6. Protecting Biodiversity and Ocean Health

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Commented [AS1]: Thematic gap: ecology is key to enabling predictions of e.g. policy or anthropogenic change - add in more info on ecology and population dynamics / connectivity.

Need to include the impacts of the extractive industries on the seafloor, which surely are an important aspect and one where Earth scientists might make a contribution.

Commented [KH2R1]: Evolution from paleo data?

Commented [AS3]: General feedback on thematic gaps for all chapters:
- Need more utilisation of emerging innovations in low-cost ocean sensing systems to supplement the current network.
- More focus on earth science.
- Need to articulate UK research priorities, strengths and opportunities

6.1. Scope and Context

Commented [AS4]: Add in scope and context for lower ocean realms, links with upper ocean and more info outside the planktonic community

Summarise societal context, scope and themes of this grand challenge; relevant national/international context and initiatives.

According to the Convention for Biological Diversity (CBD), biodiversity is the variety of life on Earth at all levels of biological organisation, including ecosystems, species, and genes. A primary cause of the so-called biodiversity crisis is accelerated anthropogenic-driven change through habitat degradation, biological resource overexploitation (fishing primarily), pollution and climate change (Jouffray et al., 2020; Rogers et al., 2022). It has been estimated that 80% of the direct economic benefits from the ocean, worth approximately £211 billion to the U.K. (Office of National Statistics, 2021), are dependent on a healthy ocean (Hoegh-Guldberg, 2019). Understanding the distribution of life in the ocean, how it maintains ecosystem functions and how ultimately these underpin human society, are science priorities to provide the knowledge required to manage a transformation, from biodiversity and health decline to recovery.

Over 3 billion people globally rely on fish as a primary source of protein but more than 33% of stocks are being fished at unsustainable levels. In addition to threats to food security, biodiversity loss resulting from anthropogenic impacts such as harmful changes in ocean use, introduce direct pressures on the ecosystem services they provide. The Global Assessment Report on Biodiversity and Ecosystem Services (IPBES 2019) projects that, with the current rate of species loss, 1 million species will be extinct within decades, resulting in a 6th mass extinction event (in effect a massive regime shift). This report (IPBES 2019) also projects that transformative change can lead to the attainment of conservation target metrics defined by the Convention on Biological Diversity by 2050, and it documents that conservation investments in recent years have resulted in a 29% decrease in extinction across mammals and bird species. Sustainable aquaculture operations are expanding globally to meet demand, yet the potential environmental impacts, including declining oxygen and increased harmful algae blooms, remain unpredictable. The promise of positive outcomes has led to the UN-defined Sustainable Development Goals, which include Zero Hunger (2) and Life Below Water (14) goals related to food security on island nations.

Several recent developments in international ocean governance provide a new framework for conservation and restoration of marine ecosystems and species. These include the Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction (the 2023 BBNJ Agreement) and the 2023 Kunming-Montreal Global Biodiversity Framework. The former provides a comprehensive legal framework for the conservation of marine biodiversity in areas beyond national jurisdiction. This means that, for the first time, the entire ocean can be subject to conservation measures including marine protected areas (MPAs) and other effective area-based conservation measures. The latter provides targets for protection of 30% of representative ecosystems by 2030 (30 by 30 initiative) as well as restoration of 30% of degraded ecosystems by 2030. Both these international agreements will require knowledge to underpin decision making for implementation (Rogers, 2024) and, given the UK is a signatory to both, significant input by the UK science community.

Despite a long-held recognition of the importance of biodiversity in the marine environment and the need to protect it, the scientific community still faces significant challenges in observing and monitoring marine biodiversity over the full taxonomic, spatial and temporal ranges needed to understand the distribution of life in the ocean, its functions, vulnerabilities and resilience (Rogers et al., 2022). These challenges arise from the size of the ocean (1.3 billion km^3 of water), that much of it is remote and extremely challenging to sample (e.g. the open ocean and deep sea), and that marine life is difficult to observe using remote and autonomous systems other than at the surface (Rogers et al., 2022). Our understanding of fundamental aspects of science such as the relationship between biodiversity and ecosystem function is rudimentary, and knowledge of how to restore marine ecosystems in its infancy (Rogers et al., 2022). Humankind has barely tapped into the vast resources of the ocean genome that have evolved over four billion years and may help to solve many challenges we face today (Blasiak et al., 2020).

However, before we can make sense of marine biodiversity, it is critical we understand the baseline conditions to allow us to identify and track temporal and spatial change. This helps in identifying trends, such as species decline or habitat degradation, which are essential for creating effective marine management and conservation policies, allowing us to set realistic targets and measure the success of ocean health initiatives. Baseline data supports scientific research by providing a foundation for studies on marine biodiversity and helps in understanding the natural state of ecosystems and the factors that ultimately influence biodiversity. This concept, however, is made more complex by the shifting baseline triggered by climate change and human impacts on the oceans.

Commented [AS5]: We can make sense of marine biodiversity now. This framework makes it a never-ending problem. I would convey this as 'before we can evaluate the impacts of policy or anthropogenic changes on biodiversity, it is critical that we define the key measures and characterise the current range of natural change.'

The UK has a reputation for supporting long-term, large-scale biodiversity surveys, such as the Continuous Plankton Recorder (CPR) Survey – the longest running, most geographically extensive marine biological survey in the world – and biodiversity reference sites such as the Western Channel Observatory (WCO), which has been running for over a century. Additionally, the UK government has committed to international marine biodiversity protection efforts, such as signing the Biodiversity Beyond National Jurisdiction (BBNJ) Agreement and pledging funding for marine protection and ocean research (https://www.gov.uk/government/news/uk-pushes-protections-for-international-marine-biodiversity). As a nation, we have world-class expertise and the capacity and infrastructure to make an impact in our understanding and management of marine biodiversity; this is critical for the sustainability of our planet.

6.2. Anticipated scientific developments by 2040

Emerging science priorities (e.g. driven by societal needs, emerging applications, advances in understanding, model developments requiring improved process understanding)

Ocean ecosystems continue to be impacted by climate change, with changes likely to have broad-ranging impacts, including but not limited to species range shifts (i.e., contraction, expansion or both), biodiversity loss, changes in benthic and pelagic fisheries, loss of habitats, and unknown changes to the efficiency of the biological carbon pump.

While methods for observing ocean biodiversity elements and indicators have historically been labour-intensive, technological advancements over the last 10-20 years have significantly enhanced our capacity to make biological and taxonomically resolved observations in the global ocean over a range of organismal and geographical scales (e.g. microscopic imaging, drones, Autonomous Underwater Vehicles [AUVs], video, hydrophones, Artificial Intelligence [AI] and Machine Learning [ML] for identification and classification). Despite these technological advancements, a recent report on the European Ocean Observing Community (Hassoun et al., 2024) has identified the following specific gaps in the collection of biodiversity data: slow progress in the adoption of up to date, fit for purpose observing technologies for biodiversity (e.g. environmental DNA [eDNA] and other high throughput methods), and a continued reliance on labour-intensive methods, especially in open ocean regions; lack of coordinated basin-scale observations for Harmful Algal Blooms (HABs) and jellyfish blooms, which can have important economic impacts, particularly with respect to fisheries and aquaculture, but also tourism; insufficient coordination and standardization of data (i.e. data is often not FAIR [Findable, Accessible, Interoperable, Reusable] thereby impeding sharing and reuse). Addressing these gaps, and thus making the best use of current state-of-the-art technologies, will yield significant improvements in observing capacity for ocean biodiversity and health indicators and support the expansion of existing technological capacity as well the continued development of new observing tools (in particular, *in situ* sensors and samplers).

Commented [KH6]: This is great! Need to draw this messaging out into recommendations somehow.

Internationally, efforts are underway to expand taxonomically resolved observations of ocean biology and biodiversity in the open ocean through the Bio-GO-SHIP (Clayton et al., 2022) and BioGeoScapes (Saito et al., 2024) programs, with a strong focus on combining ‘omics observations with bio-optics, flow cytometric and imaging technologies to link species distribution and metabolic activity to the physicochemical environment. These observing programs are supported by parallel efforts to standardise and share taxonomic data (e.g. MBON, OBIS, ODIS, OBON). On more regional scales, the development of coastal HAB observing and monitoring networks built on a combination of *in situ* cell imaging, ‘omics and Unmanned Aerial Vehicle (UAV) observations serve to demonstrate how state-of-the-art ocean biological observations can feed into operational forecasting and warning systems for HABs (Ruiz-Villarreal et al., 2022).

Commented [AS7]: This is a very biological oceanography view of biodiversity. Most of these technologies enable better observation of microorganisms or very small metazoans. There are large gaps in capability when it comes to macrofauna and many elements of megafauna. Some of these elements are being recognised as important in ecosystem function (e.g. mesopelagic biota and active transport of carbon into the dark ocean). I think there should be caution here about painting an overly optimistic picture.

These expansions in biodiversity observing capacity feed into concurrent advances in biogeochemical and ecological modelling applications, for example, for inferring species distributions, forecasting the strength of the biological carbon pump and providing sub-seasonal HAB forecasts, amongst a wide range of policy-relevant and basic science applications. These advances necessitate strong links and communication between data producers, data managers and repositories, and model developers. Increased emphasis on ML and AI-based model frameworks that combine *in situ* and remote sensing observations to extrapolate and project biodiversity indices in time and space will reinforce the need to develop robust best practices for observational technologies, data management and easily navigable sharing pipelines to ensure that the maximum value and utility can be extracted from all types of *in situ* observations.

In parallel with technological advances in biological observing technologies, the last decade has seen a step change in the use of numerical and statistical models, data assimilation and ML tools to develop predictive capacity in ocean and climate conditions over a range of spatial and temporal scales. These initiatives rely on the availability of robust data pipelines, open data sharing and ultimately funding support for proper data management and storage. Any future expansion in the breadth and volume of ocean biological observations must be matched by support for the development of the data management infrastructure needed to disseminate and serve these data streams to the widest possible range of stakeholders, end users and data product developers. Ongoing efforts towards achieving data democratization, along with a lower bar to entry for data manipulation and visualisation tools will support clearer and more compelling sharing of knowledge, cross-disciplinary communication, the translation of information into actionable insights, and co-design of science and policy actions to support ocean health and biodiversity, and drive impact opinion beyond the scientific community.

6.3. Key Science Questions, knowledge gaps and uncertainties

Summarise list (Noting we are making the case for both sustained and experimental Capability)

Here we highlight key knowledge gaps identified through a series of community discussions and consultations.

6.3.1. Baseline ecosystem state:

- How is life distributed in the ocean, what are the global patterns of species distribution and biodiversity, and what are their drivers?
    - There are large regional gaps in our baseline understanding of the distribution of marine species, particularly in the southern hemisphere, (e.g. Righetti et al. 2020 shows dearth of phytoplankton data from OBIS and other repos in IO and South Pacific in particular; see also Rogers et al., 2022)
- Which populations of marine species are most closely interconnected with human populations?
    - How do they interact and what impact do those interactions have on each other?
    - How can humans intervene to restore damaged ecosystems?
- Can elements of the baseline ecosystem state be inferred by proxies derived from sparse taxonomic observations coupled with routine, global scale environmental

Commented [AS8]: To make this more tangible to funders, it would make sense here to refer to Longhurst Provinces as an attempt to describe ecosystems without having to count everything everywhere, as bullet 1.

Commented [AS9]: This shouldn't necessarily be a main driver addressed at the top. Instead: Preservation of representative and connected ecosystems to decrease biodiversity loss. Funding population studies to understand dispersal and other ecological mechanics underpinning biodiversity- needed for modelling / predictions. Separately (another section), better quantifying the effects of biodiversity or select indicator spp to economic outcomes, including tourism (which is often perceived as too intangible). THIS is key to national investment, culture change and the legacy of marine biodiversity conservation. I think the human / economic connection better fits with 6.3.4 or it can be pulled out into its own section.

observations? (e.g. can we reliably use tools like species distribution models to extrapolate out to global biodiversity indices?)

6.3.2. Ecosystem function and trophic links:

- How do different components of the marine ecosystem interact with each other, and with the biogeochemical environment? (in the context of biodiversity, function and trophic status)
    - To what extent do different species and taxonomic groups have the capacity to respond to environmental and ecosystem change through phenotypic plasticity?
    - How are physiological (e.g. primary production, N fixation) and ecological (e.g. grazing, viral infection) rates modulated by physicochemical conditions (e.g. temperature, pH, nutrients and species diversity)?
    - How will these interactions change in the context of a changing climate?
    - How do these trophic interactions impact the biological carbon pump, dissolved oxygen concentrations, or trophic transfer?
- Can the indicator species most sensitive to ecosystem shifts and/or environmental change be identified and monitored to act as an early warning of potential regime shifts?
- For higher trophic level organisms, we still need fundamental life history and trait-based information (e.g. longevity, reproductive mode, diet, behaviour, biomass etc., including juvenile life stages) to help guide assessments of community resilience and sensitivity.

6.3.3. Resilience and response to change:

- How resilient are species and communities to environmental change and human pressures?
    - What are their physiological responses?
    - How do these responses translate into range shifts and changes in distribution?
    - Do these responses to change impact species and/or community function within the context of the ecosystem?
    - What are the directional trends in ecosystem response to change?
    - Which species are at highest risk of extinction?
- Can species, communities and ecosystems adapt to local and/or global climate and human pressures?
    - Over what timescales does adaptation and/or recover occur?
    - What are the impacts of combined stressors and how do we predict these?
    - Can we identify/predict ecological tipping points? Can they be mitigated or reversed?
- Can nature-based solutions be deployed to mitigate the negative ~~ecosystem responses to change?~~impacts of climate change and other human activities?

Commented [AS10]: I think what is missing here is population and ecosystem connectivity. Species will not be able to change range if life history or oceanography prevents migration. In some cases, such as in benthic ecosystems of southern Australia species have nowhere else to go.

Commented [AS11]: I think a gap here is consideration of the likelihood of species extinctions as well as extinctions at community level and the ecological consequences of such losses.

6.3.4. Conservation and management of biodiversity

- What are the main threats to marine biodiversity? Regionally? Globally?
  - How do they differentially impact species, communities and ecosystems?
  - How can these threats be reduced and/or mitigated?
  - How can we best conserve the marine biodiversity of the UK, UKOTs and areas beyond national jurisdiction?
  - How can the UK deliver its international commitments on biodiversity monitoring, conservation and restoration?
- How effective are MPAs and how can networks of MPAs be best designed?
  - Can climate change impacts be effectively considered when designing MPAs?
  - What other conservation measures are there and how effective are they?
- What are the ecological, societal and economic benefits of marine conservation measures and what are the barriers to their implementation?
  - How is the economic value of an ecosystem derived and expressed? (in terms of present value? potential future discoveries?)
  - How do we balance and manage the benefits and impacts of marine exploitation of biotic and abiotic resources?

6.4. Observation/Product Requirements

Consider Variables, Space/Time scales, Accuracy (taxonomic resolution) requirements (and why – linking to section 3 above). These should be ACTIONABLE recommendations.

Assessing marine biodiversity requires a comprehensive and systematic approach to capture the complexity and dynamics of marine ecosystems (Canonico et al., 2019), while also prioritising making observations of the variables which provide the most information on the system for science and policy applications (Miloslavich et al., 2018). **It is critical we remain both agile and adaptable in our approaches.** This will require a combination of sustained temporal and spatial observations (note a prioritisation of UK capability on sustained ocean observations has recently been reviewed https://ocean-observations.uk/); as well as experimental capacity on oceanographic platforms (research vessels and autonomous vehicles – each of which will have a spectrum of sampling and experimental capabilities). By addressing these key observation requirements, we can gain a deeper understanding of marine biodiversity and develop effective strategies for its monitoring, conservation and management, potentially mitigating a biodiversity catastrophe. **It will be critical to ensure a National Capability for marine biodiversity assessment to help accelerate informed decision making to restore the health of our ocean.** We recommend creating a hub (UK Marine Biodiversity [virtual] Centre) for measurement and (eventual) forecasting of marine life for a sustainable ocean. Recommendations for key components of such a Hub would include:

- Collaborations with world-class UK organisations to provide cutting-edge technology, expertise, and resources necessary for cross-disciplinary projects focused on marine biodiversity. A Hub and Spoke could be developed that would divert (or have funded) elements of their programmes towards marine biodiversity assessment and forecasting, examples could include (but not limited to):

Commented [AS12]: Would be smart to adopt ongoing international initiatives / activities rather than reinvent them. GOOS (it refers to EOVs but not GOOS); Ocean Biomolecular Observing Programme; Marine Omics Technology and Instrumentation group; MARCO BOLO (EU project facilitating eDNA data incorporation into OBIS, and understanding stakeholder requirements for biodiversity observation and data; https://oceandecade.org/publications/ocean-decade-data-information-strategy/

Commented [KH13]: Great, I will include in capability needs (people and partnerships)

- Wellcome Sanger Institute: A world-renowned genomics research centre with extensive expertise in sequencing and analysing genomes. They could work in parallel with a range of Genome Acquisition Laboratories (GALs) using a similar methodology to the Darwin Tree of Life Project (DToL)
- National Centre for Coastal Autonomy (NCCA): A facility that delivers world-leading capability in use of autonomous vessels, sub-surface coastal platforms and scientific buoys, all integrated on a unique, high-speed marine communications network. Also extending collaborations to develop eDNA sensors for use in AUVs.
- The Alan Turing Institute: The UKs national institute for data science and AI. By leveraging AI and ML, marine biodiversity researchers will gain deeper insights into marine ecosystems, improve monitoring and management practices, and enhance the effectiveness of conservation and forecasting efforts.

Commented [AS14]: A more biological oceanography / modelling view of the world. There are key gaps here:
(i) National museums and other biodiversity collections.
(ii) Universities and other marine institutes with human capacity in marine taxonomy and biodiversity science.
(iii) International databases and facilities such as OBIS, other national taxonomic and marine institutions.

➢ Ensure species composition and abundance (at all trophic levels) are monitored. These observations should encompass existing ocean Essential Biodiversity Variables (EBVs)/biological Essential Ocean Variables (EOVs), as well as emerging EBV markers currently being developed to maximise the information provided by eDNA and 'omics sampling. *Temporal and spatial composition/diversity is more useful than abundance in most cases, though this depends on the questions to be addressed – this may help with prioritisation.*
- Taxonomic Surveys: Regular surveys to identify and quantify species (even if semi-quantitative or absence-presence criteria) in a range of marine habitats (coastal to mid-ocean; surface to deep ocean; pelagic to benthic). *Surveys should be initiated in under-sampled but economically and/or ecologically significant regions, and existing long-running ecological time series must be maintained to provide crucial (but rare) data collections spanning climate change relevant time scales (e.g. > 30-60 years).*
- Genetic Diversity: Monitoring genetic variation within and between species using techniques like eDNA and genomic sequencing (note technological innovations section below and potential link with Sanger Institute).

Commented [AS15]: At present eDNA approaches are severely limited by a lack of data in DNA barcoding databases. Therefore an important enabling tool is the population of these databases for future monitoring of biodiversity using molecular tools. This is actually a challenging task given that whilst some organisms are identifiable to species level using single or a few genes others require genome skimming approaches to reveal species level identifications.

➢ Cross-cutting recommendation to ensure Environmental Drivers (non-biological Essential Ocean Variables [EOVs] and Essential Biodiversity Variables [EBVs]) Frameworks are developed (Muller-Karger et al., 2018) to include requirements for underpinning environmental information to support research into changes in ecosystems.
- Physical Parameters: Continuous monitoring of temperature, salinity, currents, and other physical parameters that influence marine biodiversity.
- Chemical Parameters: Measuring concentrations of nutrients, pollutants, and other chemical substances in the water.

Commented [AS16]: I think you need to specifically mention geological parameters here as critically important for benthic organisms.

➢ Programmes to measure Ecosystem Function (Ruhl et al., 2021) – this links to ecological and biogeochemical model development and validation.
- Primary and Secondary Productivity: Measuring the rate of photosynthesis and biomass production in marine ecosystems.
- Nutrient Cycling: Monitoring the flow and recycling of nutrients within marine ecosystems, including carbon, nitrogen, and phosphorus cycles.

- Metabolic activity and potential: e.g. nitrogen fixation. Physiological adaptation/phenotypic plasticity to changing conditions (this also comes up below).

➢ Programmes to Determine Species Interactions and Trophic Dynamics

- Food Web Analysis: Studying predator-prey relationships and energy transfer through the food web.
- Behavioural Observations: Tracking the behaviour and movement patterns of key species using tagging and telemetry.

➢ Assess Human Impacts

- Anthropogenic Pressures: Assessing the impact of human activities such as fishing, pollution, deep-sea mining, and coastal development on marine biodiversity.
- Marine Protected Areas (MPAs): Evaluating and monitoring the effectiveness of MPAs and other conservation measures in protecting biodiversity.

➢ Ensure Technological and Methodological Innovations are Progressed

- Remote Sensing: Utilizing satellite and aerial imagery to monitor large-scale changes in marine ecosystems, including patterns of human use/impacts on the ocean.
- Autonomous Systems: Deploying autonomous underwater vehicles (AUVs) and remotely operated vehicles (ROVs) for detailed exploration and data collection.
- Data Integration: Combining data from various sources and platforms to create comprehensive and FAIR datasets.

➢ Programmes to Monitor Habitat Extent and Condition

- Habitat Mapping: Using remote sensing and *in situ* observations to map the distribution and extent of critical habitats ~~such as seagrass beds~~.
- Habitat Quality: Assessing the health and condition of habitats through indicators like water quality, substrate type, and presence of key species.

6.5. General description of key capabilities

Consider in general terms how satellite, in situ observations, models will contribute to addressing requirements.

6.5.1. People, Skills and Partnerships

A key component of the future marine research infrastructure will be the development and expansion of the skills needed by the UK marine science community to respond to and support a large expansion in the volume of data being produced by new sensors and platforms.

To be expanded upon:

- *Important to address question of data management and FAIR practices in order to make the best use of combined observations across platforms (e.g. in situ data needed to validate satellite algorithms and models, as well as to train ML/AI models). This will*

Commented [AS17]: I think something missing here is ecological and functional connectivity between ecosystems. Absolutely fundamental to understanding the wider impacts of ecosystem change.

Commented [AS18]: Missing here are other forms of species interaction. For example, competition, parasitism and pathogens/disease. Also, the legacy of evolutionary assemblage of communities. Again, connectivity between populations / communities and ecosystems is critical.

Commented [AS19]: This should be much more positive. We should be looking to undertake the science to improve the sustainable management of human activities that impact the ocean, including land-based activities, extractive and other activities. This includes improving monitoring, control and surveillance of the ocean and the use of AI and big data.

See: Freestone D, Bjergstrom KN, Gjerde KM, Halpin P, Fleming KP, Hudson A, Rogers AD, Sapsford F, Tsontos VM, Vazquez J, Vousden D (2024) High seas in the cloud: the role of big data and artificial intelligence in support of high seas governance -the Sargasso Sea pilot. Frontiers in Marine Science 11:1427099.

Commented [AS20]: I think this is too specific. Seagrass beds are just one example of a habitat. It could be argued that many habitats are "critical".

Commented [AS21]: Missing here: assessing the actual health of organisms. Signs of disease or lack of reproduction (e.g. zombie populations) are obvious signs of an ecosystem in decline / in peril.

Commented [AS22]: A number of aspects of biodiversity research have been neglected and even discriminated against in favour of physical / biogeochemical sciences. This has resulted in falling capacity in many areas of marine biodiversity science (see Rogers et al., 2022). Rebuilding of human and technical capacity in marine taxonomy and some areas of ecology, such as pelagic ecology are significant needs in UK biodiversity science. Partnerships will be super-important because expertise in these areas of science is distributed across a range of UK institutions including research institutes, universities and museums. The next generation of biodiversity scientists must also be data savvy. There needs to be careful consideration of training / education of marine biodiversity scientists at undergraduate, graduate and postdoctoral level.

likely require dedicated attention to data infrastructure with sufficient support for the effort needed.

- *Globally accessible and community reviewed/tested best practices and technologies*
    - *Capacity building initiatives*
- *Synergies with other industry knowledge/facilities (e.g., medical - genomics)*

6.5.2. Observational Infrastructure

Need to retain capacity for global observations of key EBVs (such as zooplankton and phytoplankton biodiversity), which requires e.g. the collection of physical, tissue, *in situ* samples in inaccessible environments and capacity to tag organisms.

To be expanded upon:

- *Need to be able to collect physical samples from the ocean environment in order to address open questions and maintain monitoring of ocean biodiversity, but challenging to monitor changes and variability from periodic ship based sampling.*
- *Global capacity will be maintained by satellites, but these can only see the surface*
- *Autonomous assets needed to bridge the gap between shipboard sampling and global satellite observations*
- *Coordination with numerical and statistical models will be necessary to unify these disparate observing platforms/data sources (e.g. proxies for EOVs of interest when they can't be measured/observed directly)*
- *Global collaboration and coordination needed to sustain global observations (e.g. BGC-Argo, MBON/OBON…)*
- *Long-term funding and strategy encouraging collaboration, not competition, also need to recognise the importance of data management and data sharing infrastructure which needs funding and coordination with repositories*
    - *Separate infrastructure use requests from funding as this limits who can do what*
    - *Create funding for sustained observations*

Assessment of Sustained Ocean Observing Programmes vs. Experimental Capacity from Research Platforms

It is critical that the UK maintains capacity in both sustained ocean-observing programmes (as reviewed by https://ocean-observations.uk/), research platform capability (primarily research vessels) as well as new innovations in AUVs/ROVs and sensors to enable world-class capability in biodiversity and ecosystem health assessment and management.

Sustained ocean observing offers several key benefits for marine biodiversity assessments:

- Long-Term Data Collection for:
    - Trend Analysis: Detecting long-term trends and patterns in biodiversity and indicators of ecosystem health and function.
    - Baseline Establishment: Setting baseline conditions for future comparisons
    - *In situ* validation for remote sensing

- Ensuring continuity of time series when sampling and/or data collection methods change

- Comprehensive Coverage:
  - Spatial and Temporal Coverage: Ensures extensive data collection across various locations and times
  - Ecosystem Representation: Includes diverse marine ecosystems, including remote ecosystems such as polar, open ocean and the deep sea.

- Enhanced Understanding of Ecosystem Dynamics:
  - Ecosystem Interactions: Clarifies complex interactions within marine ecosystems
  - Response to Environmental Changes: Monitors biodiversity responses to changes like climate change and pollution

- Support for Conservation and Management:
  - Informed Decision-Making: Provides data for effective conservation and sustainable management of human activities in the ocean including extraction of biotic and abiotic resources.
  - Effectiveness of Conservation Measures: Evaluates the success of measures like MPAs

- Early Warning Systems:
  - Detection of Anomalies: Identifies potential threats early, such as harmful algal blooms and invasive species
  - Proactive Management: Supports early mitigation efforts to prevent significant harm

In parallel, research vessels can enhance experimental capacity by:

- Accessing Remote Areas: To enable exploration and sampling in remote (open ocean) and deep-sea environments which can't currently be accessed with remotely operated platforms alone.
- Use of Advanced Equipment: Research vessels are equipped with laboratories and specialised instruments for detailed analysis and mapping, as well as testing new innovations in sensors and samplers.
- Obtain Functional Biodiversity Data: Through rate process and controlled incubation experiments
- Explore Specific Biodiversity Features in More Detail: To gain more granular data for better understanding and future prediction on e.g. ocean fronts, gyres, upwellings
- Ground Truthing Satellite Data: To ensure accuracy in remote sensing observing
- Interdisciplinary Research: Foster collaboration among scientists from different fields
- Real-Time Data: Allow immediate analysis and adaptive research responses
- Education and Training: Provide field training and public engagement opportunities

Recommendations for investment

- **High priority**: Global ship-based sampling capability; development of Hub & Spoke collaborative model for cross disciplinary engagement with world-class UK-based capability; advanced sampling and sensor development to support future autonomous innovations; exploration of floating platform capability (visionary!)
- **Medium priority:** (semi) Autonomous physical sampling capability. Expanded in-situ imagery of plankton and seafloor ecosystems (autonomous and ship)
- **Lower priority**: Hydrophones on autonomy and moorings?

Commented [AS23]: Include info on data systems and building infrastructure for gathering data, real-time data transmission (in both directions) ship to shore, networking of infrastructure (e.g. ships, satellites, shore) use of big data approaches.

Other specific Taxonomy/Genomics questions to consider

Needs further development

- How can we accelerate the discovery of biodiversity in marine ecosystems?
- How do we secure fundamental underpinning science of taxonomy for the future?
- How can UK scientists working on biodiversity better contribute to global databases related to ocean life and make their data more accessible?
- How can eDNA databases be improved to increase the use of barcoding and metabarcoding for biodiversity monitoring and management?
- How can genomic data from marine species contribute to fundamental scientific knowledge of biology, including evolution, physiology and medicine?
- Development of a programme to sequence the genomes of all marine species around the UK and in UKOTs
- How can we improve the generation of biotechnology for UK industries from marine genomic data?

6.5.3. Digital Infrastructure

To be developed.

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