PRV *L'Astrolabe* is operated by the French Polar Institute (IPEV) and the French Navy. Transit cruises between Tasmania and Adelie Land in Antarctica are valorised through physical and pCO_2 measurements, in the Austral Ocean as well as through the deployment of moorings. Its scientific capability could be increased in the future.

There has been less activity within the fleet of research vessels with lower ice classes[35]. The Greenlandic 32m RV *Sanna* became operational in 2012. The former Norwegian RV *Dr. Fridtjof Nansen* previously owned by the Norwegian Agency for Development Cooperation (NORAD) and mainly used in Africa and the Southern hemisphere, was taken over by Institute of Marine Research (IMR) in Norway, renamed RV *Kristine Bonnevie* and given a major refit in 2016 to be used in European waters. There are a few low ice class research vessels under design or construction such as the German RV *Walther Herwig* and the new Belgian RV *Belgica II* both with ice class ICE-1C and the Swedish ice class ICE-1B vessels RV *Svea* and RV *Skagerak*. In some cases, vessels are designed to a specific ice class classification to enable operation in other ice-prone areas such as the Baltic, and this may not imply that the ship is intended for Polar operations. Plans for the replacement of the Swedish Vessel IB Oden are under development, but no firm decision has yet been made.

There is some room for concern when reviewing the number of research vessels with lower ice classes. With only a few new vessels coming into operation since 2007, the average age has increased from 16 years in 2007 to 20 years in 2019. With only a few new-builds secured, it is likely that there will be a decline in numbers and an increase in the age of ships kept in operation, beyond their normal life expectancy. Table 4.3 gives a full overview of the current European Polar research vessels fleet, as well as details of the vessels expected to come into service by 2020.

4.1.6 Status of the International Polar Research vessel fleet outside Europe

The total number of icebreaking research vessels is not high compared to the identified global needs for such a capability.

Many of these vessels have logistical support to research stations in Antarctica as their main mission, but they are also to a varying degree equipped for marine scientific research. The average age of these vessels is high, but there are plans for replacement and expansion of the fleet in some countries.

In the EUROFLEETS2 project (see Box 2.3), a 2014 report (EUROFLEETS2 Consortium, 2014b) listed 14 icebreaking research vessels (PC 1 – PC 5 or equivalent), where only two European vessels, the German PRV *Polarstern* and the Swedish IB *Oden* were included. The other 12 vessels listed belong to South Africa (RV *Aghulas II*), Russia (RV *Akademik Fedorov* and RV *Akademik Tryoshnikov*), Argentina (RV *Almirante Irizar*), Canada (*CCGS Amundsen* and RV *Louis S. St.-Laurent*), South Korea (RV *Araon*), Australia (RSV *Aurora Australis* to be replaced by RSV *Nuyina* in 2020), USA (USCGC *Healy* and RV *Nathaniel B. Palmer*), Japan (RV *Shirase II*) and China (RV *Xue Long*). In addition to the vessels listed in this report, the University of Alaska took delivery of the RV *Sikuliaq* (PC 5) in 2012.

The report also listed research vessels with a low ice class (PC 6 – PC 7 or equivalent) of which only a few exist outside Europe. It mentions vessels from Brazil (RV *Almirante Maximiniano*), USA (RV *Laurence M. Gould*), Russia (RV *Multanovski*), Chile (RV *Oscar Viel*), India (RV *Sagar Kanya*) and New Zealand (RV *Tangaroa*). In 2017, Peru also took delivery of the PC 7 RV *BAP Carrasco* and as far as the authors are aware, two new Polar research vessels are being built in China (*Xue Long 2* (2019) and another), and both JAMSTEC in Japan and India are planning new Polar vessels.

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[35] http://www.bsis-ice.de/material/table_iceclasses.pdf

Polar Code Category	IACS Class equivalency	Ice Class	Ship Name	Country	Vessel Class	Length/ beam	Year built	Operator
A	PC 1 to PC 3	Arc3	Polarstern	Germany	G	118/25	1982	AWI
		DNV Polar 20	Oden	Sweden	G	108/31	1988	SMA
		PC 3	Kronprins Haakon	Norway	G	100/21	2018	IMR
	PC 4 to PC 5	PC 5	Sir David Attenborough*	UK	G	129/24	2020	BAS
		DNV ICE 05	Laura Bassi**	Italy	G	80/17	1995	OGS
		BV Icebreaker 5	L'Astrolabe	France	O	72/16	2016	French Navy / IPEV
B	PC 6 to PC 7	Ice 1A Super	Aranda	Finland	O	59/14	1989	SYKE
		Lloyds IAS	James C. Ross***	UK	G	99/19	1990	BAS
		PC 7	Maria S. Merian****	Germany	G	95/19	2005	LDF
		Ice 1A	Sanna	Greenland	C	32/10	2012	GINR
		Ice 1A	Helmer Hanssen	Norway	O	64/13	1988	UiT
		1A Super	Dana	Denmark	O	78/17	1981	DTU AQUA
C	No PC-class (current ice class below PC-requirement)	Ice 1C	G.O. Sars	Norway	G	77/16	2003	IMR
		Ice 1C	Kristine Bonnevie	Norway	O	57/13	1993	IMR
		Ice 1C	Johan Hjort	Norway	O	64/13	1990	IMR
		Ice 1C	Hesperides	Spain	G	82/14	1991	Spanish Navy / CSIC
		Ice 1B	OGS Explora***	Italy	G	65/12	1973	OGS
		Ice 1B	Arni Fridriksson	Iceland	R	70/14	2000	MFRI
		Ice 1C	Walther Herwig*	Germany	G	85/17	2020	BAW
		Ice 1B	Svea	Sweden	O	69/16	2019	SLU
		Ice 1C	Belgica II*	Belgium	O	71/17	2020	RBINS-OD Nature
		Ice 1B	Skagerak	Sweden	R	49/16	2017	UoG
		Ice 1C	James Cook	UK	G	90/19	2006	NMF
		Ice 1D	Discovery	UK	G	99/18	2013	NMF

Table 4.3 European ice-strengthened research vessels today and in the near future[36]

* To be operational in 2020

** Previously operated by BAS, UK, transferred to OGS, Italy in 2019 and renamed Laura Bassi

*** To be decommissioned in 2020

**** Ice class currently under review

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[36] Many deep-sea vessels that also have Polar capabilities that could be relevant to this chapter. In order to give the reader the most accurate view of European demand and capability for Polar operations, we have chosen to focus on research vessels operated or capable of operation in Polar regions only in the present chapter, and to treat deep-sea vessels separately in Chapter 3. Only deep-sea vessels, which additionally have a significant research activity in Polar regions, are mentioned here.

Operating area		Major Refit	Logistics for stations	Age in 2030 (years)
Antarctica	Arctic	2002	Yes	48
Antarctica	Arctic		Yes	42
Antarctica	Arctic		No	12
Antarctica	Arctic		Yes	10
Antarctica		2001	Yes	-
Antarctica			Yes	14
	Arctic	2017	No	41
Antarctica	Arctic		No	-
	Arctic		No	25
	Arctic		No	18
	Arctic	1992	No	42
	Arctic	1992	No	49
Antarctica	Arctic		No	27
	Arctic	2016	No	37
	Arctic	2017	No	40
Antarctica	Arctic		Yes	39
Antarctica	Arctic		Yes	57
	Arctic		No	30
	Arctic		No	10
	Arctic		No	11
	Arctic		No	10
	Arctic		No	13
Antarctica	Arctic		No	24
Antarctica	Arctic		No	17

Credit: Malin Andersson / Sjöfartsverket

SLU's research vessel RV *Svea* in Vigo Bay, Spain

Credit: Guillaume Falco / Pexels

Sea ice off the Icelandic coast

The typical life expectancy for Polar research vessels, as for other research vessels, is 30 years. They are often required to continue operating beyond that age, mainly because of difficulties to secure the significant funding needed for replacement; however, they are likely to need extensive upgrades if they are to continue operating. For example, the Finnish RV *Aranda* (launched in 1989) underwent a major refit in 2018 in order to remain operational until 2030. For the Polar research vessel fleet, assuming an actual life expectancy of 40 years for heavy icebreakers and 35 years for other ice-strengthened Polar research vessels, the following trends emerge when predicting the size of the ice-strengthened research vessel fleet up to 2030 (Figure 4.2).

The trend shows the number of ice-going Polar research vessels will likely decline from 24 vessels to only 14 vessels in 2030. It is unlikely that eight replacement vessels will be built for this category within this timeframe, so a reduction in numbers and therefore research capacity is inevitable.

4.2 Operational and scientific requirements for Polar research vessels

Polar research vessels are required to operate in particularly difficult areas, and this places a number of additional requirements and constraints on their operations and capabilities in addition to what would be needed for a vessel operating in open water. This section outlines these additional requirements, which are in addition to the mandatory requirements in the Polar Code and the Polar Class rules.

4.2.1 Ice-going capabilities and operating in ice conditions

To be able to operate year-round in ice-covered waters it is necessary to have an icebreaker with at least Polar Class PC 5. To operate at the ice edge, the vessel should be a PC 6 or PC 7 to be sure that the planned cruise can be executed even if the ice coverage is wider and thicker than normal. Regardless of a vessel's ice Class, sea ice conditions will largely decide the vessel's ability to navigate and manoeuver in the ice, deploy, operate and recover equipment, and work on or under the ice. Even with a high Polar Class, vessels will always look for the "cheapest route" through the ice, looking for openings and/or areas with the thinnest possible ice to save fuel and avoid unnecessary noise, vibration and motion in the vessel. Sometimes however, the nature of the cruise, such as hydrographic mapping, dictates that the vessel must follow pre-defined tracks even in heavy ice conditions.

The vessel must have good stability in case of over-icing and be able to remove ice cluttering on masts, antennas, doors etc., preferably with heating so there is no need for extra crew to remove the ice manually. It is also necessary to have easy access to the ice from the vessel if the intention is to stay in ice-covered waters and

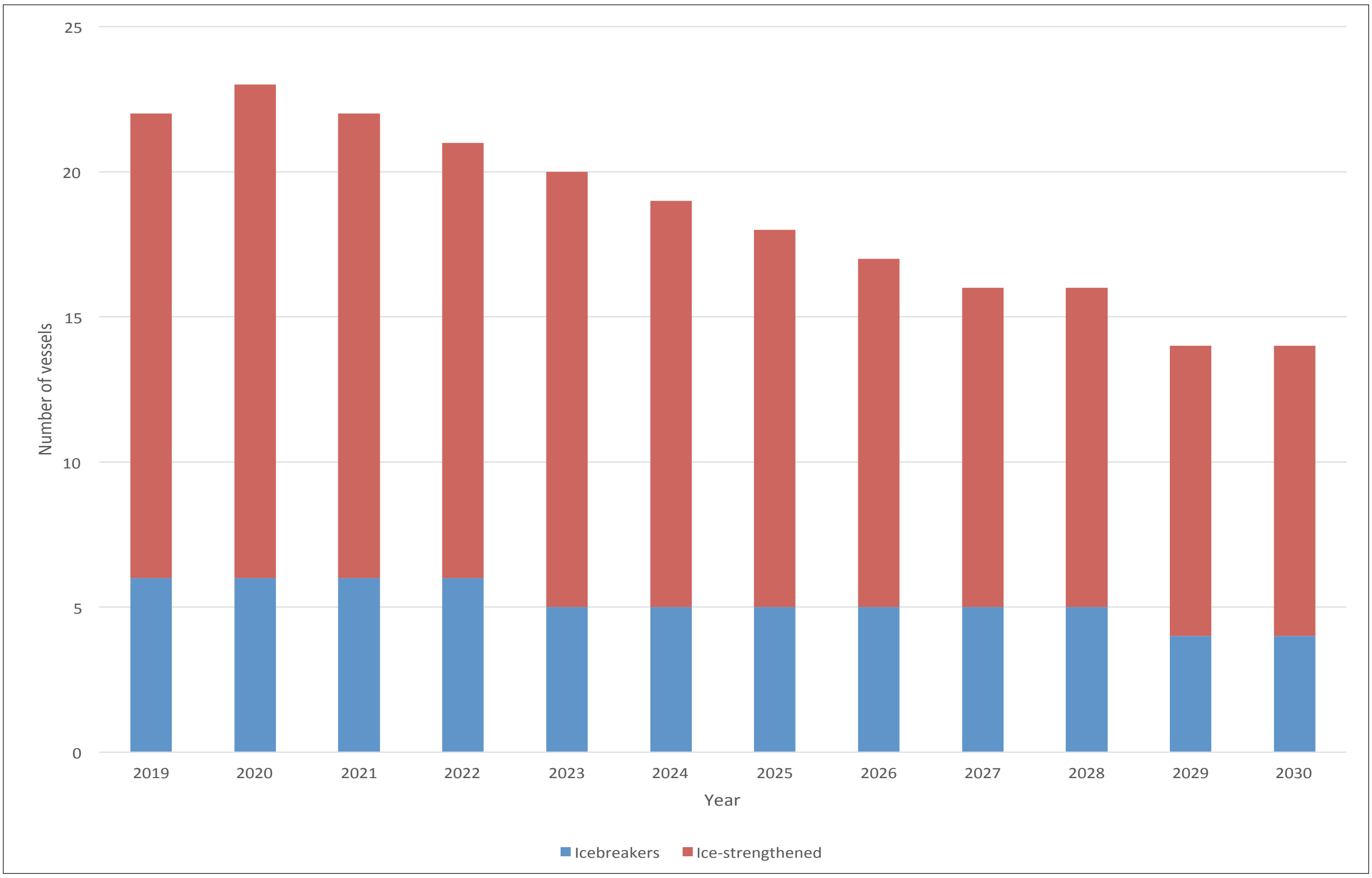


Figure 4.2 Trends in ice-strengthened research vessel fleet size

deploy equipment on the ice. Icebreaking requires large propulsion machinery, ice-classed propellers and sufficient fuel capacity to enable icebreaking when necessary without running low on fuel reserves.

Working outside, both on deck and on the sea ice will expose personnel to low temperatures and windchill necessitating additional protective equipment and stringent operating procedures. Working on sea ice introduces additional risks from the ice breaking up and low visibility due to snow-drift and fog, increasing the possibility of personnel becoming separated from their vessel. In the Arctic, the presence of polar bears makes it necessary to provide additional equipment (such as rifles, signal pistols or other noise-making items) to personnel and to train them in self-defence.

Use of smaller workboats in low temperature and ice-covered waters will increase risk and complexity and will require the use of boats that are specifically adapted for this purpose, as well as additional safety gear, training and operating procedures.

Diving in Polar waters represents a particular challenge. Low air- and sea temperatures present a danger to both the divers and the functionality of their equipment. In addition, it is of vital importance to secure free access to the surface even in the presence of sea ice. The remoteness also implies that vessels should be equipped with a decompression chamber and trained personnel to be able deal with diving accidents and provide immediate treatment to personnel until the ship can receive external assistance.

The ability to operate helicopters has proven very useful for Polar research vessels and a helicopter pad (and in some cases a helicopter hangar) is hence a common feature on all European research icebreakers. Helicopters, while incurring additional operating costs, make it possible to deploy teams of scientists and sensors into areas not accessible by the ship, and are also important for logistical support and ice reconnaissance.

4.2.2 Hydroacoustics

Icebreakers cannot have anything “sticking out” on the underwater hull since it will be damaged or even lost as soon as it encounters ice. This means that all hydroacoustic antennas must be hull-mounted and protected by titanium “ice windows”. These can reduce performance but are indispensable for protecting the antennas from ice floes. It is not recommended to lower drop-keels when in ice-covered waters, so an alternative is to have hull-mounted “arctic tanks” where the most important antennas in the drop-keel are duplicated.

4.2.3 Oceanography

Extremely low air temperatures (down to -30 or -40°C) could damage sensitive equipment and cause them to cease operating, e.g. CTD (Conductivity, Temperature and Depth) rosette-mounted sensors on their way back on board after sampling in the water column, where the water bottles or other parts can freeze. This can be mitigated by using scientific hangars (sometimes called a Baltic room). These are sheltered areas on the vessel with access to deploy equipment over the side, but providing some shelter from the worst of the elements to protect crew and equipment. A hangar sheltered from the environment from which equipment can be deployed over the side has become a standard feature on most modern research vessels. Given the inhospitable environment in the Polar regions, these become even more important on Polar research vessels and are therefore recommended.

In some cases, Polar research vessels will have limited opportunity to deploy over the side due to the danger of breaking/damaging cables on passing ice floes. This can to some extent be mitigated by using a shaft from working deck through the bottom of the hull, a so-called moon-pool. A moon-pool makes it possible to work even when the ship is completely surrounded by sea ice. Moreover, it makes it possible to launch and recover equipment under worse weather conditions than would be possible when launching conventionally over the side. Moon-pools have become a standard feature in recently built Polar research vessels. Polar vessel moon-pools should have a hatch in the bottom of the shaft to prevent large amounts of ice and/or ice slush from entering.

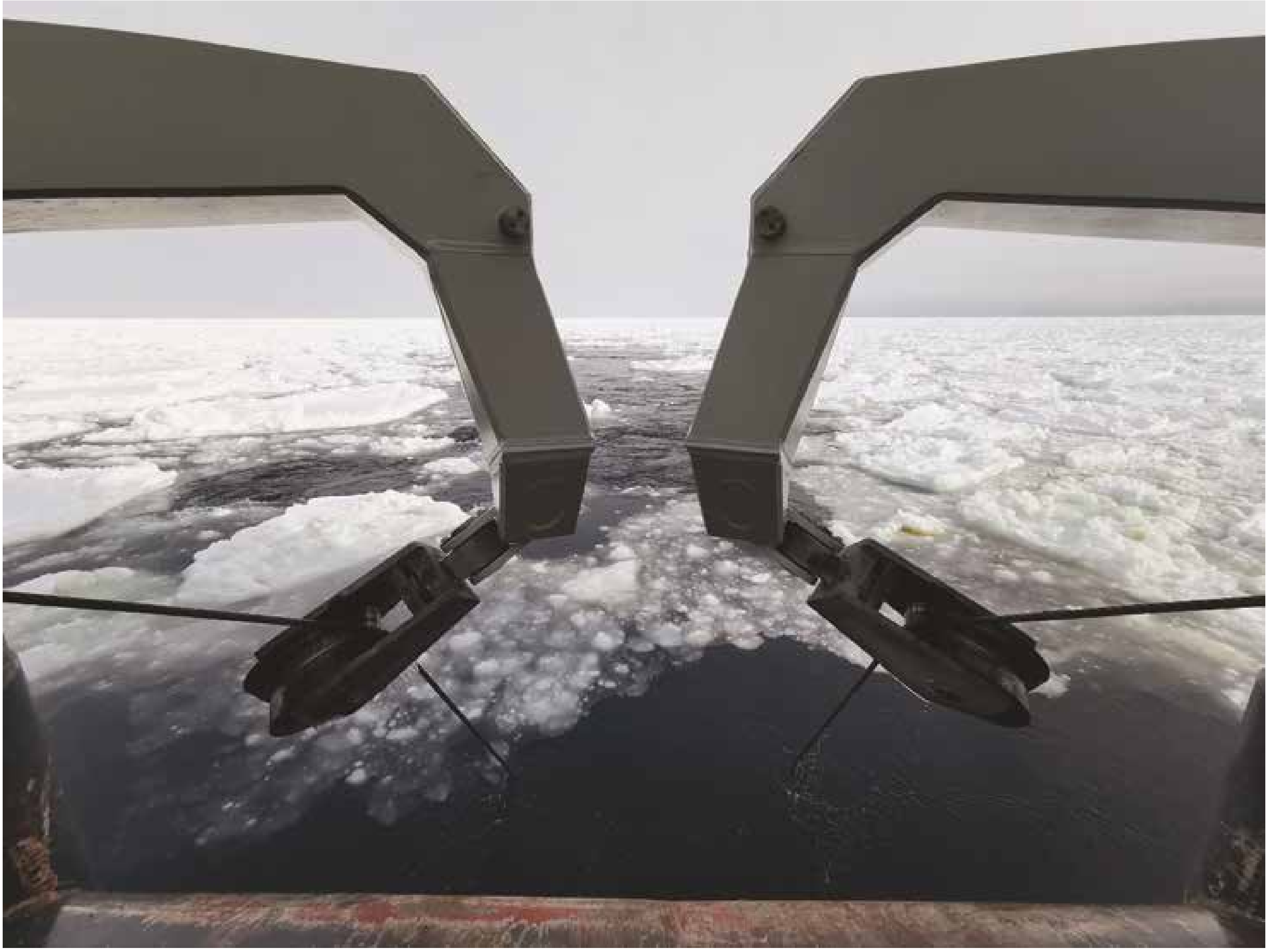
Autonomous vehicles are also increasingly used on board icebreakers and ice-going vessels. Technological developments in autonomous underwater vehicles (AUVs) mean that they can significantly increase the icebreaker's capabilities to work in ice with extraordinary underwater spatial and temporal coverage, and this is coupled with the use of airborne drones to monitor ice environments in front of the vessel. In addition, unmanned surface vessels (USVs) are used for hydrographic mapping close to shoreline if updated nautical maps are not available. These autonomous systems will therefore be of great help to sample difficult-to-access places or where the risks to scientist and/or vessels are high, although there is also a significant risk of equipment loss.

4.2.4 Biology

If the vessel is built to trawl in ice, it should be fitted with “ice trawl gallows” (see picture on page 76) that allow the trawl wires to be forced in towards the centerline behind the vessel, avoiding snagging on ice either side of the channel created by the vessel. It should be possible to deploy plankton nets vertically over the side from the scientific hangar, or through the moon-pool to protect the samples from freezing in cold weather.

4.2.5 Geology

Use of 2D or 3D seismic cables over the stern can be done in ice-covered waters and if the vessel is equipped with podded propulsion rather than conventional propellers since they can be tilted outwards in order to create a wider open field behind the vessel. This will make enough free water space for the air guns and the seismic cables. Use of a hydroacoustic sub-bottom profiler equipped with ice windows is an alternative in some cases. Use of an ROV in ice-covered waters is best done through a moon-pool to protect the cable from being hit by ice floes.



Credit: Able Seaman Robin Hjertenes, IMR

Ice trawl gallows on the stern of the Norwegian PRV *Kronprins Haakon*

4.2.6 Hydrographic mapping in Polar areas

Receding sea ice cover in the Polar regions opens up new areas for shipping, fishing and other commercial activities, which increases the need for hydrographic mapping. Few, if any, of the hydrographic services in Europe have ice-going vessels in their fleet and therefore must seek assistance from other operators who have ice-going vessels fitted with the necessary instruments and equipment such as multibeam echo sounders. Polar research vessels such as PRV *Polarstern*, IB *Oden*, PRV *Kronprins Haakon* and RRS *Sir David Attenborough* are all capable of multibeam hydrographic mapping in Polar waters. However, this work is very time-consuming if icebreaking is necessary before performing the hydrographic mapping, since multibeam data collection simultaneously with icebreaking usually gives poor data quality due to ice floes passing under the hull and disturbing the echo sounder signals.

The Polar vessels can collect hydrographic data continuously during transit and in some cases in combination with other data collecting as well as during regular scientific cruises or as an add-on activity when the Polar research vessels are in the Arctic or Antarctica anyway.

If larger Polar water areas need to be mapped in detail within a limited timeframe, using a Polar research vessel in this *ad hoc* way is not very cost efficient, and in such cases, dedicated hydrographic cruises need to be planned and executed. Such cruises must be financed by either the hydrographic service asking for the data as a nationally funded activity, or as an international co-financed cruise e.g. by the EU.

4.2.7 Geological mapping in Polar areas

The public and government interest in mapping the geology in Polar areas that are becoming ice-free for a large part of the year is rapidly increasing, especially for scientific purposes to study geological formations under the seabed. There is also commercial interest to map potential oil and gas resources and occurrence of precious metals. Conducting geological surveys in ice-infested waters is challenging, whether it is piston coring for sediment sampling, seismic surveys using sub-bottom profiler, 2D or 3D seismic, ROV or AUV. More information about these systems can be found in Annex 5.1.

In the Arctic Polar summer season with limited ice coverage it is possible to operate very far North, even with vessels with limited ice-strengthening. However, in some areas such as the Fram Strait between Greenland and Spitsbergen the ocean current is very strong with a high density of large ice floes even in the summer. In these conditions, it is necessary to operate cabled systems such as ROVs through a moon-pool to protect the cable from the ice floes. It can be difficult to keep the vessel in a stationary position during these operations due to the heavy ice drift and it can thus be necessary to run a two-ship operation where one ship is stationary and performing the data collection while the other one breaks up the ice floes drifting in the direction of the stationary vessel. During the summer of 2004, a fleet of three Arctic Class vessels worked successfully together during IODP Expedition 302, Arctic Coring Expedition (ACEX) in the Central Arctic to recover continuous cores from the Lomonosov Ridge. The icebreakers *Sovetskiy Soyuz* and IB Oden worked to break up upstream ice floes, allowing the ice–strengthened *Vidar Viking* drill vessel to keep station in 90% multi–year ice.

4.3 Towards strengthened and enhanced collaboration, access and interoperability

As described in this chapter, the design and operational requirements of Polar research vessels is highly specialized. In order to ensure that best practice and lessons learnt are shared effectively, it is proposed that countries owning Polar research vessels should cooperate within Europe and on a global scale. This could be initiated via existing platforms, for example through groups such as ERVO (see Box 1.1), OFEG (see Box 7.1) and IRSO (see Box 7.2), through the establishment of a Polar Research Vessel Network (PRVN) as a sub-group of IRSO, or as an independent group. This would help to ensure that all accumulated knowledge and experience is made available to all interested parties.

The requirements and demand for Polar research is also increasing. This demand will to some extent be met by the new and very capable Polar research vessels coming into service over the next few years. Nevertheless, the combined fleet of ice-strengthened vessels is ageing, and its numbers are forecast to decline.

To reduce the gap between need and capability, it is important to strengthen international cooperation (e.g. Transnational Access) and improve coordination of the current fleet of both European and International ice-classified research vessels, in order to maximize the availability of ship-time in the Polar regions. There are already some mechanisms and initiatives in place (e.g. ARICE (see Box 4.1), OFEG, EUROFLEETS+) that can form the basis for an improved utilization and accessibility of the existing fleet. It will not be feasible for most nations to own their own Polar research vessel, as is the case for deep-sea vessels, and enabling Transnational Access for scientific teams from these countries is of huge importance. At such a critical time for the environment, the ability to conduct excellent science in these locations should be possible for all. Examples of such initiatives are briefly outlined below and should be actively supported in Europe.

In the scope of the EUROFLEETS2 project (see Box 2.3), the following Transnational Access cruises took place in Polar areas: RV *Sanna* (Uummannaq, West Greenland in July August 2014); RV *G.O. Sars* (Norwegian Sea to West of Svalbard in June 2014); RV *Magnus Heinason* (Northern Iceland in July 2015); PRV *Polarstern* (South of Svalbard in June 2016); RV *BIO Hesperides* (South Shetland Trough, Antarctica in December 2015); RV *OGS Explora* (Ross Sea, Antarctica in February 2017). In the ongoing EUROFLEETS+ projects, a number of cruises in the Polar regions will also take place in the coming years.

OFEG represents Europe’s major oceanographic research organizations and provides a forum to consider barter, exchange and co-operation opportunities for the Global and Ocean Class research vessel fleet (see Box 7.2). Six of Europe’s ice-strengthened vessels are already committed to OFEG, and with PRV *Kronprins Haakon* and RRS *Sir David Attenborough* joining, the Polar component within the group will be significantly strengthened.

BOX 4.1 ARICE PROJECT

www.arice.eu

The Arctic Research Icebreaker Consortium for Europe (ARICE) project, funded within the EU Horizon 2020 programme, aims to provide Europe with better capacities for marine-based research in the ice-covered Arctic Ocean. The aim is to establish an International Arctic Research Icebreaker Consortium, which shares, and jointly funds ship-time for scientists on the available research icebreakers. ARICE started in 2018 and will run until 2021, and has 16 partners from 13 countries in Europe and North America.

The participating icebreakers in ARICE are:

- PRV *Polarstern*, Germany
- IB *Oden*, Sweden
- PRV *Kronprins Haakon*, Norway
- MSV *Fennica*, Finland
- CCGS *Amundsen*, Canada
- RV *Sikuliaq*, United States of America

ARICE will provide Transnational Access (TNA) to four European and two international research icebreakers. Access is granted based on scientific excellence of the research proposals submitted by researchers. ARICE will improve the efficiency of use of research icebreakers' services by working closely together with maritime industries on a vessel of opportunity programme. Through this programme, commercial vessels operating in the Arctic Ocean will collect oceanic and atmospheric data on their cruises. At the same time, science and industry will work together to explore new technologies, which can improve ship-based and autonomous measurements in the Arctic Ocean.

Several of the most ice-capable Polar research vessels in Europe have a dual role as logistic support vessels, mainly for supporting national research stations in the Antarctic. This may not represent the most efficient way to use these highly capable Polar research vessels since logistics activities can be carried out by other vessels, while research cannot. The fact that each country mostly runs their own supply operations instead of cooperating, reduces the availability of Polar research vessels for research even further, while increasing the cost and the environmental footprint. A solution would be to have dedicated ice-breaking logistics vessels that serve all Antarctic field stations, enabling research vessels to spend more of their time dedicated to research.

During the International Polar Year 2007-2008, a group of national Antarctic operators took the initiative to form the Dronning Maud Land Shipping Network (DROMSHIP) to hire a dedicated supply vessel to cater for the resupply of stations. DROMSHIP has been successfully operating ever since, annually resupplying various Antarctic stations using a dedicated ice-strengthened cargo vessel. Over the years, the vessel has supported Norway, Germany, UK, Belgium, Finland and Sweden either annually or on special occasions. Sharing a purpose-built cargo vessel reduces the environmental footprint and costs of logistics activities, and frees up time on research vessels that can be better employed in conducting research.

Another relevant Antarctic organization is the Council of Managers of National Antarctic Program[37] (COMNAP), which is an international association of organizations "responsible for delivering and supporting scientific research in the Antarctic Treaty[38] Area on behalf of their respective governments and in the spirit of the Antarctic Treaty". It would be an appropriate partner with which to collaborate more closely in relation to future initiatives and sharing of best practice.

4.4 Future trends

The Polar regions are of enormous importance for the Earth's climatic stability and are paramount to better understanding fundamental Earth system processes. They are experiencing significant environmental changes affecting both continental areas and oceans and these changes will have far-reaching effects on atmospheric and ocean circulation. The most noticeable environmental changes include sea ice retreat (both in extension and thickness), disturbances in the thermohaline circulation (THC), ocean acidification, increasingly extreme weather events, transfer of non-indigenous marine species, and changes in biodiversity and species distribution, all of which may have potentially profound impacts on our societies. It is quite clear that research in these regions is central to addressing these challenges by delivering

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[37] https://comnap.aq/SitePages/Home.aspx

[38] https://www.ats.aq/e/ats.htm

Alfred Wegener Institute, Thomas Steuer (CC BY 4.0)

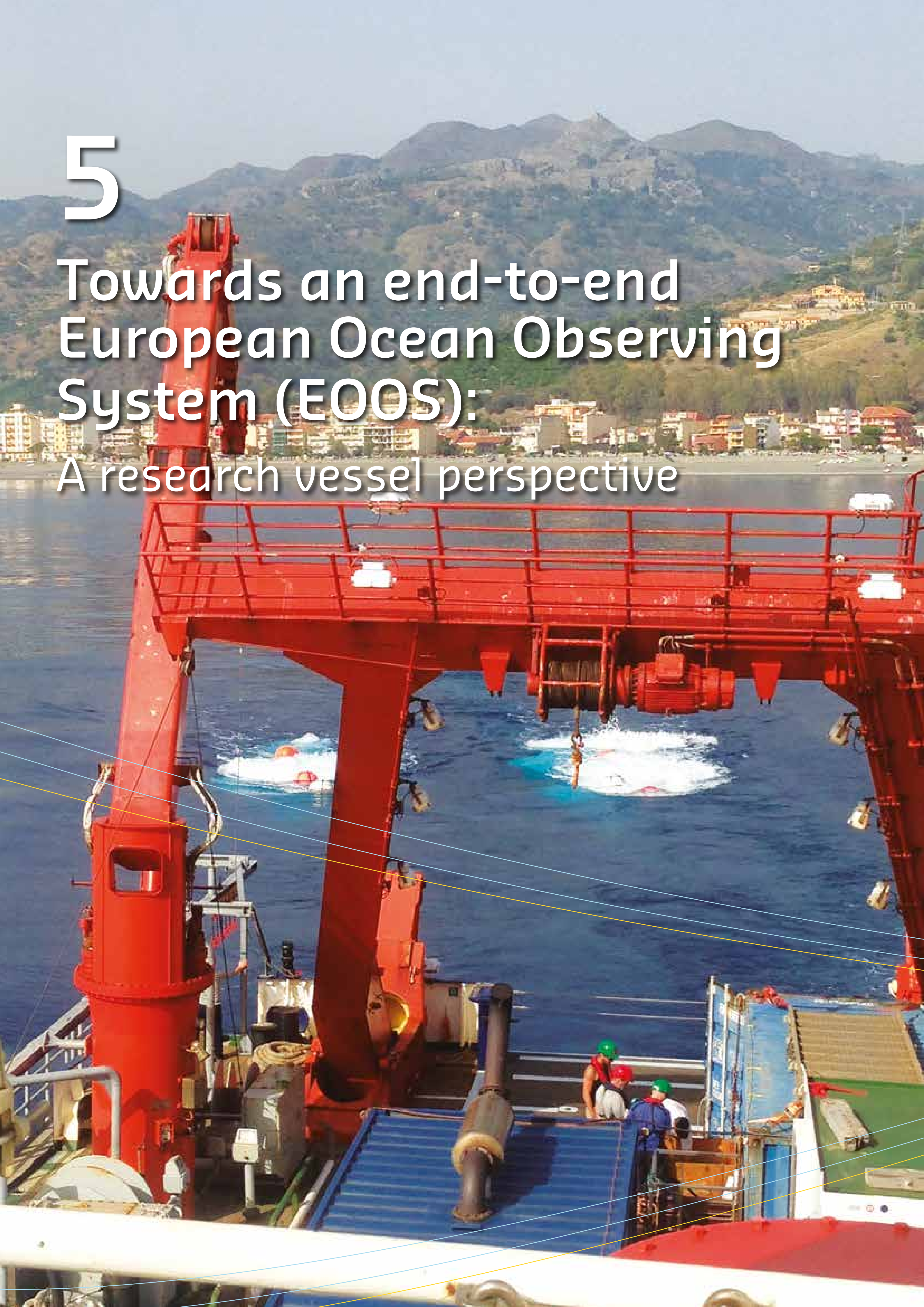
Unloading RV *Polarstern* to supply AWI's Neumayer Station III in Antarctica

knowledge and tools to enable Europe and the world to prepare for, and adapt to, these changes.

Europe has a strong tradition in Polar research in both the Arctic and Antarctica that has contributed significantly to our understanding of the global climate system. A large proportion of Polar research is currently focused on climate change owing to the fundamental role the Polar regions have in shaping the global climate and to the high sensitivity of these regions to changing conditions. A number of emerging scientific questions, as outlined in the recent EMB PP 24 *Navigating the Future V* (European Marine Board, 2019), as well as technological developments and capabilities in the context of climate change and associated impacts will drive Polar ocean research in the coming years. This has also been discussed within the context of the EUROFLEETS2 project (EUROFLEETS2 Consortium, 2016).

Addressing these questions will require Polar research vessels covering a full range of capabilities within oceanography, marine biology, marine geology, geophysics and chemistry. Such capabilities include demersal and pelagic trawling, deploying remotely operated vehicles (ROVs) and AUVs, seismic operations, piston coring and being able to launch and recover a multitude of towed vehicles, buoys, landers, observatories and moorings. To do this safely and efficiently in the Polar environment will require ships with additional features compared to conventional research vessels, as discussed above.

Chapter 9 of the EMB PP 20 *Navigating the Future IV* (European Marine Board, 2013) discusses “Challenges in Polar ocean science”, and readers interested in further details regarding scientific challenges and the regulatory frameworks for the Arctic and Antarctica are referred to this.



5

Towards an end-to-end European Ocean Observing System (EOOS):

A research vessel perspective

Background

There is a growing need for and capability to collect and combine marine data using different sensors, installations and vehicles, such as research vessels, satellites, land-based high-frequency radars, tide-gauges, “ferry-boxes”, gliders, autonomous underwater vehicles (AUVs), unmanned surface vehicles (USVs), drifters, moorings, buoys, landers, observatories, cabled systems and more. To be able to develop a robust and fit-for-purpose European network of marine data collectors and data handling centres, an initiative called the European Ocean Observing System (EOOS) has been established (see Box 5.1).

Conclusions

Research vessels are essential in ocean observation as they are used to collect a wide variety of data and samples from the atmosphere, the ocean surface, the water column, the seabed, and the ground below it. In addition, research vessels are critical for ocean observing stationary installations on the ocean floor, in the water column or on the surface as they deploy, recover and service them, as well as providing ground-truthing for AUV/glider/etc. data. EOOS will therefore need to communicate very closely with the research vessel operator community through groups such as ERVO (see Box 1.1) and OFEG (see Box 7.1) to ensure that research vessels remain fit-for-purpose with regards to servicing ocean observing components at sea. They will also need to evaluate whether the offshore industry should play a role, and to help in working towards a pan-European coordination of the European research vessel fleet. Working towards an improved service to the ocean observing community, research vessels owners should also seek a broader implementation of fast access to collected data. Most research vessels collect and transmit meteorological data, but other sets of underway data, especially Conductivity, Temperature and Depth (CTD) data, could and should also be made available in near real-time.

Recommendations

- Research vessels are integral to the success of EOOS and thus research vessel operators should have a prominent role in EOOS management. A tight cooperation and continued communication between EOOS and ERVO and OFEG, and other infrastructure operators such as EMSO-ERIC (see Box 5.2) is therefore considered important for maximizing collective objectives;
- A formal functional unit or working group established within the EOOS management system, focusing on research vessels and observatories, can override the informal nature of ERVO and OFEG since they cannot guarantee an efficient relationship with EOOS;
- In cooperation with EOOS and data centres, the research vessel community should strive towards structural provision and standard operating procedures for near real-time data transfer to shore, to benefit the scientific, ocean observation and forecasting communities.

RV *Meteor* firing airguns at the beginning of a long seismic line. The Peloritan mountains of North-East Sicily and a nearby beach are visible in the background

Credit: Marc-André Gutscher

BOX 5.1 EUROPEAN OCEAN OBSERVING SYSTEM (EOOS)

http://www.eoos-ocean.eu/

EOOS is a coordinating framework designed to align and integrate Europe's ocean observing capacity, promote a systematic and collaborative approach to collecting information on the state and variability of our seas, and underpin sustainable management of the marine environment and its resources.

The need for an end-to-end integrated and sustained European Ocean Observing System, EOOS, was expressed by the marine and scientific community during the development of the European Integrated Maritime Policy in 2007. In 2008, EuroGOOS and EMB released a joint vision document[42] to outline the concept of this framework. In 2016, EuroGOOS and EMB convened a panel acting as EOOS Steering Group, and a number of events have followed this in 2018, including a Forum[43] and a Conference[44], which also produced a Call to Action[45]. An EOOS Strategy to coordinate ocean observations in Europe, particularly for ocean health and climate, was put forward by EMB and EuroGOOS, together with an implementation plan from 2018-2022[46].

5.1 Where do research vessels sit in the EOOS landscape?

Since its inception at the 2010 EurOCEAN conference in Ostend, Belgium (European Marine Board, 2010), the European Ocean Observing System[39] (EOOS), an overarching framework that integrates all European stakeholders and actors in the field of ocean observation, has slowly but steadily grown. EOOS now strengthens communication amongst and coordinates efforts of European organizations and networks that fulfil a role within the ocean observing community. As stated in their strategy, EOOS should add value to existing initiatives and promote new cooperation, and as such maximize the European capacity in ocean observing (European Marine Board & EuroGOOS, 2018). The European Marine Board (EMB) together with EuroGOOS[40] and EMODnet[41] facilitated the setup of a strategy and an implementation plan to ensure the achievement of this ambitious goal (European Marine Board & EuroGOOS, 2018).

Marine research infrastructures include research vessels, fixed-point platforms (i.e. seabed observatories, buoys or moorings) and mobile units (gliders, Euro-Argo floats[47] etc.), remote sensing tools (e.g. high-frequency radars, satellites, aeroplanes or drones), land-based facilities (e.g. marine stations) and e-infrastructure. A stakeholder survey was carried out within the scope of this publication (see Annex 3), and 80% of research respondents felt that research vessels were important or very important within the wider scope of European ocean observing (Figure 5.1). This was also the case for all respondents from industry (four) and from funding agencies (two).

The research vessel community thus will need to play an active role in EOOS. The European Research Vessel Operators (ERVO) Group (see Box 1.1) and the Ocean Facilities Exchange Group (OFEG, see Box 7.1) are both preferred partners to maintain the relationship with EOOS for both the smaller Coastal/Regional Class and larger Ocean and Global Class vessels. However as both are currently informal networks, they cannot guarantee efficient communication with EOOS.

5.1.1 Dual role of research vessels for the ocean observing community

Research vessels have a dual role in ocean observing. Firstly, they provide the facility services for both geospatial and *in situ* data collection and calibration during survey or research tasks, and secondly, they enable operational deployment, maintenance and recovery of fixed or floating observatories and autonomous platforms.

As discussed in previous chapters, research vessels are floating laboratories and as research cruises take place, specific data are being collected chronologically and geospatially for the purpose of research projects in various coastal or ocean environments. These collected data and metadata contribute not only to the research purposes of the cruises, but also add significantly to the presence and availability of ocean observations, as well as increasing the rigour of the observational network through calibration. Consequently, research vessels function as important ocean observatories in their own right.

Research vessels are also pivotal for the operation of fixed or floating observatories. In most instances, a research vessel will carry an ocean and/or coastal data collection system (i.e. a set of sensors or sampling devices) to a specific location for deployment. Any observation system positioned for a shorter or longer period at sea will require either maintenance or recovery after a duty cycle and this will in turn require a vessel. Often, observing systems also depend on a regular visit to the site or area for validation of the continuously recorded data. Even satellite remote sensing depends on ground-truthing and thus on research vessels for collecting data and measurements at sea to support this. The development of deep-water observatories (see Section 3.3.3) only affirms the essential function of carefully designed (research) vessels for the maintenance and operational tasks in running observatories.

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[39] http://www.eoos-ocean.eu/

[40] http://eurogoos.eu/

[41] http://www.emodnet.eu/

[42] http://www.marineboard.eu/publication/emodnet

[43] http://www.eoos-ocean.eu/forum/

[44] http://www.eoosconference2018.eu/

[45] http://www.eoosconference2018.eu/call-action

[46] http://www.eoos-ocean.eu/strategy-and-implementation/

[47] https://www.euro-argo.eu/

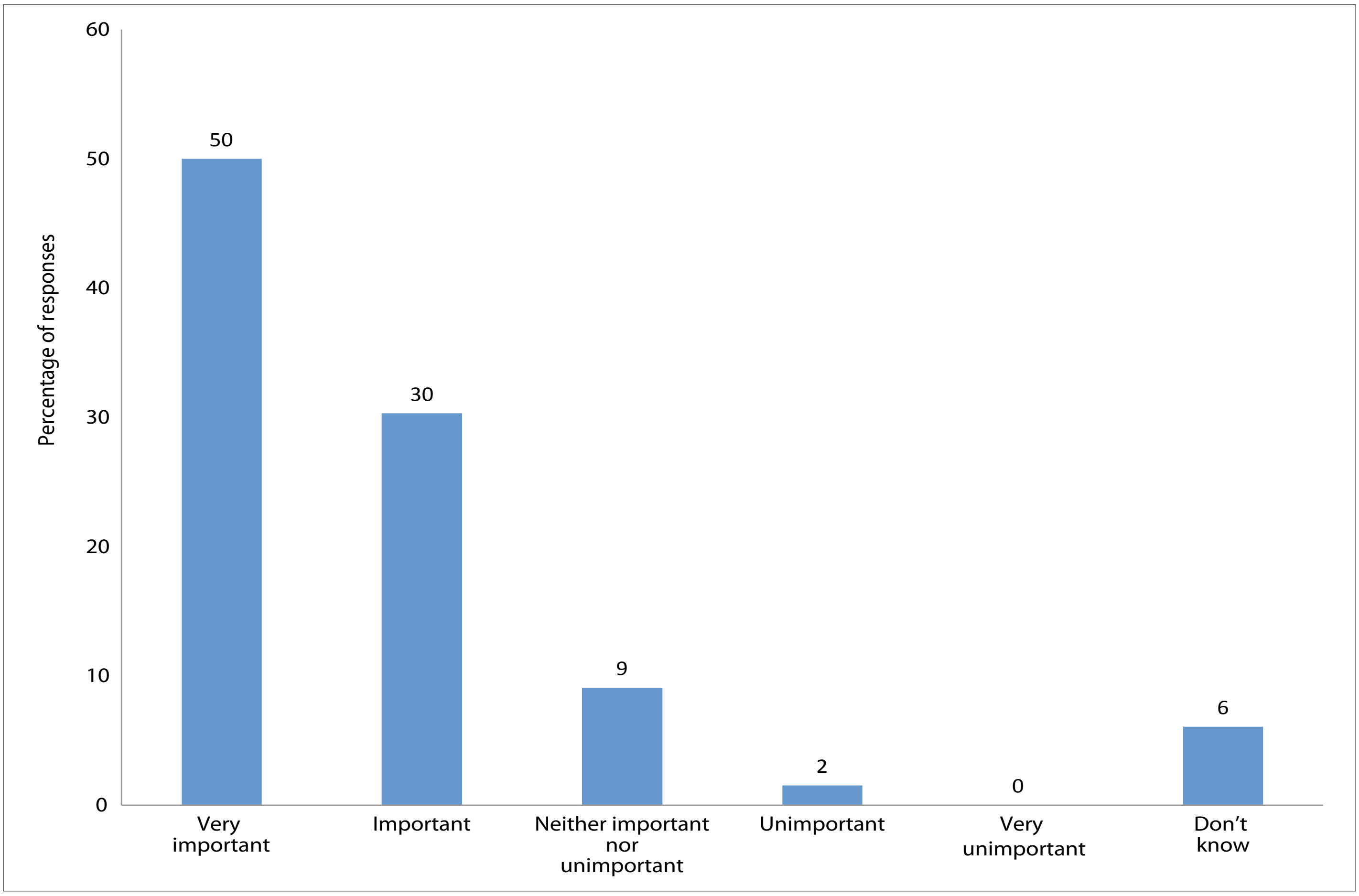

Figure 5.1 Responses to the question "How important do you feel that research vessels are within the wider scope of European ocean observing?"showing 64 responses to this question from a total of 67 researchers who responded to the survey detailed in Annex 3

Credit: GeoEcoMar / Stefan Florescu

RV *Mare Nigrum* deploying an in situ observing buoy

An increasing use of innovative technologies provides potential opportunities to decrease the dependence on research vessels to some degree. Over the past decades, different autonomous platforms have been developed and are being used on an increasing number of occasions by an increasing number of users (ARGO floats[48], AUVs, USVs, ocean gliders). These vehicles can extend and complement the capacity of both research vessels and fixed observatories in many ways. Autonomous systems can either remain at sea for extended periods or collect data over periods of time and in manners that cannot be performed by ships. These platforms can access areas that are difficult to reach or remain operational during conditions that ships cannot. Some smaller autonomous vehicles can be launched and operated from the shore and with small boats, but in many cases, research vessels still launch and recover these vehicles. In addition, especially for most biological and many biogeochemical variables, autonomous platforms are not yet able to carry out these measurements (although some ARGO floats already collect some biogeochemical data[49]) and hence the research vessels together with shore-based measurements are indispensable for this research. Every autonomous mission in a remote location necessitates the assistance of research vessels capable of handling these vehicles. The larger and more capable autonomous systems are fully reliant on research vessels for their missions.

Autonomous vehicles can now even be deployed in a swarm configuration (see Section 2.2.4.1), and hence the data collection capacity increases significantly. Autonomous systems can thus augment data collection from research vessels. However, ships will not only need to provide the safe and efficient launch and recovery facilities, but current developments also use research vessels as important data transfer nodes for such missions. It is considered likely that research vessels will even develop over time to act as essential hubs for automated systems.

5.1.2 What can EOOS mean to the research vessel community?

EOOS is currently developing its requirements and intends to consult all stakeholders periodically to inform about these requirements, and how they may develop over time. As the needs of the EOOS community evolve, new or additional sensors will become important and implementation of these sensors on board research vessels or on autonomous systems deployed by research vessels will be required. This is also one of the recommendations on a global level of a recent community white paper for the OceanObs'19 Conference[50] on *Ship-Based Contributions to Global Ocean, Weather, and Climate Observing Systems* (Smith *et al.,* 2019).

The readiness level of some biological observations within the Essential Ocean Variables[51] (EOVs) framework are generally in the concept or pilot phase compared to the mature level of most physical and biogeochemical ocean variables. Current efforts are also focusing on integrating the EOVs with the marine Essential Biodiversity Variables[52] (EBVs) (Benedetti-Cecchi *et al.,* 2018). This is a clear example of where innovation in sensors, research vessel capacity and autonomous operations will need to adapt to support future ocean observations.

European research vessels have the capacity to deploy and recover various large instruments and sampling tools up to full ocean depths during multi-disciplinary and complex research cruises. The demands placed on the design of research vessels will grow as technologies evolve and the need to study deeper areas grow. With the fast-growing blue economy, many countries are initiating new businesses in the ocean and seas. Maritime and offshore companies consequently develop technologies and activities that intensify or create new human activities, including in areas and environments that were previously less or not affected or that are not well understood (e.g. shipping in Polar regions and deep-sea mining). New high-quality observations are needed in these ecosystems to help understand the impacts of human activities. Performing these observations is far from trivial and provides new challenges for the operational and technological capacity of research vessels.

Initiatives such as the European Strategy Forum on Research Infrastructures (ESFRI) and its projects LifeWatch[53] and the Integrated Carbon Observation System (ICOS, see picture on page 85)[54] that have led to the establishment of seabed and coastal observatories. The deep ocean floor and cabled observatories of EMSO-ERIC are of specific interest in this case (see Box 5.2). The current research vessel fleet often lacks the technology and facilities to install and service deep water cabled observatories. The importance of such observatories for science is increasing and this capacity will therefore need to be developed. This may result in purpose-built research vessels or in the increased use of commercial offshore industry vessels where such specialized capacity is already available, but very expensive to hire. Not every nation will be able to invest in the deployment of such observatories or vessels to deploy, service and recover them. A European-wide approach to deal with this issue might be sought within EOOS. Multinational cooperation amongst research vessel operators or joint ownership of a few dedicated vessels would be beneficial for all EOOS stakeholders.

5.2 Engaging with the EOOS process

5.2.1 What can the research vessel community mean to EOOS?

EOOS still needs to evolve and be fully implemented to meet critical science objectives. To achieve this the implementation plan (EuroGOOS & European Marine Board, 2018) lists a number of actions to help initiate EOOS activities. The research vessel community is a key player and will contribute significantly to a number of these activities.

If EOOS desires to bring the capacity of available research vessels in line with future observation needs, periodic consultation with the research vessel community is important. In a pilot project,

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[48] http://www.argo.ucsd.edu/

[49] http://biogeochemical-argo.org

[50] http://www.oceanobs19.net/

[51] http://www.goosocean.org/index.php?option=com_content&view=article&id=14&Itemid=114

[52] https://geobon.org/ebvs/what-are-ebvs/

[53] https://www.lifewatch.eu/

[54] https://www.icos-ri.eu/home

Credit: Kosta Punkka / ICOScapes

RV *Simon Stevin* participating in the ICOS initiative

EOOS is already mapping the key operators of ocean observing infrastructures. With input from the entire ERVO community and research vessel operators beyond the ERVO network, Chapter 2 of this Position Paper feeds exactly into that exercise. A periodic update of European research vessels in operation and planned, and an assessment of the associated Large EXchangeable Instruments (LEXI) and Medium-sized EXchangeable Equipment (MEXI) they have can be a recurring task that the research vessel operators perform for the benefit of EOOS, in cooperation with EurOcean and their Research Infrastructure Database (see Box 2.1).

EOOS has to become a user-driven system and as such intends to organize events on a regular basis, focusing on a variety of EOOS aspects. With research vessels being instrumental to the entire ocean observing community, the presence of ERVO and OFEG should be ensured where relevant, to input updates of both the strategy and implementation plans, foresight activities etc. However, as previously stated both ERVO and OFEG are currently informal networks and so cannot guarantee an efficient relationship with EOOS. A potential area of formal future collaboration is through the Technology Forum of EOOS (European Marine Board & EuroGOOS, 2018; EuroGOOS & European Marine Board, 2018), which builds on previous work in Europe to develop a Forum for Coastal Technologies. It is recommended that the establishment of a formal functional unit or working group such as this within the EOOS management system would help bring the ERVO and OFEG communities into the discussion in a formal and efficient way. The research vessel community can also contribute their expertise to the EOOS objective of consulting infrastructure providers in a move towards strategic planning at a European level.

Ocean, climate and weather models would benefit from the provision of recent or near real-time data for calibration and forcing, as mentioned in the EMB Future Science Brief on marine ecosystem modelling (Heymans *et al.*, 2018). Via ERVO and OFEG, EOOS could facilitate the contacts and discussions that will enable the availability of near real-time underway data (meteorological, atmospheric and ocean surface layer) as well as CTD data upon request. Some data platforms such as the Global Ocean Surface Underway Data[55] (GOSUD) programme and the EMODnet Physics Portal[56] already support the provision of near real-time data from marine sources. All modern research vessels carry satellite communication systems on board that allow delivery of data to shore from almost any location on Earth (see Section 2.3.2), but this is expensive and therefore not always feasible. In this respect ERVO and OFEG can provide information on research vessel presence, and eventually also during or after specific research vessel activities that are of interest to EOOS.

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[55] http://www.gosud.org/

[56] http://www.emodnet-physics.eu/Portal

BOX 5.2 EMSO-ERIC

http://emso.eu/

Observatories are platforms equipped with multiple sensors, placed in the water column and on the seabed. They constantly measure different biogeochemical and physical parameters that address natural hazards, climate change and marine ecosystems. One example of long-term targeted marine observatories is the European Multi-disciplinary Seafloor and water column Observatory (EMSO-ERIC). EMSO-ERIC consists of a system of observatories placed at key sites around Europe, from the North East Atlantic, through the Mediterranean to the Black Sea (see the map in Figure 5.2). Two of the EMSO observatories, the Porcupine Abyssal Plain Sustained Observatory (PAP-SO) and the EMSO-Azores are described in more detail below.

The Porcupine Abyssal Plain Sustained Observatory (PAP-SO) has been monitoring long-term change in the environment of the North East Atlantic continuously for over 30 years. It forms a key part of the commitment to monitor change in the ocean, and records atmosphere and weather, surface ocean physics, chemistry, and biology, conditions in the deep-ocean interior, and the day-to-day lives of the animals that live on the seabed. The observatory is coordinated by the UK's National Oceanography Centre (NOC) and the UK Natural Environment Research Council (NERC). It is visited each year by research vessels deploying a range of equipment, sensors and instruments to gather the samples and data this multi-disciplinary observatory provides.

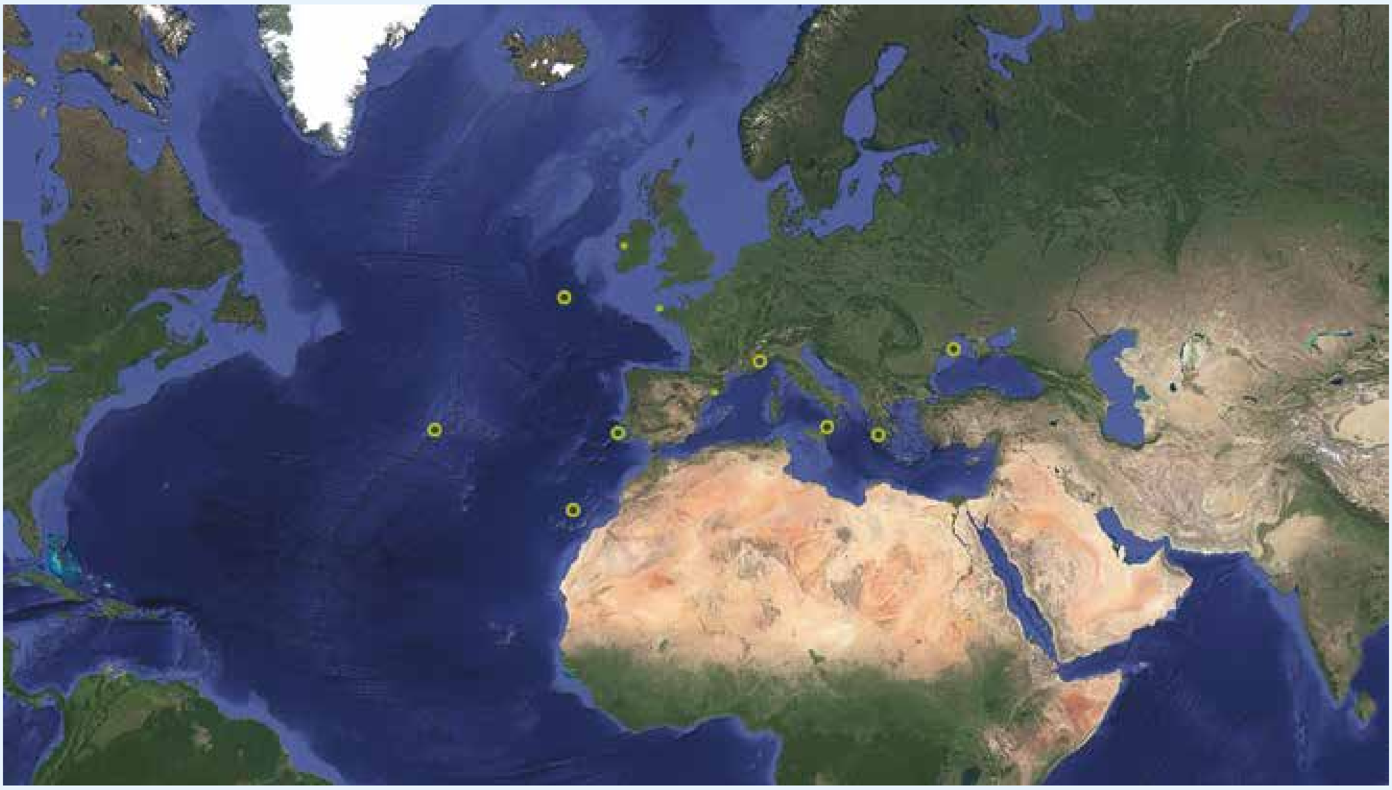


Figure 5.2 EMSO-ERIC sites, where the two most Westerly sites are PAP-SO and EMSO Azores

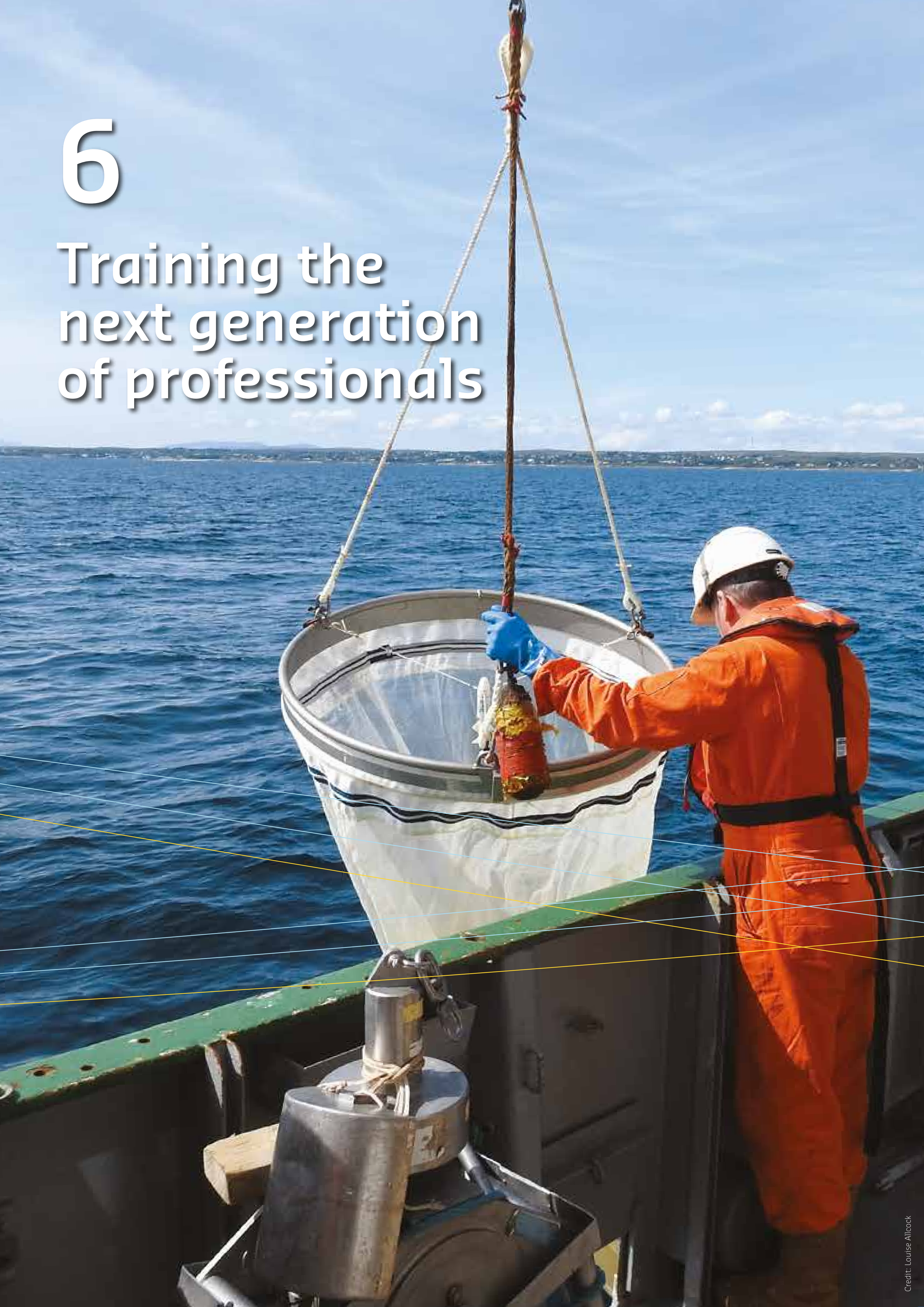
One of the EMSO-ERIC sites that needs to be serviced and maintained by a research vessel is the EMSO-Azores, which is a fixed-point buoyed observatory with a multidisciplinary approach ranging from geophysics and physical oceanography to ecology and microbiology. The observatory acquires time-series data around active hydrothermal vents in the Mid-Atlantic. The current observatory setup has been operational since 2010. The primary aim of the observatory is to provide data for research on the impact of changes in hydrothermal fluid fluxes, fluid chemistry, and water column processes on the microbial and faunal compartments of deep-sea vents, at a range of spatial and temporal scales.

Credit: The Global Ocean Observing System 2030 Strategy. IOC, Paris, 2019, IOC Brochure 2019-5 (IOC/BRO/2019/5 rev.

Figure 5.3 What does global ocean observing look like? A fully-integrated ocean observing system will deliver ocean information across three key application areas: operational services, climate and ocean health. Image and caption from the Global Ocean Observing System (GOOS) 2030 Strategy

6

Training the next generation of professionals



Credit: Louise Allcock

Background

To be able to operate research vessels and their scientific instruments and equipment, the vessel crew, marine technicians and the shore-based staff must be qualified and trained to the necessary standards. A high-quality workforce is also needed for the newest generation of research vessels and associated equipment that will be working with increasingly more complex equipment and data standards, in difficult environments such as in the deep sea and Polar regions. Based on a survey, currently available training opportunities have been evaluated, and recommendations are made based on the results.

Conclusions

From the survey results, it is obvious that training of marine shore-based staff, marine technicians and vessel crew is mainly organized in-house by individual institutions. The apparent lack of external training opportunities have and will continue to have negative effects on the efficiency of science operations on board. The vessel crew consists of professional seafarers that spend their working lives at sea, and on-the job training is therefore the most common and most cost-effective training method used. For marine technicians, no courses exist in mainstream education programs. Therefore, skills can only be acquired on-the-job, during cruises and in workshops ashore, and to some extent by attending courses provided by equipment manufacturers. The increasingly complex IT-systems on board research vessels are also a part of the portfolio of equipment that need to be supported by marine technicians. Also for shore-based staff managing the vessels, crew, equipment and marine technicians, there are no formal training opportunities, although additional insight can be gained by participating in meetings and interest groups covering relevant management topics, such as those organized by the European Research Vessel Operators (ERVO) group.

Recommendations

- ERVO should take an active role in promoting training of marine technicians, crew and shore-based staff;
- ERVO should seek a partnership with the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO), as the competent organization for marine science within the UN system, as well as other relevant European and international bodies. The UNESCO purpose includes capacity development, as demonstrated through the Ocean Teacher Global Academy (OTGA), to develop course modules on all aspects of vessel operations;
- Research vessel operators should coordinate the use of available vessel time during periods of low demand and/or availability of spare berths for conducting onboard training activities;
- To achieve long-term benefits, national governments should fund regular formal training courses for marine technicians and shore-based staff organized throughout Europe, including both practical training courses and online courses;
- It is recommended that a study be conducted to explore the current numbers of trained crew and technicians within Europe, future needs, and ways in which these numbers can be enhanced.

Ocean Sampling Day 2019
on RV *Celtic Voyager*

6.1 Sea-going research in the 21st century: changing science and personnel skill requirements

As science has developed, the requirement and methodology for data quality, quantity and the instruments used to acquire this data have become increasingly more complex. The expertise required to operate and manage data collection has moved from scientific development to established technical methodology requiring skilled and specifically educated technicians.

In the recently published EMB Future Science Brief (FSB) 2 *Training the 21st Century Marine Professional* (Vincx *et al.*, 2018) the authors note that Blue Growth, with its immense opportunities, has become the accepted terminology in Europe for the development and expansion of the maritime economy. In order to exploit the ocean's significant resources in a sustainable way, scientific research is key, not only for understanding marine ecosystems, but also in developing ways in which the world's rapidly rising population can benefit from these resources in a sustainable manner. The major technical developments of the last two decades have opened up the deep oceans for a new, high-tech level of exploitation such as oil and gas extraction and more recently deep-sea mining in ecologically sensitive areas such as the Arctic and the deep sea (see Chapter 3 for more details).

For both fundamental science and applied research in aid of newly developing economic activities, the value and reliability of the outcome depends largely on the quality standards of the sampling and data collection on board the vessels. These quality standards can be partly maintained via operational protocols. However, the effectiveness of sampling is also highly dependent on the operational experience of all personnel involved including: the scientists setting up the cruise program, taking the samples and carrying out the experiments and analyses on board; the technical support staff maintaining and operating the sampling equipment; and the crew operating the vessel. Independent of their role on board, their skills need to be obtained and maintained. However, the number of training opportunities are limited and vary widely, as discussed below.

EMB FSB 2 (Vincx *et al.*, 2018) provided an in-depth review of training availability and needs for marine graduates, and hence this aspect of training is not further addressed in this document. Instead, the focus is on the training availability and needs of the personnel connected with the research vessels themselves: the marine technicians, research vessel operators, crew and shore-based staff.

In order to assess the status of training opportunities, a review of current and past training programs available to marine professionals was conducted. Furthermore, information was gathered from the ship operators via a survey in Europe, the USA, Canada, New Zealand, Australia and Japan (see Annex 3 for more details).

6.2 Landscape of training initiatives

6.2.1 EUROFLEETS

Information on training opportunities was gathered from project reports of EUROFLEETS (EUROFLEETS Consortium, 2011), and EUROFLEETS2 (EUROFLEETS2 Consortium, 2015, 2017b). For more information about the EUROFLEETS and EUROFLEETS2 projects, see Box 2.3.

As part of the EUROFLEETS and EUROFLEETS2 projects, eight ship-based training courses were held, on RV *Oceania*, RV *Celtic Voyager*, RV *G.O. Sars*, RV *Salme*, RV *Bios DVA* and RV *Urania*. Furthermore, a floating university pilot project took place on RV *Dana*. Out of the eight training cruises, seven catered exclusively to scientists, masters and doctoral students, while only one, on RV *G.O. Sars*, invited both students and marine technicians. This training activity was further expanded in the "Student and technician access programme" embedded in the Transnational Access (TNA) activity, where Principal Investigators (PI's) were encouraged to include a training component in their research programme and to incorporate students and technicians as members of their cruise.

In EUROFLEETS2, technicians represented 11% of the embarked teams (e.g. 34 out of 329 people) during the 24 scientific cruises funded by the project. In fact, most of the participants in EUROFLEETS and EUROFLEETS2 training activities were from academia.

In the ongoing EUROFLEETS+ project the focus of the training activities has shifted to include marine technicians and research vessel managers, in addition to scientists. Floating university programs will take place on RV *Celtic Voyager*, RV *Dallaporta*, RV *Skagerak*, RV *Mar Portugal* and RV *Oceania*, with a focus on hydrographic surveying, oceanography, fisheries research, robotics and multi-disciplinary research. These programs focus on the training of early career researchers from marine related disciplines and will take place across the main European sea basins. The following new and existing initiatives will also be supported: Co-Chief Scientist programmes, which sees emerging scientists paired with experienced scientists; Marine Internship programmes, offering sea-going placements for students of marine related sciences and technologies on research vessels, utilising spare berths; and Personnel Exchange programmes, facilitating the exchange and mobility of personnel and targeted training utilizing specific equipment and technologies on board EUROFLEETS+ vessels.

For the first time in the EUROFLEETS+ Blue Skills program, labs focused on shore-based training for scientists and marine technicians in the area of ROV operations, AUV operations, seismic survey equipment and use of telepresence technology is included in the project. Blue skills workshops focusing on developing ship-time applications will be aimed at early career researchers. Research Infrastructure Management workshops delivered by a pool of highly experienced research vessel managers for marine science-related staff will also be arranged. These workshops will aim to provide the skills and competencies required to manage research vessel infrastructures successfully and to fulfil the logistical requirements of the scientific communities.

Credit: Jose-Maria Cordero Ros, Lund University

Retrieving an AUV during EUROFLEETS+ funded training in AUV operation at University of Gothenburg and onboard RV *Skagerak* from 18-23 August 2019

Credit: Niklas Conen, Technical University Dresden

EUROFLEETS+ funded training for PhD and post-graduate students on AUV operation at University of Gothenburg and onboard RV *Skagerak* from 18-23 August 2019

6.2.2 Other European initiatives

In the past, training cruises dedicated to specific types of equipment have been organized within OFEG (see Box 7.1). Unfortunately, in recent years no such activities have been developed, although marine technicians are invited to participate in trial cruises carried out by OFEG operators. On trial cruises, rather than conducting research, pieces of equipment or the vessel itself are tested by the crew and technicians.

The recently launched initiative by Institute of Marine Engineering, Science and Technology (IMarEST), the UK-based learned society for marine professionals, on ROV pilot training is also of relevance and interest[57].

6.2.3 International initiatives

Outside Europe, the picture is similar. Trainee places on board research vessels and dedicated training cruises are available for students, early career researchers, teachers and sometimes artists or journalists. These include the opportunities that were provided through the IOC-UNESCO initiative “Training Through Research programme”[58] and that are provided through the Partnership for Observation of the Global Ocean (POGO) Fellowships for shipboard training[59], aimed at young scientists. However, no training activities are organized where marine technicians can acquire the skills they need to support science at sea. The only exception appears to be the MATE (Marine Advanced Technology Education Center)[60] program organized by UNOLS, the US University-National Oceanographic Laboratory System, which coordinates the US federally-supported oceanographic facilities such as the academic research vessel fleet.

The MATE Center organizes both short-term and long-term internships: short-term MATE Marine Technology internships are designed to expose students to the field of marine technology, while long-term internships are designed for soon-to-graduate or recently graduated students who are interested in pursuing a career as a marine technician. The intensive 6-month program, for which 12 posts are available annually, combines at-sea and on-shore components to help the intern gain more experience with shipboard science support of instrumentation and equipment, while helping them develop key skill sets necessary for technical work. Cooperation with this initiative could be a good way to initialize training opportunities within Europe.

Another option to explore for formal provision of shore-based research vessel-related training would be to link with IOC-UNESCO and its Ocean Teacher Global Academy[61], with the intention to develop specific course modules on relevant topics, which would be open to all interested parties.

6.3 Survey set-up and results

To get a better picture of how European research vessel operators train their staff, a survey was sent to 70 European research vessel operators from 25 countries (see Annex 3). Responses were received from 22 countries, covering more than 70% of the European research vessel fleet described in Chapter 2. The survey contained questions about research vessel management (discussed in Chapter 7) and training of staff. The questions were related to: i) marine crew (deckhands and navigators), ii) marine technicians and iii) research vessel operators (shore-based staff for the management of the vessel operations).

Respondents were asked about the availability of training opportunities for each target group using statements to which they could agree or disagree. They were asked for their thoughts on training opportunities for: a) state-of-the-art equipment (including acoustic instruments, ROVs, AUVs, gliders) or highly specialized equipment (including sediment coring systems, moorings, nets) for marine technicians, b) in the operation and deployment of marine equipment for vessel crew, and c) in the management of vessel operations for shore-based staff. The possible answers were: (strongly) disagree, neither disagree or agree/ do not know, (strongly) agree. Responses are displayed in Figure 6.1.

As a follow-up to the statement, respondents were asked, for marine technicians and crew, to identify how frequently they would use training provided by manufacturers of the equipment, training in the scientific/academic environment, training provided by the offshore sector or industry, or in-house training and transfer of knowledge. Possible answers were often, sometimes, rarely or never. Responses obtained for the training options “often” used are displayed in Figure 6.2.

In addition to these questions, respondents were asked if their marine technicians participated in the bi-annual INMARTECH[62] meetings, in the OFEG-TECH[63] meetings or in other meetings. They were also asked if they felt that it would beneficial for marine technicians if an additional meeting, for instance run by ERVO (ERVOTECH), would be organized. 24 respondents expressed interest in such meetings, while nine were not interested. Two respondents said they felt that INMARTECH meetings were probably sufficient or that an additional meeting would only be of interest if it offered something different. Interestingly, neither of these two respondents typically send their marine technicians to INMARTECH meetings.

Concerning the training of shore-based staff in vessel operations, a final set of questions explored whether respondents would be willing to contribute to the organization of relevant training events, and if their research vessels could be made available for such training events. To both questions, 30 respondents said yes, although for some, the availability of the vessel would depend on funding.

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[57] https://www.imarest.org/policy-news/technical-leadership/item/5041-imarest-pushes-agenda-to-increase-support-for-rov-operators

[58] http://portal.unesco.org/en/ev.php-URL_ID=42888&URL_DO=DO_TOPIC&URL_SECTION=201.html

[59] http://www.ocean-partners.org/research-cruise-training

[60] https://www.marinetech.org/

[61] https://classroom.oceanteacher.org/

[62] https://www.irso.info/inmartech/

[63] http://ofeg.eurocean.org/np4/46

6.4 Interpretation of survey results

It was difficult to interpret the responses to the survey, because they partly reflect the various ways in which the organization of marine research and support of research is set up in the different countries. Certain countries have a national equipment pool with a group of supporting marine technicians trained to operate it; in other countries, the equipment is owned by universities and institutions and is operated by the scientists on board or by the vessel crew. For these latter countries, training sessions would automatically have to be provided within the scientific environment. The vessel crew is sometimes part of the operating institution and managed in-house, and is sometimes provided by a dedicated professional crewing agency.

Responses received on the availability of opportunities to train marine technicians and vessel crew were mixed and inconclusive and provided no clear picture on the training landscape (see Figure 6.1). Even though on average 15 out of 43 respondents (strongly) agreed that sufficient opportunities to train sea-going staff were available, more than two-thirds (or 13 respondents) out of this group of 43 respondents often organized the training in-house, while only four respondents often used training provided by the manufacturers of the equipment. This could mean that the questions were phrased in such a way that they could be interpreted in multiple ways, thereby resulting in answers that provide little useful information. However, from the survey it is obvious that a large majority of the operators use in-house transfer of knowledge as the preferred or only known method available to train their technicians and vessel crew in the deployment and operation of marine equipment (Figure 6.2 on page 94).

When considering research vessel operators, the majority of the respondents (strongly) disagreed with the statement that sufficient training opportunities are available for this group. Unfortunately, none of the respondents that did agree with this statement provided any additional information on the training to which they were referring.

It is noted from the results above that there appears to be a situation where significant funding for research on research vessels is underpinned by a small group of crew and technicians for whom there are limited training opportunities and most likely limited investment in this training. It is beyond the scope of this Position Paper to investigate this discrepancy, however it is recommended that such a study is conducted.

Furthermore, with a significant use of in-house training options by operators, they are very reliant on the experience and knowledge currently available within their staff (crew and

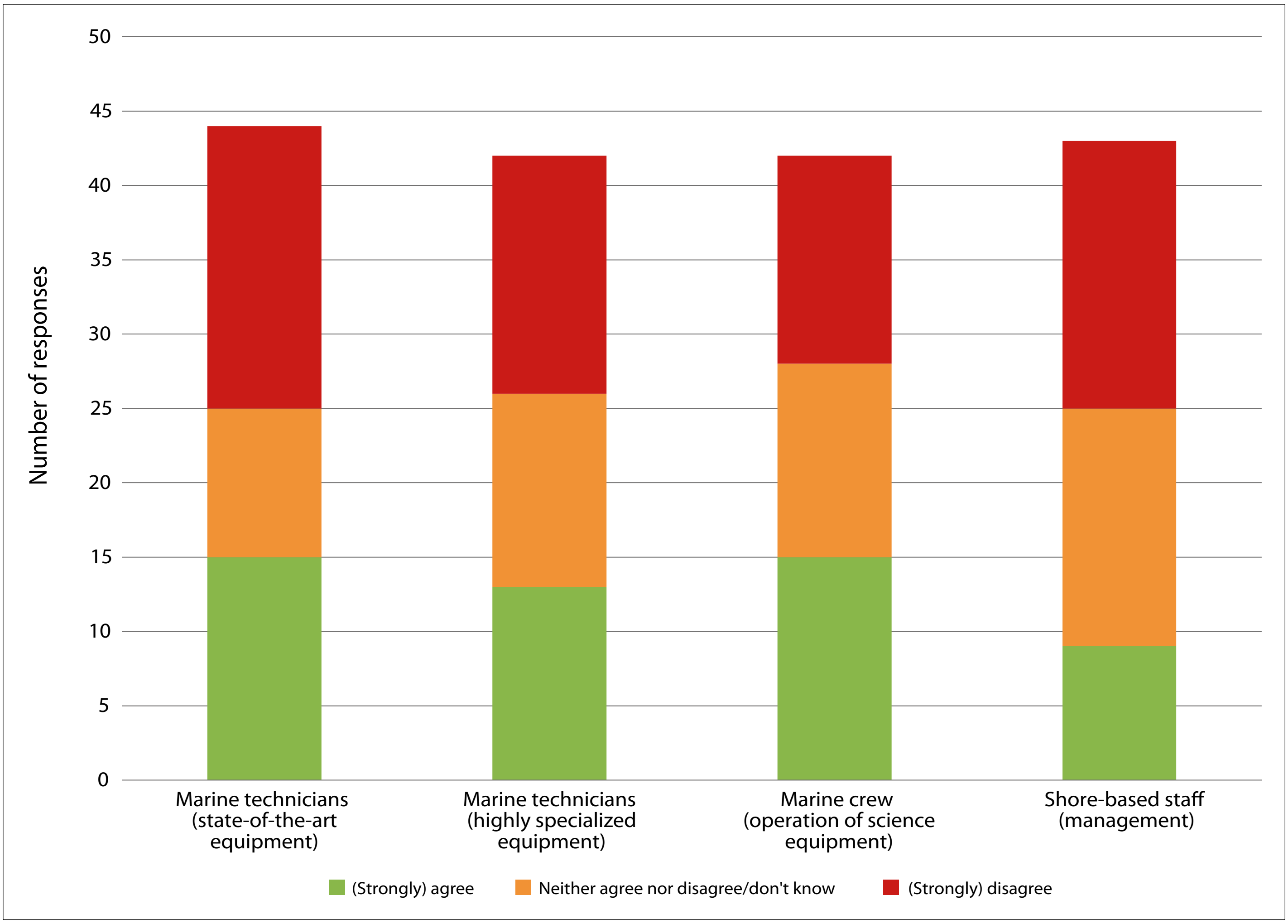

Figure 6.1 Responses to the question "How much do you agree or disagree with the following statement?: There are sufficient opportunities available to train different groups of personnel"

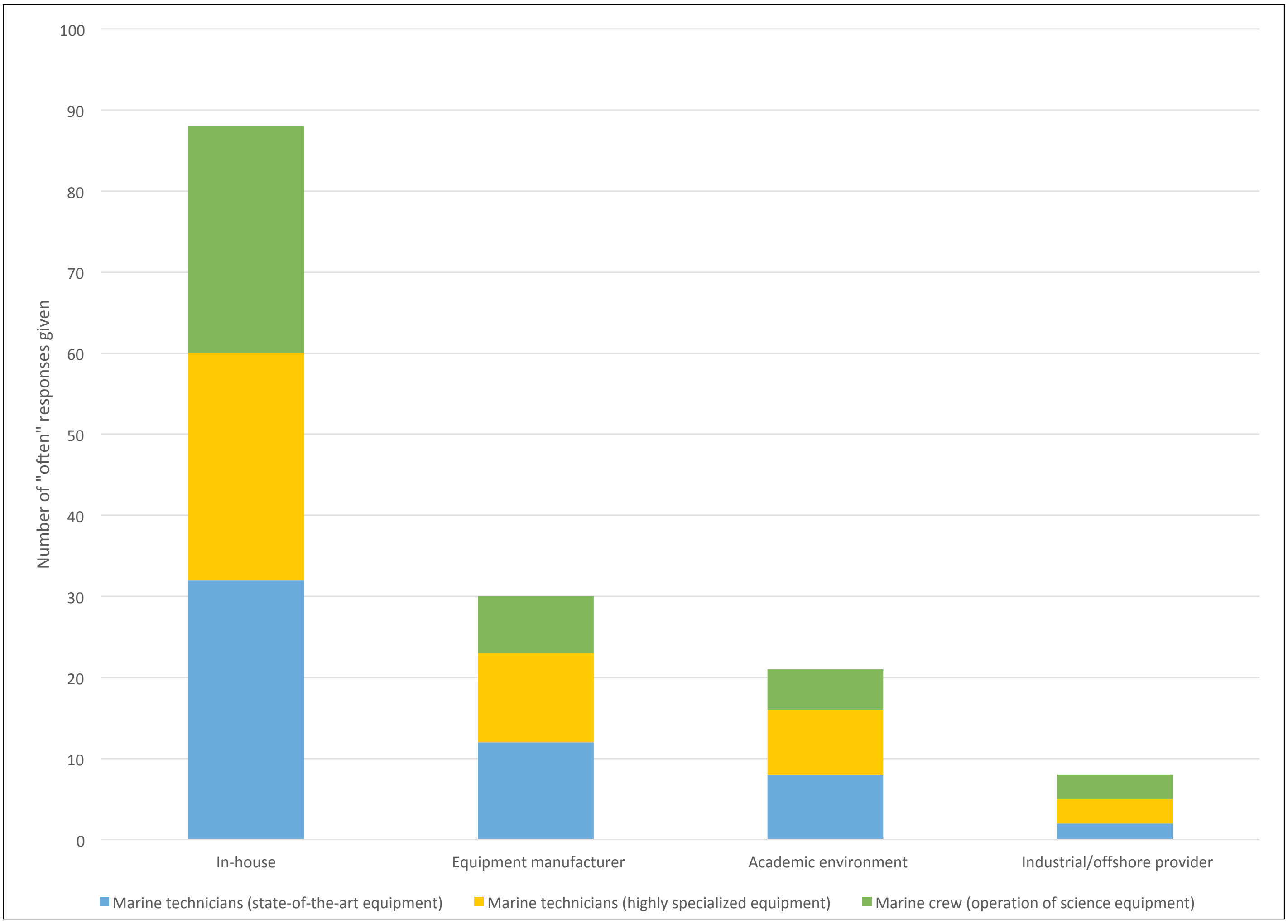

Figure 6.2 Frequency of training methods "often" used for marine technicians and vessel crew in answer to the questions "What options do you use to train (personnel) in the use of equipment?"

technicians), and this is a reason why most operators choose to employ permanent crew and marine technicians. Should any critical staff member leave or retire, this ability to provide in-house transfer of knowledge would be significantly impacted. It is therefore also recommended that a study is conducted to investigate the current numbers of trained crew and technicians in Europe. This study should look at their numbers in different countries and institutes, their age profiles, and the mix of expertise as well as their employment status (permanent or contracted staff). It should then investigate what future needs will be in terms of capacity, and explore ways in which more people could be attracted to these career paths. This will help to understand the status, vulnerabilities and future needs better within this critical sector for marine research.

Credit: Jorn Urbain - Belgian Navy

Training of research vessel crew and technicians, such as those seen here deploying a tripod from RV *Belgica*, is vital to support the needs of science

7

Management processes in the countries and partnerships developed in Europe

Credit: Artevelde Hogeschool

Background

Research vessels provide scientists with a platform to carry out marine research and environmental monitoring, but they can also provide logistical support to remote areas such as Antarctic research stations. Research vessels are diversely owned, managed and operated, and this is heavily influenced by national research policies and management structures. This also influences the tasks they are ultimately assigned. The different research vessel management processes within Europe are described and discussed, and an overview of collaborations and partnerships that exists within Europe to enhance access, cost-efficiency and interoperable use of the research vessels and Large EXchangeable Instruments (LEXI) is given.

Conclusions

European research vessels are generally owned by a public body, often a research institution. The management processes differ by country, from a centralized management of almost all research vessels (e.g. France, Germany) to nations with up to 8 different operators (e.g. UK). Research vessel management processes, such as funding, scheduling and cruise planning, technical and logistic support demonstrate a similar diversity, depending on the country's science budgets, fleet size, and areas and periods of operation. The level of service provided for the science party varies, but technical support by vessel staff on board is often automatically included in a cruise. However, if ownership is distributed, the science party may be responsible for the technical support themselves. Within Europe, collaboration is a key issue. Since 2007, several formal and informal collaborations and partnerships have developed to enhance the use of vessels and equipment, and stimulate interoperability.

Recommendations

- Given its size, the European research vessel fleet as a whole has huge potential for more cost-effective use of research vessels and equipment including LEXI, which could be realized if countries would be more willing to pool resources. Some cooperation already exists for Global and Ocean Class vessels, but collaboration on a regional level is limited;
- Sharing resources would also be efficient at a national level, creating national pools of equipment, marine technicians and trained vessel crew. For countries with a relatively small research vessel fleet and few instruments, cooperation with neighbouring countries could be an alternative;
- Using common cruise management and planning tools can make it easier to exchange information about planned utilization and deployment of research vessels and LEXI. Available capacity can then be easily recognized and requested by those needing ship-time or access to LEXI;
- Transnational Access (TNA) to research vessels and LEXIs, such as in EUROFLEETS+ (see Box 2.3) and ARICE (see Box 4.1) should continue to be supported to enlarge the community of users and foster scientific exchange, collaboration and excellence at European and international level.

7.1 Current status of research vessel management processes

Science policy, or the different ways in which marine science and infrastructure are funded have important implications for the implementation of management processes in different countries. The variety of tasks given to research vessels, ranging from only supporting fundamental science to any combination of science, monitoring and logistical support, also play an important role here. Consequently, the management of research infrastructure is diversely organized and does not follow a common standard within Europe.

In order to gain insight into the management processes that are currently in place for the European research vessel fleet, a survey was sent to research vessel operators (this is discussed in more detail in Annex 3). The trends and conclusions presented in this chapter are results from this survey, with responses received from 45 research vessel operators in 22 countries, representing about 73% of the European research vessel fleet. The first section of this chapter describes how the European research vessels are managed, and the second section illustrates issues related to the management of the sea-going scientific equipment and supporting marine technicians. Finally, an overview is given of current collaborations and partnerships within Europe, providing recommendations that could lead to a more efficient use of the European research vessel fleet.

7.1.1 Distribution of ownership of European research vessels

The European research vessel fleet is a substantial fleet, with 99 vessels available for science, operated by 23 countries, as reported in Chapter 2. In some cases, the same organization both owns and operates one or more research vessels, but this is not the case for all national fleets.

Most European research vessels are owned by public bodies (i.e. Government, Universities, Federal States and Ministries or Navies). The majority of research vessels covered in this Position Paper are owned by research institutions, followed by government bodies, universities and other public institutions, e.g. Environmental protection agencies (Figure 7.1).

Research vessels can be co-owned or jointly operated at a national level, and this generally occurs between research institutes and/or universities. Examples of such co-ownership are found in Norway and Poland:

- RV *G.O. Sars*, RV *Kristine Bonnevie* and RV *Hans Brattström* are jointly owned by the Institute of Marine Research (IMR) and the University of Bergen in Norway;
- PRV *Kronprins Haakon* is jointly owned by the Norwegian Polar Institute, the Institute of Marine Research (IMR) and the University of Tromsø in Norway;
- RV *Baltica* is jointly owned by the National Marine Fisheries Research Institute (NMFRI) and the Institute of Meteorology and Water Management (IMGW) – Gdynia Marine Branch in Poland.

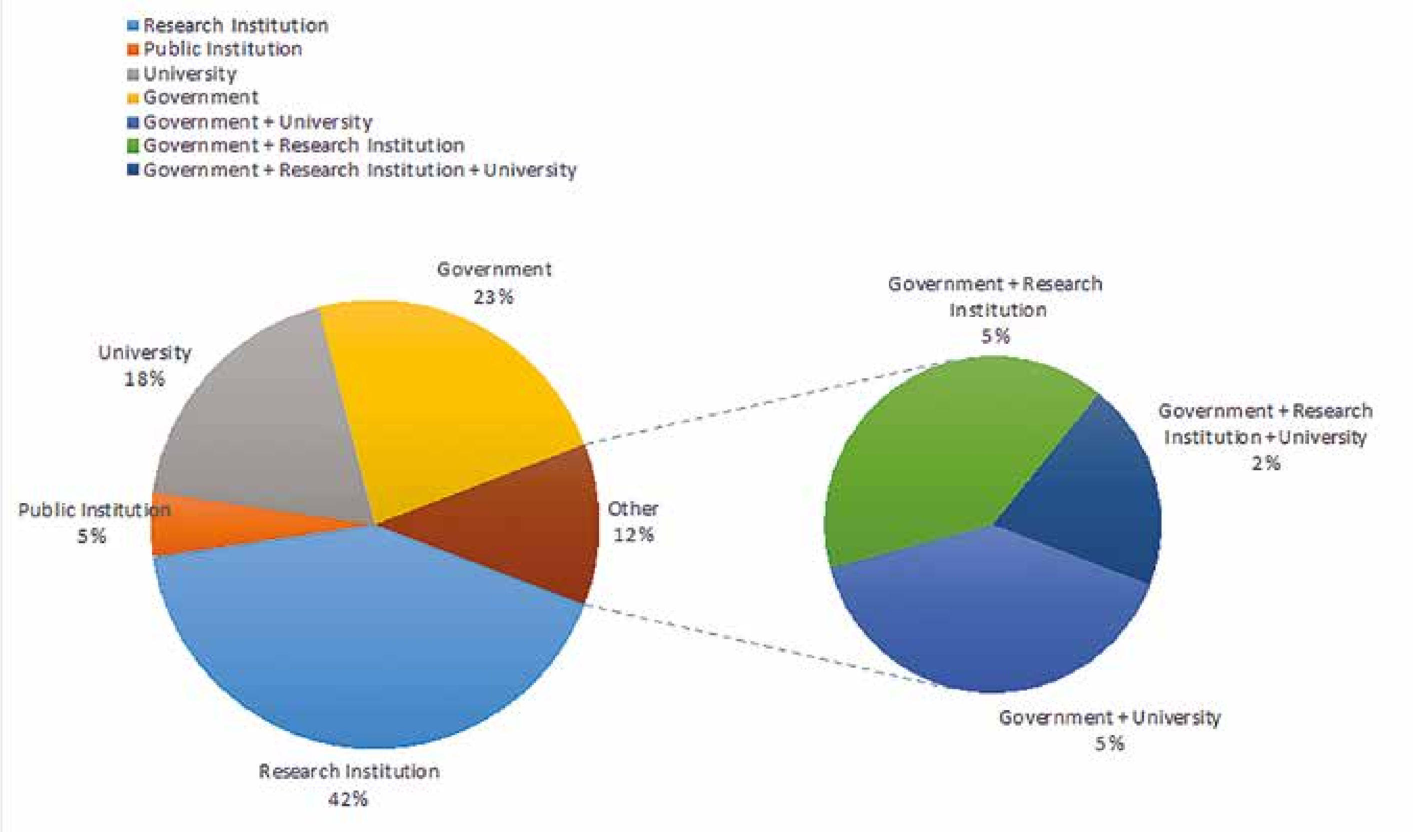

Figure 7.1 Research vessel ownership in Europe

Co-ownership at an international level is not a common research vessel management model. This is mainly due to issues that arise concerning the legal status of the vessel. A vessel can only fly one unique national flag, generally the national flag of the owner, hence if it is jointly owned by several countries, it is not obvious which flag is should fly. The national flag also makes research vessels highly visible at a national level and hence they are considered as national assets. Operating a vessel between two national governments with conflicting science priorities will always be problematic and will therefore remain an unlikely approach. This can also complicate diplomatic clearance issues for operating in foreign waters. However, shared investment (including sharing running costs) has existed in the past:

- Ifremer (France) and IEO (Spain) for RV *Thalassa*, however it is currently fully owned by Ifremer;
- NATO members for RV *Alliance*; currently the research vessel is manned and operated on behalf of NATO by the Italian Navy under a Memorandum of Understanding signed on 22 December 2015.

7.1.2 Distribution of research vessel operators

Sixty-two different research vessel operators manage the 99 research vessels from 23 European countries considered in this publication. For the full list of research vessels see Annex 4.1.

Figure 7.2 gives an overview of the number of vessels and operators per country, based on the research vessels identified in Chapter 2, and it immediately becomes apparent that individual countries have very different approaches when it comes to organizing and operating their national research vessel fleets.

As discussed previously, management of research vessels is not always centralized per country, but rather by institutions, universities or government bodies focusing on environmental monitoring and/or marine research. The most striking and recent example of centralized fleet management is France, where the French Research Fleet has been managed by one single operator, Ifremer, since 2018. This national research fleet comprises of ten vessels (excluding RV *Beautemps-Beaupré*, which is operated by the Navy[64]) which were previously operated by four different operators. In Spain, an agreement for the creation of a joint management unit called FLOTPOL[65] was signed between CSIC and IEO in 2013 in order to strengthen collaboration and optimize the operation of the research vessels and equipment owned and operated by these two institutions. In other countries where several research vessels are operated, three and even up to eight operators can be identified, such as three different operators managing five (Italy) or seven (Portugal) research vessels. In Norway, the Institute of Marine Research (IMR) operates seven research vessels that are owned and co-owned by five different public institutions belonging to four different ministries.

In the survey, most of the research vessel operators indicated that there was no major change in the way they manage their research vessels since 2007.

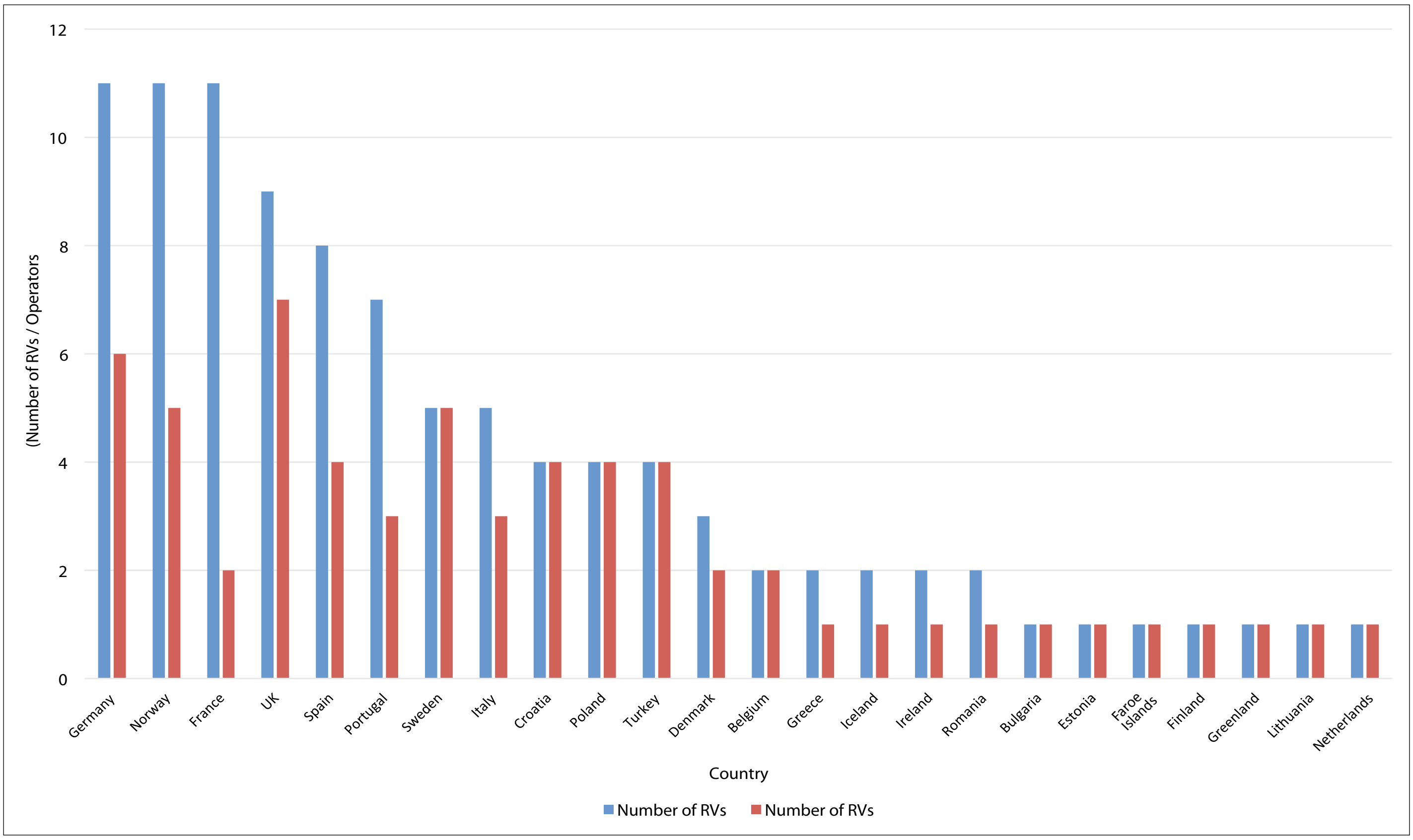

Figure 7.2 Number of research vessels and number of operators per country

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[64] RV *Beautemps-Beaupré* is available for science for 10 days per year and hence is still included in this document.

[65] http://www.utm.csic.es/en/historia

7.1.3 Funding

Funds to operate research vessels mainly come from the national governments although the funding schemes differ between countries. Some institutions (e.g. in Germany, Lithuania, Poland, Spain and UK) have a fully funded research infrastructure, where all costs associated with the vessel and the science conducted on board are covered.

In other countries, part or all of the costs other than the vessel's fixed operating costs, such as transportation of equipment to be used on the cruise, travel for the science party to/from the vessel etc. have to be covered by the scientific users.

In Denmark, scientific users have to cover the full costs (running and logistic costs) of a research cruise on RV *Dana* (DTU AQUA) and RV *Aurora* (Aarhus University), but can apply to the Danish Centre for Marine Research (financed by the Danish government) to gain the appropriate funds. If the application is successful, funds are then paid to the research vessel operator via the Principal Investigator's (PIs) institution. In France (Ifremer), logistics costs are not automatically funded, but since 2015 specific funding has been in place to support cruise applications whose logistics costs (scientific staff, equipment) cannot be fully funded by the participating organizations.

At national level, running costs can be shared by jointly operated research vessels. In Germany, the University of Kiel and GEOMAR Helmholtz Centre for Ocean Research share the operational costs for RV *Littorina*. Other examples include the cooperation between the University of Bergen and IMR for running RV *G.O. Sars*, RV *Kristine Bonnevie* and RV *Hans Brattström*, and the University of Tromsø, the Norwegian Polar Institute and IMR for the operation of PRV *Kronprins Haakon*. Ifremer and the French Navy share the running costs of RV *Pourquoi pas?* owned by Ifremer and RV *Beautemps-Beaupré* owned by the Navy. At an international level, SMHI (Sweden) and SYKE (Finland) currently share the running cost of RV *Aranda* for monitoring activities.

The long-standing international collaboration mentioned above between Ifremer and IEO for the use of RV *Thalassa* also shows that this shared-use model of the same research vessel can be successfully implemented between operators from different countries who have compatible and complementary requirements for ship-time.

Additional funding sources to cover research vessel running costs can come from research or long-term monitoring programmes, but also from delivering services or supporting commercial activities. Successfully implemented examples of projects, both short-term and long-term, funded by the EU include Transnational Access within the EUROFLEETS and EUROFLEETS2 projects (2009 to 2017, see Box 2.3), the ARICE project (2018-2021, see Box 4.1) for icebreakers, the EUROFLEETS+ project (2019-2023, see Box 2.3) and the ongoing BONUS programme[66] for the Baltic Sea.

Credit: Ilkka Lastumäki, SYKE Marine Research Centre

RV *Aranda* working together with the Swedish Coast Guard vessel KBV181 to take intercalibration samples in the Bothnian Sea

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[66] https://www.bonusportal.org

7.1.4 Scheduling

In almost all countries, vessel scheduling is carried out by the operating institution. The introduction of online or web-based cruise applications, scheduling and equipment management tools, now used by several operators, opens up a wide range of options for co-operation that were not available in 2007, when EMB PP 10 was published.

If these tools are co-used between countries, sharing ship-time and equipment could be more easily facilitated. An example of such a tool is the Marine Facilities Planning[67] tool, jointly developed for NERC (UK) and NIOZ (Netherlands) and now in use in other institutions within and outside Europe (e.g. Geomar in Germany and CSIRO in Australia).

A main complication for joint scheduling remains the differences in lead time for research cruise planning. In general, globally operating vessels need longer periods to arrange logistics and carry out cruise preparations than vessels that operate regionally. Global and Ocean Class vessels operating in wide geographical areas often expect cruise applications years ahead of the cruise itself and arrange schedules on an annual basis. Some Global Class research vessels, like the vessels operating in Polar regions and in particular PRV *Polarstern*, require a very long lead-time for cruise scheduling, which means that ship-time applications have to be submitted from three to five years before the cruise. Regional or Coastal Class vessels often allow a more flexible scheduling approach, sometimes with no fixed deadlines for the submission of ship-time applications, or with ship-time applications that can be submitted only a few months before the cruise.

7.1.5 Crew and marine technicians

Vessel crew and marine technicians to support the operation of research vessels can be part of the operator's organization, but they can also be provided by a commercial crewing agency. For the European research vessel fleet as a whole, approximately 20% of the operators currently use an external company to provide the crew and/or marine technicians. Both options have their advantages. In the case of the crew members, where they are employed by the research vessel operator they may develop a closer connection to the vessel and feel more involved in the science programme. On the other hand, a crewing agency will probably have access to a larger pool of crew members, which is advantageous in case of absence, although the crew are less likely to have specific training and/or experience in working on a specific research vessel.

Similarly, organizations operating only one vessel, or a small number of vessels might gain by pooling their vessels into a fleet at national level, and hence create built-in reserve capacity, allowing for efficient management of research vessel crews and marine technicians. This approach has the added advantage of providing a pool of trained crew and marine technicians who already have specific experience of supporting science on a research vessel. The same approach could also be applied at an international level. Considering the services provided for the science party by the vessel crew and technicians, the survey responses show that support is provided for general "on board" aspects, such as technical items (i.e. ship-based equipment and marine technical support) and data collection. Meanwhile the support for "shore-based" aspects such as equipment or data management is not typically provided by the research vessel operator.

7.1.6 Management of scientific equipment within the European fleet

Marine research equipment is an essential part of a research vessel's capability and for most disciplines sea-going research can only be carried out when such instruments and equipment are available to the science party. The ways in which provision of marine equipment is organized differs per country and depends on the national funding and management processes. Some countries (e.g. Netherlands) manage one single National Marine Equipment Pool (NMEP) that contains standard and specialized sea-going equipment, and the marine technical support personnel to operate the equipment. In general, an NMEP would be funded (in terms of acquisition, replacement and maintenance) directly by the government and operated together with the national fleet and thus available on all national vessels. Other countries with decentralized fleet management may operate more than one institutional equipment pool. Where no equipment is available via a central organization, the science party may be expected to provide the equipment themselves.

In the UK, the centralized NMEP pool is owned and paid for by NERC and managed in-house by the National Marine Facilities (NMF) at NOC together with their research vessels. However, multiple universities and research centres still hold their own equipment, and MASTS (the Marine Alliance for Science and Technology in Scotland) has collated a list of equipment in Scotland[68] presenting the equipment, its location and a contact point. The list is open to all MASTS members, however all loan and use arrangement are made directly by the parties involved, and therefore aspects such as technical support have to be negotiated. In France, Ifremer and the company GENAVIR manage the equipment deployed from Global, Ocean and Coastal Class research vessels in the French Research Fleet, while DT-INSU (CNRS) manages a pool of portable equipment (CTD Rosettes, moorings, coring systems etc.) that can be used on board all French research vessels (as well as research vessels from other countries, e.g. during joint cruises).

If an NMEP is in place and technical support is provided with the equipment, the marine technicians will often operate the equipment in direct co-operation with the vessel crew. Certain types of state-of-the-art or high-tech equipment such as remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs), giant piston coring systems, seismic systems etc. will have a dedicated technical team to operate the instrument. If dedicated technical support is not provided, marine equipment has to be operated by the crew and/or by the science party.

If an equipment pool is available, applications for marine equipment can normally be made when applying for ship-time. In other cases, equipment must be requested directly from the owners.

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[67] https://www.marinefacilitiesplanning.com/

[68] https://www.masts.ac.uk/resource-centre/resource-map/

BOX 7.1 OCEAN FACILITIES EXCHANGE GROUP (OFEG)

http://ofeg.org

The Ocean Facilities Exchange Group (OFEG) members[69] are NERC (UK), Ifremer (France), Bundesministerium für Bildung und Forschung (BMBF, Germany), NIOZ (Netherlands), CSIC (Spain) and IMR (Norway). It provides a closed forum of barter, exchange and co-operation opportunities for the members' Global and Ocean Class research vessel fleet. The main objectives of OFEG are to facilitate:

- Joint cruises;
- Exchange of ship-time; and
- Exchange of marine equipment.

The underlying principle is that no money changes hands: For every cruise on another organization's vessel, the benefiting organization must mount a full cruise on one of its own vessels in return, and to an equivalent "value". The operating costs still fall to the vessel owners. An equivalence points system has been agreed for the value of each of the vessels, to ensure like-for-like "value". The original agreement was signed in 1996.

To ensure that OFEG is capable of delivering state-of-the-art marine scientific facilities across all OFEG vessels, interoperability of large equipment, adoption of common working practices, harmonized mechanisms, protocols and tools is highlighted. To assist OFEG with equipment-related matters, OFEG-TECH was set up.

An instrument pool, at national or international level, or managed by two or more institutions, is extremely cost-efficient: a jointly owned equipment pool removes the need for different organizations to purchase similar equipment and it provides the means to build up redundancy. Other benefits include sharing of insurance, maintenance, transport and storage costs.

7.2 Collaborations and partnerships at European level

Formal and informal co-operation between the European research vessel operators range from bilateral agreements to official partnerships and vessel operator networking platforms (e.g. ERVO – see Box 1.1, IRSO – see Box 7.2 and INMARTECH[69]). All these initiatives aim to enhance efficiency and interoperability, resulting in a more effective use of research vessels and their associated marine equipment.

Many examples of bilateral agreements exist in Europe, from the general bilateral agreements that exist between European research institutions and universities to the more specific agreements dedicated to research vessel operations.

Research vessel-related bilateral agreements covering shared ship-time exist between NERC (UK) and the Marine Institute (Ireland) and between NERC and the US National Science Foundation (NSF).

OFEG, the Ocean Facilities Exchange Group (see Box 7.1), is an example of an informal partnership. Over the last five years, there has been a marked increase in OFEG ship barter exchange activity, and the majority of this has been between partners in France, Germany, the Netherlands and the UK.

Bilateral agreements are also used to market available vessel time via chartering (e.g. SLU, Sweden, charters RV *Dana* from DTU AQUA, Denmark). Additionally, bilateral agreement may cover the sharing of equipment, such as the joint use of a seismic system by NERC and CSIC.

Extensive recent networking activities (ERVO, OFEG, IRSO, EUROFLEETS etc.) have allowed research vessel operators to integrate interoperability of equipment into the design of their research vessels. Furthermore, successful collaboration has been implemented based on the interoperability of the equipment, especially in the deployment of the Large EXchangeable Instruments (LEXI), where for example:

- The MeBo, the MARUM (German seabed rock drill rig), has been developed in such a way that it can be deployed from several European research vessels (e.g. PRV *Kronprins Haakon* and RV *Pourquoi pas?*) as well as by some of the German fleet. This has required collaboration to ensure that the designs and capabilities of the supporting vessels are compatible;
- The ROV *Victor* (Ifremer, France) can also be deployed from the German PRV *Polarstern* and from the Spanish RV *Sarmiento de Gamboa*;
- The ROV *Kiel 6000* (Geomar, Germany) can also deployed from the UK's RRS *James Cook*.

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[69] https://www.irso.info/inmartech/

Credit: MARUM – Center for Marine Environmental Sciences, University of Bremen, T. (CC BY 4.0)

The seabed drill rig MARUM MeBo200 is lowered into the water from RV *Sonne II*

Besides the long-term collaborations and partnerships mentioned above, a number of short-term initiatives have been organized, mainly funded via European projects. The Transnational Access (TNA) activities of the EUROFLEETS projects (see Box 2.3) and the on-going ARICE project (see Box 4.1) have successfully widened the access to research vessels and equipment, and substantially furthered the development of synergies and collaborations between international users.

Another example is JPI Oceans'[70] *Ecological aspects of deep-sea mining*[71] project where research is carried out in an integrated transnational project, which includes the RV *Sonne II* as well as additional equipment. This cost-effective approach allows researchers from different countries to work as a team for a joint project in the same place at the same time. This contributes to trust-building amongst researchers, the development of a common understanding and the integration of national research activities around a common scientific objective. At an operational level, the shared use of research infrastructure facilitates standardized data collection, coordination of research methods and open access to research data. This in turn allows for more effective collective European contributions to international policymaking. This work by JPI Oceans is presented as a case study for current approaches for aligning national research strategies, programmes and activities online[72].

The IODP[73] (International Ocean Discovery Program) serves as another example of international marine research collaboration. It explores the Earth's history and dynamics using ocean-going research platforms to recover data recorded in seabed sediments and rocks, and to monitor sub-seabed environments. IODP depends on facilities funded by three platforms (European Consortium for Ocean Research Drilling (ECORD), US National Science Foundation (NSF) and Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT)). The programme also receives financial contributions from five partner agencies: China's Ministry of Science and Technology (MOST), Korea Institute of Geoscience and Mineral Resources (KIGAM), Australian-New Zealand IODP Consortium (ANZIC), India's Ministry of Earth Science (MoES) and Coordination for Improvement of Higher Education Personnel, Brazil (CAPES). Together, these entities represent 23 nations whose scientists participate in IODP research cruises conducted across the world.

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[70] http://www.jpi-oceans.eu/

[71] http://www.jpi-oceans.eu/ecological-aspects-deep-sea-mining

[72] https://www.era-learn.eu/documents/era-learn-publications/eralearn2020_t4-2_compilation-of-all-inra-case-studies_v2.pdf

[73] https://www.iodp.org/about-iodp/about-iodp

BOX 7.2 INTERNATIONAL RESEARCH SHIP OPERATORS (IRSO)

https://www.irso.info/

International Research Ship Operators (IRSO), originally known as International Ship Operators Meeting (ISOM), was founded in 1986. It is a global group of research ship operators representing 49 organizations from 30 countries worldwide, who manage over 100 of the world's leading marine research vessels. Members gather annually to share information and solve problems of mutual interest, and IRSO acts as a voice to promote the research vessel operators' community globally and to provide independent advice to policy makers and funding agencies worldwide.

7.2.1 Bathymetric crowdsourcing

Large parts of the world's oceans, and in particular, international waters are poorly mapped, if at all, and there is a growing interest in exploring and mapping the oceans, in particular the Polar regions and the deep-sea areas where the lack of bathymetric data is the most significant.

Many research vessels, in particular the Global Class and Ocean Class vessels are equipped with multibeam echo sounders, navigation systems, computer resources, and together with trained marine technicians and scientists, these vessels are fully capable of collecting and processing bathymetric data to required standards.

Since most nations prioritize hydrographic mapping of their territorial waters and in some cases their continental shelf, international waters are seldom covered by hydrographic services-run vessels. Large research vessels are more likely to sail in international waters and should, where possible, contribute to the mapping of the high seas and Polar regions.

Two ongoing initiatives connect research vessel owners and operators to map the ocean floor: 1) The Seabed 2030 project[74], in which the International Hydrographic Office (IHO) and Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO) are partners together with the Nippon Foundation[75] and GEBCO[76] (General Bathymetric Chart of the Oceans), and 2) The AORA-CSA[77] - Atlantic Ocean Research Alliance Co-ordination and Support Act, who are planning to map the entire seabed of the Atlantic[78].

Credit: Rolls Royce

Elevation and deck plan of the RRS *Sir David Attenborough*

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[74] https://seabed2030.gebco.net/

[75] https://www.nippon-foundation.or.jp/en/

[76] www.gebco.net

[77] www.atlanticresource.org/aora

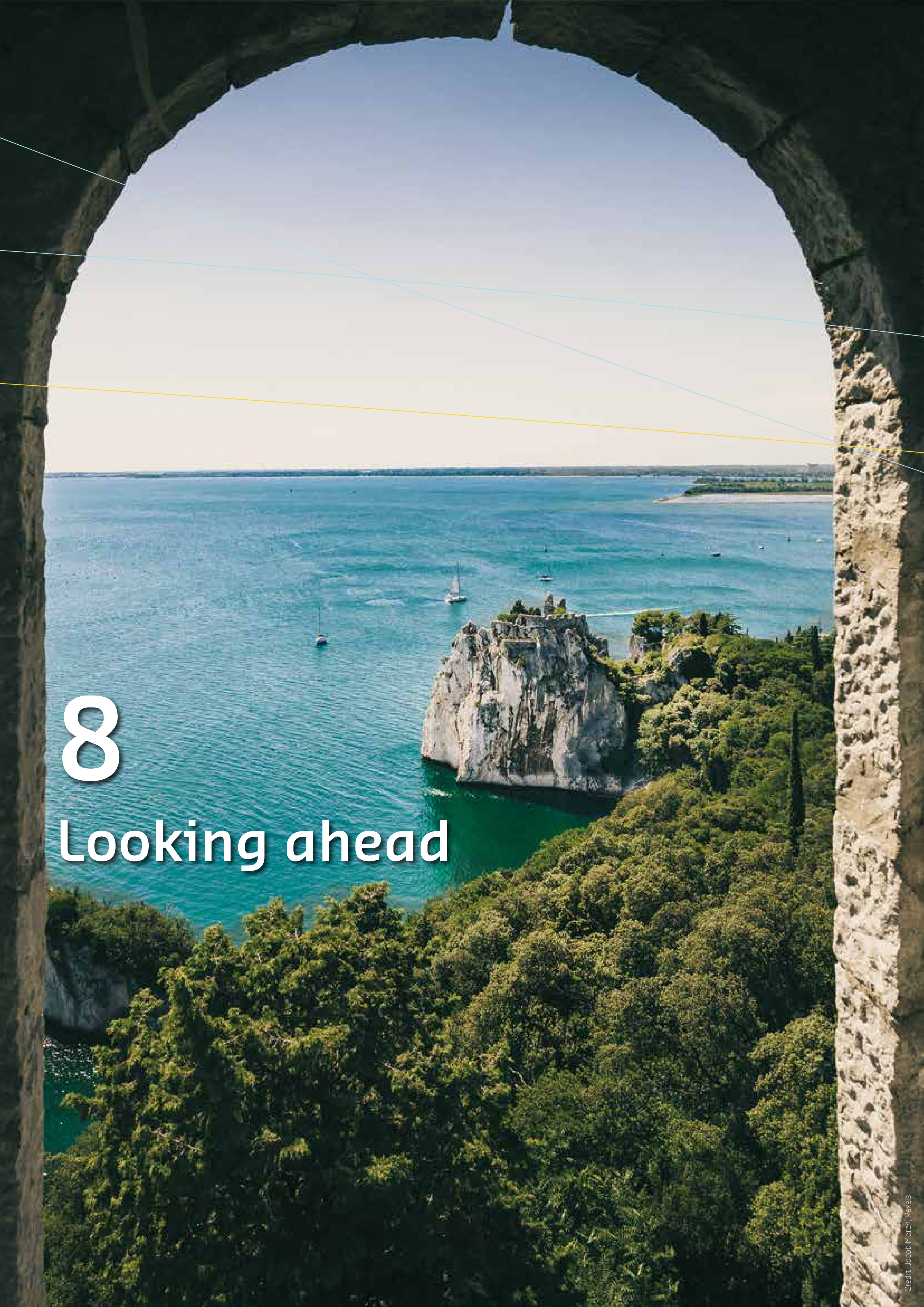
[78] https://www.atlanticresource.org/aora/mapping-our-ocean

Credit: DTU AQUA

Bilateral agreements can be used to market available vessel time via chartering, for instance SLU charters RV *Dana* from DTU AQUA.

8

Looking ahead



Credit: Jacob Morch, Pexels

Marine research and monitoring of the oceans is, and will for the foreseeable future (i.e. for the 10 year horizon to 2030 discussed in this publication) be based on collecting data and physical samples from the water column, the seabed, the ground below the seabed and the atmosphere above. Beyond that, we cannot yet fully envision what the future will bring.

The development pace of new technology for marine data collection and physical sampling is extremely high and we expect to see major innovations in this field in the coming years. One forecast for this can be found in the epilogue of EMB's latest marine science foresight document, *Navigating the Future V* (European Marine Board, 2019), which proposes the concept of a virtual ocean based on actual, real-time and historical data. This would enable people to explore the ocean in a way they have never been able to before, developing knowledge of how it functions and understanding the implications of management and policy decisions and approaches.

Such a vision cannot be realized without research vessels carrying many of the data collection and physical sampling instruments. Research vessels will also for the foreseeable future 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. Therefore, research vessels will remain a vital component of the Earth and ocean observation and monitoring system.

Technological developments in automation and artificial intelligence will undoubtedly change the way in which marine research is conducted in the future, and ever-greater focus on a carbon-neutral and sustainable society will require development of new energy carriers (e.g. batteries and fuel cells) and new types of propulsion systems for vessels of all kinds, including research vessels. This will have a significant impact on the way in which future research vessels are designed and operated in the longer-term beyond the 2030 time horizon of this publication. Some innovations may render existing techniques and equipment redundant, and trends towards greater use of autonomy (e.g. using fleets of autonomous vehicles) and digital technology (e.g. livestreaming of science) will most likely influence the numbers of personnel required on board research vessels. Other innovations will produce smaller, lighter and more powerful sensors. All of this will affect how future research vessels and indeed fleets looks, creating a new balance in vessel sizes, categories and capabilities.

The key 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. Scientific needs and the demands of the scientific community will drive technology advancements, but at the same time, technological developments will also continually push the boundaries of what is possible. Closer collaboration between research vessel owners and operators will support more efficient operations and increase both the availability and accessibility of ship time. Most importantly, the whole research vessel and marine community will need to engage with the wider society to foster understanding of the importance of Earth and ocean observations, and the role that research vessels play. Without a clear justification for the contribution and growth in funding, and ultimately, without societal support, the research vessel fleet in Europe will not be able to continue to underpin globally relevant marine research. Without it, the vision of a sustainably managed and globally valued ocean will remain just that: a vision.

Credit: Artevelde Hogeschool

Leaving port on a research vessel

Image left: view
from Duino, Italy

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Glossary

2D seismic – The creation of 2D images of complex seabed sedimentary structures using a seismic survey system that consists of a sound or vibration source and a single streamer of receivers.

3D seismic – The creation of 3D images of complex seabed sedimentary structures using a seismic survey system that consists of a sound or vibration source and a multiple streamers of receivers.

Acoustic Doppler Current Profiler (ADCP) – This is an instrument that uses the Doppler Effect where sound waves are returned back from particles in the water column in a scattered way, in order to measure water current velocities over a range of depths.

Anemometer – This is an instrument that is used to measure wind speed.

Augmented reality - Augmented reality is an interactive experience where the real-world environment is enhanced with computer-generated information.

Blister – An extension of the vessel hull to place hydroacoustic equipment on the inside.

Cavitation – Cavitation occurs when the movement of the propeller through the water causes a rapid change of pressure. The water effectively "boils", leading to the formation of small vapour-filled cavities or bubbles, which collapse generating shock waves and hence noise.

Classification Society – This non-governmental organization establishes and maintains technical standards for the construction and operation of ships and offshore structures.

Containerized winch – This is a winch system that is housed in a standard-size shipping container, making it portable.

Control van – This is the mission control room for ROV operations.

CTD (Conductivity, Temperature and Depth)-rosette – This is a rosette of seawater sampling bottles housed in a frame, with instruments for measuring depth, temperature and conductivity of the water.

Data Collection – In this Position Paper, this is specifically referring to research vessel activities using sensors and equipment to collect digital information.

Dampers – This is a secondary mounting system for large vessel machinery items, which are designed to reduce the vibrations, which are transferred into the vessels main structure.

Demersal trawling – This is trawling designed to catch fish living at large depths or on the seabed, and uses a cone shaped net with a closed end to hold the catch.

Drop-keel – This retractable unit is deployed through the bottom of the ship's hull. It typically house hydro-acoustic instruments like sonar, echo sounder, etc. and can improve sensor performance by isolating them bubbles generated by the hull.

Dynamic Positioning - Dynamic positioning is an automatic computer-controlled system on board a vessel that helps it to maintain position. The system uses the vessels own propellers and thrusters.

Expendable bathythermograph – This small probe measures water temperature as it falls through water. It is dropped over the side of the vessel to deploy it.

Ferry-box – This system allows continuous and automatic measurement of physical, chemical and biological marine parameters. Water continually flows through the system, which is installed on board vessels of opportunity, such as ferries or cargo ships.

First-year ice – This is ice that has grown for no more than one year, forming during autumn and winter but melting again in the spring and summer.

Gondola – A container connected to the vessel hull with holding bars making space between the hull and the container filled with hydroacoustic antennas.

Grabs – This is a range of equipment that are designed to sample disturbed sediment in the seabed.

Gravimeter – This equipment measures variations in gravitational force to understand the geological composition of the Earth mass below the vessel as different types of mass (rocks, magma etc.) have different densities and therefore different gravity.

Ground-truthing – This is where *in situ* observation data is used to check the accuracy of remotely sensed data.

Ice class – This is a notation that a classification society of a national authority can assign to a vessel to acknowledge its capabilities for operating in some degree of sea ice.

Ice inclusions – In this cases refers to old or multi-year ice inclusions, where pieces of older ice are found encased within newer ice in Polar waters.

Ice trawl gallows – These are structures on the stern of the vessel that push the trawl wires towards the centre of the vessel and within the channel created by the vessel, to avoid them becoming snagged or caught in the ice.

***In situ* sensing** – This is any observations that are taken with the instruments in direct contact with the medium (e.g. seawater) that they are measuring.

Large EXchangeable Instruments – These large and valuable items of equipment are typically not permanently installed on the vessel but are portable and can be deployed from different vessels.

Medium-sized EXchangeable Instruments – These items of equipment are smaller than the LEXI and are typically not permanently installed on the vessel but are portable and can be deployed from different vessels, including smaller classes of vessels.

Moon-pool – This is a shaft through the bottom of a vessel used for lowering and raising equipment into or from the water.

Mooring winch – This is a winch system which is used to secure the vessel to its berth ashore.

Multinet – This is equipment designed for quantitative sampling of plankton in successive water layers, and features a multiple net system.

Multi-year ice – This ice has grown for over two years and has survived more than two summer melting seasons.

Otter boards – These are a pair of large, heavy, square or rectangular plates or boards of metal or weighted wood attached to the streamer to hold it out and prevent tangling during operation.

Podded propulsion – This is an alternative to a traditional propeller system for propelling the vessel, where a rotatable pod sticking out from under the vessel contains an electric motor, driving a propeller fixed to the back of the pod.

Polar Class – This is a set of rules published by the International Association of Classification Societies (IACS) in 2007 that sets out requirements for building ice-classed vessels.

Polar Code – This is an international code, which sets out regulations for ships operating in Polar waters, principally defining ice navigation and ship design requirements. It was adopted by the International Maritime Organization (IMO) in 2014 and came into force in 2017.

Portable winch – This is a winch system that is portable, and can be moved to different vessels.

Sampling – In this Position Paper, this refers to research vessel activities where physical samples are collected.

Scientific hangar – This is a sheltered area on the ship's open deck which still allows equipment to be deployed over the side, but provides some protection to the equipment and personnel.

Second-year ice – This ice has grown for two years and have survived two summer melting seasons.

Seismic systems – This refers to a group of equipment that the reflection of sound or vibration to study the seabed and subsurface.

Shaft generator – This is a device that is fitted on the main propeller shaft of a vessel and uses its rotation to generate electricity.

Shore power – This is cabled electricity that the vessel can access when berthed ashore.

Sledge – This is a group of equipment used for biological sampling on the seabed, and features a net(s) attached to skids and a frame.

Small towed body – This refers to any small item of equipment that is towed behind the vessel in order to carry out data collection.

Source array – This a collection of sound or vibration generators in a seismic survey system.

Streamer – This is typically a floating marine cable that connects hydrophones, that record reflected sound or vibrations in a seismic survey system.

Streamer winch – This is a winch system designed specifically for use with the streamer(s) in a seismic survey system.

Sub-bottom profiler – This is a type of acoustic seismic survey equipment used to determine physical seabed properties and characterize subsurface geological information.

Swath width – the width of the area that can be imaged, for example when using a multibeam echo sounder system.

Vessel flag – A vessel operates under a single national flag and this dictates which national and international regulations the vessel should be compliant with, covering issues such as technical aspects and crew employment laws. Vessel flags also regulate access to waters under national jurisdiction.

Vessel of opportunity – This is any commercial or non-commercial vessel that may voluntarily agree to collect data or operate sampling equipment during their normal operations, e.g. through the installation of a ferry-box on board.

List of Abbreviations

ADCP	Acoustic Current Doppler Profiler
ACEX	Arctic Coring Expedition
AFBI	Agri-Food and Biosciences Institute (UK)
AIS	Automatic Identification System
ANZIC	Australian-New Zealand IODP Consortium
AORA-CSA	Atlantic Ocean Research Alliance Co-ordination and Support Act
ARICE	Arctic Research Icebreaker Consortium for Europe project
ASV	Autonomous Surface Vehicles
AUV	Autonomous Underwater Vehicle
AWI	Alfred Wegener Institute (Germany)
BAS	British Antarctic Survey
BELSPO	Belgian Federal Science Policy Office
BGS	British Geological Survey
BMBF	Bundesministerium für Bildung und Forschung (Germany)
CAPES	Coordination for Improvement of Higher Education Personnel (Brazil)
CEFAS	Centre for Environment, Fisheries and Aquaculture Science (UK)
CESAM	Centre for Environmental and Marine Studies (Portugal)
CFP	Common Fisheries Policy
CNR	Consiglio Nazionale delle Ricerche (Italy)
CONMAP	Council of Managers of National Antarctic Program
CPT	Cone Penetration Testing
CSIC	Consejo Superior de Investigaciones Científicas (Spain)
CTD	Conductivity, Temperature and Depth
DCF	Data Collection Framework
DROMSHIP	Dronning Maud Land Shipping Network
DTU AQUA	Danmarks Tekniske Universitet – Institut for Akvatiske Ressourcer (Denmark)
EC	European Commission
ECORD	European Consortium for Ocean Research Drilling
EEZ	Exclusive Economic Zone
EFARO	European Fisheries and Aquaculture Research Organisations
EMB	European Marine Board
EMFF	European Marine Fisheries Fund
EMODnet	European Marine Observation and Data Network
EMSO-ERIC	European Multi-disciplinary Seafloor and water-column Observatory
EOOS	European Ocean Observing System
EOV	Essential Ocean Variables
ERIC	European Research Infrastructure Consortium
ERVO	European Research Vessel Operators
EU	European Union
EuroGOOS	European Global Ocean Observing System network

List of Abbreviations

FCT	Foundation for Science and Technology (Portugal)
FEG	Fleet Evolution Group from the EUROFLEETS project(s)
FP	EU Framework Programme for research funding
FRCT	Fundo Regional de Ciência e Tecnologia (Azores, Portugal)
GeoEcoMar	National Institute for Research and Development of Marine Geology and Geoecology (Romania)
GINR	Greenland Institute of Natural Resources
GOOS	Global Ocean Observing System
GOSUD	Global Ocean Surface Underway Data programme of the International Oceanographic Data and Information Exchange (IODE) of IOC-UNESCO
HCMR	Hellenic Centre for Marine Research (Greece)
HHI	Hrvatski Hidrografski Institut (Croatia)
HI	Hydrographic Institute (Portugal)
HOV	Human Occupied Vehicle
HROV	Hybrid Remotely Operated Vehicle
I3	Integrating Infrastructure Initiative
IACS	International Association of Classification Societies
ICBM	Institut für Chemie und Biologie des Meeres der Universität Oldenburg (Germany)
ICES	International Council for the Exploration of the Seas
IEO	Instituto Espanol de Oceanografia (Spain)
Ifremer	Institut Français de Recherche pour L'exploitation de la Mer (France)
IHO	International Hydrographic Organization
IMarEST	Institute of Marine Engineering, Science and Technology
IMGW	Institute of Meteorology and Water Management (Poland)
IMO	International Maritime Organization
IMR	Institute of Marine Research (Norway)
IO-BAS	Institute of Oceanology, Bulgarian Academy of Sciences
IOC-UNESCO	International Oceanographic Commission of UNESCO
IOCCP	International Ocean Carbon Coordination Project
IODE	International Oceanographic Data and Information Exchange of IOC-UNESCO
IODP	International Ocean Discovery Program
IO-PAN	Instytut Oceanologii Polskiej Akademii Nauk (Poland)
IOW	Leibniz Institute for Baltic Sea Research (Germany)
IPEV	French Polar Institute Paul-Emile Victor
IPMA	Instituto Português do Mar e da Amosfera (Portugal)
IRSO	International Research Ship Operators
ISM	International Safety Management code
ISO	International Organization for Standardization
IZOR	Institute of Oceanography and Fisheries (Croatia)
KIGAM	Korea Institute of Geoscience and Mineral Resources

LARS	Launch and Recovery System
LDF	Leitstelle Deutsche Forschungsschiffe (Germany)
LEXI	Large EXchangeable Instruments
LN2	Liquid Nitrogen
LNG	Liquid Natural Gas
LPG	Liquid Petroleum Gas
MARPOL	International Convention for the Prevention of Pollution from Ships
MARUM	Center for Marine Environmental Sciences, University of Bremen (Germany)
MASSMO	Marine Autonomous Systems in Support of Marine Observations (UK)
MBES	Multibeam Echo Sounder
MeBo	Meeresboden Bohrgerät (German seabed rock drill rig)
METU-IMS	Middle East Technical University - Institute of Marine Sciences (Turkey)
MEXI	Medium-sized EXchangeable Instruments
MEXT	Japan’s Ministry of Education, Culture, Sports, Science and Technology
MFRI	Marine and Freshwater Research Institute (Iceland)
MI	Marine Institute (Ireland)
MOCNESS	Multiple Opening/Closing Net and Environmental Sensing System
MoES	India’s Ministry of Earth Science
MOST	China’s Ministry of Science and Technology
MSFD	Marine Strategy Framework Directive
NATO CMRE	North Atlantic Treaty Organization - Centre for Maritime Research and Experimentation
NERC	Natural Environment Research Council (UK)
NFMRI	National Marine Fisheries Research Institute (Poland)
NGU	Norges Geologiske Undersøkelse (Norway)
NIOZ	Nederlands Instituut voor Zeeonderzoek (Netherlands)
NMEP	National Marine Equipment Pool
NMF	National Marine Facilities (UK)
NOC	National Oceanographic Centre (UK)
NO_x	Nitrogen Oxide
NORAD	Norwegian Agency for Development Cooperation
NPI	Norwegian Polar Institute
NSF	US National Science Foundation
NTNU	Norwegian University of Science and Technology
OBH	Ocean Bottom Hydrophones
OBS	Ocean Bottom Seismometer
OFEG	Ocean Facilities Exchange Group
OGS	Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (Italy)
OTGA	Ocean Teacher Global Academy
PAP-SO	Atlantic Porcupine Abyssal Plain Sustained Observatory

List of Abbreviations

PC	Polar Class
pCO_2	Partial Pressure of Carbon Dioxide
PI	Principal Investigator
PIRATA	Prediction and Research Moored Array in the Tropical Atlantic
POGO	Partnership for Observation of the Global Ocean
PP	Position Paper (by European Marine Board)
PRV	Polar Research Vessel
PRVN	Polar Research Vessel Network
RBINS-OD Nature	Royal Belgian Institute of Natural Sciences-Operational Directorate Natural Environment
RD2	British Geological Survey rock drilling rig
ROV	Remotely Operated Vehicle
RRS	Royal Research Ship (UK)
RV	Research Vessel
SAR	Search and Rescue
SBP	Sub-Bottom Profiler
SEEMP	Ship Energy Efficiency Management Plan
SEPA	Scottish Environment Protection Agency
SGU	Sveriges Geologiska Undersökning (Sweden)
SHOM	French Naval Hydrographic and Oceanographic Service
SLAM	Simultaneous Localization and Mapping
SLU	Sveriges Lantbruksuniversitet (Sweden)
SMA	Swedish Maritime Administration
SMHI	Swedish Meteorological and Hydrological Institute
S/N	Signal-to-noise-ratio
SO_x	Sulphur Oxide
SOCIB	Balearic Islands Coastal Ocean Observing and Forecasting System (Spain)
SVP	Sound Velocity Profile
SWL	Safe working load
SYKE	Suomen Ympäristökeskus (Finland)
TAAF	French Southern and Antarctic Territories
THC	Thermohaline Circulation
TMS	Tether Management System
TNA	Transnational Access
TTU	Tallinn University of Technology (Estonia)
UCA	Universidad de Cádiz (Spain)
UK	United Kingdom
UNCLOS	United Nations Convention on the Law of the Sea
UiO	University of Oslo (Norway)
UiT	The Arctic University of Norway

UoG	University of Gothenburg (Sweden)
URN	Underwater radiated noise
USBL	Ultra-short Baseline (acoustic positioning system)
USV	Unmanned Surface Vehicle
VLIZ	Flanders Marine Institute (Belgium)
VSAT	Very Small Aperture Terminal
WFD	Water Framework Directive
WMO	World Meteorological Organization
XBT	Expendable Bathythermograph

Annex 1: Members of the European Marine Board Working Group on Next Generation Research Vessels (WG Research Vessels)

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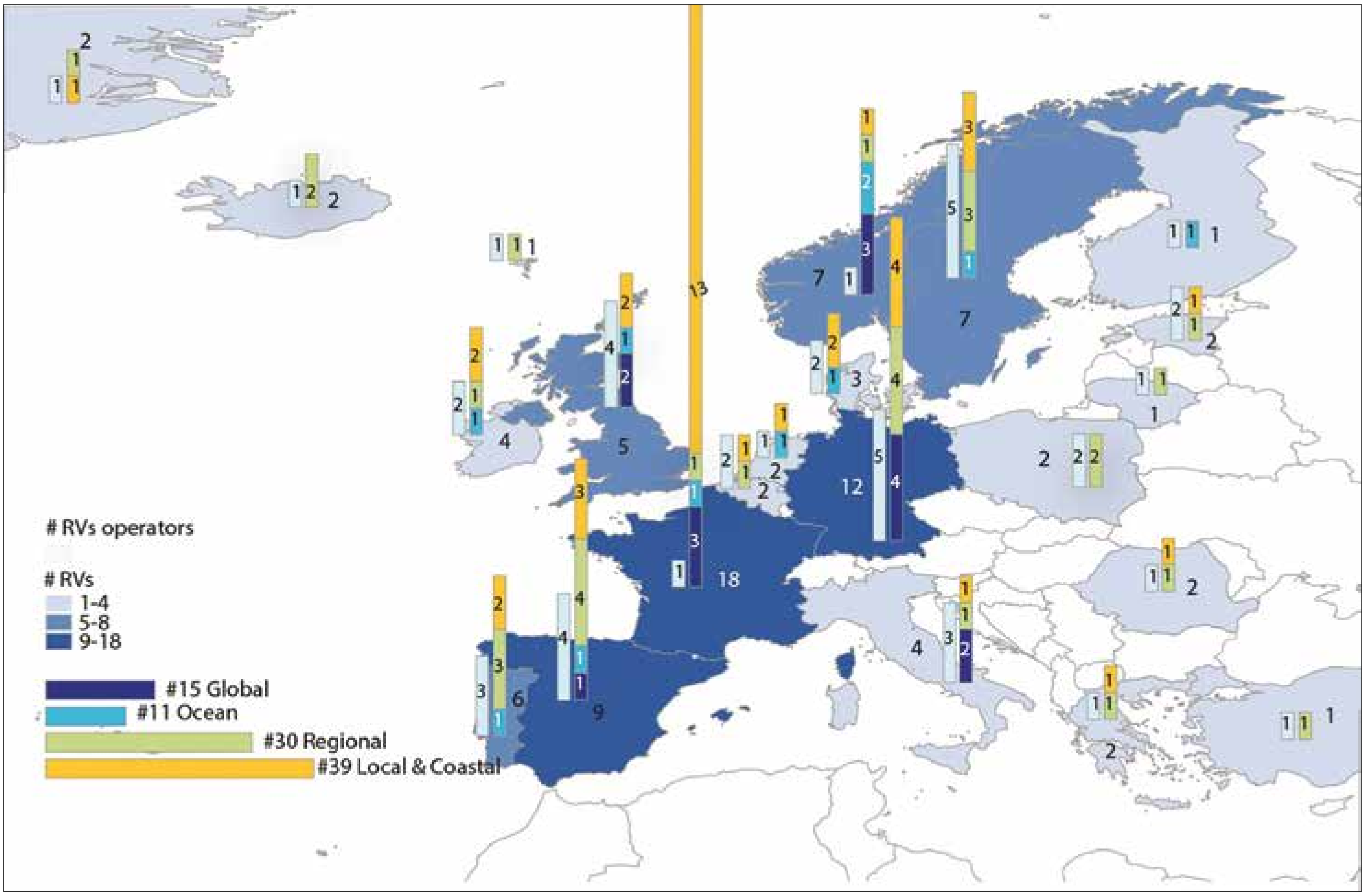
Annex 3: Stakeholder interaction

The European Marine Board coordinated stakeholder interaction activities for this publication. Two surveys were conducted.

The first survey targeted research vessel operators in Europe in order to collect up-to-date information on the national management of the European research fleet, including funding mechanisms, investment plans, collaborations and partnerships, training options and opportunities for marine science support personnel, as well as marine technicians, marine crew and shore-based staff. This survey ran in Summer 2018 and 45 research vessel operators responded to the survey, covering 104 European research vessels from 22 countries. Vessels covered by the survey ranged in size from Local to Global, and everything in between. The main results of this survey can be found online[79].

The figures below show the geographical and class distribution of vessels covered by the responses received from the research vessel operator survey. Figure A3.1 shows the full response of 104 vessels and Figure A3.2 shows only those responses which cover vessels that are included within this document and fulfil the criteria set out in Section 2.2.1.1 (see Annex 1 for the full list).



Credit: European Marine Board

Figure A3.1 Geographical and class overview of the total responses received to the Research Vessel Operator survey. The left-hand bar shows the number of operators, and the right-hand stack shows the number of each class of vessel. The number on the country shows the total number of research vessels owned by that country

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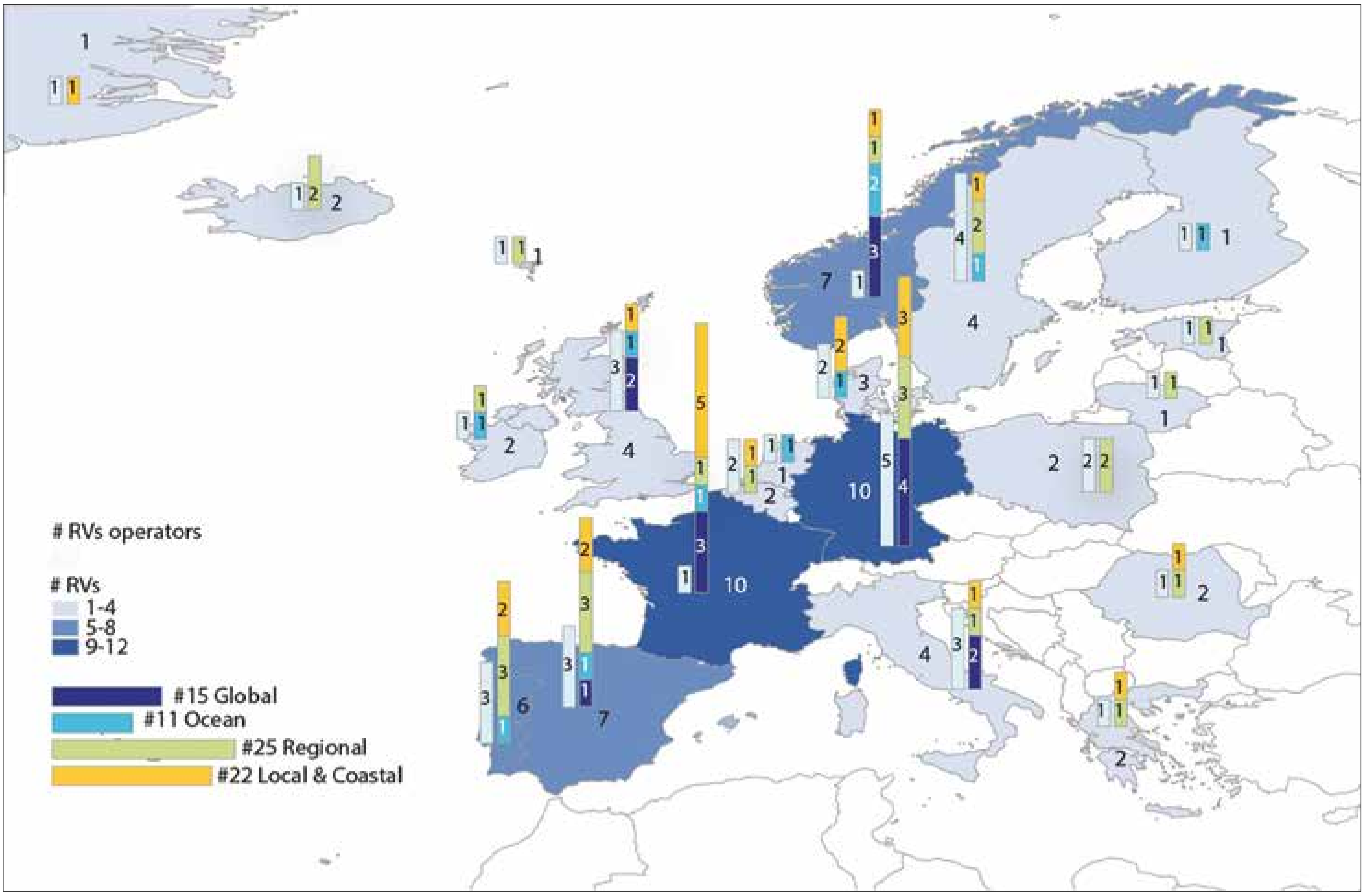
[79] https://mailchi.mp/7e85532fe6d9/research_vessel_operators_survey_summary_2018-1148401



Credit: European Marine Board

Figure A3.2 Geographical and class overview of the responses received to the Research Vessel Operator survey, which correspond to the vessels included in this Position Paper (See Annex 1). The left-hand bar shows the number of operators, and the right-hand stack shows the number of each class of vessel. The number on the country shows the number of research vessels owned by that country for which we received a response

The second survey, which also ran over Summer 2018, was targeted at research vessel stakeholders. This survey covered four main groups of respondents: i) Research groups/Academy/National research institutions; ii) Funding agencies; iii) Industry/Public or Private Companies/Government or non-academic research vessels, and iv) Technology developers. The aim was to survey the wider research vessel community in order to collect up-to-date information regarding research vessels and their use in Europe. From the research community, 67 survey responses were received, from 20 different countries (Figure A3.3). Responses were also received from two funding agencies in two different countries, and from four industry / public or private companies / government or non-academic vessel organizations, again in four different countries. No clear responses were received from technology developers. The main results of this survey can also be found online[80].

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[80] https://mailchi.mp/b03729676e9c/research_vessel_operators_survey_summary_2018-1148413

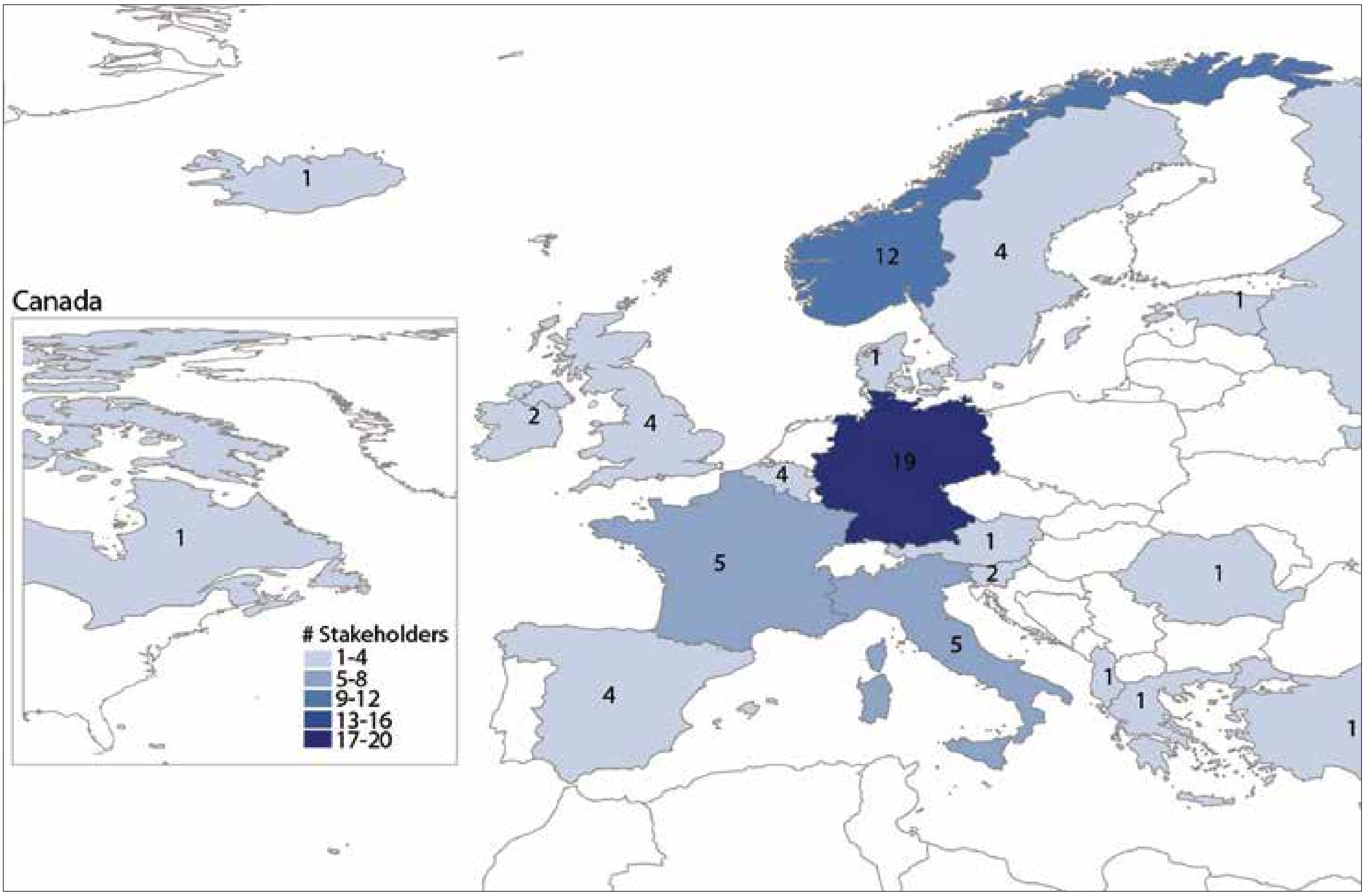

Figure A3.3 Respondents to the stakeholder survey, per country, considering all four respondent groups

Credit: European Marine Board

Throughout the activities of the working group, its progress was also presented at a number of events, including:

- 6th ENVRI week – Marine Domain, 14-18 May 2018, Netherlands
- ERVO meeting, 12-14 June 2018, Valletta, Malta
- IRSO 2018, 4 October 2018, Barcelona, Spain
- EurOcean open event "Marine Research and Knowledge in support of Policy Making and Society: Deep-sea Research as a Case Study", 15 October 2018, Azores, Portugal
- EOOS Conference 2018, 21-23 November 2018, Brussels, Belgium
- 7th ENVRI week – Marine Domain, 15 February 2018, Riga, Latvia
- Round table discussion at 3rd Conference of Italian Marine Geologists, Marine geology in Italy, 21-22 February 2019, Rome, Italy
- EUROFLEETS+ Project kick-off meeting, 5-7 March 2019, Galway, Ireland
- EurOCEAN 2019 Conference, 11-12 June 2019, Paris, France
- ERVO Meeting, 11-13 June 2019, Hamburg, Germany
- EMSO-ERIC Workshop on Sea Operations for Ocean Observatories, 25-26 September 2019, Toulon, France

A number of relevant international organizations were also consulted in connection with the work on training (see Chapter 6), including: Fisheries and Oceans Canada, National Institute of Water and Atmospheric Research (New Zealand), Japan Agency for Marine-Earth Science and Technology, University - National Oceanographic Laboratory System (US), Commonwealth Scientific and Industrial Research Organization (Australia), and the Schmidt Ocean Institute.

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[79] https://mailchi.mp/7e85532fe6d9/research_vessel_operators_survey_summary_2018-1148401

Annex 4: European research vessel fleet

Annex 4.1 Current European Research Vessel Fleet (2019)

COUNTRY	NAME	CLASS	LENGTH (M)	YEAR BUILT	NAME OF OPERATOR
Belgium	Belgica	Regional	50.90	1984	RBINS-OD Nature
	Simon Stevin	Coastal	36.00	2012	VLIZ
Bulgaria	Akademik	Regional	55.50	1979	IO-BAS
Croatia	BIOS DVA	Regional	36.80	2009	IZOR
	Hidra	Coastal	22.10	1993	HHI
	Nase More	Regional	31.35	1991	University of Dubrovnik
	Vila Velibita	Coastal	25.50	1948	Ruder Boskovic Institute
Denmark	Aurora	Coastal	28.00	2014	Aarhus University
	Dana	Ocean	78.43	1981	DTU AQUA
	Havfisken	Coastal	17.18	2015	DTU AQUA
Estonia	Salme	Regional	31.40	1974	TTU
Faroe Islands	Magnus Heinason	Regional	44.50	1978	FAMRI
Finland	Aranda	Ocean	66.30	1989	SYKE
France	Alis*	Coastal	28.40	1987	French Oceanographic Fleet
	Antéa	Regional	34.95	1995	French Oceanographic Fleet
	Beautemps-Beaupré	Ocean	80.64	2002	French Navy
	Cotes de la Manche	Coastal	24.90	1997	French Oceanographic Fleet
	L'Atalante	Global	84.60	1990	French Oceanographic Fleet
	L'Europe	Coastal	29.60	1993	French Oceanographic Fleet
	Marion Dufresne	Global	120.50	1995	French Oceanographic Fleet
	Pourquoi pas?	Global	107.70	2005	French Oceanographic Fleet
	Thalassa	Ocean	74.50	1996	French Oceanographic Fleet
	Thalia	Coastal	24.50	1978	French Oceanographic Fleet
	Thetys II	Coastal	24.90	1993	French Oceanographic Fleet
Germany	Alkor	Regional	54.90	1990	GEOMAR
	Elisabeth Mann Borgese	Regional	56.50	1987	IOW
	Heincke	Regional	55.00	1990	AWI
	Littorina	Coastal	29.80	1975	Kiel University / GEOMAR
	Ludwing Prandtl	Coastal	32.50	1983	Helmholtz Centre
	Maria S. Merian	Global	94.76	2006	LDF
	Meteor	Global	97.50	1985/86	LDF
	Polarstern	Global	117.91	1982	AWI
	Poseidon	Regional	60.80	1976	GEOMAR
	Senckenberg	Coastal	29.71	1976	Senckenberg Institut
	Sonne II	Global	118.42	2014	ICBM
Greece	Aegaeo	Regional	61.51	1985	HCMR
	Philia	Coastal	26.10	1986	HCMR
Greenland	Sanna	Coastal	32.30	2015	GINR

* *Capable of operating in coastal seas from Papua New Guinea to French Polynesia in the Pacific Ocean*

COUNTRY	NAME	CLASS	LENGTH (M)	YEAR BUILT	NAME OF OPERATOR
Iceland	Arni Fridriksson	Regional	70.00	2000	MFRI
	Bjarni Saemundsson	Regional	56.00	1970	MFRI
Ireland	Celtic Explorer	Ocean	65.50	2003	MI
	Celtic Voyager	Regional	31.40	1997	MI
Italy	CRV Leonardo	Coastal	28.60	2002	NATO CMRE
	Dallaporta	Regional	35.30	2001	CNR
	Laura Bassi**	Global	80.00	1995	OGS
	NRV Alliance	Global	93.00	1988	NATO CMRE
	OGS Explora***	Global	65.40	1973	OGS
Lithuania	Mintis	Regional	39.20	2014	Klaipeda University
Netherlands	Pelagia	Ocean	66.00	1991	NIOZ
Norway	Dr Fridtjof Nansen	Global	74.50	2016	IMR
	G.M. Dannevig	Regional	27.80	1979	IMR
	G.O. Sars	Global	77.50	2003	IMR
	Gunnerus	Regional	31.00	2006	NTNU
	Hans Brattstrom	Coastal	24.30	1992	IMR
	Helmer Hanssen	Ocean	63.80	1988	UiT
	Johan Hjort	Ocean	64.40	1990	IMR
	Kristine Bonnevie	Ocean	56.75	1993	IMR
	Kronprins Haakon	Global	100.00	2017	IMR
	Seisma	Local	16.80	1985	NGU
	Trygve Braarud	Coastal	21.80	1983	UiO
Poland	Baltica	Regional	41.00	1993	NFMRI / IMGW
	Imor	Regional	32.50	2006	Maritime Institute in Gdansk
	Oceanograf 2	Regional	49.50	2016	University of Gdansk
	Oceania	Regional	48.50	1985	IO-PAN
Portugal	Arguipelago	Coastal	25.00	1993	University of Azores
	Mar Portugal	Ocean	75.60	1986	IPMA
	Noruega	Regional	47.50	1978	IPMA
	NRP Almirante Gago Coutinho	Regional	68.30	1985	Portuguese Navy / HI
	NRP Andromeda	Coastal	31.40	1985	Portuguese Navy / HI
	NRP Auriga	Coastal	31.40	1987	Portuguese Navy / HI
	NRP Don Carlos I	Regional	68.30	1989	Portuguese Navy / HI
Romania	Istros	Local	31.86	1986	GeoEcoMar
	Mare Nigrum	Regional	82.00	1071	GeoEcoMar
Spain	Ángeles Alvariño	Regional	46.70	2012	IEO
	Francisco de Paula Navarro	Coastal	30.46	1987	IEO
	Garcia del Cid	Regional	37.20	1979	CSIC
	Hesperides	Global	82.50	1990	Spanish Navy / CSIC
	Ramon Margalef	Regional	46.70	2011	IEO
	Sarmiento de Gamboa	Ocean	70.50	2007	CSIC
	SOCIB	Coastal	23.76	2012	SOCIB
	UCADIZ	Coastal	25.00	2016	UCA

** Previously operated by BAS, UK, transferred to OGS, Italy in 2019 and renamed *Laura Bassi*

*** To be decommissioned in 2020

COUNTRY	NAME	CLASS	LENGTH (M)	YEAR BUILT	NAME OF OPERATOR
Sweden	Electra	Coastal	24.30	2016	Stockholm University
	New Skagerak	Regional	49.00	2017	UoG
	Ocean Surveyor	Regional	38.00	1984	SGU
	Oden	Global	108.00	1988	SMA
	Svea	Ocean	69.50	2019	SLU
Turkey	Bilim 2	Regional	40.70	1983	METU-IMS
	Seydi Ali Reis	Coastal	22.50	2012	Sinop University
	TÜBİTAK Marmara	Regional	41.20	2013	TÜBİTAK
	Yunuz	Local	32.00	1994	Istanbul University
United Kingdom	Alba Na Mara	Coastal	27.00	2008	Marine Scotland
	Cefas Endeavour	Ocean	73.00	2003	Cefas
	Corystes	Regional	52.25	1988	AFBI
	Discovery	Global	99.70	2013	NMF
	James Cook	Global	89.50	2006	NMF
	Prince Madog	Coastal	34.90	2001	Bangor University/ P&O Maritime Services
	Sir David Attenborough****	Global	128.00	2019	BAS
	Sir John Murray	Coastal	23.90	2004	SEPA
	Scotia	Ocean	68.60	1998	Marine Scotland

**** To be operational in 2020

Annex 4.2 European research vessel fleet as presented in EMB Position Paper 10 (2007)

Criteria for research vessel selection in EMB PP 10 meant that the following research vessels were excluded:

- Ships built/used for local and/or coastal research only;
- Ships not readily accessible to academic research (mostly naval research vessels, many fisheries research vessels, monitoring vessels or hydrographic services);
- Ships used for educational purposes only.

The following academic research vessel were included:

- >35m length;
- Accessibility for academic research, at least partly on a regular basis. Time for stock assessments, Polar supply, naval research, and educational courses and non-academic research were not considered in this context;
- Multipurpose (although not all-purpose), i.e. the ship can cover many of the present research fields and technical requirements.

COUNTRY	NAME	LENGTH (M)	YEAR BUILD	STATUS	REPLACEMENT
Belgium	Belgica	51.00	1984	Active	
Bulgaria	Akademik	56.00	1979	Active	
Finland	Aranda	60.00	1989	Active	
France	Marion Dufresne	121.00	1995	Active	
	Pourquoi pas?	105.00	2005	Active	
	L'Atalante	85.00	1990	Active	
	Le Suroit	56.00	1975	Decommissioned	
	Thalassa	74.00	1996	Active	
Germany	Polarstern	118.00	1982	Active	
	Meteor	98.00	1986	Active	
	Maria S. Merian	95.00	2006	Active	
	Poseidon	61.00	1976	Active	
	Alkor	55.00	1990	Active	
	Heincke	55.00	1990	Active	
	Sonne	98.00	1969	Replaced	Sonne II
Greece	Aegaeo	62.00	1985	Active	
Iceland	Arni Fridrikson	70.00	2000	Active	
	Bjarni Saemundsson	56.00	1970	Active	
Ireland	Celtic Explorer	65.00	2003	Active	
	Celtic Voyager	31.00	1997	Active	
Italy	OGS Explora	73.00	1973	Active	
	Urania	61.00	1992	Decommissioned	
	Universitatis (new name: Minerva Uno)	45.00	2003	Active	
Lithuania	Vejas	56.00	1980	Replaced	Mintis
Netherlands	Pelagia	66.00	1991	Active	

COUNTRY	NAME	LENGTH (M)	YEAR BUILD	STATUS	REPLACEMENT
Norway	G.O. Sars	77.00	2003	Active	
	Jan Mayen (new name: Helmer Hanssen)	64.00	1992	Active	
	Johan Hjort	64.00	1990	Active	
	Fridtjof Nansen (new name: Kristine Bonnevie)	57.00	1993	Active	New Dr. Fridtjof Nansen
	Haakon Mosby	47.00	1980	Replaced	Kristine Bonnevie
Poland	Oceania	48.00	1985	Active	
Portugal	Don Carlos I	68.00	1989	Active	
	Capricornio	47.00	1969	Decommissioned	
	Noruega	47.00	1971	Active	
Romania	Mare Nigrum	82.00	1971	Active	
Spain	Hesperides	83.00	1991	Active	
	Cornide de Saavedra	67.00	1980	Sold	
	Visconze de Eza	53.00	2001	Active	
	Garcia del Cid	37.00	1979	Active	
	Sarmiento de Gamboa	70.50	2007	Active	
Sweden	Argos	61.00	1974	Replaced	Svea
Turkey	Bilim	42.00	1983	Active	
UK	James Clark Ross	99.00	1991	Replaced	RRS David Attenborough
	Discovery	90.00	1992	Replaced	Discovery
	Charles Darwin	69.00	1984	Replaced	James Cook
	Prince Madog	35.00	2001	Active	

Annex 5: Large EXchangeable Instruments

Annex 5.1 Overview of Large EXchangeable Instruments

This section provides details of the main classes of Large EXchangeable Instruments (LEXI): unmanned surface and underwater vehicles, seismic systems and sediment sampling systems.

A5.1.1 Unmanned Surface and Underwater Vehicles

Unmanned surface and underwater vehicles are the newest generation of research tools: high-tech, state-of-the-art instruments that require dedicated technical support teams to operate them due to their technical or operational complexity. The following types of vehicles have been included in the overview:

A5.1.1.1 Unmanned surface vehicles

Unmanned surface vehicles (USV) or autonomous surface vehicles (ASV) are robotic vehicles that operate on the sea surface and record oceanographic and meteorological data across a range of variables. They are also routinely used for harvesting data from the seabed and from mooring systems. Different types of USV and ASV use various methods of propulsion, but they are mainly wave-powered or propeller-driven. Unmanned surface vehicles pose unique challenges to the pilot, especially when working inshore in congested waters or when operating among commercial shipping.

The basic tool installed in the vast majority of USVs operating out of direct line of site communication is the Automatic Identification System (AIS). This continuously transmits a vessel's position as well as some metadata on the vessel type, while receiving the same information from any other AIS-equipped vessel. In addition, with USVs now routinely operating over-the-horizon, a variety of sophisticated integrated sensor and modelling suites are becoming more common. Most

Credit: L3Harris

MASSMO mission control operations for an ASV, as part of a programme to explore the UK seas with a fleet of innovative marine robots of these supplement AIS with visible bandwidth imaging and automatic target recognition algorithms, while some have additional optronic sensors operating in the infrared band, as well as radar and passive acoustics. The actual fit varies widely from low-power long endurance USVs to high-powered short endurance vessels; however, an increasing number of both types are in use for oceanographic research activities. Indeed, some of these sensors are being used as research tools for detection and identification of seabirds, marine mammals and pollutants (including litter). An increasing amount of data fusion and collision avoidance modelling is taking place on-board the USVs because of the restrictions imposed by low bandwidth communications and latency to shore. Nevertheless, long-range over-the-horizon operations are now becoming routine.

An active radar reflector is a more direct way of being seen by larger vessels, and finally navigation lights and day-marks should be visible to vessels of all sizes. Legislation requires all USVs and ASVs to carry a radar reflector and lights.

A5.1.1.2 Autonomous underwater vehicles

AUVs are autonomous vehicles that are deployed from vessels for survey missions at remote distances from the vessel (see picture below). The AUV can maintain pre-programmed distances from the seabed and can use onboard sensors to manage collision avoidance with obstacles autonomously. As well as being pre-programmable, many of these vehicles can also be positioned in real- and/or near-real time in communication with a surface platform. These types of vehicles generally do not have tools for taking samples of the seabed, but they can use multibeam echo sounders, synthetic aperture sonar and a range of equipment for surveying and sampling in the water column. The current generation of AUVs typically have operational durations of 24 – 36 hours with long range AUVs now operating for up to four to six weeks.

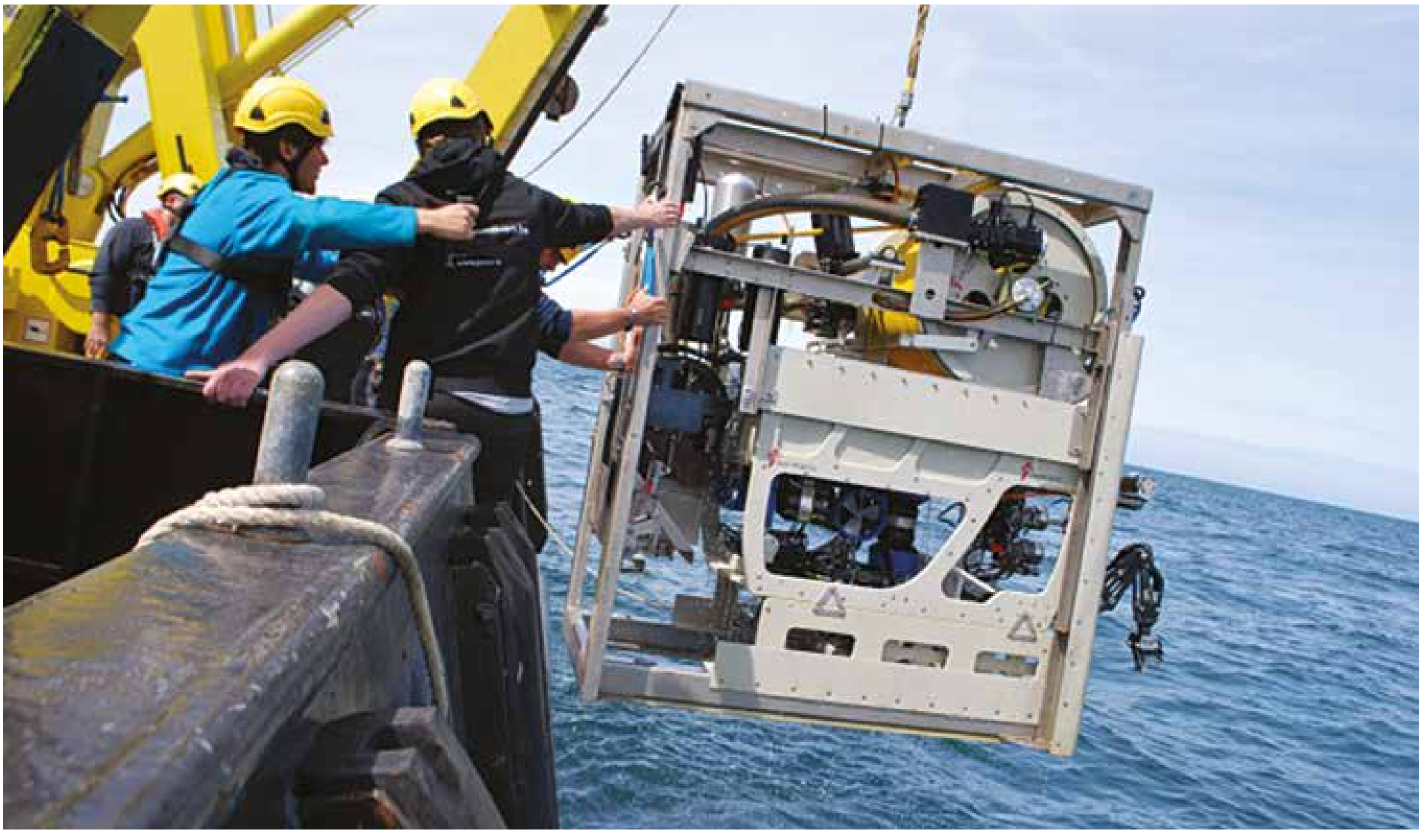
A5.1.1.3 Remotely Operated Vehicles

Remotely operated vehicles (ROV) are tethered systems that are operated from the vessel (see picture on page 129). ROVs are heavier (5 tonnes for large ROVs) than AUVs and are often slower to manoeuvre, but they have more power, can operate for extended periods, carry an array of sensors and can take samples from both the seabed and the water column.

ROVs are complex systems that require dedicated technical teams, including pilots to operate the vehicle. Because the ROVs are pilot-controlled they can operate in complex environments such as submarine canyons and mid-ocean ridges, where they can be manoeuvred to the area of interest, guided by visual observation via the camera systems on board the ROV and/or acoustic and inertial positioning systems. ROVs generally have exchangeable payloads and can support a range of survey, sensing and sampling equipment. Hybrid ROV (HROV) systems also exist; these can be either remotely or autonomously operated, depending on whether they are connected by a tether.

Credit: IMR

Retrieval of a 6000m Hugin AUV on RV *G.O. Sars*



Credit: Karen Rappé – VLIZ

ROV *Zonnebloem* (formerly *Genesis*) being deployed from RV *Simon Stevin*

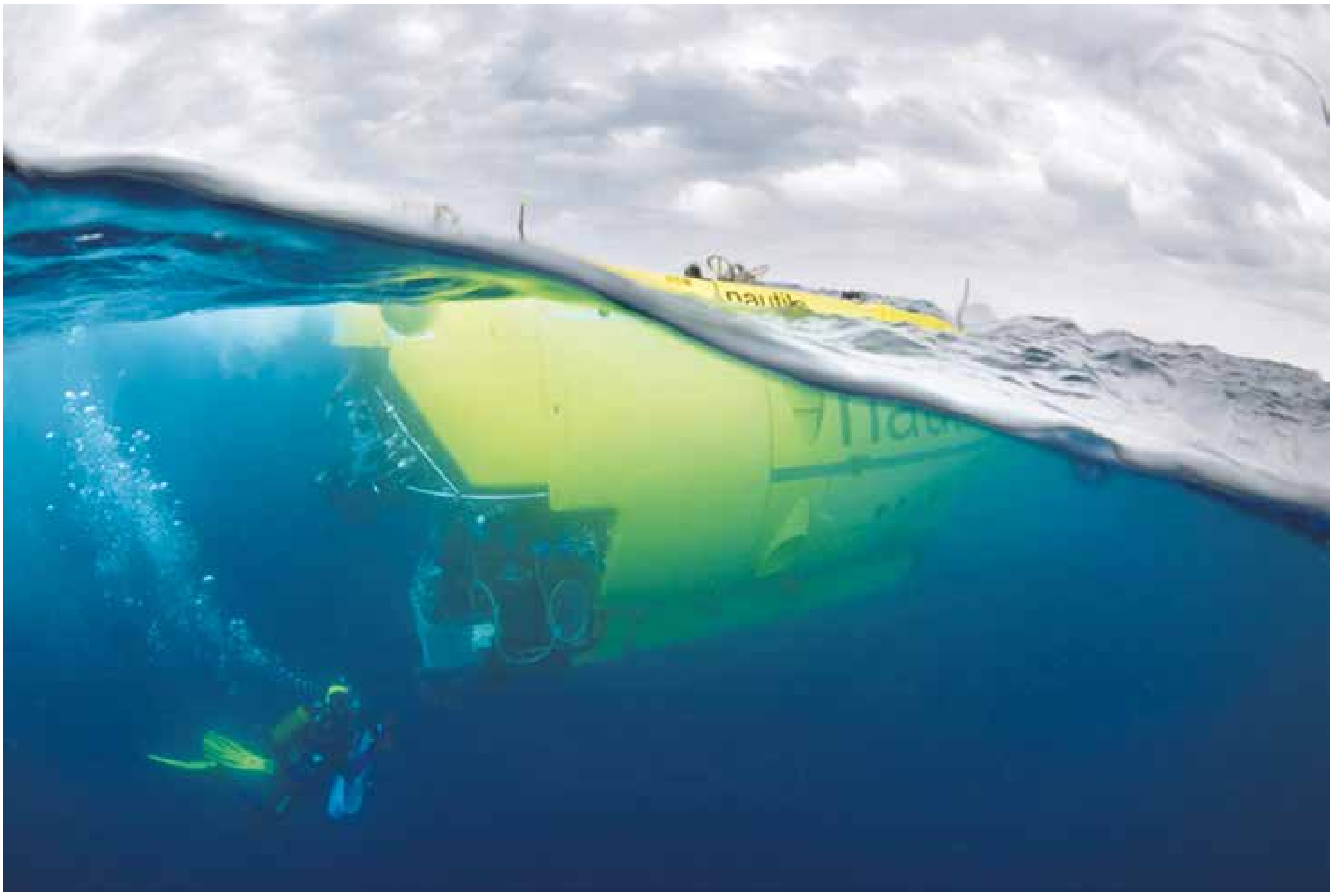
A5.1.1.4 Human Occupied Vehicles

Human occupied vehicles (HOV) or manned submersibles are deployed and recovered on a daily basis from the vessel. Historically they were the first and only systems that could observe the study objects in their own environment. They are also significant tools for public outreach and science awareness. However, there are always risks involved when bringing people to the deep sea and many operators now prefer to use ROVs. HOVs are also very heavy (up to 20 tonnes for large deep-sea HOVs such as *Nautile* owned by Ifremer) and very expensive to maintain and operate, requiring significant over-engineering to maintain the factors of safety required for human occupancy. Camera and video transfer systems have also improved significantly. HOV's have therefore largely been replaced by ROVs.

A5.1.2 Seismic systems

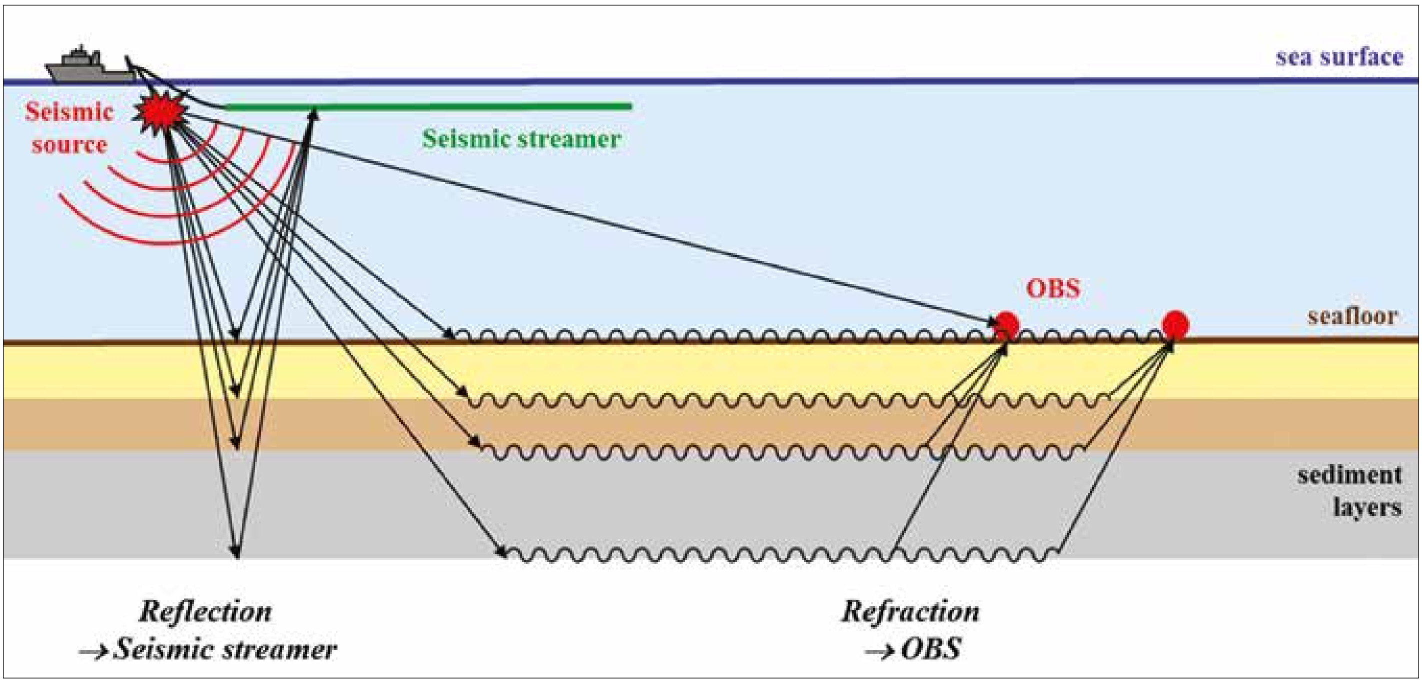
Marine seismic systems have contributed to a large number of fundamental discoveries in earth sciences. Seismic imaging is especially useful to study plate tectonics, etc. for understanding subduction zones, for earthquake hazard assessment, and tsunami warnings, which can affect lowland coastal areas. It is a fundamental tool for mapping and exploration of mineral resources. Seismic imaging is also a dedicated tool for studying the subsurface fluid-related processes, which are key phenomena affecting the global ocean carbon budget and seabed properties.

Marine seismic devices consist of a towed acoustic source and one or more seismic streamers (reception cables with a set of pressure sensors or hydrophones) towed by the survey vessel (see Figure A5.1). Seismic signals, resulting from the reflection of the incident wave energy at sediment layer interfaces and received on the streamer hydrophones, are combined to produce 2D (using one streamer) or 3D (using several streamers) images. 2D marine seismic devices range from "small" systems, with a streamer from 150m to 1500m long, to "large" systems deploying a single streamer of several kilometres, typically 3km - 6km (potentially up to 9km) in length for long offset seismic surveys and high penetration in the sediment using a low-frequency acoustic source. They require very large winches up to 30 tonnes in weight, and dedicated air gun handling systems. These large systems can deploy clusters of air guns requiring very high volume air supply from large ship-fitted or containerized compressors, requiring large amounts of deck space and significant power. 3D systems aim at imaging complex sedimentary structures requiring more resolution. Generally used with higher-frequency sources, they exist in several configurations depending on the objective. They can range from several short streamers systems towed in parallel between otter boards (from 20 to 100m in length), to two or three longer streamers (typically 600m in length).



Credit: Ifremer - Olivier Dugornay

HOV *Nautile* (Ifremer, France) deployed from RV *L'Atalante* during the ESSNAUT 2016 cruise



Credit: Ifremer

Figure A5.1 Marine seismic setup with sources and streamers deployed from the vessel and OBSs on the sea floor

Ocean Bottom Hydrophones (OBH) and Ocean Bottom Seismometers (OBS) can also be deployed autonomously on the seabed, where they can be used for active and passive seismic experiments such as detection systems for earthquakes and associated tsunami warning systems. These need to be deployed from and recovered by a vessel.

A5.1.3 Sediment sampling systems

Sediment sampling systems are traditional marine geology tools first developed at the end of the 19th century and in the first half of the 20th century. They range from gravity corers (developed around 1880) and early box type corers (early 1900's) to piston corers (around 1947). The different sediment samplers in the LEXI database are described below and an example is shown in the image on the right.

Calypso corer on board RV *Pourquoi pas?* during the WACS (West Africa Cold Seeps) cruise in 2011

Credit: Ifremer - Stéphane Hourdez

A5.1.3.1 Corers

Gravity corers and **giant box corers** are sediment samplers that penetrate into the seabed sediment aided only by the weight of the barrel on the upper part of the corer. The sampling pipe for the gravity corer will generally be around 6m in length, although 12m samples can also be retrieved depending on the size of the vessel from which the corer is operated. Early gravity corers could only sample 1 to 2m depth in soft sediments, while newer corers can sample of up to 21m. Gravity corers are useful tools because they can also be deployed from small vessels in very shallow waters that are not much deeper than the length of the barrel. A multicorer is a variant of a gravity corer and is capable of taking multiple corer samples at the same time. Box corers will usually take a rectangular sediment sample.

Vibrocorers or vibracorers, created in the 1950s, are gravity corers that are modified for sampling in coarse sediment, where normal gravity or piston cores would only penetrate a few centimetres. The vibrating mechanism of a vibracorer, sometimes called the "vibrahead", operates on hydraulic, pneumatic, mechanical or electrical power from an external source. The attached core tube is driven into the sediment by gravity together with vibration energy.

Piston corers were developed to address the need for ever-longer cores. Piston corers are free-falling corers that make use of the hydrostatic pressure at the seabed. This pressure ensures that no vacuum can be created between the stationary piston and the seabed sediment surface, thereby allowing for long and relatively undisturbed sediment samples. Release of the corer is triggered by a counter-weight or trip corer that will hit the bottom first, releasing the corer to drop into the sediment at high velocity. Depending on the method of deployment and retrieval, the total length of core that can be retrieved with the piston corer is related to the deck length of the vessel from which the corer is deployed. Although piston corers are generally heavy systems that are fixed to the vessels, they can sometimes be deployed from other vessels as well. For example, the Norwegian Calypso giant piston corer system is mobile and is being used on both the RV *G. O. Sars* and the PRV *Kronprins Haakon*.

Seabed penetrometers are another type of device enabling the collection of data in soft sediments. The Penfeld is a penetrometer designed to analyze seabed soil characteristics up to a depth of 6000 meters. It is lowered to the seabed and lifted by cable. A linear hydraulic winch which is integrated into the machine unwinds and pushes a long stainless steel rod into the sediment at a constant rate, up to a depth of 50m. Geological data are acquired and stored inside the electronics during penetration from the probe integrated at the rod tip.

The most used probe is the Cone Penetration Testing (CPT) tip. The main application of CPT is for soil profiling and soil type analysis. This probe records several parameters including point resistance, lateral friction and pore pressure. However, the CPT tip cannot give accurate predictions of soil type based on physical characteristics, such as grain size distribution but it provides a guide to the mechanical characteristics such as strength and stiffness of the soil. Physical characteristics of the soil can be predicted using a sonic tip. This special probe provides information about the velocity of p-waves in the soil. These measurements can be directly compared to seismic survey data (see Section A5.1.2).

A5.1.3.2 Seabed rock drill rigs

Rock drilling devices were created to sample bedrock. There are three types of portable drill rig systems in Europe at present capable of drilling over 30m: the MARUM MeBo70 & MeBo200 and the British Geological Survey (BGS) Rock Drill (RD2) systems (see the picture below), and three units currently exist in Europe (see Annex 5.3). These systems are bespoke systems designed by their institutions to acquire samples up to 70m, 200m and 55m in length respectively in water depths up to 4000m. These systems were developed to be used as portable supplements in contrast, but complementary to, the very expensive dedicated drill ships such as RV *Joides Resolution* and RV *Chikyu*. These systems are designed to operate from research vessels of opportunity and typically require deck space to accommodate around 100 tons of equipment consisting of launch and recovery systems, deep-sea umbilical winches, control containers, workshop and spares containers. These systems are typically operated by eight technicians and require a deck power supply similar to that of a large work-class ROV, USBL positioning and a DP-enabled vessel.

Credit: CP19/079 BGS © UKRI 2019. All rights reserved Source: https://www.bgs.ac.uk/scienceFacilities/marine_operations/sampling_equipment.html

The British Geological Society Rock Drill (RD2) system

Annex 5.2 Underwater and surface vehicle capacity in the European research vessel fleet

COUNTRY	UNDERWATER AND SURFACE VEHICLES								
	ASV / USV	AUV ≤1000m	AUV 1000≤ 5000m	AUV >5000m	ROV ≤1000m	ROV 1000≤ 5000m	ROV >5000m	HROV 1000≤ 5000m	HOV ≤1000m
Belgium	X	X				X			
Bulgaria									X
Croatia	X	X			X				
Cyprus									
Denmark									
Estonia					X				
Faroe Islands									
Finland									
France			X				X	X	X
Germany			X	X	X	X	X		X
Greece					X	X			
Greenland									
Iceland									
Ireland						X			
Italy	X	X			X				
Latvia									
Lithuania									
Malta									
Netherlands									
Norway			X		X	X	X		
Poland					X				
Portugal	X	X			X		X		X
Romania					X				
Slovenia									
Spain		X				X			
Sweden			X		X	X			
Turkey									X
UK	X	X		X	X		X		
Total units	14	21	6	7	21	9	5	1	7

The white lines in the table indicate cases where no information was received, whereas the light blue lines indicate no equipment owned.

Annex 5.3 Large EXchangeable Instrument capability in the European research vessel fleet

COUNTRY	SUBMERSIBLES					GEOLOGY AND GEOPHYSICS		
	AUV	ROV	ASV / USV	HROV	HOV	MULTI CHANNEL SEISMIC SYSTEM	DEEP TOWED SEISMIC SYSTEM	SEISMIC INSTRUMENTS
Belgium	1	1	1					
Bulgaria					1			
Croatia	1	2	1					
Cyprus								
Denmark								
Estonia		1						
Faroe Islands								
Finland								
France	2	1		1	1	1	1	1
Germany	3	4			1	2		2
Greece		3						
Greenland								
Iceland								
Ireland		2						
Italy	3	2	4					1
Latvia								
Lithuania								
Malta								
Netherlands								
Norway	1	3				1		
Poland		1						
Portugal	6	6	4		2			
Romania		1						
Slovenia								
Spain	2	1				2		
Sweden	1	3						
Turkey					2			
UK	14	4	4			1		1
Total units	**34**	**35**	**14**	**1**	**7**	**7**	**1**	**5**

		TOWED VEHICLES				SEABED SURVEY	OTHER	TOTAL PER COUNTRY
SEABED ROCK DRILL RIG	CORER	TOWED SIDE SCAN SONAR	TOWED CAMERA SYSTEM	PLANKTON SAMPLING EQUIPMENT	TOWED VEHICLE WITH PAYLOAD	MULTI-BEAM SONAR		
	3					1		7
		1						2
						2		6
								0
								0
								1
								0
								0
	1		1					10
2			1					15
								3
								0
								0
								2
								10
								0
								0
								0
								0
	1			1	3		1	11
								1
	2	1					1	22
								1
								0
								5
								4
								2
1	11		1		3		4	44
3	**18**	**2**	**3**	**1**	**6**	**3**	**6**	

Annex 6: Contribution from EFARO

In the early 2000's EFARO[81] undertook a series of workshops and meetings to address the issue of the use and coordination of Fisheries Research Vessels in Europe. This of course is strongly linked to the overall development of the European Research Vessel fleet.

The issues of the costs of operating a research vessel, the age of Europe's fisheries research vessel fleet and the issue of coordination of use of ship-time are still valid today. In 2016 SCARFish[82], COFASP[83] and EFARO conducted a small survey among the Members of SCARFish on the use and management of research vessels and research vessel time. The focus of the survey was on research and monitoring activities. It is important to note that there is a distinction in many countries between research vessels / vessel time used for routine monitoring of fish stocks or the marine environment and research vessels / vessel time for basic research. In some countries, different ships exist for these different tasks and in other countries the time of a single vessel is divided over these tasks.

The main question this short research was trying to address is how across Europe research vessels and research vessel time is being managed, and to collect any suggestions that could optimize their use, especially at regional and/or sea-basin scale. To start with the latter, all respondents indicate that some form of sharing of sea going research vehicles in principle is possible. This indicates that there are no formal objections against (regional) cooperation. However, when going into the details of how the current fleet of research vessels is being managed, and especially the way priorities are assigned to several research programmes, in practice there is little room to manoeuvre in developing regional cooperation in sharing research vessels.

As for the monitoring under the data collection framework (DCF) programme, the main issue is that at a certain period in time all Member States are at the same time implementing monitoring activities. In addition, for the more basic research programmes it seems that the general conclusion is that if spare time is available this could be used by others, yet this would have low priority in planning and prioritisation. In addition, quite some respondents interpret the question of regional cooperation as scientists of other countries to be welcome to join any national research trip to implement research, as far as these activities do not interfere with the further research programme.

We received responses from 12 countries (Spain, Poland, Iceland, Germany, Finland, UK, Belgium 2, Scotland 2, Romania, the Netherlands, Norway and Ireland). This sample has quite a North East Atlantic bias to it. In addition, answers and analysis presented below should be viewed with this in mind.

Eight respondents indicated that they were responsible for the management of a research vessel. Five respondents indicated they were scientists, three respondents indicated they were the owner of a research vessel. This already is representative of the many constellations already present in this relatively small sample of countries as to the ownership, finance and management of research vessel capacity. In almost 36% of the cases (five out of 14) countries have separate vessels for basic research and routine surveying and monitoring activities such as DCF data collection. In nine out of 14 cases, one or more vessels are used for both monitoring and more fundamental research activities.

Ten out of 14 respondents indicate that their organisation owns the research vessel; four out of 14 do not own the research vessel. What we see in our sample is that in some cases the government (relevant ministry or agency) owns, manages and finances the operations of the research vessels. This indicates that the government makes the research vessel available to the science community for research activities. In other cases, although the government owns the vessel, the management of the vessel is in the hands of the research organisation. Moreover, in some cases the research institution is the owner of the research vessel.

For the funding of the deployment of research vessel ship-time, in 50% of the cases the funds come from the research institution, in 29% of the cases the funds are derived from the relevant ministry and in 21%, another form of finance is found. It should of course be noted that when the funds for the operations of the research vessel are managed by the research institution, these funds are usually derived from the government as well. As for the management of the research vessel, it is

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[81] http://www.efaro.eu/

[82] The Fish committee of the EU Standing Committee for Agriculture Research, https://scar-europe.org/index.php/fish

[83] The ERAnet COFASP, Cooperation in Fisheries, Aquaculture and Seafood Processing, ran from 2013-2017

the Research Institutes that in five out of 13 cases manage the deployment of the research vessel. The relevant Ministry or Research Council each manages the research vessel in 23% of the cases. In 15%, another constellation is in operation.

In five out of 14 cases in its basic fabric there is a fundamental separation between routine monitoring activities and basic research; also in six out of 14 cases there is cooperation between the two fields. This division, contrary to what one may expect, does not significantly follow the division between countries that do have separate research vessels for fundamental research and monitoring and countries that do not have separate vessels for the two activities.

The allocation of time for specific research and hence allocation of vessel time really presents a mixed basket of modalities. Two respondents indicate that there is no direct management of the allocation of research vessel time between routine monitoring activities and basic research. In two cases, there is a clear form of coordination between the research fields. In addition, in three more cases a form of cooperation in this allocation process can be found. The most common form of management is allocating ship-time based on pre-set priorities. Only in two cases there is no coordination between regular monitoring and basic research, in the other 13 cases there is some form of a coordination mechanism in operation.

As for the coordination mechanisms used, in three cases it is indicated that basic research has priority over regular monitoring activities. In five cases, the opposite is indicated: regular monitoring activities have priority over basic research. Other coordination mechanisms used are prioritising of activities based on available funding and seeking to coordinate as much as possible the implementation of the different activities. In one case, it was indicated that since the two activities are operating on different platforms there were no coordination issues.

As mentioned above, the vast majority of respondents indicated that their research vessels would be available for other researchers (also from other countries). Yet the priority of this (regional) sharing of infrastructure appears rather low. In addition, almost all respondents indicated that in principle, it is possible in the current management and operational system to combine requirements of different ministries and policies so for example combine surveying requirements for the Common Fisheries Policy (CFP) and the MSFD.

A vast majority of respondents indicate that a more multi-purpose vessel would be preferred rather than a highly specialized vessel. However, there are two exceptions: the case in which a highly specialized vessel is required and the case in which a multi-purpose vessel would combine fisheries specific and non-fisheries research tasks (especially when fisheries research is not taken as the prime task) with e.g. buoy handling, oil spill prevention, inspection is not preferred as these tasks require very specific vessel characteristics on their own.

Closely related to the use of the European fisheries research vessel fleet is the issue of coordination of data collection. Through a series of meetings and workshops over the past two years, EFARO has put this issue on the agenda. Especially the coordination between data being collected under the DCF and data collected for implementation of the MSFD is a major issue. As the two programmes are closely related and data collected are complementary, coordination of the two programmes could result in more effective and efficient data collection.

In order to explore possibilities for connecting the programmes more closely, EFARO together with ICES proposed a pilot programme in which Member States would look at their monitoring programme and see how the two data collection programmes could be integrated more closely. Although this initiative was widely applauded by the European Commission's Directorate-Generals on Maritime Affairs and Fisheries, and on Environment and by the Marine Directors of the Member States, no active engagement from the side of the Member States followed.

Therefore, as for the future, EFARO reiterates the message that having more multi-purpose type vessels available and embarking on a programme of multi-use of vessels for data collection is required. For the longer run, rethinking the kind of data required for fisheries and marine management and the way these data are being collected, away from invasive techniques towards automated remote data collection, is to be considered.

Cover Photo: View from the *L'Atalante* afterdeck while the ship is maneuvering. The *L'Atalante* is a research vessel of the French oceanographic fleet operated by Ifremer. This operation named Cassiopée, took place in the Pacific Ocean in 2015.

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