

UN Decade of Ocean Science workshop report

Introduction

The UN Decade of Ocean Science for Sustainable Development (hereafter the Ocean Decade) challenges nations to identify the '*science we need for the ocean we want*'. It seeks to strengthen international collaboration to build a shared framework, across the science-policy interface, for the sustainable management of global oceans for the benefit of humanity.

In October 2020, the Royal Society's [Global Environmental Research Committee](#) hosted a virtual workshop, which brought together representatives of the UK's ocean research, policy and funding community to discuss how the UK can make a successful research contribution to the Ocean Decade. Presentations, panels and group discussions identified priority research areas to provide advice to funding organisations, Government, and research institutions. This

report forms part of the workshop output and presents a detailed overview of the workshop discussions. It is accompanied by a short synthesis of the high-level findings of the workshop. The workshop agenda and attendees list can be found in **Annexes B and C**, respectively.

The workshop was split into four sessions. Session 1 brought together speakers from international organisations and UK Government departments to introduce national and international perspectives on the Ocean Decade. Session 2 then invited researchers to outline pressing science issues in line with Ocean Decade requirements. This foundation was used by participants in sessions 3 and 4 to collaboratively prioritise and further develop the research themes and approaches needed to meet the objectives of the Ocean Decade.

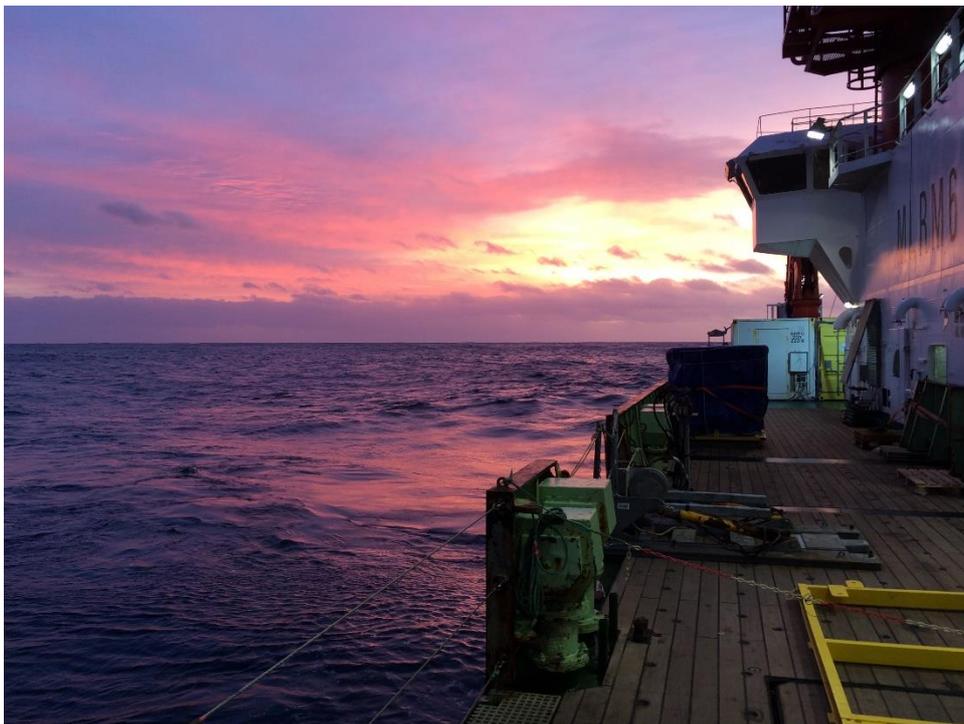


Image: James Cook JC156 voyage to the Mid-Atlantic Ridge
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Session 1: International context and policy needs for evidence - talks

Session 1 included four talks introducing Ocean Decade objectives, providing examples of national and international actions around the Ocean Decade, and outlining the science that policy makers need to address critical ocean challenges. Below is a synthesis of the key information shared by the talks.

Talk 1: Introducing the Ocean Decade: context and personal perspective - Professor Angela Hatton, Director of Science and Technology, National Oceanography Centre

This talk introduced the UN Ocean Decade and its objectives.

There is only one ocean. The ocean represents roughly 96% of the habitable space on Earth and provides the primary protein source for roughly 1 billion people. It is vital for the functioning of our planet; it absorbs and redistributes carbon, excess heat, and nutrients.

In addition, the ocean is fundamental to economies and livelihoods. In 2016, the OECD forecast the ocean economy would double by 2030, from \$1.5 trillion to \$3 trillion per year¹. However, this relies on healthy marine ecosystems.

Protecting and enhancing the ocean relies on collective global efforts to investigate the changes affecting our oceans. Large scale research, observation, prediction systems, and data sharing are essential to help policy makers make evidence-based decisions about the ocean.

Science is at the heart of the Ocean Decade, but science is broad. We must bring together the natural science and social sciences to deliver large scale, transformative, solutions-driven research. The Ocean Decade is an opportunity to help influence funding calls so that funding supports the science we need for the ocean we want.

The Ocean Decade has set out [Decade outcomes, and Decade challenges](#). In addition to this, there are a number of underlying needs which can be identified:

- Leadership; people, communities and organisations who can make things happen.

- Collaboration and co-operation; both internationally and between disciplines.
- The ability to inspire and engage the next generation.
- A transformation in the way we work; embracing new technologies.
- Clear communication of ocean knowledge.
- Natural and social scientists and ocean stakeholders working together to design and deliver solution-orientated research.
- Capacity development.
- Commitments from Governments and policy makers.
- Funding and calls for action.

These needs can act as guiding principles to help us meet the objectives of the Ocean Decade.

Talk 2: Efforts underway outside the UK: Action from global to national scale - Julian Barbière, Head of Marine Policy and Regional Implementation, Intergovernmental Oceanographic Commission - UNESCO

This talk provided an overview of how the development and implementation of the Ocean Decade is progressing at global, regional, and national scales.

The Ocean Decade was developed to be a non-prescriptive, adaptive framework which allows diverse actors at all scales to create programs and projects. The [Ocean Decade Implementation Plan](#) identifies a variety of mechanisms to enable multi-level engagement.

The implementation plan outlines [ten Ocean Decade challenges](#). These cover the most immediate priorities for the Ocean Decade and can be translated into action across scales to achieve the [Ocean Decade outcomes](#) and build 'the ocean we want'.

¹ OECD (2016), The Ocean Economy in 2030, OECD Publishing, Paris, <https://doi.org/10.1787/9789264251724-en>.

Several global initiatives to facilitate the Ocean Decade objectives will be implemented, most notably the Global Stakeholder Forum (due to be established in 2021) and the [Ocean Decade Alliance](#). The former will organise communities of practice around the Ocean Decade challenges. The latter is a large-scale resource mobilisation mechanism.

Initiatives to facilitate the Ocean Decade objectives also exist at the regional scale, for instance: the Arctic Ocean Plan; the West Tropical Atlantic Taskforce; the Pacific Regional Programme; and the African Action Plan. Regional platforms can be registered as Ocean Decade stakeholder networks and can enable regional actors to identify priority issues to meet regional needs.

Finally, national level initiatives exist in the form of National Decade Committees. These are multi-stakeholder platforms which co-ordinate between regional and global initiatives, design and develop Ocean Decade actions, facilitate access to Ocean Decade outputs, and leverage funds and resources. Currently, there are National Decade Committees in Brazil, Canada, Colombia, France, Germany, Italy, India, Japan, Norway, Portugal, the UK (see talk 4) and the USA, with more planned including in Egypt, Iran, and Russia. The exchange between these committees will be facilitated by the Intergovernmental Oceanographic Commission (IOC) governing bodies and the Global Stakeholder forum.

Talk 3: Relevant efforts for the UN Ocean Decade -

Professor Sheila Heymans, Executive Director, The European Marine Board

This presentation introduced the European Marine Board and outlined the work the organisation is undertaking in support of the Ocean Decade.

The [European Marine Board](#) is a European partnership between major marine and oceanographic institutes, research funding agencies, and networks of universities. It focuses on science strategy and foresight, and provides advice through published materials targeted at the European Commission and Parliament, the science community, and the public to shape

research areas, investments and ocean management practices.

A major recent output has been their position paper entitled '[Navigating the Future V: marine science for a sustainable future](#)'. This focusses on envisioning a 4D ocean, in which changes over space and time were predicted.

The paper highlighted several priorities for the Ocean Decade:

- A clean ocean – tackling pollutants;
- A safe ocean – the ability to understand and predict extreme events;
- A healthy ocean – an ocean that is interconnected and functioning;
- A transparent ocean – accessible and real time data.

The European Marine Board also acknowledged that ecosystem models can help meet the goals of the Ocean Decade. Ecosystem models must be connected to other models, such as physical models, food models, socio-economic models, and biogeochemical models, as well as addressing uncertainty and multiple spatial and temporal scales.

Finally, the European Marine Board has been working to highlight the interlinkages between ocean health and human wellbeing, notably through the [SOPHIE Project](#). The European Marine Board use the work from the SOPHIE Project alongside wider research on the interrelations between human and ocean systems to inform the Ocean Decade.

Talk 4: Evidence Needs for Policy Making: Defra perspective - Professor Gideon

Henderson, Chief Scientific Advisor at Defra

This talk outlined some thoughts on the UN Ocean Decade from a Defra perspective, and highlighted knowledge gaps that should be addressed to enable evidence-based policymaking in critical areas.

Defra is committed to ensuring that outputs of the UN Ocean Decade will be transformational in ensuring a sustainable ocean for all, and are

liaising with international partners to facilitate increased collaboration on the Ocean Decade.

The Blue Planet Fund, set to launch in 2021, was noted as the flagship scheme which aligns with Ocean Decade goals. It will provide £500 million of UK development assistance to support the protection of the marine environment and reduction of poverty in developing countries, including through investment in marine science. It aims to: improve marine biodiversity and livelihoods; resilience, adaptation to and mitigation of climate change; reduce marine pollution; and ensure sustainable use of marine systems. The Fund marks an important contribution to achieving the goals of the Ocean Decade.

There are several areas in which greater understanding of foundational science is needed for policy making.

A major area in which more research is needed is Blue Carbon and the role of nature-based solutions. Coastal ecosystems are important for carbon sequestration, in addition to protecting communities against climate change by providing coastal protection and food security. Conserving coastal ecosystems is an integral part of nature-based solutions to tackling climate change and its impacts, and meeting the Ocean Decade challenges for sustainably managing coastal systems and better understanding ocean-climate interactions.

A second area where more evidence is needed is science of marine protection and the effectiveness of Marine Protected Areas (MPAs). MPAs can form a cornerstone for meeting the Ocean Decade challenges. Research questions include: do Marine Protected Areas work? What are the ecological, social, economic, and cultural costs and benefits of MPAs? What technologies can we use to implement management and conservation measures? What framework can be used to establish MPAs on the high seas? Can MPAs tackle pollution from a variety of sources and materials or is a new framework needed?

Thirdly, more research is needed on the science for adaptation and resilience to: extreme weather; sea level rise and coastal flooding; ocean acidification, deoxygenation and changing

nutrient cycles; disease risk; and invasive species and ecosystem disruption. Better understanding these areas individually and in relation to each other is needed to meet the desired Ocean Decade outcomes.

Finally, understanding the sources and impacts of pollution, including plastics, metals, and organics, is needed to address the Ocean Decade's objectives. The impact of pollutants on catalysing antimicrobial resistance is of particular importance. Research will be needed on the role of pollutants from emerging sources, including offshore wind development and decommissioning, and carbon capture and storage.

It was noted that the UK has major strengths which it can bring to the Ocean Decade. Such strengths include capacity building, technology, modelling and ocean observation, and existing networks (such as the Commonwealth and the Science and Innovation network).

To close, it was acknowledged that the Ocean Decade is broad and international. To make progress and emerge as a leader in Ocean Decade progress, the UK could set a specific agenda, focussing on smaller and realisable goals.

Talk 5: Evidence needs for policymaking: FCDO perspective - Lowri Griffiths, Head of Ocean Policy Unit, FCDO

This talk provided an overview of the role of the FCDO Ocean Policy Unit and the [Marine Science Coordination Committee \(MSCC\)](#) within the Ocean Decade.

The Ocean Policy Unit (formerly the Maritime Policy Unit) is centred on the implementation of the UN Law of the Sea (UNCLOS). UNCLOS has two parts of relevance to the Ocean Decade: [part 13](#) is dedicated to marine scientific research, and [part 14](#) is dedicated to the development and transfer of marine technology. These outline the international rules and obligations that must be adhered to by Ocean Decade programmes, as well as policies related to ocean research and technological development and transfer.

The Ocean Policy Unit is involved in two international negotiations. The first is Biodiversity Beyond National Jurisdiction legislation. Two research questions which could support the development of this multilateral agreement are:

- How to identify and establish effective MPAs?
- How best to undertake modern environmental assessments in marine systems?

A second multilateral agreement in development relates to regulation of deep-sea mining in areas beyond national jurisdiction. Scientific evidence is important to developing and implementing regulation which takes into account the likely damage caused to ocean health by deep sea mining.

The MSCC is a body that aims to align UK marine science to inform policy and implement the UK Marine Science Strategy. It has been designated as the UK's national co-ordination committee for the Ocean Decade, ensuring relevant information is made available to the UK science community. The MSCC will maintain a log of the UK projects endorsed as Decade programmes and communicate Governmental priorities for the Ocean Decade, to help researchers align their work with policy objectives.

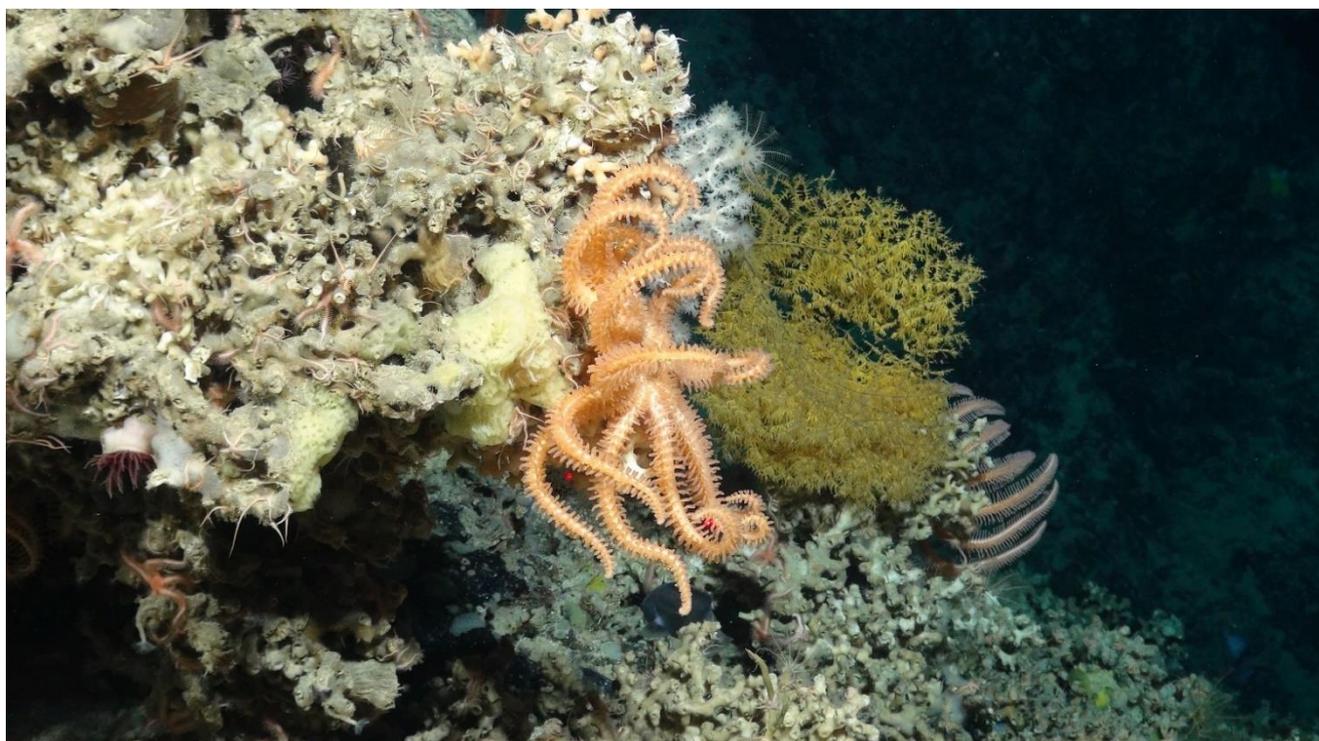


Image: A deep sea ecosystem. Photo courtesy of the NERC funded Deep Links Project – University of Plymouth, University of Oxford, the British Geological Survey, and the Joint Nature Conservation Committee.

Session 2: Identifying research questions – panel discussions

Session 2 featured nine short talks across three panels, which together provided an overview of marine habitats, outlined major challenges facing the ocean, and offered possible solutions. Details of each talk can be found in **Annex D**.

Panel Discussion 1: Marine habitats

Panel 1 explored a range of ocean systems, from coastal oceans and coral reefs to the deep sea. The discussion drew links between ocean and human systems, highlighting their interdependence.

The multifaceted impacts of climate change on ocean physics, and the subsequent consequences for fish stocks in coastal systems, were identified as a priority area for research. Coral reef and mangrove systems support the lives and livelihoods of over 100 million small-scale fishers, but these systems are in serious decline due to over-extraction, climate change and pollution. In these contexts, understanding the drivers of change and developing bespoke solutions were agreed research foci.

The deep sea was noted as having high biodiversity, despite comparatively little being known about it. Improved exploration of the dynamic relationship between the deep sea with other Earth systems and human health was outlined as a frontier for research.

Modelling, data gathering, local empowerment, data democratisation, and interdisciplinary systems were highlighted as the primary mechanisms for understanding these complex interrelations and developing solutions which will be context appropriate and effective over space. The UK was discussed as being particularly well placed to play a leading role in this research, due to its strong transdisciplinary research base, overseas territories, and international partnerships.

Panel Discussion 2: Challenges and threats in the marine environment

Panel 2 addressed major uncertainties around challenges and threats faced by the ocean, and, in turn, the consequences to human society. The

extent of sea level rise, long-term impacts of plastic pollution, and biological and biogeochemical changes were outlined as frontiers for impactful research.

Understanding the multifaceted impacts on ecosystem services, weather, infrastructure, and geomorphology from sea level rise was acknowledged as an important emerging area of research. The impacts of climate change on carbon sequestration and food supply were also found to be significant. Finally, it was agreed that strategies to reduce the long-term accumulation of nano and microplastics in the oceans are pivotal.

Understanding complexity and broad systems thinking was a prominent theme, from exploring the varied trade-offs involved in addressing plastic pollution sources on land, to understanding the full suite of impacts on ocean systems from ice sheet melt.

Panel Discussion 3: Ocean-based opportunities, solutions and management

Governance, equity, and partnership building across scales featured prominently in the final panel discussion. Understanding the multifaceted trade-offs between the environment, society, and the economy, in addition to the interests of decision makers, countries, industries, communities, and individuals was identified as an area which needed to be more carefully considered.

Better understanding of trade-offs can enable integrated management and help build optimal and equitable solutions to major challenges. It was noted that questions of equity and partnership building are an important tenet of the Ocean Decade and should be integral to future research designed to contribute to the Decade.

Sessions 3 and 4: Prioritising and Developing Research Questions - breakout discussions

The outcome of session 2 was used to design eight research ideas for discussion in session 3. The later focussed on identifying four salient research areas using a set of criteria:

- (i) Fit to the remit of the Ocean Decade;
- (ii) Transformative nature;
- (iii) Need for a large-scale research programme;
- (iv) Opportunity for the UK to make a leading contribution; and
- (v) the opportunities for international connections and synergies.

Session 4 took the four priority research areas and further structured and developed them. The guidelines used for the refinement of ideas during session 4 were:

- (i) Statement of the idea, the research needs to address the idea, and its outcomes;
- (ii) Potential research sub-themes; and
- (iii) Links with UK and international capacity, as well as potential funders.

A key recognition emerging from the discussion in session 3 was that priority research areas are those which are both poorly understood and have complex interactions within and between ecosystems and societies. These priority research areas examine uncertainty at the society-environment interface, looking at how human impacts affect ecosystems, and how ecosystem changes in turn affect society. In particular, priority research areas rely on engagement with local communities, moving away from top-down research and integrating the knowledge and experiences of communities who live at the forefront of ocean ecosystems.

It was felt that the UK is particularly well positioned to tackle each of the priority research areas, due to the breadth and standard of UK research expertise and the track-record of strong

international partnerships, most notably overseas territories and Commonwealth countries.

The following four questions were identified as priority research areas to: advance the science needed for the Ocean Decade; expand the impact of UK science in partnership with international colleagues; and to address pressing challenges facing the UK and Commonwealth countries.

Overall, those ideas not selected to be taken forward were felt to be key components of either the framing of all Ocean Decade work or could be encompassed within the four chosen themes.

Four research priorities for the UN Ocean Decade

What is the science necessary to deliver a breakthrough in our understanding of how coral reef socio-ecological systems respond and adapt to climate change and other stressors?

Coral reefs and associated coastal systems, like mangroves, are the most biodiverse marine ecosystems. It is estimated that approximately 850 million people worldwide (many of whom are among the world's poorest) derive benefits from reef ecosystems². They are therefore both ecologically and socially important. However, these systems are very sensitive to climate change and human impacts. In recent decades, approximately 50% of these ecosystems have been severely degraded to non-coral dominated systems through human and environmental pressures. There is therefore a pressing need to better understand these ecosystems and their relationship with human societies to address the Ocean Decade objectives.

'Socio-ecological systems' (SES) refers to the complex and dynamic interrelations between ecosystems and human society, outlining that the

²Burke, L., Reyntar, K., Spalding, M. and A. Perry. 2011. *Reefs at Risk Revisited*. World Resources Institute, Washington DC, USA.

two are not independent of one another, but in fact inextricably interwoven. This is particularly clear for coral reef SESs: many societies worldwide depend on the biodiversity of reef ecosystems for food and livelihoods, and, in turn, reef ecosystems are highly sensitive to direct and indirect human pressures.

This research question was found to be of great priority in driving the science needed to meet the Ocean Decade objectives, benefitting ecosystems and communities worldwide, and further developing the impact of collaborative UK research.

At its core, this research question depends on participatory action, bringing together place-based managers, scientists, and local communities who directly depend on coastal coral ecosystems, hold traditional knowledge and expertise, and are best placed to manage these systems.

To capture the need for participatory action and the fact that coral SESs extend to wider ecosystems, such as mangroves, the question was restructured as:

Accelerating participatory solutions to the rapid changes facing coral coast ecosystems and dependent communities.

A number of research angles and needs were identified as being necessary to address this question:

- A better understanding of the sensitivities and stressors faced by coral coast systems.
- A better understanding of the global and local stressors relevant to different coral coasts across space.
- The need for real-time monitoring and data gathering in coral reefs, deep-water corals, and wider coastal ecosystems to better understand the stressors faced by these systems at different scales.
- Social science approaches, alongside physical sciences, to integrate local historical knowledge. Doing so can help identify past biodiversity and therefore predict future trends.

Research in this area could help deliver a number of impacts:

- Forming the basis for stronger coastal ecosystem management.
- Supporting the SDGs and wider societal outcomes.
- Development and roll-out of technologies and approaches to enable measurement of coral coasts both by local communities, as well as at the national level.
- Greater data generation at a global scale, which could be democratized and shared. This may prove to be a diplomatic boon for the UK.
- A better understanding of ecosystem tipping points and the associated human vulnerability to tipping points.

It was felt that the UK is very well placed to address this research question. For instance, overseas territories and associated Exclusive Economic Zones (EEZs) contain a vast array of coral coast systems. UK Non-Governmental Organisations (NGOs), universities, social scientists, and Government agencies are currently working on a breadth of topics which relate to this theme.

What is the key fundamental knowledge required to manage and monitor human impacts on deep sea ecosystems?

The deep sea is very much 'out of sight', yet is an essential marine ecosystem which interacts with the rest of the ocean. For instance, exchanges of energy, mass and nutrients between the open ocean and the ocean floor, known as benthopelagic coupling, is a globally important relationship between the deep sea and wider ocean. It is also fundamentally tied to the global carbon cycle, helping to 'lock away' carbon and therefore regulating Earth's climate. However, the deep sea is facing substantial, and rapidly increasing human pressures. There is a risk that the sea floor and its associated ecosystems will be devastated before we knew they existed or how they worked, with unknown knock-on effects on wider ocean health.

The technological challenges of studying the deep sea means there remains a lot of fundamental knowledge to uncover about this important ecosystem. Research is essential to understand how the deep sea will be impacted by human activity, as well as the knock-on impacts on the wider ocean and human society.

Industry is increasingly active in the deep sea; collaborating with industry is essential to progress this research area, as is working collaboratively with nations and organisations around the world.

To strengthen the applicability of this area to the Ocean Decade, and to highlight that the deep sea is interconnected with the rest of the ocean as well as human society, the question was reframed as:

Connecting the deep sea to society to support sustainable development.

Several research sub-themes are valuable to engage with this area in the context of the Ocean Decade:

- The response of the deep sea environment to human and climatic pressures.
- Better understanding the processes and mechanisms governing the response of the deep sea to external pressures.
- The links between the deep sea and society: quantifying the impacts on ecosystem services will enable better understanding of the impacts of deep sea change on society.
- Study of past oceanic change using archives from the deep sea, to inform the changes that may occur in the future.
- Incorporating traditional and indigenous knowledge to inform sustainable management.
- Understanding the vulnerability of benthopelagic coupling systems, to help understand possible consequences of human disturbance for the cycling of carbon, nutrients and pollutants.

Research in this area could help deliver a number of impacts:

- A better understanding of a ‘frontier’ ecosystem, and its relationship to human society, can be used to underpin management.
- Addressing the above research sub-themes will help us develop frameworks for the sustainable use of the deep sea.
- Deeper understanding of the stressors on the deep sea, including what impacts and stressors are the most salient, and which areas of the deep sea are most important to protect from such stressors.
- Greater knowledge of the physical interaction between the deep sea, ocean circulation and the global transport of heat and carbon, to improve projections of future climate.
- Better collaboration with other countries.
- Better data to conduct future research.

The UK is one of the few countries with both the expertise and existing technological capabilities to access and monitor the deep sea; there is therefore an opportunity for the UK to become an even more prominent leader in deep sea research. Indeed, the UK is already a leader in this field, operating the few existing long-term time series data on the deep sea. UK universities have extensive research using paleo records which can complement understanding of historic deep sea changes to inform possible future change. All this considered, the UK is in a good position to enable capacity building in this space and to lead this component of the Ocean Decade.

What breakthroughs are required to revolutionise our ability to reduce uncertainty on how sea level rise impacts the coast under different societal choices to facilitate adaptation in the most vulnerable communities and beyond?

Sea level rise (SLR) is a critical indicator of climate change and will impact the lives and livelihoods of hundreds of millions of people globally. Coastal cities, low-lying deltas, and small islands are particularly vulnerable. It will impact coastal environments, ecosystems, assets and economies across the world.

While the challenge is global, the type and scale of impacts and, therefore, their solutions are often specific to local geographies and regions; not everywhere will experience the same impacts of SLR, nor have the same capacity to respond. As such, research to understand the impacts of SLR over space must integrate regional and local realities and priorities.

There are three interrelated areas of uncertainty under this research theme: uncertainty surrounding the level of SLR itself; uncertainty about how coasts and ecosystems will respond (e.g. can corals keep up with sea level and still provide for and protect communities?); and uncertainty over how people and the economy will respond (e.g. where will people migrate? Where and how might they adapt?). Addressing this research theme under the context of the Ocean Decade requires an approach that considers all three.

The research question was reformulated to heighten focus on the tools needed to better predict sea level rise for the support of sustainable adaptation approaches. Sea level rise is a global challenge, requiring adaptation which is appropriate and sustainable in local contexts:

Improving our capacity to understand and predict sea level rise and its extremes to enable sustainable adaptation.

There are several areas of research which can contribute to this research theme and address these three areas of uncertainty:

- Enhanced modelling of SLR will help define space-specific management strategies. Modelling will be dependent on data availability and, where more localised management strategies are considered, access to local observational data.
- The consequences and magnitude of ice loss and glacier collapse for SLR.
- Better prediction of extreme weather events under a changing climate will help those in vulnerable areas anticipate the impacts of SLR-related hazards.
- Identifying tipping points of environmental systems impacted by SLR will help understand

thresholds and impacts on vulnerable ecosystems. Coastal ecosystem modelling and computational fluid dynamics will be useful to this research.

- The amount of saltwater intrusion and its impacts on drinking water availability and irrigation.
- The possible impacts on human health from coastal flooding.
- The resilience of coastal infrastructure.
- Understanding the role of nature-based and technology-based solutions (and hybrids of the two) for adaptation will be crucial, and the efficacy of each will vary spatially.
- Better understanding of the amount of habitat loss and change in coastal ecosystems, and the associated impacts on societies, can help develop adaptive management frameworks for coastal areas.

A number of impacts can occur from engagement with this research area:

- Better communication of the impacts of SLR to decision makers.
- Scientific evidence integrated into risk management strategies for SLR and associated hazards and impacts.
- Better-informed resilience strategies, underpinned by interdisciplinary research.
- Future coastal management and urban planning will be informed with more certain knowledge.

This cross-cutting question relies on both the physical, biological and social sciences to design and deliver solutions-focused research. The UK has excellent research capacity in each of these areas. However, the UK must work to develop the infrastructure needed to address this question, including access to suitable observational platforms and monitoring equipment, a global digitized tide gauge network and data, and greater continuity and interoperability of satellite measurements. Working with other nations will be needed to help bridge these gaps.

How can we transform our understanding of multiple concurrent environmental changes to enable prediction and forewarning of the impacts on marine ecosystem services?

There are many interlinked ocean ecosystems which provide ecosystem services to society. Direct and indirect stressors compound to affect these ecosystems and, in turn, impact society. Such stressors, compounding effects, and impacts on environmental and human systems vary geographically, and each ecosystem and society will have differing levels of vulnerability.

This research theme is cross-cutting and broad, taking a holistic approach to the challenges faced by ocean ecosystems and the knock-on impacts on livelihoods, health, and economies worldwide. As environmental change continues, understanding how these challenges manifest over space and time will underpin work to better our ocean, meet international objectives like the SDGs, and benefit human wellbeing.

The question was restructured to highlight three complementary tenets for addressing marine pressures: understanding, forewarning and mitigation.

Understanding, forewarning and mitigating the impacts of multiple pressures on marine ecosystems and the services they provide

This research theme relies on modelling, observation and laboratory-based work. In particular, an ensemble of models that enables forewarning of hazards could underpin adaptation and mitigation strategies, and can help inform policy and sustainable management of natural capital. Such models would require:

- Process studies and mechanistic understanding, supported by strong theoretical frameworks.
- Integrated human behaviour and local knowledge.
- Representation of terrestrial activities and land-sea interactions.

While modelling has a role to play, addressing this research under the Ocean Decade also relies on

broader integrated research themes which serve to link the physical sciences with the human dimension. These include an assessment of:

- What the non-climate anthropogenic pressures on marine ecosystem services are (such as sediment influx and pollutants), and how these pressures might change in the future.
- How land-use change affects blue carbon ecosystems (such as coral reefs, fisheries, seagrass ecosystems, mudflats, and maerl beds), and associated impacts on the blue carbon sink.
- The impact of expansion of ocean-based activities including offshore renewable energy infrastructure and deep sea mining.
- The impact of human behaviour, such as 'shifting baseline syndrome', and how this needs to be mitigated in management strategies.
- The role of local knowledge and traditional expertise.
- New frameworks and data for conducting multi-stressor experiments and models.
- Developing indicators of ecosystem health and vulnerability. This requires gathering time series data for multiple stressors over space.

Focussing the research regionally could help to narrow the scope of this broad theme and create outputs applicable to different locations. Specific questions that need addressing include: where are stressors causing the most change? where could marine ecosystems be most rapidly restored? at what rate are stressors having an impact on ecosystems and communities? To address these spatially focussed questions, integrating local knowledge and expertise is essential.

Research under this theme could have several benefits supportive of the Ocean Decade objectives:

- Better understanding and forewarnings of the pressures that ecosystems face, and the subsequent risks to communities dependent on these systems.
- Improved models that can better inform policy.

- A better understanding of how marine biota responds to concurrent and compounding pressures, and the resultant implications for ecosystem services.
- Assessment of cumulative effects of multiple stressors.
- Assessment of the efficacy of potential interventions in different ecosystems and regions around the world.
- Stronger engagement with local people and communities.
- Management interventions, including adaptation and mitigation strategies, underpinned by evidence-based advice.

The UK has excellent modelling capabilities, including the NERC funded [Marine Ecosystems Research Programme](#) (MERP), supported by expertise in long-term monitoring and time series data gathering. UK researchers are adept at working across a range of scales and disciplines and integrating field-based observations with experimental process-based work. This will enable research to more easily bridge terrestrial and marine boundaries to assess impacts.

The UK has a strong track-record in experimental observations and capacity to measure the parameters needed for physical and biogeochemical models, as well as good long-term coastal benthic data, which is essential to this field of inquiry. The UK also has a sensor and platform base from which to undertake small scale and wider observations. These will need to be equipped with new biogeochemical sensors, imaging capability coupled with in situ measurements that can be integrated on a variety of spatial and temporal scales.

It is important that adaptation and mitigation are combined with an improved understanding of the impacts of multiple pressures on marine ecosystems and the services they provide to allow better forewarning.

Four research questions not taken forwards to session 4

The following four research questions were identified as important areas for future research, but were not selected as priorities in the context of the Decade because they either represented higher level cross cutting compartments of UN Decade Science or could be encompassed in the four priority areas.

How do we fully integrate the changing physio-chemical environment into our understanding of the dynamics of fish stocks to significantly enhance sustainable management strategies in key regions worldwide?

Sustainable management of fish stocks is essential if we are to ensure a healthy ocean which can support human needs. Understanding the environments fish live within and interact with is necessary to underpin evidence-based sustainable management strategies.

This question focusses not just on fish stock numbers and the science of primary production, but rather how fish use complex and interconnected environments. It aims to reframe environments through a holistic lens at a large scale, looking at the life course of fish and the organisms and processes they depend on. For instance, consideration is needed of the many factors controlling biogeochemistry, the transport pathways for larvae and fish to and from spawning grounds, the pressures on plankton, and the life cycles of shellfish and fin fish, alongside a range of wider ecosystem processes. There is also a need to link different ecosystems, such as the open seas and tropical shallow ecosystems.

Ocean and marine ecosystems are facing substantial challenges from climate change, such as temperature rises, de-oxygenation, acidification, and sea level rise. These will drastically impact the ecosystems to which fish belong. An ecosystem approach is therefore critical to understanding how fish stocks may be impacted in the future.

A number of innovations can arise from research in this area:

- Improved ecosystem modelling, directly relevant to the prediction of fish stock size and fish movement. Forecasting can link local climate to fish dynamics.
- A transformation in how we understand environments, not just for human value but for marine value (which in turn can yield human value).
- The deployment of new technologies such as automated sampling.
- An opportunity to link science with local experts such as fishermen; moving science ‘from papers into pockets’.
- Further evidence on the effectiveness of Marine Protected Areas.

Modelling is central to this research area. Physical models of relevant processes exist but are not yet able to go down to the 1 km scale relevant to fish stocks. Linking existing physio-chemical models like ERSEM-NEMO, food web models such as Ecopath, OSMOSE or Atlantis, and socio-economic models would be a way to make meaningful progress under this research theme. A challenge will be to ensure the models are dynamic and interact with each other effectively, for instance capturing how socio-economic changes can impact fisheries and the food-web, and how changes in the food-web can in turn impact socio-economics. Using multiple models in an ensemble approach can help quantify uncertainty in such work.

There is also a lot of existing data on fish stocks and ecosystems; the challenge is to link up the different researchers, organisations, industries and communities who are gathering this data to help contribute to holistic modelling. Improved data gathering, for instance through automated sampling, can help support models, but planning is needed before developing such data gathering methods.

As with other research themes, bringing together researchers and local communities can progress understanding of this field. For instance, past research has found that fishermen are able to advise fish stock models by telling researchers what lines they take when on the water, and researchers can align their routes with simulations

to help understand which processes are most important for shoal movement.

Science outputs can then be democratised; for instance, forecasts of fish stocks can be sent to local fishermen to aid their fishing and support sustainable management strategies.

Closer integration of human systems, in addition to physical processes, would help further align this research area to the Ocean Decade objectives.

What is the science necessary for an integrated understanding of (and solutions to) the long-term impacts of plastics and persistent pollutants on ecosystems throughout the ocean?

Plastics and persistent pollutants are a significant stressor in marine ecosystems and are important to the public and politicians globally. Pollutants accumulate in the environment, can damage ecosystems, and can harm human health by entering the food web.

This question has two main dimensions. The first is how plastics and pollutants accumulate in the ocean, the direct and indirect impacts of these pollutants, and their synergistic effects. Impacts are not confined to the oceans; the effects of microplastics and marine pollutants on human health is receiving growing attention. Coastal communities who depend on marine ecosystems are particularly vulnerable to this stressor.

Secondly, this research area also addresses the source of pollutants. Most plastics and pollutants originate on land. Therefore, there is a need to adopt a systems approach, bringing together land and marine science, to better understand land and sea interactions. Research on the different sources and flows of pollutants from the land would better inform strategies to reduce the impacts of these pollutants in marine environments. There are numerous sources of pollutants, driven by a variety of processes and entering the ocean via many different routes. For instance, agricultural chemicals can enter soils and weathering can then lead to increased

sediment flux to river systems. Meanwhile, microplastics may transfer to the ocean via the atmosphere. Better understanding these pathways and how they might change in the future can narrow the focus for policy recommendations.

Tackling the sources of pollutants requires engagement from organisations, governments, and industries. It was noted that trade-offs exist in managing the sources of pollutants; how must society and industry change to minimise input of pollutants to the ocean, and how can we adapt to the impacts of pollutants?

Several research themes arise under this area:

- The primary pathways through which pollutants enter the ocean, and the magnitude of each pathway.
- The trade-offs and co-benefits of managing land-based pollution alongside industry, governments, and wider society.
- How flows of pollutants vary geographically.
- What the most important pollutants are, including which are most abundant, most toxic, and most challenging to remove.
- The ways in which different pollutants accumulate and behave in the ocean.
- The synergistic and compounding effects of multiple pollutants.
- The impacts on human health.

The group agreed that this question could form a component of the broader priority research area: Understanding, forewarning and mitigating the impacts of multiple pressures on marine ecosystems and the services they provide.

What is needed to deliver better quantification, management and understanding of the benefits and vulnerabilities of blue carbon in the face of ongoing climate change?

Blue Carbon is the carbon stored in marine environments. It is an area of great interest to governments and industry, as nature-based solutions and approaches to valuing carbon

become increasingly seen as ways to reach net zero emissions. Some countries have already included coastal ecosystems in their national emissions inventories. However, the contribution of blue carbon solutions to climate mitigation and sustainable development depends on the health of these ecosystems.

Research on this important question can help progress the Decade outcomes, but in order to do so it must go beyond the value of blue carbon as a climate mitigation action and instead focus on the numerous other services offered by these ecosystems. There exist many different possible trade-offs; what may be beneficial from a climate perspective may not benefit local communities or ecosystems. For instance, encouraging seagrass growth in areas where it does not normally grow can sequester carbon, but will also disrupt existing ecosystems. Therefore, blue carbon strategies must be based in enhancing and protecting existing marine ecosystems, for the benefit of local environments and communities.

There are many uncertainties in this area that need addressing. Ecosystems are under pressure from climate change and human impacts. It is therefore important to understand the extent to which blue carbon can contribute to climate mitigation and support livelihoods while subject to such pressures. Physical science on current and future carbon uptake, alongside social science on development, can fill this knowledge gap.

Locally grounded research can help identify a balance between climate mitigation and adaptation aims, while also helping to identify appropriate adaptation measures. Such research should be conducted alongside local communities.

Research sub-themes which emerge from this question include:

- Linking marine and terrestrial ecosystem models, along with sea level rise models, to identify pressures faced by blue carbon ecosystems.
- Assessment of various adaptation strategies, and their efficacy into the long term, using modelling and local expertise. This could be done for different emissions scenarios.

- Linking the global contribution of blue carbon for climate mitigation and the local-scale usefulness for adaptation.
- Understanding the trade-offs between different desired outcomes, against the context of net zero and sustainable development agendas.
- Developing approaches to carbon storage assessments of different blue carbon ecosystems.

The group agreed that this question could form a component of all of the broader priority research areas.

How can we catalyse a transition to an equitable distribution of the benefits from seafood systems among multiple users in a changing ocean?

‘Blue food’ is an increasingly important topic. Fish are a major source of micronutrients for many of the world’s populations, especially those in coastal communities. However, distribution of the benefits of seafood systems is inequitable, and such inequalities are expected to increase with continued climatic and human pressures on the ocean. The question transcends many issues, including nutrition, food security, poverty, and equity.

The research question has two complementary aims. The first is how to create a sustainable seafood system. The second is how to ensure equitable distribution of the benefits of the system. Ensuring equitable distribution is essential to meeting the Ocean Decade outcomes as well as broader development objectives such as the SDGs.

The question not only relates to the open ocean. Aquaculture accounts for approximately 50% of global fish production, so there is a need to ensure research considers marine and land-based aquaculture, in addition to how the benefits of these systems are distributed.

The question is inherently rooted in both global and local nested systems. Local food systems

based on aquaculture and reef fishing may harbour inequalities, in the same way globalised systems of fishing and distribution contain entrenched inequalities. Working alongside governments, industries, and local communities is necessary for building a sustainable and equitable seafood system.

To meaningfully engage with this topic, the following research areas were proposed:

- The micronutrient content of different species, and how species are consumed in different regions.
- The impacts of climate change and human activities on both localised and global seafood systems.
- The co-benefits of seafood systems, as well as the trade-offs.
- The social science needed to ask *why* the current system is structurally unequal.
- The values and roles of communities to respond to and reshape their food systems, as well as the vulnerabilities faced by communities by pressures on the system.

The group agreed that the challenges raised by this question should form an overarching component of all priority research areas.



Image: A coral reef ecosystem. Image by Joakant, Pixabay.

Essential Elements for Ocean Decade Research

The discussion of these research priorities highlighted the tools and evidence needed to support a healthy ocean and to make progress towards the Ocean Decade outcomes. From this discussion, five **Essential Elements** for Ocean Decade research were created. These elements mark a new approach to carrying out research and can become a framework that distinguishes Ocean Decade research programmes. They are:

1. Assess the changes to, and resilience of, marine systems across different space (from local to global) and time scales;
2. Deliver a step change in the predictive capacity required for forecasting and management of diverse marine resources;
3. Link ocean and ecosystem services to the quality and equity of people's lives and livelihoods;
4. Address human health and well-being in the context of the Decade outcomes;
5. Assess ecological and societal solutions, including their equity and scalability, via ocean literacy actions.

More information on the Essential Elements can be found in the accompanying summary paper.

Conclusion

The workshop successfully identified several priority research areas through which the UK could make a substantial research contribution to achieving the objectives of the Ocean Decade. It also outlined how Ocean Decade research programmes could be supported and delivered.

Interdisciplinarity and international collaboration were the hallmarks of the most salient and pressing research needs. Research that can support policy, deepen understanding of fundamental marine systems, integrate both environmental and human systems, and acknowledge trade-offs was identified as the most useful and of the highest priority to help the UK contribute to wider Ocean Decade goals. The Ocean Decade presents an opportunity for policy makers, researchers, industry, and local communities to come together and work towards a sustainable and equitable ocean. In May 2021, the G7 Ministers responsible for Climate and Environment and the European Commission issued [a communiqué](#) reaffirming their support for ocean action aligned with the objectives of the Ocean Decade.

Priority research areas were designed through an iterative process encompassing sessions 1-4 of the workshop. Research needed to support policy, and fundamental research questions were used to

create four holistic and broad priority areas through which future UK research can begin to address the Ocean Decade. These are:

1. **Connecting the deep sea to society to support sustainable development.**
2. **Accelerating participatory solutions to the rapid changes facing coral coast ecosystems and dependent communities.**
3. **Improving our capacity to understand and predict sea level rise and its extremes to enable sustainable adaptation.**
4. **Understanding, forewarning, and mitigating the impacts of multiple pressures on marine ecosystems and the services they provide.**

Each of these areas are designed to be compatible with existing UK research expertise, while also helping to further develop new UK research expertise and provide opportunity for interdisciplinary and international work, innovation, use of new technology, and participatory research. Addressing these research areas in the future is a key opportunity for effective engagement with the Ocean Decade, and will help the UK create a sustainable future for the ocean on which we depend.

Annex A: Acknowledgements

The workshop and accompanying reports would not have been possible without the contribution from a range of individuals. In particular, we gratefully acknowledge the contributions of:

Chairs and lead organisers

Professor Alessandro Tagliabue, University of Liverpool

Professor Angela Hatton, National Oceanography Centre

Professor Pete Smith FRS, University of Aberdeen

Breakout group Chairs and co-organisers

Dr Katharine Hendry, University of Bristol

Professor Michael Meredith, British Antarctic Survey

Professor Nick Graham, Lancaster University

Professor Rachel Mills, University of Southampton

Speakers

Professor Alexander Tudhope, University of Edinburgh

Professor Christina Hicks, Lancaster University

Professor Gideon Henderson FRS, Defra, University of Oxford

Lowri Griffiths, Foreign, Commonwealth and Development Office

Dr Ivan Haigh, University of Southampton

Professor Jonathan Sharples, University of Liverpool

Julian Barbière, International Oceanographic Commission of UNESCO

Professor Kerry Howell, University of Plymouth

Professor Melanie Austen, Plymouth Marine Laboratory

Dr Philip Williamson, University of East Anglia

Professor Richard Thompson FRS, University of Plymouth

Professor Sheila Heymans, European Marine Board

Dr Stephanie Henson, National Oceanography Centre

Dr Vladimir Ryabinin, International Oceanographic Commission of UNESCO

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Professor Mark Inall, The Scottish Association for Marine Science

Stephanie Ockenden, Department for Environment, Food & Rural Affairs

Professor Pete Smith FRS, University of Aberdeen

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The Royal Society [Global Environmental Research Committee](#)

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Hélène Margue, Senior Policy Advisor

Leo Marioni, Policy Advisor

James Musisi, Project Coordinator

Shema Bhujel, Project Coordinator

Benjamin Konnert, Programme Manager

Frances Bird, Policy Advisor

Jack Pilkington, Senior Policy Advisor

Annex B: Agenda for GERC workshop on UK research priorities for the UN Decade of Ocean Science for Sustainable Development

Dates: 9, 12, 16 and 19 October 2020

Location: Zoom

Workshop objective:

The Royal Society's [Global Environmental Research Committee](#) (GERC) is hosting this workshop with the aim to identify priority areas for UK research within the UN Decade of Ocean Science at a level suitable for possible UK research programmes. The intention is to produce a set of priority topics that will be synthesised into an overarching document for wide dissemination. Priority areas will take account of the Sustainable Development Goals, and of UK research strengths in science and the application of science to society.

Workshop format: 4 sessions over 11 days. The sessions will be recorded to allow people who have missed a session to catch up.

9 October 2020	Session 1: Introduction to the Decade (2h30)
	Chair: Prof Pete Smith FRS, Chair of GERC, University of Aberdeen
9:15 -9:30	Please join the Zoom room at 9:15 to allow the event to start promptly at 9:30.
9:30 -10:00	<p>Welcome by the Royal Society (5 min) Prof Richard Catlow FRS, Vice-President and Foreign Secretary, Royal Society</p> <p>Opening remarks by IOC-UNESCO (5 min) Dr Vladimir Ryabinin, Executive Secretary, Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO)</p> <p>Introducing the UN Decade and putting it into context (10 min) Prof Angela Hatton, Director of Science & Technology, National Oceanography Centre</p> <p>Overview of the meeting format and objectives (10 min) Prof Alessandro Tagliabue, University of Liverpool</p>
10:00-10:50	<p>UN Decade related activities abroad 2 x 10 min talks + 30 min Q&A</p> <ul style="list-style-type: none"> – Relevant efforts underway outside the UK Julian Barbière, Head of the Marine Policy and Regional Implementation Section, IOC-UNESCO – Relevant efforts underway outside the UK Prof Sheila Heymans, Executive Director of the European Marine Board
10:50-11:00	Break
11:00-11:50	<p>Evidence needs for policymaking 2 x 10 min talks + 30 min Q&A</p> <ul style="list-style-type: none"> – Evidence needs for policymaking - Defra perspective Prof Gideon Henderson FRS, Chief Scientific Advisor, UK Department for Environment, Food & Rural Affairs (Defra) – Evidence needs for policymaking - FCDO perspective Lowri Griffiths, Head of the Maritime Policy Unit, UK Foreign, Commonwealth & Development Office (FCDO)
11:50-12:00	Conclusion of session 1 and what to expect at session 2 (10 min) Prof Pete Smith FRS
12 October 2020	Session 2: Identifying research questions (2h45)

	Chair: Prof Alessandro Tagliabue, University of Liverpool
9:15 -9:30	Please join the Zoom room at 9:15 to allow the event to start promptly at 9:30.
9:30 -9:40	Welcome and objectives of session 2 (10 min) Prof Alessandro Tagliabue The following panels have been designed to stimulate debate on possible UK research priorities for the Decade by workshop attendees and the chosen topics are not designed to be exhaustive. Each panel has been asked to come up with three science questions and attendees are encouraged to participate actively in the discussion. Questions for speakers on the broad relevance and suitability of their idea for the Decade and suggestions for additional science questions not covered by the panels are encouraged and are kindly requested to be submitted using the chat facility.
9:40 – 10:25	Panel discussion: Marine habitats 3 x 5 min talks + 30 min discussion <ul style="list-style-type: none"> – Coastal ocean Prof Jonathan Sharples, University of Liverpool – Coral reefs and associated systems Prof Sandy Tudhope, University of Edinburgh – Deep sea Prof Kerry Howell, University of Plymouth
10:25-11:10	Panel discussion: Challenges and threats in the marine environment 3 x 5 min talks + 30 min discussion <ul style="list-style-type: none"> – Sea level rise Dr Ivan Haigh, University of Southampton – Impacts of climate change on the high seas Dr Stephanie Henson, National Oceanography Centre – Plastic pollution Prof Richard Thompson FRS, University of Plymouth
11:10-11:20	Break
11:20-12:05	Panel discussion: Ocean-based opportunities, solutions and management 3 x 5 min talks + 30 min discussion <ul style="list-style-type: none"> – Marine resource governance Prof Melanie Austen, University of Plymouth – Blue carbon solutions Dr Phil Williamson, University of East Anglia – Sustainability of marine food supply Prof Christina Hicks, Lancaster University
12:05 – 12:15	Conclusion of session 2 and what to expect at session 3 (10 min) Prof Alessandro Tagliabue

16 October 2020	Session 3: Prioritizing research questions (2h30)
	Chair: Prof Angela Hatton, National Oceanography Centre
9:15 -9:30	Please join the Zoom room at 9:15 to allow organizers to set up the breakout groups. The session will start at 9:30.
9:30 -9:40	Welcome and explanation of challenge to break out groups (10 min) Prof Angela Hatton
9:40 – 10:40	Breakout groups (60 min) The challenge to groups is to discuss and prioritize research questions for UK focus within the remit of the UN Decade, based on the outcome of sessions 1 and 2. Further guidance will be provided closer to the session.
10:40-10:50	Break
10:50 – 11:50	Feedback from breakout groups and discussion (60 min) Prof Angela Hatton
11:50 – 12:00	Conclusion of session 3 and what to expect at next session 4 (10 min) Prof Angela Hatton

19 October 2020	Session 4: Development of champion research questions into pitches (2h30)
	Chair: Prof Alessandro Tagliabue, University of Liverpool
13:45 -14:00	Please join the Zoom room at 13:45 to allow organizers to set up the breakout groups. The session will start at 14:00.
14:00 -14:10	Welcome and explanation of challenge to break out groups (10 min) Prof Alessandro Tagliabue
14:10 – 15:10	Breakout groups (60 min) The challenge is to flesh out the champion research questions identified at session 3 into 1-page pitches and consider possible funding routes.
15:10-15:20	Break
15:20 – 16:20	Feedback from breakout groups and discussion (60 min) Prof Alessandro Tagliabue
16:20 – 16:30	Conclusion of the meeting (10 min) Prof Alessandro Tagliabue

Annex C: Attendees List

Name	Affiliation
Alasdair Harris	Blue Ventures
Alan Evans	National Oceanography Centre
Alessandro Tagliabue	University of Liverpool
Angela Hatton	National Oceanography Centre
Anne Magurran	University of St Andrews
Beth Scott	University of Aberdeen
Ben Konnert	The Royal Society
Chris Hauton	University of Southampton
Christina Hicks	Lancaster University
Christopher Pearce	National Oceanography Centre
Cristina Vina-Herbon	Joint Nature Conservation Committee
Colin Moffat	Scottish Government's Chief Scientific Advisor Marine
Daniela Schmidt	University of Bristol
Edward Hill	National Oceanography Centre
Frances Bird	The Royal Society
Gabi Hegerl	University of Edinburgh
Gideon Henderson	Department for Environment, Food & Rural Affairs
Harry Bryden	University of Southampton
Helene Margue	The Royal Society
Hilary Kennedy	Bangor University
Ivan Haigh	National Oceanography Centre
Jack Pilkington	The Royal Society
James Musisi	The Royal Society
Jane Francis	British Antarctic Survey
Jane Rumble	Foreign, Commonwealth & Development Office
John Siddorn	UK Met Office
Jonathan Sharples	University of Liverpool
Julian Barbière	Intergovernmental Oceanographic Commission of UNESCO
Julie Robidart	National Oceanography Centre
Karen Diele	Edinburgh Napier University
Katharine Hendry	University of Bristol
Kerry Howell	University of Plymouth
Lora Fleming	University of Exeter Medical School
Lowri Griffiths	Foreign, Commonwealth & Development Office
Mark Inall	The Scottish Association for Marine Science
Matthew Frost	Marine Biological Association
Melanie Austen	Plymouth Marine Laboratory
Michelle Devlin	Centre for Environment, Fisheries and Aquaculture Science
Michael Meredith	British Antarctic Survey
Murray Roberts	University of Edinburgh
Nick Graham	Lancaster University
Nicola Bridge	Ocean Conservation Trust
Peter Liss	University of East Anglia
Pete Smith	University of Aberdeen

Phillip Williamson	University of East Anglia
Rachel Mills	National Oceanography Centre
Richard Catlow	The Royal Society
Richard Haigh	University of Huddersfield
Richard Thompson	University of Plymouth
Ruth Cooper	The Royal Society
Sandy Tudhope	University of Edinburgh
Sheila Heymans	European Marine Board
Shema Bhujel	The Royal Society
Stephanie Ockenden	Department for Environment, Food & Rural Affairs
Stephanie Henson	National Oceanography Centre
Steve Widdicombe	Plymouth Marine Laboratory
Susan Waldron	Natural Environment Research Council
Tarquin Dorrington	Department for Environment, Food & Rural Affairs
Tracy Shimmiel	The Lyell Centre
Vladimir Ryabinin	Intergovernmental Oceanographic Commission of UNESCO

Annex D: Session 2 - Identifying research questions

Session 2 featured nine talks across three panels. An overview synthesis of each panel is contained in 'Session 2: Identifying research questions – panel discussions'. This annex contains more detailed information on each of the nine talks.

Panel Discussion: Marine habitats

Coastal oceans

Professor Jonathan Sharples, University of Liverpool

Ocean physics and fish stocks are closely interlinked. Understanding the impacts of the physics of climate change on fish stocks at a range of scales will help address biodiversity and inform sustainable harvesting practices. A key research question is:

- How can we link interrelated physical processes to fish stocks at different spatial scales?

Impacts of interest include: migration triggered by seawater temperature; mixing, stratification and nutrient supplies; impacts of currents and frontal jets on egg and larvae transport; coastal circulation and interlinkages around entire shelves; relationships between localised internal waves, plankton community structure and fishing vessels; physical processes affecting prey availability; and oxygen depletion. A move from linear to systems approaches will yield insight. The UK has strong interdisciplinary research, autonomous instrument development and modelling capabilities, which would be well-placed to address this global scientific question.

Coral reefs and associated systems

Professor Sandy Tudhope, University of Edinburgh

Tropical coral reefs and associated mangrove systems provide ecosystem services to coastal communities that include food security and income as well opportunities for climate mitigation and adaptation, and biodiversity conservation. Human stressors are severely degrading these systems; this is an ecological and humanitarian crisis. The questions which emerge from this are:

- How can tropical coastal socio-ecological systems adapt to climate change and other stressors?
- How can we climate-proof food security and livelihoods on tropical and coral coasts?

Empowering local communities to develop bespoke solutions will enable transformative approaches towards addressing these issues. Fundamental and citizen science, in addition to the co-creation and democratisation of data can support research driven, community focussed approaches. The UK's science capabilities, distributed territories and experience in transdisciplinary research offer unique strengths to facilitate this.

The deep sea

Professor Kerry Howell, University of Plymouth

The deep sea is the largest habitat on Earth. It is highly biodiverse, and its linkages with the rest of the ocean biosphere and Earth systems make it crucial for human health. However, comparatively little is known about it. Fundamental science questions regarding deep sea ecosystems need to be answered, to understand the relationship to human health and other Earth systems. Major fundamental questions are:

- What is the biodiversity of the deep ocean?
- How are humans and deep sea habitats connected?
- What is the role of living organisms in ecosystem function and service provision?
- How do deep sea species, communities and ecosystems respond to disturbance?

Modelling is needed to understand human impacts on the deep sea, for instance from use of machinery or opening of fisheries, and the knock-on effects on services. Understanding dynamic interactions between humans and the deep sea requires interdisciplinary research.

The UK has a strong history of deep-sea science, and a number of UK-led research projects, such as

the GRCF-funded 'one ocean hub', could immediately feed into the global research programme.

Panel Discussion: Challenges and threats in the marine environment

Sea level rise

Dr Ivan Haigh, University of Southampton

Global mean sea level has risen 3.2 mm per year since 1993 (compared to an average 1.4mm per year from 1901-1990)³. It will rank among the most costly consequences of climate change. Historic sea level rise is well understood, but the magnitude of future rise is uncertain, as are the impacts on coastal communities. There remains uncertainty around future emissions scenarios, and the amount of sea level rise that instability in Greenland, Antarctic, and marine ice sheets will contribute. Important research questions include:

- What will the global coastline look like with 1, 3, or 5m of sea level rise?
- What will the implications of these changes be to the people, infrastructure, cultural heritage and the environment?
- What adaptable and sustainable options are available to manage such change?

Impacts of climate change on the high seas

Dr Stephanie Henson, National Oceanography Centre

The high seas are crucial for global ocean carbon storage and the sustainability of marine food supply. However, the impacts of climate change on the high seas is uncertain, and the infrastructure for studying high-sea ecosystems is limited. A key question is:

- How will the interacting multiple stressors experienced by the ocean affect its productivity and resilience?

It is particularly important to understand the biological and biogeochemical responses to

multiple stressors, as these are crucial for carbon sequestration, security of food supply, and healthy ecosystem functioning. Changes in temperature, pH, oxygen and nutrient levels may interact synergistically, which could make the cumulative impacts worse than the sum of their parts, but there remains much uncertainty in this area. Collaborating internationally will be crucial to address this question.

Plastic pollution

Professor Richard Thompson, University of Plymouth

Plastic is now ubiquitous in the oceans. The short-term economic, health, and biodiversity impacts are clear, while there remains uncertainty on the long-term ecological impacts of plastic, particularly from nano and microplastics there is a general consensus on the need to implement solutions. The most effective solutions to tackling plastic are predominantly on land. Building systems thinking, interdisciplinary research and funding, and understanding trade-offs to proposed solutions is essential to identify the most effective strategies for tackling plastics. A research question that emerges from this is:

- Using a transdisciplinary, systems approach, what are the trade-offs between measures to reduce the accumulation of plastics in the environment;
- Do these vary regionally? Could better understanding of this be transformative in how we link science to societal benefit?

The UK's strong scientific background on plastics coupled with its strength in interdisciplinary research, and international and commonwealth links, make it exceptionally well suited to address this research challenge.

³ Oppenheimer, M., B.C. Glavovic, J. Hinkel, R. et al., 2019: Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. et al., (eds.)]. (2019).

Panel Discussion: Ocean-based opportunities, solutions and management

Marine resource governance

Professor Mel Austen, University of Plymouth

Marine resource governance and ocean research brings together a range of stakeholders. Trade-offs exist between the environment, society, and the economy, and also between services, decisionmakers, countries, industries, communities and individuals. Identifying the beneficiaries and associated trade-offs of ocean research needs to be undertaken at the onset of research, using an outcome driven approach. By identifying the desired outcomes and drawing on interdisciplinary research, conflict between stakeholders can be reduced and risks minimised, to achieve optimal outcomes. The key research challenge will be:

- To improve the integrated management of, and for, ocean services.

Transboundary partnerships were flagged as being of major importance, in addition to localising decision making to enable marginalised communities to take ownership of their environmental resources and implement context appropriate solutions to bespoke challenges.

Blue carbon solutions

Dr Phillip Williamson, University of East Anglia

Marine ecosystems sequester and store vast amounts of carbon from the atmosphere. The Sustainable Ocean Economy initiative estimates that coastal ecosystems could capture up to 1.4 Gigatons of CO₂ per year by 2050⁴. Understanding the feasibility and scale of possible blue carbon solutions, and their interactions with the carbon cycle, is essential. However, there are a number of challenges to blue carbon solutions.

Transboundary governance is challenging; ecosystems which sequester CO₂ are also impacted by climate change and may not have the same functionality over time; half of global vegetated regions have been lost to aquaculture, agriculture, and urban development; cost-benefit analysis of restoration will be prominent in decision making; and the net carbon removal potential is uncertain.

An important research area is:

- How can coastal blue carbon ecosystems be better managed, and how can we increase their benefits?

The UK's strong interdisciplinary research, and international and commonwealth links, make it well suited to address this research challenge.

Sustainability of marine food supply

Professor Christina Hicks, Lancaster University

The benefits of seafood systems are inequitably distributed. Unequal food systems are geared towards maximising production and consumption, which creates environmental inefficiencies and externalities, undermines labour rights, and creates vulnerabilities in the food system. Understanding the distribution of the many benefits of seafood systems across different groups is needed to tackle inequalities and, in turn, support a broader and more equal distribution of benefits. This should be complemented by the impacts of policies, processes, and practices. A guiding research question to address this challenge is:

- Can we develop policies that support a more equitable distribution of benefits from seafood systems, particularly as seafood becomes ever more relevant in global food discussions?

⁴ Konar, M., and H. Ding. "A Sustainable Ocean Economy for 2050. Approximating Its Benefits and Costs." (2020): 2020-07.