IMBeR's Future Science Objectives 2021-2025

Future science objectives were developed through assessment of the scientific achievements within the regional programmes, working groups, task teams and associated IMBeR activities since 2015, and the identification of remaining knowledge gaps in the context of international research. This knowledge gap analysis was progressed through IMBIZOs, the keynote and overview presentations and discussions at the Future Oceans 2 Open Science Conference, SSC meetings, associated IMBeR workshops and interaction with IMECaN Organising Committee members.

Grand Challenge I

Synthesis of presentations and attendee discussions at the Future Oceans 2 conference helped identify the most important knowledge gaps, including:

- Mechanistic understanding of the interplay between multiple drivers
- Cumulative impacts of multiple climate and non-climate stressors
- Effectiveness of interventions to mediate climate impacts
- Development of linked model and observational networks at the full socio-ecological scale
- The interdependencies between humans and ecosystems other than through fisheries

The interplay between multiple drivers will be progressed through interaction with COBS, while we have developed a new Innovation Challenge on climate interventions (IC5). The three priorities under GCI through to 2024 are thus:

1. Evaluate and predict the cumulative effect of multiple stressors

The cumulative effect of multiple stressors such as warming, deoxygenation, ocean acidification, pollution, etc. will be addressed through research within the regional programmes and working groups, and contribute to model development and prediction under GCII, and human responses under GCIII. Coastal areas are the location of most human activities, and hence the most stressors on marine ecosystems and services. Nutrient runoff, sediment transport, habitat loss, and warming in coastal seas all combine to change the balance of ecosystem structure and function. These stressors can result in emergent new system states, such as coastal eutrophication. In collaboration with Future Earth Coasts and the Continental Margins Working Group, this objective will describe the multiple eutrophication pathways evident in coastal seas around the world. This will also involve studying the combination of stressors and cumulative impacts in these coastal ecosystems, and the changes on key environmental variables.

2. Integration of climate change and climate variability

IMBeR science achievements so far suggest that studies of climate change and climate variability have been largely separate. However, it is now clear that climate change and variability are linked, particularly through the emergence of extreme events (e.g., marine heatwaves). We will pursue research which endeavours to integrate change and variability. Examples include upwelling regions, utilising new connections between observations and modelling at a range of time scales, with case studies in the Indian Ocean which assess the impact of variability and change on ecosystem function and fisheries. In addition to upwellings, ICED, ESSAS and SIBER will continue to focus on impacts of climate variability and change on polar regions and the Indian Ocean. Integrated consideration of variability and change will better allow the resilience of ecosystems to be described, and the potential for ecosystem service disruption predicted, linking to the objectives for GCII and GCIII.

3. Impacts on society – preparation for a changed future

The IMBeR regional programmes have all had a major focus on interactions between ecosystem structure, fisheries and to a lesser extent, humans. By 2024, we will renew the focus on elucidating the linkages between humans and society, and changes in the ocean, and broaden the scope from fisheries to a wide range of human uses, including recreation, energy generation, tourism, and aquaculture. In particular, we will work to develop observation and prediction systems for extreme events (e.g., marine heatwaves, coastal flooding), and use these to improve the preparation and options for maintaining socio-ecological systems (linking with GCIII). The non-stationarity in marine ecosystems due to climate change and human population pressures also means that past management practices may no longer be suitable, and so approaches such as scenario testing (GCII) and foresighting will be increasingly important to consider alternative pathways and outcomes for the ocean.

Grand Challenge II

Synthesis of presentations and attendee discussions arising from the Future Oceans 2 open science conference identified the following knowledge gaps:

- Inclusion of feedbacks between future states and the climate system in in next generation climate models
- Understand model differences, constrain projections and account for more complex biological and biogeochemical properties
- Development and implementation of approaches for combining global and regional models and for combining large scale projections with specific regional information
- Improve integration of humans in global models, including quantitative, non-monetary measures of human well-being
- Extend scenarios of climate change to include fisheries, habitat loss, pollution, climate impact interventions etc.

The priority objectives for GCII over the next four years are thus:

4. Development of integrated data systems and approaches for predictions and projections

Parameterising and constraining models is a crucial requirement for developing future projections. The development of the Marine Data Hub has been an excellent initiative. Over the next four years we aim to consolidate and develop the hub to provide a data resource for global and regional ocean modelling communities. To avoid duplication of effort we will create a Data Hub Working Group, which will develop

links with key global and regional data management and observation groups (e.g. IODE, OBIS, SOOS and GOOS). To underpin the development of species and food web models, a key focus for IMBeR in collaboration with the wider community will be the synthesis of data on ecological traits across major marine taxa. The incorporation of social science data will be supported by linking with IC4 activities, especially in expanding economic, political and social datasets. The rapid development of ocean observing and autonomous systems also requires new approaches for data analyses for the assessment of ocean ecosystem processes, the incorporation of observing system information and for model validation and assessment. These approaches include the development of Machine Learning and Artificial Intelligence based methodologies, which are being developed for climate model projection studies. We aim to bring together the data observing, analysis and modelling communities to advance integrated approaches for predictions and projections.

5. Development of predictive models and projections for use at regional scales

We will encourage a coordinated approach for the development of higher resolution coupled models, to downscaling projections and regional scenarios. This will involve the assessment of approaches to downscaling from low to high resolution and for predicting and projecting outcomes in regional ecosystems over years to decades. The aim will be to improve current ecosystem models through the development of a regional scale comparative approach, which will consider the trade-offs in alternative model representations of biogeochemical and ecological processes. It will draw on the data integration activities to develop approaches for integrating observations/data and social science data into predictive models for regional ecosystems. This will include an assessment of the types of social science data (disciplines, scales, methods) currently available and required for use in regional/local projections and their accessibility.

6. Development of alternative scenarios to bridge the gap between physical climate sciences and humanities

The development of global and regional models for delivering climate change projections at the scale relevant for decision making and management requires the on-going development of appropriate scenarios. To foster the integration of the physical with the socio-ecological dimensions, Ocean System Pathways (OSPs) need to be developed incorporating economic, social and cultural data relevant to the selected OSPs. Activities will include the development of approaches to provide multi-scale storylines for local communities. This would require assessment of data relating to locally specific value systems that underlie livelihood practices and other human activities, resource use, wellbeing and governance systems. An important supporting activity will be the development of coupled socio-ecological models in areas with limited capacity. The development of multi-scale storylines requires analyses of processes and interactions over a wide range of spatial and temporal scales. This will involve consideration of how global or regional drivers (e.g., fisheries supply chains and global food security) influence communities that depend on local fisheries.

Grand Challenge III

Remaining knowledge gaps within the remit of GCIII identified at Future Oceans 2 included:

- Development of governance practices for transformative change
- Development of knowledge co-production as a catalyst for sustainable governance

- Identification of the effects of adaptive management responses and governance systems on human related risk exposure and impacts
- Assessment of risks and vulnerabilities arising from new frontiers of economic exploitation of marine resources and synergistic impacts of climate change and use of the marine environment

which inform the prioritization of the following objectives:

7. Support and advance sustainable, equitable and inclusive governance approaches to ocean climate adaptation and mitigation

With adoption of the Paris Agreement in 2015, climate adaptation and mitigation have been placed at the forefront of ocean governance challenges with two overarching questions to be addressed through GCIII by 2024. How are regions, countries and local communities adapting to shifting marine species and ecosystems and what best adaptive governance practices can be identified? What is the status of scientific and technical knowledge regarding potential marine options for climate mitigation through carbon dioxide removal (CDR) strategies and what ocean governance responses are needed to control CDR research and implementation? So far, governance approaches have been initiated mostly at the national and global levels, based on international agreements, national policies and action plans. However, the social implications of these governance initiatives and responses to climate change, specifically incorporating issues of sustainability, equity and social inclusion and ensuring that these issues are adequately addressed in governance systems remains a challenge. GCIII aims to address this gap by building upon past and on-going research to support and advance sustainable, equitable and inclusive governance approaches.

8. Support and advance sustainable, equitable and inclusive governance approaches to fisheries and aquaculture

Fisheries and aquaculture provide employment to almost 60 million people across the globe and produce around 179 million tons of fish for the world (FAO, 2020). The levels of biological sustainability of fish stocks in the ocean have decreased from 90% in 1974 to 65.8% in 2017 (FAO, 2020). This decline in fish stocks has been compensated to some extent by the exponential growth of aquaculture, which has increased by 527% from 1990 to 2018 (FAO, 2020), accompanied by its own set of social and ecological challenges. Given the importance of the fisheries sector economically and socially, considerable research has been conducted on fisheries governance at multiple levels, including the differences and contradictions across levels. Less work is available on governance of the growing aquaculture sector. Aquaculture has often been included in fisheries policies and regulations nationally and globally, although its activities, which include access to resources (land, water, brood stock, inputs) and control of disease, are more closely related to sustainability issues in agriculture. In relation to the economic and ecological dimensions of fisheries and aquaculture, there remain knowledge gaps in social issues around governing both of these sectors sustainably, equitably and inclusively. Moving principled governance in fisheries and aquaculture from paper into effective practice continues to be a challenge and so this objective will address three implementation questions. How are key sustainability principles, such as precautionary and ecosystem approaches and social equity, being applied (or not) at regional, national and local levels? What are the major governance constraints? How might law and policy frameworks be improved?

9. Supporting implementation of international targets for marine spatial planning, marine protected areas and other effective area-based conservation measures

Marine spatial planning (MSP) intersects with governance in that it is conceived as a public process of analysing and allocating the spatial and temporal distribution of human activities in the marine biosphere. It is centred on a political process to achieve ecological, economic and social objectives. Similarly, the engagement of local stakeholders is critical to achieve conservation objectives of marine protected areas (MPAs), especially in delineating no-take zones and ensuring compliance. New directions for MSP and the establishment of MPAs and other effective area-based conservation measures are emerging with related ocean governance challenges. New targets for expanding the application of MSP and the coverage of MPAs by 2030 are expected to be adopted under the Convention on Biological Diversity in October 2021 while a new international instrument on the conservation and sustainable use of marine biodiversity beyond national jurisdiction, still under negotiation, promises to provide a framework for integrated planning and establishment of MPAs on the high seas. GCIII will address key governance questions in the wake of the new responsibilities and institutional arrangements. For example, how are countries and regions proposing to implement the global targets? What are the roles of scientists and stakeholders in identifying and promoting MPAs and other effective area-based conservation measures? Are national laws and policies up to the task of ensuring social equity and justice in new protected and conservation area designations? Will international and regional organizations and arrangements cooperate in strengthening high seas governance?