# *Setting Course*

*A community vision and priorities for marine research developed by the National Oceanography Centre Association*

# Foreword

### From Professor Peter Liss, Chair of the National Oceanography Centre Association's Steering Board and Professor Ed Hill, Executive Director, National Oceanography Centre.

*The importance of the oceans to the well-being of human society cannot be overstated. We depend on the marine environment to sustain life and support economies; the need to grow our understanding of the oceans' role in climate is ever more urgent.*

*The National Oceanography Centre (NOC) has been given a remit by the Natural Environment Research Council (NERC) to help create a more integrated UK marine science community that will enable the country's research institutions to tackle some of the most pressing concerns facing our planet. The first step has been the creation of the NOC Association of key universities and research institutes funded by NERC and working in the marine environment.*

*Setting Course is a visionary statement, developed by the members of the Association to facilitate a wide strategic view of UK marine science priorities.*

*It scopes the future for the UK's marine science priorities, marine national capability and research infrastructure, outlining our ambitions for major platforms, such as research ships, sustained observations, development of technologies, modelling and prediction, and data. It also underlines the impact of high quality marine science in shaping policy and business decision making.*

*Setting Course will see us develop our collective skill base in areas of international strength and strategic importance to the UK.*

*December 2011*


*Artist's impression of the new RRS* Discovery

# Introduction

Setting Course is a vision that has been developed by the National Oceanography Centre Association[1], in consultation with the wider marine science community. It has been produced as part of the remit given to the National Oceanography Centre (NOC) by the Natural Environment Research Council (NERC) to help create a more integrated marine research community to tackle the environmental challenges of our age.

To achieve this vision, we advocate a shared approach that identifies the big marine science questions; influences the UK, European and global research agendas; improves the coordination of world-class research; develops new technologies and trains the scientists of the future. We need to work with users of our research to ensure that society benefits from knowledge about the ocean.

Here we set out the case for continued investment to address the key marine scientific challenges and opportunities and inform the development of strategic priorities by NERC and other research funders. All UK organizations that deliver funding or use marine research are invited to embrace this vision.

This vision will:

- guide NOC and its Delivery Partners[2] in providing access to large scale research marine infrastructure and wider underpinning activities that are responsive to the needs of the academically funded research community. This national capability includes the global-range Royal Research Ships, deep submersibles, advanced ocean sensors and instruments, sustained observations, ocean models and data management – as well as activities that underpin knowledge exchange, policy formulation and national and international representation and coordination
- enable Government, industry, other national and international partners, funders and researchers to appreciate not just the breadth of research and capability within NERC-funded marine science, but also the way it benefits society
- place the global ocean and regional seas in the context of the whole Earth system, connecting them to the land surface, Earth interior, atmosphere, polar regions and living systems – including human society.
- complement the Government's UK Marine Science Strategy (2010), which sets a broad direction for marine science input to public policy, achieved by greater national coordination and improved alignment of research programmes.

The main reason for our scientific interest in the ocean is its profound effect on human wellbeing. Curiosity-driven research also makes its contribution; indeed, the intersection of pure and applied marine research often provides the greatest intellectual, social and economic benefits.

This vision was arrived at by consensus of the NERC-funded marine science community. It is an ambitious yet pragmatic vision that takes into account wider priorities for the UK marine science base, including NERC's large national capability investments. Not all aspects will be implemented on the same time-scale; but the vision highlights where most work is needed and where the greatest opportunities lie.

The overall aim is to ensure that UK researchers continue to deliver world-class ocean research, as a community, shaping the international research agenda and ensuring that scientific and technological excellence is translated into making a real, practical difference.

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*[1] The NOC Association is a strategic platform facilitated by NOC that brings together representatives of UK academic institutes and Centres who comprise the NERC-funded marine science community. It aims to enhance the community's influence and the impact of its science on society.*

*[2] The Delivery Partners are those organisations that provide NERC-funded national capability which enables the UK to deliver world-leading environmental science and support national strategic needs. These are NOC, Plymouth Marine Laboratory, British Geological Survey, British Antarctic Survey, Scottish Marine Institute – home of SAMS, Sir Alister Hardy Foundation for Ocean Science, Sea Mammal Research Unit, Marine Biological Association.*

## Societal Context

1. Seven billion humans live on what might be more accurately described as Planet Ocean: directly and indirectly, we all depend on the marine realm for our survival and prosperity.
2. Human society depends upon the marine environment for a life-sustaining climate, as well as for much of our energy, food – even the air we breathe. Those needs are growing: the human population is currently rising by around one billion every 12 years, with the fastest increases in coastal regions through rapid urbanisation and migration. Many of these regions are susceptible to flooding, erosion, salt water intrusion of agricultural land and aquifers, and natural hazards such as storm surges and tsunamis. Humans also directly impact the sea through pollution, habitat destruction and over-exploiting fisheries. Coastal seas are subject to many overlapping and conflicting uses, but are poorly understood, inadequately characterised and often mismanaged. It is therefore essential to understand the complex relationships between humans and the marine environment.
3. The marine environment provides sources of energy, high-protein food, medicines and transport for global trade. Seas around the UK are crucial to our national competitiveness in the emerging global green economy, securing sustainable economic growth and jobs. In easing pressure on natural resources and living with environmental change, we must place our natural science against a framework that encompasses social, economic, governance, legal, political and ethical concerns; addressing challenges posed by issues such as fisheries policy; competition for deep sea resources (deep-sea mining, bio-prospecting); coastal zone engineering, management and planning and an increasingly ice-free Arctic Ocean and geo-engineering (ocean fertilisation, brightening marine clouds). The ocean and seas respect no national or administrative boundaries. Marine science is therefore inherently international in outlook, requiring partnership with others. We must continue to embrace this way of working.

### The importance of the ocean

The influence of the marine environment on human society is profound and pervasive. Without it, there would be no life on Earth. The ocean and seas:

- recycle about half of all the oxygen we breathe
- regulate weather and climate worldwide by storing and redistributing heat (the top five metres of the ocean contains as much heat as all the atmosphere)
- produce about half of the world's production of new plant material annually – with about a third of that in coastal seas
- are the last true wilderness, providing home to over 80 per cent of all known plant and animal species on Earth
- provide a valuable source of protein: about one billion people, largely in developing countries, rely on fish as their primary animal protein source
- contain over 97 per cent of all water on earth and cover just over 70 per cent of the Earth's surface
- have absorbed about 40 percent of all $CO_2$ generated by fossil fuel burning, although this proportion is probably in decline.

## Scientific Context and Vision

4. The ocean is integral to the way the Earth system works, linking with the atmosphere, land, seafloor and cryosphere in complex ways that pose challenging scientific and societal questions. For example, nutrient dynamics in coastal seas are not just affected by marine chemistry, physics and biology, but also processes in rivers and soils, and land use practices. To predict global environmental change and ensure sustainability, we must understand how the whole system interacts. This requires fundamental knowledge about ocean circulation, biogeochemical cycles, deep Earth and crustal processes, and biodiversity changes – as well as the probabilistic study of complex system behaviour (eg rapid state transitions) – on a wide range of timescales, to quantify the dynamic coupling between different Earth system components. Such knowledge will enable us to manage more effectively the increasing risks posed to the growing human population by environmental variability and change, both natural and human-induced.
5. The UK marine research community is renowned for the excellence of its science, technology and engineering and has a strong reputation for effective collaboration with researchers in Europe and worldwide. To pursue challenging science questions – where unexpected and hidden connections are frequent – we need to ensure the health of our intellectual capital base, with a funding environment that stimulates collaborative research; nurtures curiosity-driven, strategic, applied and translational research and is enabled by fit-for-purpose, forward-looking national research infrastructure and capability.
6. We intend to:
   (a) remain at the heart of shaping the European and international research agenda

   (b) maintain and develop collaborations with the best researchers worldwide

   (c) ensure the UK remains an attractive and stimulating place for researchers from overseas.
7. As we tackle ever more complex problems, the success of our research will increasingly depend on:
   (a) maintaining the core disciplines underpinning marine science – physics, chemistry, biology, mathematics and engineering – to benefit from advances in these areas

   (b) closer connectivity between observation, theory and modelling

   (c) more integrated scientific approaches, with emphasis on understanding whole-system complexity in both physical and living systems

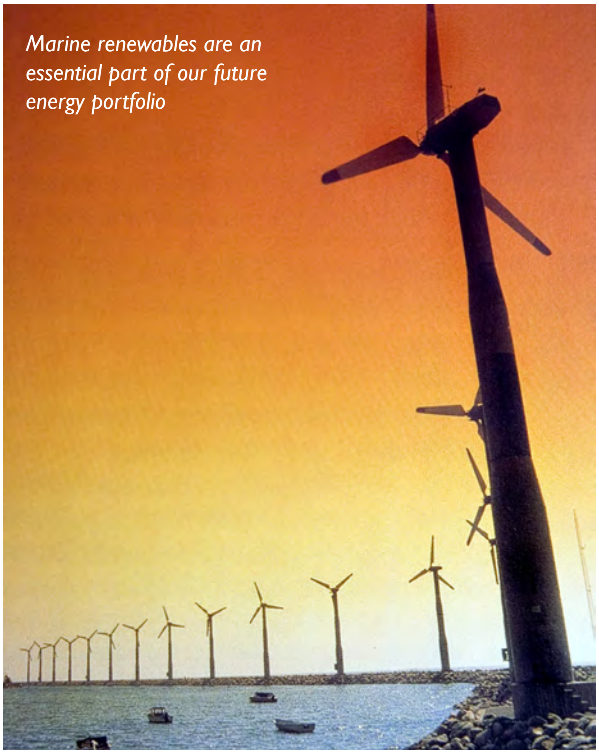
   (d) new technologies to change fundamentally the way we observe and investigate the ocean, address under-sampling and the current lack of variables that can be rapidly and accurately measured using *in situ* sensors

   (e) investment decisions by governments and businesses to ensure that high quality science leads where possible to high societal impact – and recognising too, that history teaches us that new fundamental science questions are often stimulated initially by straightforward practical questions that prove hard to answer with existing knowledge.

8. Progress depends on NERC's ongoing funding support, allocated on a competitive basis, for investigator-led and curiosity-driven research, that addresses fundamental science questions and enables promising ideas to emerge. This alone is not enough, however. There must also be mechanisms to identify and build strategic programmes in important emerging areas, to support multi- or interdisciplinary approaches that straddle traditional organisational or sectoral boundaries, and to solve complex scientific problems over extended timescales (~10 years). This requires funding sources (NERC, governmental and European) that support:
   (a) issue-led research programmes (directed and strategic) in major emerging or ongoing priority topic areas, which might not be addressed at the scale required by individual research grants
   (b) national or international research capability, including major research infrastructure, facilities and platforms (such as ships, satellites, aircraft, high-performance computers); data centres; and sustained programmes of observation, mapping and survey, technology development, and community model innovation and improvement
   (c) timely translational research and knowledge exchange, to ensure that new and existing research results are quickly and efficiently translated into quality information that meets society's evidence needs and contributes to sustainable investment and sound policy decisions by business and government.

9. To achieve the best scientific and societal impact increasingly requires the effective combination of diverse funding streams (eg NERC Responsive Mode, issue-led research programmes, national capability, applied science and non-NERC funding) both at individual researcher and at programme level.

10. Knowledge exchange involves:
   (a) the active two way dialogue at all stages of the research process – from planning to communication of outcomes – between the science community and potential beneficiaries of research
   (b) facilitating the commercial exploitation of research, through engagement with the private sector, so that society might derive direct and indirect economic benefits
   (c) recognising that the main outputs of marine research (knowledge, data and information) often need translation or synthesis into a usable form before they provide outcomes that are useful for society; for example, by combining with data and information from other parts of the natural environment or from socio-economic studies
   (d) engaging research users and other stakeholders at all stages of research, from design to delivery, to maximise opportunities for beneficial impacts – a minor change in an experiment, field survey or model simulation may, for example, make a major difference in the usability of results, whilst providing the same or closely similar science benefits


*Marine renewables are an essential part of our future energy portfolio*

   (e) ensuring that existing as well as new research outputs are absorbed into the knowledge exchange process, including international efforts. Existing knowledge is often undervalued but, properly translated, can have important outcomes and immediate practical benefits.

11. Progress in marine science is increasingly dependent on technological advances. National capability in marine technology that is responsive to users' needs enables us to access, observe, sample, model and predict our changing environment in new and increasingly efficient ways. For example, novel genomic tools and bioinformatic techniques have provided radical insights into biodiversity, ecosystem interactions and evolutionary processes, whilst also identifying a wide range of biotechnological opportunities.

12. Although the need for marine research is increasing, the financial resources to support it are not. The following strategic framework will assist in determining the appropriate balance of investment and effort against a background of constrained resources and competing priorities:
   (a) with limited resources they need to be focussed on the highest-quality science, addressing key challenges for maximum impact
   (b) the essential role of investigator-led responsive mode research should be maintained, even if resources for issue-led strategic science increase as a proportion of NERC spend
   (c) long-term national marine research infrastructure and capability must be maintained through appropriate investment in sustained marine observing and prediction systems, commensurate with the scale of key scientific challenges, policy needs, long-term research ambitions (eg decadal-scale change and variability) and

participation in international programmes

(d) the UK marine science community should play an active role in shaping the priorities and programmes of NERC and other research funders, nationally and internationally. These include:

- Living with Environmental Change (LWEC)
- 'Horizon 2020' – the Framework Programme for Research and Innovation
- the Intergovernmental Oceanographic Commission of UNESCO (UNESCO-IOC)
- the European level Joint Programming Initiative for Oceans and Seas
- the World Climate Research Programme (WCRP)
- the International Geosphere–Biosphere Programme (IGBP)
- Diversitas; the International Human Dimensions Programme (IHDP); and
- the Integrated Ocean Drilling Programme (IODP).

(e) international connectivity will be achieved through engagement with individual programmes, and projects and overview bodies (eg, the International Council for Science, ICSU), the Marine Board (Europe); using well-established channels for influence and developing initiatives such as those of the Belmont Forum, a high level group of the world's major and emerging funders of global environmental change research. The Belmont Forum's initial priorities include coastal vulnerability, ecosystem services and carbon budgets.

(f) the culture of multidisciplinary, multi-investigator, and multi-institution collaboration will be expanded further, in the UK and internationally, extending beyond conventional disciplinary boundaries and actively engaging research users. We must accept that collaboration requires effort and compromise.

(g) access to national and international capability to secure maximum effectiveness of science effort must be maintained. This capability includes large facilities, technologies, research infrastructures, observing systems, data and co-ordination mechanisms, and involves international, national and local partnerships.

(h) we will sustain and enhance the flow of new researchers and enable career development for current staff, in order to nurture and equip a research community with the skill-range necessary to work in large multidisciplinary consortia and the ability to translate research for policy makers, business and society.

(i) at the same time we will emphasise the importance of sustaining fundamental expertise and effort in key marine processes in order to ensure a sound foundation for engaging in trans-sector science.

## The vision

Understanding the marine environment and its interactions with Earth systems and human society is one of the most complex and challenging questions of our age. The vision is that this greater understanding will make a profound contribution to sustainable development globally and also to the UK's well-being and competitiveness in the green economy.

We will do this by focussing on science and developing our skill-base in areas of clear international strength and strategic importance to the UK. We will:

- maintain a reputation for excellence in science and technology development
- remain an acknowledged international leader in developing the very best researchers and technologists of the highest quality
- be a highly valued collaborator with distinctive aptitude for working with others across traditional disciplinary boundaries
- possess global capability in marine science with access to first rate facilities and research infrastructure through both UK investments and international partnerships.

## Making Strategic Decisions

13. Hard choices will be needed to achieve our vision. These include where to invest in people and research infrastructure. Prioritisation will be informed by:

(a) international research excellence as measured by established metrics (publications, citations and the international esteem of individual researchers and teams) as well as newer measures and judgements

(b) delivery of high societal and/or economic impact for the UK as recognised by users of science, and, where feasible and appropriate, expressed by their co-funding

(c) timeliness of research outputs in relation to scientifically important or pivotal areas, particularly in relation to stakeholder needs, whilst acknowledging that strategically significant research may require long-term effort.

(d) capacity to lever further investment from research users, to include access to facilities, skills and data as well as new sources of funding

(e) achievement of a considered balance between responsive short-term investments and sustained programmes (eg, long-term observing), bearing in mind the scale of the scientific challenges to be addressed

(f) exploitation of opportunities for strategically important collaborations and partnerships, and the development of next-generation skills

(g) the ability to deliver research in a highly efficient and cost-effective manner through the pooling of facilities and resources (especially with regard to major capital investments) and co-ordinating activities (capacity, frameworks and networks), nationally and internationally

(h) opportunities to link with the strategies of other Research Councils and other major funders, including the European Commission

(i) opportunities to acknowledge multidisciplinary and transdisciplinary research achievements, which are not always well recognised by university departmental structures and the Research Excellence Framework (REF) assessment process.

## Scientific Priorities

14. In this context, the high-level scientific priorities from a marine perspective derive from the need to understand and quantify the role of the oceans and coastal seas in the Earth system and their influence on human populations on timescales from days to centuries, and on spatial scales from local to global. Components include:

(a) greater integration of prediction with understanding of how and why climate has changed throughout Earth's history; learning from past (palaeo) climate and Earth system changes on timescales ranging from decades to millions of years. For example, using the palaeo record to inform our projections of future sea-level change

(b) greater understanding of the role of the ocean processes (physical, chemical and biological) in regulating the Earth's climate and their responses to a high $CO_2$ world, particularly with regard to heat transport; sea-level rise, the potential for rapid climate changes in the Earth system, the carbon cycle; ocean acidification and deoxygenation; ocean interactions with atmosphere, land and ice; and the potential for climate instabilities or long-term state changes, driven by circulation changes

(c) understanding and quantifying changes in the Arctic and Southern Oceans and their ecosystems, which are among the most rapidly changing environments on Earth. This includes sea-ice extent and thickness, glacier melt, sea level, impact of ocean warming on marine ecosystems and seafloor processes, an ice-free Arctic, water-mass changes and impacts on global ocean circulation

(d) quantifying the risk of dangerous marine-influenced environmental and climate change, with greater understanding of the role of the large-scale ocean circulation and mixing processes in regulating the Earth's climate, through uptake and transport of heat, carbon and salt, with better knowledge of the associated consequences and uncertainties, and evidence from long-term, quality-controlled datasets and process-based understanding

(e) improving knowledge of marine-related risks and hazards. Known and potential risks include:

- Geohazards – eg, earthquakes, underwater landslides and associated tsunamis, sediment methane release
- Hydrological hazards – eg, coastal erosion and flooding, due to storm surges and other extreme weather events
- Biohazards – eg, harmful algal blooms and the bioaccumulation of toxins

(f) understanding, quantifying, and synthesising within Earth system models the marine components of key global biogeochemical cycles, and how they respond to and drive environmental change, and the role of physical, biogeochemical and microbial processes

(g) developing the ability to consider change and adaptation at all levels of biological organisation, from cells to ecosystems, and to separate inherent variability from anthropogenic signals of change

(h) improving understanding of the sustained delivery of biologically-based marine ecosystem services (pelagic and seafloor, open ocean and shelf seas), to include biological change and adaptation at all levels, from cells to ecosystems; the separation of inherent variability from direct and indirect human impacts; and research to support the evidence base for sustainable exploitation of fisheries, aquaculture and other marine bio-resources (eg, for novel materials, medicine and biotechnology) and their ecological component functions. Such work will facilitate marine planning, and protection of resources and marine biodiversity, including through the designation and management of marine protected areas, and a comprehensive valuation of marine ecosystem services – for example, to support the UK evidence needs to achieve 'good environmental status' for its seas in accordance with UK and European policy and legislation

(i) understanding and quantifying interactions and driving forces between the Earth's interior and the oceans (particularly geochemical flux and energy/momentum), ocean and land interfaces and ocean-atmosphere over varying timescales of minutes to millennia

(j) increasing understanding of human impacts in coastal margins (estuaries, the littoral zone, and near-shore waters), where most of the population interacts with the marine environment, where economic activity takes place, and where biodiversity loss and environmental damage are most apparent.

15. Applications of marine science most likely to impact society and the economy are those concerned with environment-people interactions in three broad ways:

(a) our active use of living and non-living marine resources (fisheries, aggregates, energy, working or recreational space, tourism and wellbeing) inevitably involves modification of the marine environment (eg, placement of marine infrastructure; extraction of minerals, energy or bioresources, with associated impacts)


*Understanding impacts in coastal margins is increasingly important*

(b) our use of the marine environment for waste disposal, deliberate and direct or unintentional and indirect (via the atmosphere, or land run-off/rivers), that introduces pollutants that may result in global-scale impacts (eg, ocean acidification)

(c) the natural (and modified) marine environment exposes us to risks with significant socio-economic consequences (eg, extreme weather, flooding, toxic organisms, radiation).

16. Focussed, new research, developed in dialogue with users, and other knowledge exchange activities are needed in relation to the above. Many of the drivers are shared by other players in the wider marine community such as the Met Office, Environment Agency, the Marine Management Organisation and Cefas; the NERC community must seek to work with and complement these. Priority issues include:

(a) improved natural resource and ecosystem services security, resilience and sustainability of exploitation:

- Fisheries, aquaculture and marine bio-resources
- Marine renewables – resource security, cumulative impacts
- Novel energy sources from the sea – algal biofuels, gas hydrates, marine geothermal
- Mineral and marine aggregate extraction
- Novel marine products, including enzymes and polymers
- Alien and invasive species and their ecological and socio-economic impacts
- Ecosystem services for natural flood protection and maintenance of coastal and seabed integrity
- The designation and management of marine protected areas.

(b) Better understanding and management of the impacts of human activities in the marine environment:

- nitrogen and phosphorous loading from land use
- sub-seafloor carbon sequestration
- ocean warming, acidification and de-oxygenation
- potential marine geo-engineering approaches
- effects of chemicals, plastics and other wastes
- radioactive nuclides, heavy metals, organic compounds and other long-duration contaminants, including legacy contamination and remobilisation risks
- effluent discharge
- offshore and coastal infrastructure
- marine habitat loss and degradation.

(c) Understanding and quantification of the risk and impact of global and local environmental change for improved risk management:

- quantify sea-level trends and changes in extremes due to changing storminess and mean sea level changes
- quantify and predict changing patterns of coastal erosion and inundation
- improve weather, seasonal, decadal and climate observation and prediction systems (for droughts, floods, heat waves, cold spells) through integration and incorporation of ocean processes in environmental prediction systems and improved uncertainty quantification
- understand the distribution, recurrence interval and societal impact of marine geo-hazards (submarine earthquakes, volcanoes, landslides, tsunamis)
- predict and manage marine bio-hazards (harmful algal blooms, alien species).

(d) Enhance quality of life, prosperity, and jobs through sustainable use of the marine environment by:

- Understanding the health benefits of marine systems (food, well-being)
- Determining the value of marine ecosystem services and their societal benefits
- Developing integrated information products and services – both specifically marine for maritime application (eg, sea floor and habitat maps) or incorporating marine information for wider non-marine applications – (eg, climate services) to improve strategic decision-making by public bodies, private businesses and individuals
- Drawing on marine biotechnology for wealth generation through the development of new products and services.

*Grey seal* Halichoerus grypus

## Key Supporting Capabilities and Infrastructure

17. Typically, 40-50% of the total cost of marine science in advanced scientific nations is concerned with large infrastructure – including ships, remotely operated vehicles, ship-deployable autonomous vehicles and instruments, and experimental mesocosms (containment facilities enabling controlled experiments on living systems outside the laboratory and within the marine environment). Marine science is also reliant on satellites to access and measure environmental variables globally, although such remote-sensing is mostly limited to ocean-surface observations and therefore cannot fully replace *in situ* measurements. Powerful computers and sound data interpretation are necessary for high resolution, coupled ocean/ecosystem models. Moreover, the oceans are grossly under-sampled at all scales. Sustained observations over decadal timescales, using both *in situ* observatories and drifting platforms, are crucial to complete the 'global jigsaw' of environmental understanding and ensure we can distinguish natural year-to-year variability from human-induced climate change and other adverse impacts – as well as detecting the benefits from management interventions.

18. Many of these long-term capabilities are essential for the UK to remain a lead player in international marine research. They also need to be responsive to new opportunities and requirements presented by the NERC community's 'blue skies' research.

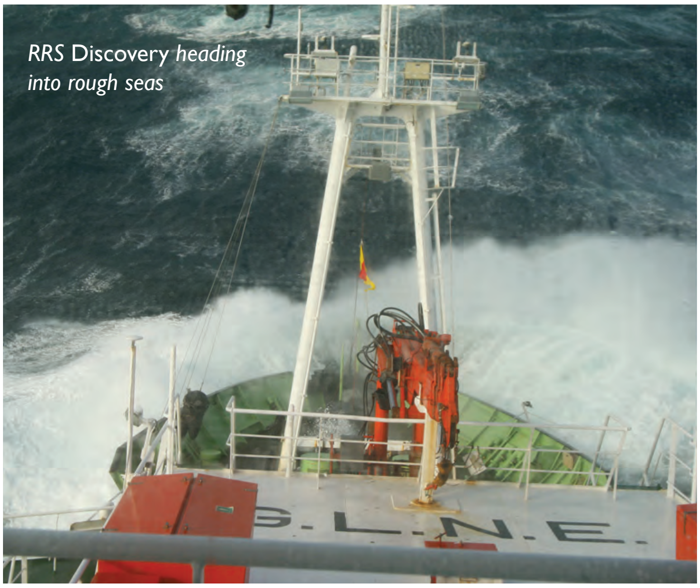
19. Nevertheless, infrastructure demands and costs may be modest for some elements of marine research, such as near-shore ecology, taxonomy and organism–environment relationships, provided the necessary skills base exists.

20. The UK should be selective in using its skills and strengths. National and international partnerships can give us access to additional research infrastructure and capabilities. Our engagement should be based on our priorities. We need to influence our partners' strategies and reinforce mechanisms to understand the core capabilities we require and the areas where we currently have a distinctive current or future capability.

21. In many cases, more integrated development and management of these capabilities with other Earth system sectors may lead to efficiencies, new opportunities and more integrated Earth system approaches to vital questions. The active engagement of the marine science community in developing NERC's national capability strategy will be essential to ensure that its views inform NERC decision making.

### Research Infrastructure: Major Platforms

22. The need for multi-purpose, ocean-going and polar research ships will remain. Whilst giving global coverage, satellites observe only the surface ocean. Ships are essential where significant water samples are needed; for access and exploration of the deep sea, seabed and sub-seabed; and for most *in situ* experimentation. Ships are also critical for multidisciplinary studies of processes and regions and for many types of biological sampling, both pelagic and benthic.



*RRS Discovery heading into rough seas*

23. The key priorities relating to major platform infrastructure are to:

(a) maintain a minimum fleet of two global class, multipurpose 'blue water' research ships with access to vessels with polar capability as well as regional-class and coastal/inshore vessels

(b) bring into service the new multi-purpose RRS *Discovery* (delivery in mid-2013; operational in 2014) to complement RRS *James Cook* (multi-purpose) and RRS *James Clark Ross* (polar)

(c) integrate management and scientific programming of research ships

(d) participate in national and international ship barter to lever access to specialist ships

(e) continue to secure access to ocean drilling capability through participation in a refocused Integrated Ocean Drilling Programme (IODP)

(f) secure access to 'regional class' research vessels and smaller inshore vessels operated by UK research institutes and universities. This is particularly important given the growing challenges associated with continental shelf and coastal seas. It will be achieved through ship barter, commercial charter, and partnerships with other Government research/survey ship owners. Work undertaken by the UK Marine Science Co-ordination Committee will be particularly relevant to determining progress in this area

(g) extend efficient and cost-effective barter arrangements to secure access to a range of large facilities (eg, remotely operated vehicles) to complement UK capacity; such capital equipment sharing may involve the development of integrated trans-national technical support teams

(h) further facilitate resource sharing by working through international forums to enhance interoperability of research ships and major equipment suites and access to satellite and other major platforms

(i) improve awareness of facilities owned by external providers to co-ordinate usage; examples include physical flume tank facilities and resources for specialist equipment testing and sea-survival training.

## Research Infrastructure: Sustained Observing Systems

24. Sustained observations are essential for a full understanding of the oceans, seas and coasts and their interactions with other Earth system components. Long-term observations are needed to address questions about events and extremes, decadal-scale variability, rapid regime shifts, tipping points and long-term change. Apart from satellite coverage of surface processes, the oceans and seafloor remain grossly under sampled in space and time. Increased emphasis should be on observing and modelling the deep ocean. Sustained ocean observing increasingly synergises with global and regional-scale observing programmes and infrastructure, and is required for greater integration with other parts of the natural environment such as the atmosphere and river catchments.

(a) the UK has a broad marine monitoring and sampling capacity, ranging across universities, research institutes, environmental protection agencies, government research laboratories, conservation and in-shore bodies. However, better co-ordination of these activities should lead to greater impacts and more cost-effective delivery. It should be recognised that the oceans remain grossly under-sampled in space and time, but that many *in situ* marine observing systems and technologies are becoming more mature and reliable. This has important implications for how to prioritise and resource an impending step change in ocean observing capability

(b) over the next ten years, routine, systematic observing programmes should increasingly be delivered wherever possible by autonomous platforms, combined with satellite monitoring systems. To avoid duplication of effort some consolidation of technical, legal, and operational support may be needed, particularly for observations in the open ocean, and on an international scale. Measurable progress in this area is expected within five years

*A chain of temperature sensor chips is lowered through the ice in the Canadian Arctic. The chains use satellite modems to transmit profiles of data from the sea to improve understanding about the sea ice.*

(c) there will be greater emphasis on marine equipment pooling to avoid duplication, enable strategic planning of equipment needs, achieve critical mass of technical support skills and capability and facilitate international barter and exchange of equipment

(d) marine observations should be made within the context of a wider 'Earth observatory' where there is clear ownership of key areas of linkage between marine, Earth, atmospheric and terrestrial systems

(e) marine observing will take place within the context of co-ordinated and sustained international, national and regional programmes and their integration for delivery of climate and ecosystem services, especially the Global Climate Observing System (GCOS), the Global Ocean Observing System (GOOS) as the ocean component of the Global Earth Observing System of Systems (GEOSS); the Global Geodetic Observing System (GGOS); regional organisations such as the Convention for the Marine Environment of the North East Atlantic (OSPAR), the International Council for the Exploration of the Sea (ICES), and the European Global Monitoring of Environment and Security (GMES) programme; UN organisations such as the Intergovernmental Oceanographic Commission; and the UK Marine Monitoring and Assessment Strategy (UKMMAS)

(f) the rationale for and expectations of sustained observing programmes must be clear and have appropriate review mechanisms. These should encompass full understanding of the scientific rationale and hypothesis generating/testing, timescale and duration of the measurement programme, and the respective roles and expectations of partners. Exit and handover strategies should be defined with respect to science funding, avoiding 'cliff-edge' decisions

(g) the design of observing programmes must be reviewed to ensure they are fit for purpose and relevant to scientific challenges, ensuring that historical and geographical legacy does not take primacy over scientific rationale

(h) there will be increased emphasis on biogeochemical and ecosystem processes as well as biodiversity trends in sustained observing programmes, both in the ocean and on the seafloor. These observations should contribute to improved environmental management and conservation

(i) there will be greater interplay between observing programmes, ocean models and Earth-system models. This will be taken into account in the design of observing systems, and will help identify critical parameters or locations. The aim is to achieve more integrated Earth system analysis and prediction systems. We advocate the development of a national Earth Observing strategy (including the oceans and both space-borne and *in situ* observations) to complement the emerging national Earth System Modelling Strategy

(j) the UK will explore the scope for leading European Marine Observatory programmes and using their outputs where they complement UK expertise and strategy.

## Technology Development

25. Many of the most significant advances in marine science over the past century have been achieved as a consequence of innovations in ocean measurement technologies – and the same is likely to be true in coming decades. The development of new low cost, high value techniques will enable us to measure and access the oceans and seafloor in new ways and to address the problem of gross under-sampling.

(a) the marine technology community must become well networked with engineers and technologists from other fields, recognising the opportunities for technology transfer between sectors

(b) the drive for sampling of the oceans and seafloor must be supported by developing or acquiring suitable autonomous platforms and by developing novel miniaturised biological or biogeochemical sensors for use on these platforms

(c) mechanisms will be set in place to enable the wider science community to steer platform and sensor development according to strategic science needs, and to allow rapid technology uptake by science users

(d) systems must be made complementary and inter-operable to increase operation efficiency and avoid duplicated effort. This will involve the development of common standards, interfaces, information exchanges, etc.

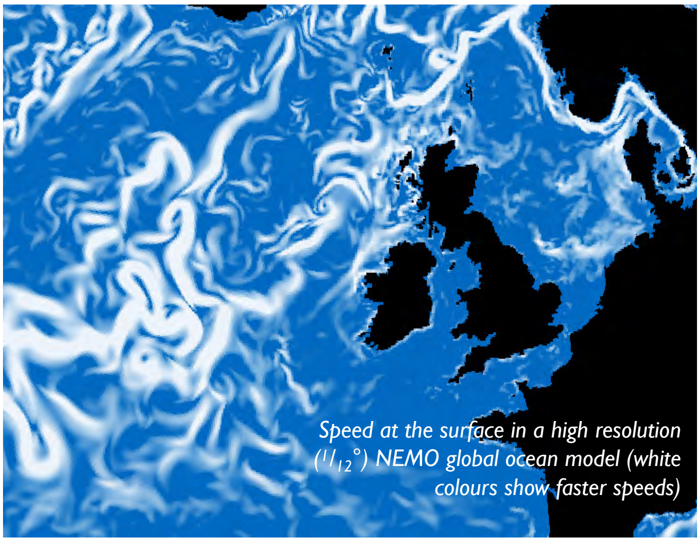
(e) engagement with the international marine technology community, both in the public and private sectors, will be necessary to deliver complementarity and economies of scale

(f) where appropriate, the community will seek intellectual protection and then make new technologies available to others through commercialisation.

## Modelling and prediction systems

26. Predicting based on known uncertainty levels is central to understanding the future development of the planet's life support systems. Addressing the 'what might happen next' question is crucial for major planning and investment decisions, whether by business or Government. Models can inform the next few decades and longer (eg, commitment to multi-century sea-level rise) through the Intergovernmental Panel on Climate Change (IPCC) process. They can therefore be used to simulate the effects and feedbacks of climate change far into the future.

27. Models allow systematic understanding of marine and Earth system processes, and the UK is at the forefront of ocean modelling and climate prediction. However, we need to improve our abilities in hindcasting, nowcasting and forecasting and ensure greater community access to model tools and data outputs. This is especially important given the links to EU Directives for Habitats and Species, the needs of Strategic Environmental Assessment and the Water Framework and Marine Strategy Framework Directives. We will:



*Speed at the surface in a high resolution ($^1/_{12}$°) NEMO global ocean model (white colours show faster speeds)*

(a) welcome the development of a national Earth System modelling strategy. We advocate that the oceans and marginal seas and their ecosystems be fully integrated within it; that it be capable of generating synthesised information and predictions concerning many earth system properties of interest (not solely climate-related), and that the strategy be urgently linked to an Earth Observing strategy (including the oceans and seas and space-borne and *in situ* observations)

(b) develop models in partnership with key end users for climate service and marine forecasting applications (particularly the Met Office) and support the ocean modelling requirements of the NERC science community

(c) develop physical, biogeochemical and ecosystem models of the global ocean and regional shelf-seas within an Earth-system modelling framework

(d) define more closely the parameters and improve the resolution of the more problematic sub-grid-scale processes; develop novel diagnostic techniques

(e) articulate the requirements for high-performance computing and mass-storage resources necessary to address high-resolution coupled ocean–atmosphere, ocean-ecosystem and ocean–ice modelling

(f) increase our capability to couple seafloor processes (eg, benthic ecosystems and methane) into ocean and shelf-sea models for Earth system applications

(g) develop a framework for greater collaborative working in marine ecosystem modelling, recognising the need to model varying levels of ecosystem complexity

(h) work with the international community to develop models of sea-ice dynamics and thermodynamics, and the coupling of sea-ice into ocean models, and implement these in an Earth system context

(i) engage with users of marine information (both direct and indirect users) to understand their specific needs

*Computer systems in the control van for the Remotely Operated Vehicle (ROV) Isis record deep sea biology and monitor the ROV*

for information to enable the opportunities to be maximised for ocean and regional seas models and their outputs and products to contribute to 'decision support tools' for planning and investment (eg, marine planning, cumulative impact assessment, emergency response; marine resource management)

(j) ensure the effective pull-through and use of enhanced understanding of ocean model processes to improve forecasting and feed into developing 'marine services' and 'climate services', eg, working through the National Centre for Ocean Forecasting, with the Met Office's Hadley Centre and other key players nationally and internationally

(k) evaluate models through greater interaction between the observation, palaeo-climate and modelling communities.

## Marine Data and Information

28. Primary marine data and associated metadata are the foundation of all subsequent new knowledge and information products and the basis for knowledge exchange leading to societal benefit. It is essential that marine data, collected often at considerable expense, are safeguarded, managed for the long term and widely accessible to both the research community and other users to maximise their impact. We will:

(a) work in a more integrated way with NERC's Data Centres supporting other Earth system sectors (eg, through discovery services, portals, data and metadata standards), and ensure that marine and other relevant data are made easily and rapidly accessible and interoperable using international standards where appropriate

(b) continue to work closely in the context of national (eg, the Marine Environmental Data and Information Network (MEDIN) and international (eg, IOC IODE) networks of marine and other data centres to support open release (transparency) and accessibility by the science community of data collected by others (eg, government agencies and industry wind farms, offshore energy, aggregate producers, fishing industry), for mutual benefit

(c) develop our understanding of the needs of users, including public, private and third-sector bodies, especially relating to innovative information products for climate and marine 'services'

(e) ensure that marine mapping activities, both in UK and international waters, are undertaken in a co-ordinated fashion to deliver a fit-for-purpose evidence base that is adapted to the needs of Government, science, industry and conservation

(f) continue to recognise the importance of preserving collections, maintaining long-time data series in enhancing opportunities for access and reanalysis in assessing impacts of environmental change.

## People

29. People are central to achieving this vision. We will:

(a) ensure that leading scientists, engineers and technicians are attracted into and retained in the UK marine research community, by offering an internationally competitive environment

(b) help people develop the skills for working in an Earth system context and foster opportunities for training and gaining experience of other disciplines, including discipline-hopping grants

(c) encourage greater interaction between scientists and research-users, enabling scientists to develop the skills to engage with social science disciplines

(d) ensure that development of multidisciplinary capability is not done at the expense of specialist expertise necessary in key subject areas[3]

(e) call upon NERC and other funders to ensure that a good range of faculty and Centre positions are available in appropriate areas for senior scientists and 'highfliers'

(f) offer doctoral training opportunities in ways which may help stimulate future research clusters

(g) ensure that staff contributions to core capability and knowledge exchange are recognised

(h) promote the wide range of career paths available to marine science graduates

(i) develop networks of emerging early career scientists across all marine disciplines

(j) provide training and education to ensure that we maintain fieldwork capacity

(k) strengthen interactions between NERC research centres and universities, and encourage two-way secondments to the policy and industrial sectors

(l) work with intellectual leaders and professional associations in the UK community, taking advantage of mechanisms to enhance our ability to offer advice and knowledge exchange.

[3] *Environment Research Funders Forum report 'Most wanted: skills needs in the environment sector' lists taxonomists and systematics, biostatisticians, physiologists, microbiologists, modellers, data managers, risk assessment and evaluation skills, as well as underpinning numeracy and statistical skills and the need for people able to conduct skilled field research. It also encourages the development of multidisciplinary skills and the ability to translate research for policy makers, business and society.*

## New and Enhanced Ways of Working

30. Despite constrained resources, we need to address the science challenges, and deliver both strategic and curiosity-driven research, linking the research needs of industry and governance bodies. To achieve these aims, we will develop new ways of working, including:

(a) formation of large multidisciplinary, multi-institution collaborative teams to tackle large key issues

(b) a more intensive focus on building partnerships with key research organisations in the academic sector as well as with the Met Office, the British Antarctic Survey (BAS), the British Geological Survey (BGS), the National Centre for Earth Observation (NCEO), Cefas, and others

(c) more systematic, collective engagement, for example with the relevant learned societies and professional associations, for example to influence European research agendas to lever funding and expertise

(d) greater sharing of facilities and infrastructure, especially in light of severe reductions in capital

(e) engaging more strongly with end-users of marine science (especially non-traditional users) as a community, for example, via industry associations and at a sector representative level, as well as with individual companies and government departments (eg, Defra, Marine Scotland, Department of Energy and Climate Change, the Marine Management Organisation, UK Space Agency and others)

(f) increasing and sharing awareness of the research conducted by the UK community

(g) collaborating with other funding councils, most notably Engineering and Physical Sciences Research Council and Economic and Social Research Council, to enable research that spans traditional remits

(h) capitalising further on resources already in place to facilitate co-ordination nationally (in particular the UK Marine Science Co-ordinating Committee, (MSCC) for cross Governmental interaction) and internationally

(i) engaging strongly in the integrated Earth system science agenda (cross sectoral approaches, NERC's integrated National Capability strategy).

## Impact

31. Marine science has a track record of excellence and at the same time influencing public policy (eg, Marine and Coastal Access Act; European Marine Strategy Framework Directive) working with bodies such as the Marine Management Organisation, devolved equivalents and key industry sectors.

32. By working with other environmental science sectors and partners such as the Met Office, we are more likely to deliver impact by supporting public and business investment decision making. This will be achieved with better information products, know-how, and technologies that assess risk and resource availability and security (eg, engaging with the insurance and reinsurance industries where the concern about natural hazards embraces a holistic view of all environmental hazards and their interactions; the 2011 Japanese earthquake caused a marine hazard but its effects were compounded into risks that went far beyond the marine environment).

33. Effort and resources are needed to make use of new knowledge about the marine environment and Earth system. Outputs from marine scientific research include knowledge and information that can be used to inform decision-making, for example, in public policy and business investments. The timing of decisions is determined by multiple factors – and by the 'best available scientific evidence at the time' rather than the best that could be done with funding and the time to undertake new research.

34. Consequently we need to anticipate needs and develop mechanisms, skills and partnerships to enable existing research to be absorbed, synthesised and translated in a timely way to address significant strategic user needs. We will:

(a) work closely with Government and industry partnerships and consortia to identify strategic user

*Cold water coral* Lophelia Pertusa

needs and to engage them in programme designs to maximise opportunities for successful impact outcomes

(b) make marine information our key product, while recognising that it often makes most sense when delivered in combination with wider non-marine information

(c) improve communication of our achievements, in particular though greater cross-working of Association communications teams, through engagement with the MSCC communications sub-group activities and with media and online platforms to inform a wide public and stakeholder audience

(d) present the case for marine science by fostering awareness and understanding of its importance with key decision makers to exert influence on the development of marine sciences worldwide

(e) work with others to develop a more coherent and concerted approach to tracking the level of industry and government co-funding for marine research, including that levered from NERC funding.

## Achieving the Vision

35. The delivery of this vision will require many actions by a wide range of individuals and institutions. In particular the collective participation of the NERC-funded marine science community is required in agenda setting and prioritisation, in influencing NERC and others. The NOC Association can help harness this engagement, strengthen community links and co-ordination, and keep track of progress. Through this and other mechanisms it is hoped that shared aims can also be picked up and built into the ongoing business of all interested players.

36. The National Oceanography Centre has a particular responsibility for the delivery of this vision, especially in respect of its provision of national capability for the community. NOC will develop and publish a delivery plan that sets out its commitments, based on the opportunities and drivers identified in this vision. The plan will be web-based to facilitate consultation and allow for progress updates, interim milestones and specific actions to be highlighted.

## Measuring Success

37. Overall we will know that our community approach has made a real difference when, after five years:

(a) there is greater scientific excellence as measured by appropriate scientific metrics such as citation rates, and increased standing of UK marine research in international league tables

(b) funders adopt an Earth system approach in their strategic environmental research programmes which takes full account of the marine system as evidenced by a balanced presence of marine science

(c) there is greater interaction with industry and the policy arena through programmes of translational research and knowledge exchange, as evidenced by co-funding of research and by explicit reference to the marine research evidence base in the development of public policy

(d) sustained funding mechanisms for vital long-term marine observations – and the systems to make them – are in place, along with high-performance computing platforms to deliver enhanced modelling capability

(e) there is improved public engagement and understanding, including evidence of public participation in the setting of research priorities, wider engagement through online and social networking platforms and frequent, sustained national and international media coverage of marine research

(f) we have achieved further integration and alignment of university, NERC Research Centre and Government Agency research delivery and enhanced international collaboration, as measured by co-authorship of research papers and reports, joint funding of proposals, co-design of programmes and leverage of funding resources and measurable societal and economic impact that demonstrably depends upon being able to more seamlessly tackle scientific questions and address practical needs that cut across conventional disciplinary and established organisational boundaries.

*Autosub6000, an autonomous underwater vehicle capable of diving to depths of 6000 metres*

# NOC Association Membership *(at December 2011)*

| | |
|---|---|
| | National Oceanography Centre |
| Hosting partners: | University of Southampton<br>University of Liverpool |
| Delivery partners: | Plymouth Marine Laboratory<br>Marine Biological Association<br>Sir Alister Hardy Foundation for Ocean Science<br>Scottish Association for Marine Science, Scottish Marine Institute<br>Sea Mammal Research Unit<br>British Antarctic Survey<br>British Geological Survey |
| Clusters: | MASTS (Marine Alliance for Science and Technology for Scotland) |
| University associates: | Aberdeen<br>Cambridge<br>Cardiff<br>Dundee<br>Durham<br>East Anglia<br>Edinburgh<br>Glasgow<br>Heriot-Watt<br>Hull<br>Imperial College (Grantham Institute)<br>Leeds<br>Leicester<br>Newcastle<br>Nottingham<br>Oxford<br>Plymouth<br>Portsmouth<br>Queen's University Belfast<br>Reading<br>Sheffield<br>St Andrews<br>Stirling<br>Strathclyde<br>Swansea<br>University College London<br>University Marine Biological Station Millport |
| Centre associates: | National Centre for Earth Observation |

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*For further information see:* www.noc.ac.uk/about-us/noc-association/national-oceanography-centre-association

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