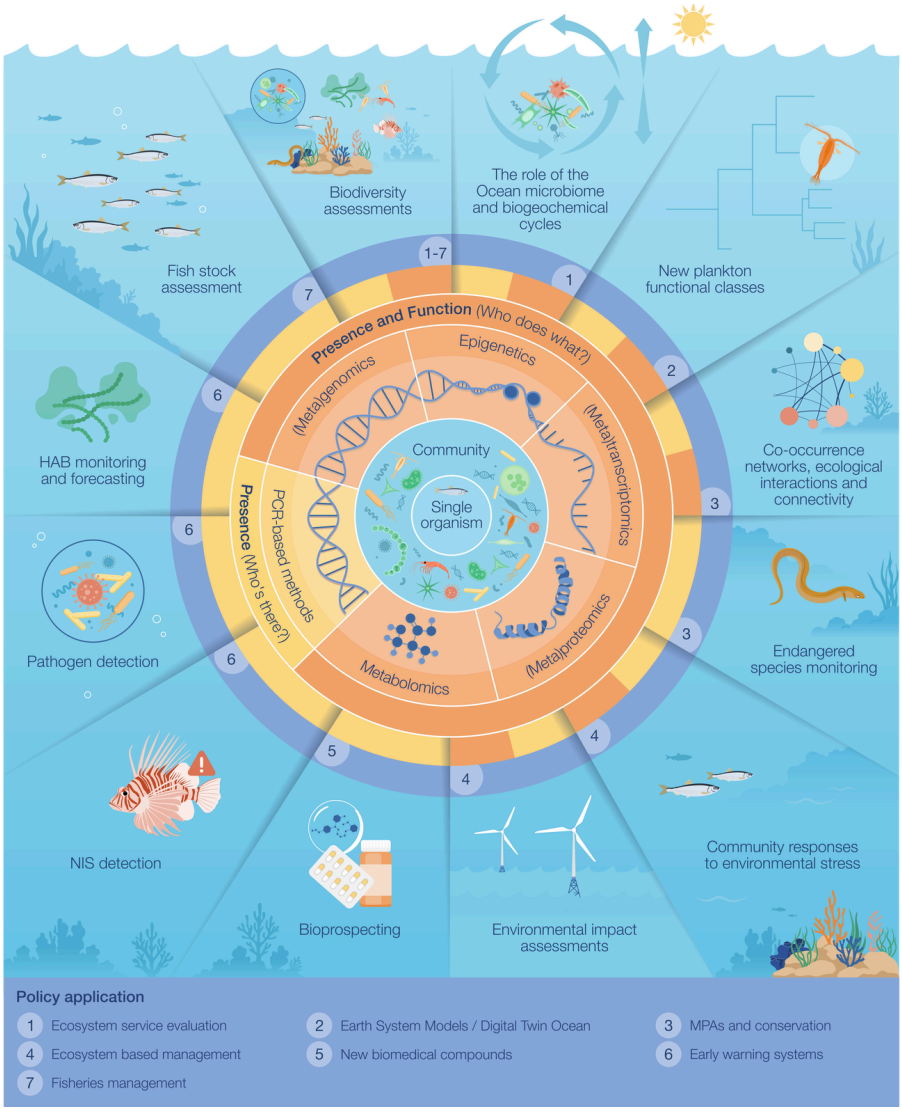
Biomolecular approaches to observe and manage marine life

There is a critical need for comprehensive biodiversity assessments to support effective marine ecosystem-based management. This is particularly relevant for the implementation of the Agreement on Marine Biological Diversity of Areas Beyond National Jurisdiction (BBNJ), as well as European Directives including the MSFD, Nature Restoration Regulation and 2030 Biodiversity Strategy. Biomolecular tools, including -omics and eDNA sampling, are becoming increasingly important components of Ocean observation systems. When combined with traditional approaches, these "augmented observatories" have potential to provide high-resolution biodiversity and ecosystem insights for the predictive and mechanistic understanding of the Ocean that is required for conservation and ecosystem-based management under rapid environmental change. This document highlights the potential of biomolecular tools to address marine research questions, their implementation in marine monitoring and policy, as well as the research and innovation required to scale-up their use.



Policy applications

Biomolecular tools can fundamentally change the way we observe, monitor and assess marine biodiversity. Comprehensive molecular inventories capture the full spectrum of marine life, from microorganisms to megafauna, and from cells to entire communities, revealing species presence, abundance and functions. These tools can be used to collect high-resolution biological data to answer many questions in marine science including: establishing reliable biological baselines, improving the scientific basis for monitoring protected species, providing early warning for pathogens, invasive species and harmful algal blooms; assessing environmental impacts of human activities and climate change; and supporting conservation measures such as Marine Protected Areas. In addition, data provided by biomolecular tools can support ecosystem service valuation, fisheries management, the discovery of new bioactive compounds, and Earth system modelling, feeding into Digital Twins of the Ocean.

Infographic credit: Stacey McCormack, Visual Knowledge Pty Ltd.

Scaling from research to routine monitoring

Biomolecular methods for monitoring, managing and protecting marine environments are currently used predominantly in research applications, and should be scaled up to improve the efficiency, accuracy and cost-effectiveness of routine marine monitoring. Biomolecular tools hold the potential to transform the implementation of European Directives and international agreements on biodiversity.

Recommendations
for policymakers:

- **Integrate insights on biodiversity and ecosystem function from biomolecular data into the design of protected areas and restoration initiatives** to support EU policies including the Habitats Directive and Nature Restoration Regulation;
- **Embrace novel frameworks to value ecosystem services based on molecular functions;**
- **Commission solutions for emergent environmental issues from data-driven approaches** including big data analyses and large-scale models, and adopt management practices that are backed by large and interdisciplinary datasets; and
- **Promote the adoption of FAIR and CARE principles for data collected within monitoring programmes** and the publication of data as open as possible and as restricted as necessary.

for research funders:

- **Fund co-designed research, including the exploitation of large, interdisciplinary datasets** that link biomolecular methods to policy applications. This includes research on molecular traits, -omics-based functional knowledge and plankton metabolism. Machine-readable indicators will enable data integration into climate models and Digital Twins of the Ocean to improve future spatial climate scenario projections;
- **Fund exploratory and curiosity driven fundamental science to investigate baseline molecular mechanisms** in marine organisms and Ocean ecosystems to advance understanding of ecosystem function and dynamics. Research is needed to: characterise genes with unknown functions; determine the speed of DNA degradation; analyse existing datasets; advance multi-omics; better link organisms, genes and functions; and improve ecological models;
- **Invest in accessible and interoperable computational and digital infrastructure**, including repositories, visualisation tools and federated reference libraries. Support is needed for data generation, storage, curation, quality control and adherence to FAIR metadata standards, while enabling long-term monitoring and compliance with the Nagoya Protocol and the BBNJ Agreement. This will facilitate integration of biomolecular data into Digital Twins of the Ocean for EU policy implementation;
- **Fund the targeted expansion and improvement of molecular reference databases through sequencing campaigns** that generate barcodes, genomes, transcriptomes and proteomes from organisms that are currently not, or poorly, represented in reference databases;
- **Support long-term -omics observatories alongside traditional sampling and monitoring networks (i.e. augmented observatories)** that feed into holistic ecosystem monitoring and assessments;
- **Fund innovation in automated and miniaturised *in situ* biomolecular samplers and sensors**, including scaling-up and commercialisation of existing technologies, and the expansion of AI for rapid sequence identification and association of -omics data with other environmental parameters to predict planetary-scale trends;
- **Enforce rigorous standardisation for biomolecular protocols and ethical open-access frameworks** across the entire -omics workflow to ensure data reuse and interoperability. Embed FAIR and CARE principles in research funding;
- **Fund interdisciplinary biomolecular standardisation task forces** within international research networks to ensure that biomolecular discoveries translate into actionable management knowledge; and
- **Fund sustained training, collaboration and stakeholder engagement** connecting technology developers, data experts and practitioners to improve data and metadata quality, develop AI-ready datasets, and support long-term citizen science. Provide sustained support and resources to developing regions to ensure expertise advances equitably.

Download the EMB Future Science Brief No. 14 "Biomolecular approaches for the observation and management of marine life" on the EMB website.

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