

Appendix 6 Integrated Marine Biosphere Research (IMBeR) Project

Annual Report to SCOR 2016 – 2017

A. Introduction

The Integrated Marine Biosphere Research project (IMBeR, formerly the Integrated Marine Biogeochemistry and Ecosystem Research project, IMBER) is a global environmental change research initiative co-sponsored by the Scientific Committee on Oceanic Research (SCOR) and until December 2015, by the International Geosphere- Biosphere Programme (IGBP). In 2016 IMBeR signed a Memorandum of Understanding to become a co-sponsored global research project with Future Earth.

Since its start in 2005, IMBeR has aimed to develop a comprehensive understanding and accurate predictive capacity of the ocean's response to accelerating global change and the consequent effects on the Earth system and human society. In 2016 IMBeR produced a science and implementation strategy for the next decade, underpinned by the vision, "*Ocean sustainability under global change for the benefit of society*".

This vision recognises that the evolution of marine ecosystems (including biogeochemical cycles and human systems) is linked to natural and anthropogenic drivers and stressors, as articulated in the new IMBeR research goal to "*Understand, quantify and compare historic and present structure and functioning of linked ocean and human systems to predict and project changes including developing scenarios and options for securing or transitioning towards ocean sustainability*".

To implement its new vision and goal, IMBeR's mission is to "*Promote integrated marine research and enable capabilities for developing and implementing ocean sustainability options within and across the natural and social sciences, and communicate relevant information and knowledge needed by society to secure sustainable, productive and healthy oceans*".

IMBeR science aims to foster collaborative, interdisciplinary and integrated research that addresses important ocean and social science issues and provides the understanding needed to propose innovative societal responses to changing marine systems. The implementation of the new IMBeR Science Plan is underpinned by the International Project Office (IPO) in Bergen, Norway sponsored by the Institute of Marine Research (IMR) and the Norwegian Research Council, and the Regional Project Office (RPO) in Shanghai, China supported by the State Key Laboratory of Estuarine and Coastal Research (SKLEC) at the East China Normal University (ECNU). The IMBeR research goal is progressed through the activities of four regional programmes, five working groups and numerous endorsed projects, and is facilitated through focussed IMBIZO workshops, conferences and symposia and the training of early career researchers at biennial ClimEco summer schools (Figure 1).

IMBeR Implementation

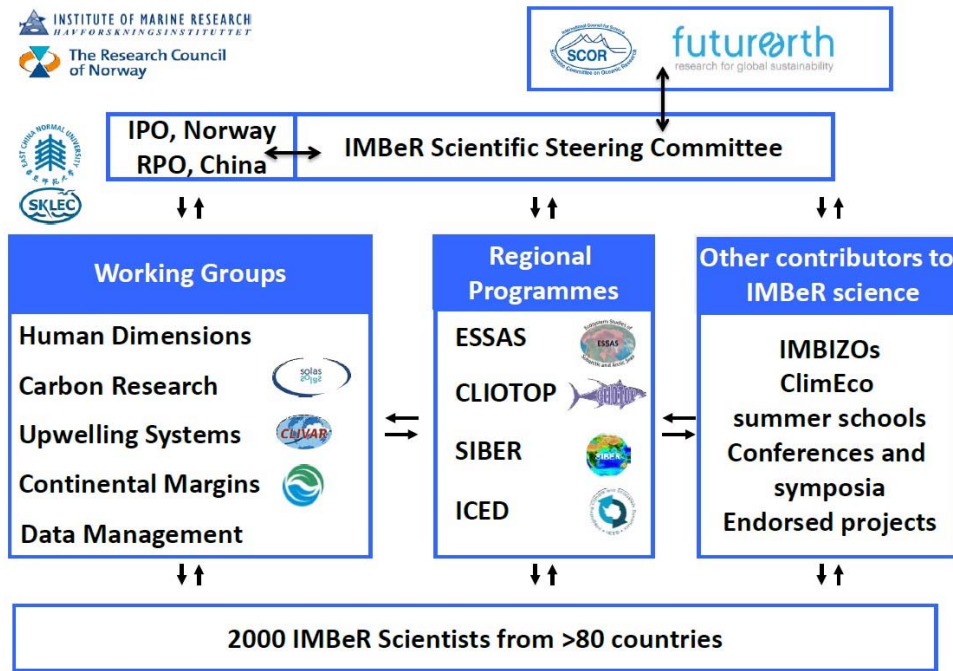


Figure 1. Implementation of IMBeR’s research goal.

B. Science Plan (2016-2025)

The Science Plan and Implementation Strategy (SPIS; 2016-2025) is developed around three Grand Challenges (GC) focussing on climate variability, global change and drivers and stressors. The qualitative and quantitative understanding of historic and present ocean variability and change (Grand Challenge I) are the basis for scenarios, projections and predictions of the future (Grand Challenge II). These are linked in Grand Challenge III to understand how humans are causing the variability and changes, and how they in turn are impacted by these changes, including feedbacks between the human and ocean systems. Priority research areas with overarching and specific research questions are identified for each Grand Challenge. The Grand Challenges are supplemented with four Innovation Challenges (IC) that focus on new topics for IMBeR where research is needed and where it is believed that major achievements can be made within three to five years. The Innovation Challenges also provide a means for IMBeR to adjust its focus as major science discoveries are made and new priorities arise (Figure 2).

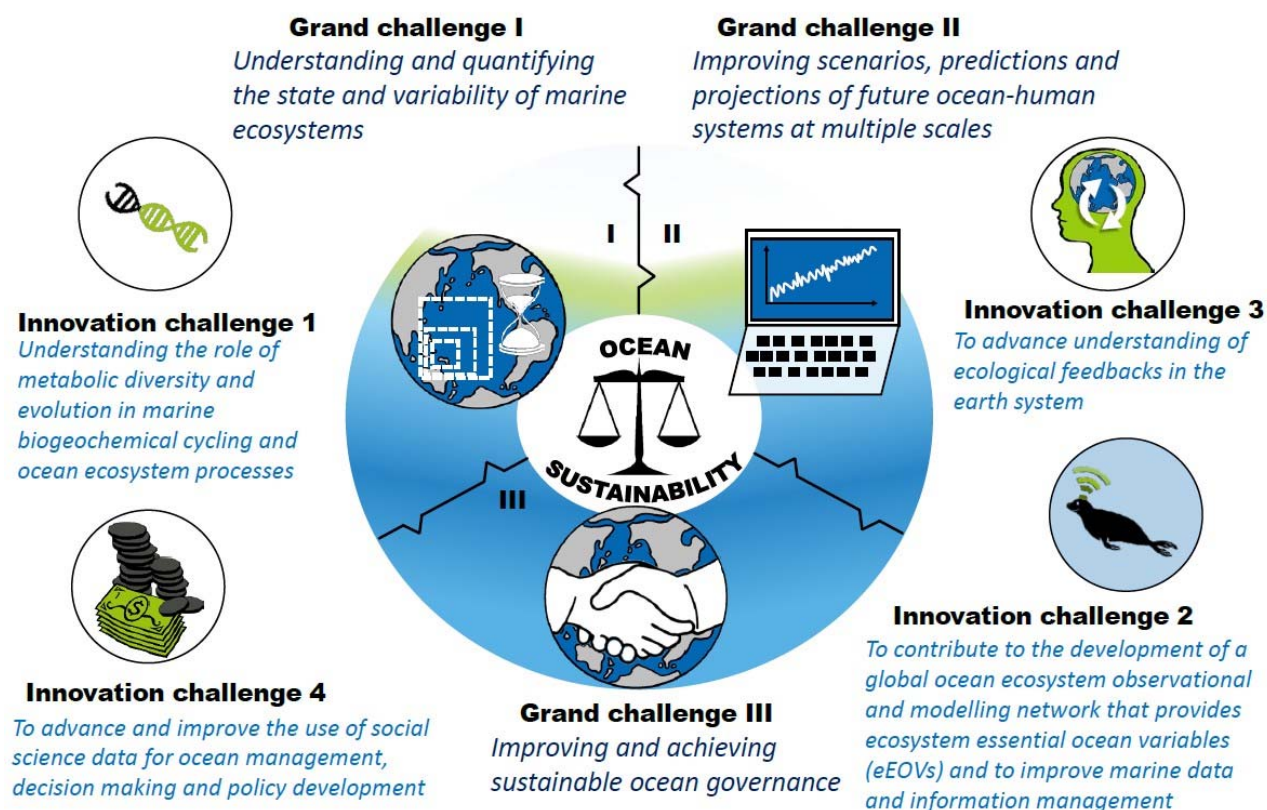


Figure 2. The Grand and Innovation Challenges

C. Selected science highlights in 2016

A list of publications is given in section K, and activities which have specifically progressed the objectives of the Science Plan are given in section G. Here we identify a selection of studies where IMBeR has contributed to the progression of fundamental knowledge in marine ecology and biogeochemistry.

Members of the IMBeR regional programmes ESSAS (Ecosystem Studies of the Subarctic and Arctic Seas) and ICED (Integrating Climate and Ecosystem Dynamics) led a comparative study of the ecological impacts of atmospheric and oceanic circulation on polar and sub-polar marine ecosystems. The study highlights the effect of the strikingly different polar circulation patterns on the amount, thickness and duration of sea ice and the ecology of zooplankton, fish, seabirds and marine mammals (Hunt et al. 2016; <http://dx.doi.org/10.1016/j.pocan.2016.10.004>).

1. A session on the ecology of the polar cod *Boreogadus saida*, held at the ESSAS 2014 Annual Science meeting, led to the publication of a special issue of *Polar Biology* (Mueter et al. 2016; doi:10.1007/s00300-016-1965-3). The combined publications represent the largest single step towards understanding the ecology, life history and distribution of Arctic gadids in a changing Arctic.
2. A combined ESSAS and ICED study (Murphy et al., 2016; <http://dx.doi.org/10.1098/rspb.2016.1646>) proposes a conceptual framework that links the life histories of pelagic species and the structure of polar foodwebs, and highlights the low functional redundancy at key trophic levels which makes these ecosystems particularly sensitive to change.
3. Members of ICED used the Framework on Ocean Observing (FOO) to begin developing ecosystem Essential Ocean Variables (eEOVs) for the Southern Ocean Observing System (SOOS). The authors

outline the rationale, including establishing a set of criteria, for selecting eEOVs for the SOOS, develop a list of candidate eEOVs for further evaluation and discuss the importance of simulation modelling in helping with the design of the observing system in the long term (Constable et al. 2016; <http://dx.doi.org/10.1016/j.jmarsys.2016.05.003>).

4. An ICED study explored the views of representatives from the scientific, conservation and fishing industry sectors on the sustainability of the Antarctic krill fishery. The analysis identified key differences in viewpoints such as the priority given to different management approaches, and to continuing commercial fishing. However, the results also revealed considerable overlap between viewpoints. The study suggests that identifying shared management objectives based on stakeholder aspirations provides a strong basis for developing practical management solutions (Cavanagh et al. 2016; <http://dx.doi.org/10.1016/j.marpol.2016.03.006>)
5. As part of the IMBeR regional programme SIBER (Sustained Indian Ocean Biogeochemistry and Ecosystem Research), CO₂ and pH sensors were deployed on a mooring in the Bay of Bengal in November 2013 to provide the first continuous set of surface water and air CO₂ and pH measurements in the northern Indian Ocean. Data from the time series reveal strong seasonal variations in pCO₂ in the surface water relative to the air, which are associated with the monsoon seasonal cycle, with a slight predominance of ingassing over the annual cycle. Pronounced increases in pCO₂ during the early intermonsoon are driven by increasing temperatures and reduced CO₂ solubility, and decreases in pCO₂ during late intermonsoon and monsoon time periods are driven by decreasing temperatures and elevated CO₂ solubility.
6. SIBER has also motivated bio-Argo deployments in the Indian Ocean through a joint Indian-Australian project in the northern and southeastern Indian Ocean. The targets of these deployments have been biogeochemical hotspots in oxygen minimum zones, island wakes, enhanced-productivity eddies and subtropical convergence zones. About 40 biogeochemical Argo floats have been deployed in the Indian Ocean to date, providing insights into productivity and carbon cycling, oxygen distributions, phytoplankton community composition and eddy nutrient dynamics. The radiometric and chlorophyll data from these floats have been further applied to satellite ocean colour validation.
7. A special issue of *Deep-Sea Research II* outlines research arising from the CLIOTOP (Climate Impacts on Oceanic Top Predators) regional programme 2015 symposium, spanning topics such as conservation biology, trophic ecology, fisheries science, climate change and adaptive management (Hobday et al., 2017; doi:10.1016/j.dsr2.2017.03.008).
8. The CLIOTOP Task Team 2016-02 aims to build policy relevant scenarios for the sustainability of global oceanic ecosystems and fisheries. Maury et al., (2017; <http://dx.doi.org/10.1016/j.gloenvcha.2017.06.007>) developed five contrasting Oceanic System Pathways (OSPs) based on the shared socioeconomic pathways used in climate change research. These OSPs have been chosen to form the official scenario basis of the FishMIP (Fisheries Model Inter-Comparison initiative), the marine component of the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP), used to inform model studies in the context of IPCC and IPBES.
9. The SOLAS-IMBeR Ocean Acidification Working Group working through the IAEA Ocean Acidification International Coordination Centre (OA-ICC) co-sponsored the 4th International symposium on the Ocean in a High-CO₂ World, hosted by the University of Tasmania's Institute for Marine and Antarctic Studies, New Zealand and the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Hobart, Australia. The event, held every four years, discussed the latest developments in ocean acidification science, identified future research needs and trends, and offered prime networking opportunities to hundreds of international scientists working on ocean acidification.
10. The OA-ICC contributed to the 3rd GOA-On Science Workshop that followed the Symposium on the Ocean in a High-CO₂ World. The workshop brought together more than 100 scientists from 40 countries, and discussions tackled issues including GOA-On national and regional status, linkages to other global programmes, data management, developing regional hubs to facilitate national programmes and capacity building.
11. The IMBeR Human Dimensions Working Group has submitted a collation of 20 marine case studies which use the I-ADApT (Assessment based on Description and responses, and Appraisal for a Typology) framework to identify the natural, social and governance aspects of approaches used to deal with global change to the *Routledge Studies in Environment, Culture and Societies* book series.

12. Guillotreau et al. (2017), analysed six commercial bivalve industries affected by mass mortalities using I-ADApT, to assess the impacts and consequences of these perturbations on the natural, social, and governing systems, and the consequent responses of stakeholders to these events.
<https://doi.org/10.5751/ES-09084-220146>

D. Regional Programmes

Ecosystem Studies of Subarctic and Arctic Seas (ESSAS)

ESSAS objectives are to understand how climate variability and climate change affect the marine ecosystems of Subarctic and Arctic seas and their sustainability, and in turn, how changes in the marine ecosystems affect humans.

The Resilience and Adaptive Capacity of Marine Ecosystems in the Arctic (RACArctic) is an ESSAS initiative between Japan, the USA and Norway and is funded by the Belmont Forum. It is a 3-year project, now in its second year. Its objective is to synthesize information from completed and ongoing regional studies in order to examine how variability and changes in advection, temperature, pH and ice dynamics in the Subarctic to Arctic transition zone may affect future marine ecosystems of the Pacific and Atlantic Arctic. Of particular interest is how fish populations and their prey respond to, and may adapt to, natural and anthropogenic changes in the Arctic and how these responses are expected to affect existing and future fisheries, subsistence harvests, and the socio-economic systems that depend upon them. The first meeting was held in February 2016, in Hakodate, Japan. The first day was dedicated to a stakeholder forum with representations from the fishing industry, food processing, grocers, fisheries management, transportation industry, and a weather services company. It was conducted mostly in Japanese with translation into English. The stakeholders provided information on the kinds of information they need in order to meet the challenges of climate change. They stressed the desire to see more such meetings. Days 2 and 3 of the meeting were devoted to scientific presentations and discussions from representatives of each of the countries on topics of climate and meteorology, biogeochemistry, phytoplankton productivity, zooplankton, fish and higher trophic levels.

ESSAS co-chaired a session at the **Ocean Sciences** meeting in New Orleans in February 2016 on ‘Biophysical processes at the Arctic-Sub-Arctic Interface’ which explored patterns and processes at the interface between Subarctic and Arctic waters of the Pacific Arctic, the gradients in physical characteristics and biological communities that shape this region, and the role of climate change in modifying biophysical processes in the region.

ESSAS co-chaired several sessions at the **Annual PICES meeting** in San Diego in November 2016. The session on ‘Resilience, transitions and adaptation in marine ecosystems under a changing climate’ explored the concept of resilience in both physical ocean systems and in the associated ecological systems from plankton to fish. Presentations on theoretical studies and applied case studies examined resilience in a marine ecosystem context, provided practical approaches to measuring resilience, defined the “essential structure and function” of marine ecosystems, identified thresholds beyond which essential structure and function may be lost, examined ways in which resilience of marine ecological systems can be enhanced, and explored the phenotypic and evolutionary adaptive capacity of marine organisms to deal with gradual changes and transitions.

The 2016 ESSAS Annual Science Meeting was held in Yokohama, Japan. Fifty attendees participated in sessions on Challenges to the climate, ecological, biogeochemical and socio-economic sciences in a changing Arctic and Subarctic. The 2017 ESSAS Open Science Meeting will be held in Tromso, Norway.

Integrating Climate and Ecosystem Dynamics in the Southern Ocean (ICED)

The ICED regional programme aims to better understand the climate interactions in the Southern Ocean, the implications for ecosystem dynamics, the impacts on biogeochemical cycles, and the development of sustainable management procedures. www.iced.ac.uk/index.htm.

ICED scientists contributed various oral presentations and posters at the **Scientific Committee on Antarctic Research (SCAR) Open Science Conference**, in August 2016, in Kuala Lumpur, Malaysia. ICED co-coordinated a mini-symposium on Linking Antarctic science with environmental protection, which aimed to highlight the relevance of the research carried out by the international community of Antarctic scientists, under SCAR, to the Antarctic Treaty System.

ICED scientists attended the **4th International Symposium on the Ocean in a High-CO2 World**, in May 2016, in Hobart, Australia to present work on the effects of ocean acidification on Antarctic pteropod and phytoplankton species, as well as the development and delivery of scientific knowledge and policy guidance on high latitude ocean acidification.

ICED has continued to provide input to the Antarctic Treaty System (via SCAR; CCAMLR; Commission for the Conservation of Antarctic Marine Living Resources and CEP; the Antarctic Treaty's Committee for Environmental Protection), the Convention on Biological Diversity (CBD) and Marine Protected Areas. There is now an established recognition by these bodies of ICED's role as the provider of valuable, external input on climate change impacts on Southern Ocean ecosystems to their work.

ICED was represented at the second Joint Workshop of the CCAMLR Scientific Committee (SC-CCAMLR) and CEP, in May 2016 in Punta Arenas, Chile. The workshop aimed to identify the drivers and effects of climate change that are considered most likely to impact the conservation and management of Antarctica and its resources, and to identify existing and potential sources of research and monitoring data relevant to the work of the CEP and SC-CCAMLR on this topic. This led to ICED representation at the CCAMLR Working Group on Ecosystem Monitoring and Management meeting in Trieste, Italy, July 2016.

ICED scientists have been involved in key International Whaling Commission (IWC) work following on from a Southern Hemisphere humpback whale assessment (Jackson et al. 2016). Funding has been secured to support two inter-disciplinary voyages to study the sub-Antarctic right whale feeding population off South Georgia. Investigations will include identifying habitat use with satellite tracking, connecting these grounds to low-latitude calving grounds using photo identification and genetic matching, investigating the main prey sources through skin isotope analysis, and determining the health of the whales from photographs of body condition and analyses of whale hormones and microbiomes. Two years of surveys will allow whale abundance estimations at this site and contribute towards an assessment of right whale recovery in the southwest Atlantic.

ICED scientists have been involved in the agreement to establish the world's largest Marine Protected Area (MPA), in Antarctica's Ross Sea, via CCAMLR. This new MPA will come into force in December 2017 and will limit, or entirely prohibit, certain activities in order to meet specific conservation, habitat protection, ecosystem monitoring and fisheries management objectives. Seventy-two percent of the MPA will be a 'no-take' zone, which forbids all fishing, while other sections will permit some harvesting of fish and krill for scientific research. This is a significant achievement and has been several years in the making. A number of publications have been submitted by ICED scientists to CCAMLR in support of the development of future MPA's.

ICED scientists participated in delivering a chapter updating knowledge on the effects of climate change on Antarctic marine ecosystems to an International Union for the Conservation of Nature (IUCN) publication on the effects of climate change on the oceans.

The EUROMARINE science network represents the merger of three former Networks of Excellence (EUR-OCEANS, MarBEF and Marine Genomics Europe) that involved ICED Scientists. ICED scientists attended this year's EUROMARINE General Assembly, to maintain links between ICED and the network.

CLimate Impacts on Oceanic TOp Predators (CLIOTOP)

The CLIOTOP regional programme organises large-scale comparative studies to elucidate key processes involved in the interaction between climate variability and change and human use of the ocean on the structure of pelagic ecosystems and large marine species.

CLIOTOP scientists contributed to a number of workshops and working groups in 2016 including the **Commission for the South Pacific Regional Fisheries Management Organisation**, Adelaide Australia in January 2017, the IOC-UNESCO (GOOS)/OceanObs Research Coordination Network co-ordinated workshop on the **Implementation of Multi- Disciplinary Sustained Ocean Observations (IMSOO)**, Miami, USA 8-10 February 2017, and the United Nations Group of Experts for the second cycle of the Regular Process for **Global Reporting and Assessment of the State of the Marine Environment**, including Socioeconomic Aspects, New York, USA March 2017.

The major activity of CLIOTOP in 2017 will be the development and organization of the Fourth CLIOTOP Symposium in late 2018. Members of CLIOTOP submitted a proposal for a SCOR working group 'Expanding Regional Application of Dynamic Ocean Management (ERADOM)'.

Sustained Indian Ocean Biogeochemistry and Ecosystem Research (SIBER)

The SIBER regional programme is co-sponsored by the Indian Ocean GOOS (IOGOOS) Programme with close ties to CLIVAR's Indian Ocean Panel (IOP). It focuses on understanding climate change and anthropogenic forcing on biogeochemical cycles and ecosystems in the Indian Ocean, to predict the impacts of climate change, eutrophication and harvesting.

The 2nd International Indian Ocean Expedition (IIOE-2) was motivated by SCOR, SIBER, IOGOOS and IOP and has become the main scientific focus of SIBER. The first cruise was launched in December 2015. SIBER contributed to an IIOE-2 Town Hall meeting at the Ocean Sciences meeting, February 2016, New Orleans, USA, to the organisation and plenary presentations of the IIOE-2 symposium in February 2017 in Perth, Australia, and to the Bio-Argo workshop also held in February 2017 in Perth Australia.

A new SIBER website was launched in 2016, serviced from the Indian National Centre for Ocean Information Services (INCOIS) and linked to the IMBeR website, and a SIBER International Project Office has been set up at INCOIS, Hyderabad, India.

Together with IOP, SIBER is organising a winter school in 2018 at the National Institute of Oceanography, Goa, India.

E. Working Groups

IMBeR-Future Earth Coasts Continental Margins Working Group (CMWG)

The CMWG aims to compare a sparsely-populated northern Arctic shelf region with a shelf in a heavily-populated Southeast Asian region. IMBeR received funds from IGBP and the European Space Agency (ESA) to support a workshop to identify the relevant issues and knowledge needs for the Arctic margins case study. A special session was organized at the XMAS-III conference in Xiamen, China in early 2017 to discuss similar issues relating to the East China Sea case study. The IMBeR and Future Earth Coasts CMWG co-chairs are establishing a core group to take these case studies forward.

Human Dimensions Working Group (HDWG)

The HDWG continued development of the I-ADApT management tool. In March 2017, the manuscript of a book titled *Societal and Governing Responses to Global Change in Marine Systems* was submitted to Routledge. Objectives of the book are to explore and illustrate how the responses of the governance system have addressed the issue under consideration in 20 marine case studies from around the world.

HDWG members convened a session 'How to integrate natural and social science into advice for policy makers' with PICES, ICES and CLIOTOP at the World Fisheries Congress in Korea in May 2016, and contributed to the MSEAS Understanding Marine Socio- ecological Systems: Including the Human Dimension in Integrated Ecosystem Assessments conference in Brest, France in June 2016.

The 6th HDWG meeting was held at the Tokyo University of Marine Science and Technology, Japan in May 2016 and the 7th meeting will be held in France in 2017.

IMBeR-CLIVAR Eastern Boundary Upwelling Systems Working Group (EBUS)

EBUS contributed to the CLIVAR Open Science Conference “Charting the course for climate and ocean research” in Qingdao, China in September 2016, and held a workshop to refine the tasks of the working group in the context of the CLIVAR Science Plan. EBUS submitted a proposal for a SCOR working group in 2016 which unfortunately was not successful. They will revise the application and submit it again in April 2017.

SOLAS IMBeR IOCCP Carbon working group (SIC)

During 2016, it was decided to close the surface water and mid water SOLAS IMBeR carbon working groups as many of the original tasks were completed, and to create a new carbon working group with new objectives and incorporating the SCOR and IOC-UNESCO International Ocean Carbon Coordination project (IOCCP). The production (and review by IMBeR) of a new CLIVAR Science Plan also afforded an opportunity to align this group with CLIVAR. A small group of scientists representing IMBeR, SOLAS, CLIVAR and IOCCP will meet at the International Carbon Dioxide Conference (ICDC10) in Switzerland in August 2017 under the chairmanship of Nikki Gruber to propose new objectives for a new carbon working group.

SOLAS-IMBeR Ocean Acidification (SIOA)

The SOLAS-IMBeR Ocean Acidification Working Group continues to make advances, through the Ocean Acidification International Coordination Centre (OA-ICC), to its core activities of setting up a Global Observing Network, organising joint experiments and intercomparison exercises, maintaining advice on best practises and contributing to capacity building and outreach.

Selected highlights can be found in the quarterly releases from the OA-ICC available on their web page at <https://www.iaea.org/ocean-acidification>.

F. Endorsed projects

Atlantic Meridional Transect (AMT)

AMT is a multidisciplinary programme which undertakes biological, chemical and physical oceanographic research during an annual voyage between the UK and destinations in the South Atlantic. The AMT provides a platform for scientists to capture and analyse data related to a range of oceanographic science areas. Over 256 scientists have participated in AMT cruises and many more have worked with the data which is accessible through the British Oceanographic Data Centre (BODC). The data has produced over 300 scientific papers, and the long-term nature of the data collected is useful in analysing trends and forecasting future outcomes.

Gulf of Trieste Time series (GoTTs)

The Department of Biological Oceanography of the Italian National Institute of Oceanography and Experimental Geophysics is responsible for the Gulf of Trieste site as part of the Long Term Ecological Research network in the North Adriatic. The research activities, which have continued since 1970, range from marine biogeochemistry to ecology and are aimed at understanding the dynamics governing marine ecosystems and to evaluate the role of the oceans in the global energy balance.

Living-resource & Ecosystem Dynamics on the Slope of the South China Sea (LEDS) The northern slope region of the South China Sea is the breeding and nursing ground for commercially-valuable fish species such as octopus and tuna. Their vertical migration behaviour potentially forms a key link between lower and higher trophic levels as they act as predators on zooplankton and as prey for bottom and pelagic fishes, and feed in the surface layer during the night while resting and excreting in the deep layer (400-1000 m) during the day. This project aims to progress understanding of the role of mesopelagic fish in marine ecosystems, resource protection and utilization, and carbon sequestration in the ocean.

Mechanisms of Marine Carbon Storage and Coupled Carbon, Nitrogen and Sulphur cycles in response to global change (MCS-CNS)

The sensitivity of marine biogeochemical cycles to climate change remains unclear, especially for key processes which influence the long-term health of marine ecosystems. By understanding the interactions between the

microbial carbon pump and the biological carbon pump, this project aims to decipher the mechanisms of marine carbon storage, and the response of biogeochemical processes to climate change and anthropogenic activities.

Processes and Approaches of Coastal Ecosystem Carbon Sequestration (PACECS)

This project aims to investigate the key processes and mechanisms of carbon sequestration in coastal ecosystems in order to propose ways in which to increase the ocean carbon sink. Most of this 'Blue Carbon Sink' resides in the biomass of phytoplankton, bacteria, archaea, and protozoa, and so maximising the efficiency of this sink requires fundamental knowledge of the dynamics of marine microbes.

The Study of Kuroshio Ecosystem Dynamics for Sustainable Fisheries (SKED)

This interdisciplinary study aims to investigate the paradox of high fisheries production in the low nutrient Kuroshio western boundary current of the North Pacific Ocean, in order to ensure sustainable use of this ecosystem.

Variability of Ocean Ecosystems around South America (VOCES)

The goal of this project is to assess the impact of climate variability - both natural and anthropogenic - on the Humboldt, Patagonia and South Brazil Large Marine Ecosystems (LMEs) which are amongst the most productive in the southern hemisphere.

Integrated Arctic Observation System (INTAROS)

INTAROS will develop an integrated Arctic Observation System (iAOS) by extending, improving and unifying existing systems in the different regions of the Arctic. An integrated Arctic Observation System will enable better-informed decisions and better-documented processes within key sectors (e.g. local communities, shipping, tourism, fishing), in order to strengthen the societal and economic role of the Arctic region.

Ocean Foodweb Patrol – Climate Effects: Reducing Targeted Uncertainties with an Interactive Network (OCEAN CERTAIN)

The goals of OCEAN CERTAIN are to 1. Determine qualitative and quantitative changes in the functionalities of the foodweb and the efficiency of the biological pump to export carbon as a response to multi-stressors, 2. Identify the interactions (impacts and feedbacks) between climate-related oceanic processes and global climate dynamics, 3. Integrate marine ecosystem scenarios with probable socio-economic scenarios to help estimate/quantify human feedbacks to the coupled socio-ecological system, relevant to mitigation and adaptation pathways, 4. Develop scenario-based impact prediction capacity, and 5. Produce and test decision support tools and systems and assess their ability to support the sustainable exploitation of marine resources.

G. Implementation of the Science Plan in 2016

The IMBeR regional programmes and working groups are working towards the research goal outlined in the SPIS (2016-2025). In order to ensure efficient progress towards this goal, a number of task teams led by members of the Scientific Steering Committee (SSC) were initiated at the 2016 SSC meeting in New Orleans. At the 2017 SSC meeting in Shanghai a more comprehensive gap analysis was undertaken, and specific SSC members were tasked to scope out relevant activities already being undertaken in the international community and to propose a plan of action for IMBeR to achieve the SPIS Grand and Innovation Challenges. Progress towards achieving the IMBeR research goal during 2016 is outlined below:

Grand Challenge I: Understanding and quantifying the state and variability of marine ecosystems

The Challenge: To develop whole system level understanding of ecosystems, including complex biogeochemical cycles and human interactions, together with understanding of the scales of spatial and temporal variability of their structure and functioning.

ESSAS contributes to this challenge through The Resilience and Adaptive Capacity of Marine Ecosystems in the Arctic (RACArctic) initiative, which examines how variability and changes in advection, temperature, ocean acidity and ice dynamics in the Subarctic to Arctic transition zone may affect future marine ecosystems of the Pacific and Atlantic Arctic.

ICED has continued to develop whole ecosystem level understanding of the structure and functioning of Southern Ocean ecosystems, and their variability and response to change across a range of spatial and temporal scales. They have focussed on key species from Antarctic krill to whales (e.g. Silk et al. 2016; Jackson et al. 2016), and the structure of food webs (e.g. Horswill et al. 2016), as well as furthering work on comparative studies with the Arctic, focussing on the role of biodiversity in ecosystem structure and function (Murphy et al. 2016b). ICED have also examined physical, chemical and biological interactions (e.g. Hunt et al. 2016) and the effects of past and recent variability and change, such as ocean acidification (e.g. Manno et al. 2016).

The long-term overarching goal of SIBER is to improve understanding of the role of the Indian Ocean in global biogeochemical cycles and the interaction between these cycles and marine ecosystem dynamics. In order to quantify the state and variability of Indian Ocean ecosystems, and importantly, the physical forcing that drives this variability, SIBER was instrumental in fostering the development of the 2nd International Indian Ocean Expedition (IIOE-2) and the Eastern Indian Ocean Upwelling research Initiative (EIOURI).

CLIOTOP Task Team 2016-01 has been working to improve understanding of the trophic pathways that underlie the production of tunas and other pelagic predators in the open ocean, the movements of these predators, and the natural variability forced by the environment. Improved understanding resulting from the outputs of this task team will directly assist IMBeR-CLIOTOP in progressing understanding of marine ecology, food web dynamics, movements of top predators in a changing climate, and ocean biogeochemistry.

CLIOTOP Task Team 2016-05 is focussed on developing a standard set of metrics for describing the movements of marine animals that could be used across multiple platforms and multiple species, thereby allowing for multi-species, multi-platform comparisons in investigating the environmental and physiological drivers of movement in marine animals.

The Human Dimension Working Group (HDWG) continues to develop I-ADApT - an integrated assessment framework and learning platform for global change response. I-ADApT is developed from case-studies that cover a wide range of natural and social systems around the world that have been challenged by critical global change issues, allowing cross-case comparisons within specific social and ecological contexts.

Grand Challenge II: Improving scenarios, predictions and projections of future ocean-human systems at multiple scales.

The Challenge: To incorporate understanding of the drivers and consequences of global change on marine ecosystems and human societies at multiple scales into models to project and predict future states.

Progress towards this challenge is led by IMBeR SSC member Laurent Bopp and will be the focus of one of the workshops at the IMBIZO5 conference in October 2017.

An initiative to produce policy-relevant future scenarios of ecosystem services in the oceanic realm was recently published (Maury et al., 2017), and the five contrasted Ocean System Pathways (OSPs) developed have been chosen to form the official scenario basis of FishMIP (the Fisheries Model Inter-comparison initiative).

A dataviz tool is under development to provide easy access to the recent CMIP5 climate model projections for ocean ecosystem stressors (warming, pH, oxygen, primary productivity). This tool will enable selection of any ocean region, and show visualization of projections for surface temperature, surface pH, sub-surface oxygen, integrated primary production.

ICED have continued their model development in support of creating a suite of models of physical dynamics (ocean circulation and climate), biogeochemical cycles, and biological dynamics (life histories, population dynamics, food web structure) within a hierarchical framework of models of different spatial, temporal and trophic resolution. The ultimate aim of these activities will be to advance end-to-end ecosystem modelling approaches that integrate physical, chemical and biological processes.

CLIOTOP Task Team 2016-03 is developing dynamic seasonal forecasting models relevant to fisheries and conservation management. This has included submission of a book chapter on 'Predicting the distribution of

bluefin tunas in a changing ocean’, presenting at the US CLIVAR workshop on ‘Dynamical and statistical modeling for ecosystem forecasts’, and attending the ICES conference on ‘Seasonal to decadal prediction of marine ecosystems: opportunities, approaches and applications’.

CLIOTOP Task Team 2016-06 is developing process-based animal movement models that are biologically reasonable and capable of i) modelling behavioural response in relation to environmental covariates, and therefore ii) predicting animal movements in response to climatic changes.

Grand Challenge III: Improving and achieving sustainable ocean governance

The Challenge: To improve communication and understanding between IMBeR science, policy and society to achieve better governance, adaptation to and mitigation of global change, and transition towards ocean sustainability.

A scoping exercise for this Challenge is being led by SSC member Mark Dickey-Collas.

One of the objectives of ICED is to determine how Southern Ocean ecosystem structure, functioning and projections should be incorporated into adaptation, mitigation and sustainable management procedures by improving communication and understanding between science, policy and society. ICED is continuing its work with the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), the Antarctic Treaty’s Committee for Environmental Protection (CEP) and the International Whaling Commission (IWC) to ensure that ICED science is relevant and that scientific results are translated appropriately into messages that resonate with policy makers.

The SIBER activities that are most relevant to this IMBeR Challenge are related to IIOE-2 and the governance structure that has been created to guide it. The IIOE-2 is overseen by an international steering committee that aims to leave a lasting legacy of the expedition throughout the Indian Ocean region. This will be accomplished by establishing the basis for improved scientific knowledge transfer to wider segments of society and regional governments, and through the creation of educational and capacity development opportunities that target regional and early career scientists.

I-ADApT is an integrated assessment framework that builds on knowledge and lessons learned from past experience of responses to global change and is designed to enable decision makers, researchers, managers and local stakeholders to: (1) make decisions efficiently; (2) triage and improve their responses; and (3) evaluate where to most effectively allocate resources to reduce vulnerability and enhance resilience of affected people.

Innovation Challenge 1 To enhance understanding of the role of metabolic diversity and evolution in marine biogeochemical cycling and ocean ecosystem processes.

Progress towards completion of this challenge will be led by SSC members Gerhard Herndl and Tatiana Rynearson. The first activity will be a workshop at the IMBIZO5 meeting in October 2017 leading to publication of a synthesis of current understanding of metabolic diversity in the light of environmental change and identification of approaches needed to include metabolism and evolution in marine ecosystem models at multiple scales, from individual organisms to systems.

Innovation Challenge 2 To contribute to the development of a global ecosystem observational and modelling network that provides essential ocean variables (EOVs) and to improve marine data and information management.

A scoping exercise for this challenge is being undertaken by SSC member Dan Costa. Dan contributed to the organisation of the **Autonomous and Lagrangian Platforms and Sensors Scientific and Technical Review (ALPS-II)** held at the Scripps Institution of Oceanography in February 2017. The aim of the workshop was (1) to survey progress in autonomous platforms and sensors for ocean research since the original ALPS meeting 13 years ago, and (2) to assess future prospects and challenges.

Dan and CLIOTOP Co-Chair Kevin Weng participated in the The Global Ocean Observing System of the IOC-UNESCO (GOOS) and the OceanObs Research Coordination Network workshop on **Implementation of Multi-**

Disciplinary Sustained Ocean Observations in Miami, Florida, USA in February 2017. This workshop was tasked with identifying priorities for improving the coordinated planning and implementation of multi-disciplinary observing activities and demonstrations, by bringing together experts in physical, biogeochemical and biological/ecosystems ocean observations and modelling, users of established observing networks, and communities of practice.

The ICED community has made strong links with the SCAR-SCOR Southern Ocean Observing System and the CCAMLR Ecosystem Monitoring Program to progress integrated ecosystem observing to (i) support assessments of current status and trends of Southern Ocean ecosystems and (ii) provide foundation data for assessing the likelihood of future states of the system. Substantial progress has been made in identifying ecosystem Essential Ocean Variables as well as co-ordinating a year of field activities, proposed for 2022, to benchmark Southern Ocean ecosystems as a natural extension of the Census of Antarctic Marine Life undertaken a decade ago.

Several CLIOTOP members provided feedback on a draft paper on essential ocean variables for fish abundance and distribution circulated by the GOOS Panel on Biology and Ecosystems.

Innovation Challenge 3 To advance understanding of ecological feedbacks in the Earth System.

Implementation of this challenge will be discussed at the 2017 SSC meeting in Shanghai. ICED scientists have undertaken a review of marine biogeochemical feedbacks resulting from plankton community stoichiometry changes to ocean acidification and climate change as part of the SCAR Ocean Acidification review.

Innovation Challenge 4 To advance and improve the use of social science data for ocean management, decision making and policy development

Implementation of this challenge will be discussed at the 2017 SSC meeting in Shanghai.

ICED scientists have been actively developing studies to expand analyses of ecosystems to consider human social and economic system interactions. Following IMBIZO IV, Stuart Corney and Eugene Murphy have been working on an opinion piece “Integrating human dimensions into marine ecosystem models will improve management” that is under review with *Fish and Fisheries*.

H. Other IMBeR activities

IMBeR ClimEco 5 Summer School

The ClimEco 5 Summer School, was held in Natal, Brazil in August 2016 with the theme ‘*Towards more resilient oceans: Predicting and projecting future changes in the ocean and their impacts on human societies*’. Sixty four participants were chosen from more than 200 applicants based in 26 different countries. Topics that were covered include: Delineating the issues of climate change and impacts on marine ecosystems, Modelling approaches for natural and social science data, and Using science in management.

Early Career Researcher Network

An IMBeR Early Career Researcher (ECR) network is being established to create a forum for interdisciplinary ECRs focussed on building capacity in developing nations, providing leadership roles for ECRs, and to promote gender equality throughout the marine sciences. An organizing committee has been established, and proposals are underway to attract funding for the first ECR meeting.

Gordon Research Conference on Ocean Biogeochemistry

The conference was held at the Chinese University of Hong Kong in June 2016 and co- convened by past IMBeR SSC Chair Eileen Hofmann. One of the keynote presentations was given by the current IMBeR SSC Chair Carol Robinson, and several of the ICED community participated. The meeting emphasis was on the biologically-driven ocean carbon pumps, and included sessions on variations through geological time, microbial oxidation of organic matter within the water column, and the linkage of the carbon pump with silicon, nitrogen, phosphorous and iron cycles.

IMBeR-Future Earth Norway workshop

In September 2016, IMBeR and Future Earth Norway collaborated to convene a workshop to explore priorities for Norwegian research on ocean sustainability, oral presentations are available at www.futureearth.org/norway/results-IMBeR-fen-wshop-2016, and the meeting report at [http://www.imber.info/resources/images/prosjekter/imber/IMBER_Future- Earth_Norway_Worshop_Report-Final-1-Dec.pdf](http://www.imber.info/resources/images/prosjekter/imber/IMBER_Future-Earth_Norway_Worshop_Report-Final-1-Dec.pdf).

Future Earth – Ocean Knowledge-Action Network (KAN)

IMBeR continues to contribute to the development of the Future Earth Ocean KAN.

As part of a Future Earth core research project meeting in Bern, Switzerland in June 2016 Peter Liss chaired a brainstorming session to produce a draft proposal to be presented to the Belmont Forum for consideration for funding as a Collaborative Research Action (CRA). At its annual Plenary Meeting in Doha in October 2016, the Belmont Forum agreed to progress with the full scoping process of a Future Earth — Belmont Forum co-branded CRA on "Transdisciplinary Research for Ocean Sustainability". This process will be coordinated by the Swedish Research Council FORMAS, and the first scoping workshop will be held in May 2017.

In conjunction with this, Future Earth, the International Council of Science (ICSU), WCRP- CLIVAR, IOC- UNESCO and ICSU-SCOR organized a scoping workshop on the development of an integrative Ocean Knowledge-Action Network (Ocean KAN) hosted by the Kiel Cluster of Excellence "The Future Ocean" on 4-5 December 2016. The workshop was overseen by a scientific committee (including the IMBeR SSC Chair) and assembled nearly 100 representatives from 27 countries. As part of this meeting, the scientific committee and executive committees met to discuss the formation of an Ocean KAN development team. The Terms of Reference and call for applications for the Development Team were discussed extensively and the call will be released in 2017. Once established the Ocean KAN Development Team will develop a Research and Engagement Plan and a Funding Strategy based on the scoping activities held during the workshop. The aim is to formally launch the Ocean KAN at the UN Ocean Conference in June 2017.

IMBIZO 5

The fifth IMBIZO conference 'Marine biosphere research for a sustainable ocean: Linking ecosystems, future states and resource management' will be held from 2-5 October 2017 at the Woods Hole Oceanographic Institution, USA. Three concurrent but interacting workshops aim to progress specific aspects of the IMBeR Science Plan. These are: 1) Critical Constraints on Projections of Marine Systems (Laurent Bopp and Eric Galbraith), 2) Metabolic Diversity and Evolution in Marine Biogeochemical Cycling and Ocean Ecosystem Processes (Gerhard Herndl/ Tatiana Rynearson) and 3) Managing Strategy Evaluation: Achieving Transparency in Natural Resource Management by Quantitatively Bridging Social and Natural Science Uncertainties (Ingrid van Putten/Cisco Werner).

A capacity building workshop will be held the day before the start of the IMBIZO on how to create infographics to communicate science.

IMBeR China / Japan / Korea Symposium 2018

Planning is underway for the next CJK symposium, to be held in Shanghai in October 2018.

IMBeR Open Science Conference 2019

IMBeR received seven international applications to its open call to host the next open science conference. Brest, France was chosen to be the host, and planning is underway.

International Project Office (IPO, Norway)

Einar Svendsen, Lisa Maddison and Svein Sundby successfully applied for and were awarded funding for the IPO from March 2017 to March 2020 from the Norwegian Research Council and the Institute for Marine Research.

Einar Svendsen retired from the Executive Officer post at the end of June 2016. Gro I. van der Meeren was Executive Officer between 1 August 2016 and the end of June 2017. The post is currently being advertised, with applications due in September 2017.

IMR have confirmed that a renewal of funding after 2020 is unlikely, and so IMBeR has begun to investigate other possible hosts for the IPO from 2020.

During 2016, the IPO revised the IMBeR communication strategy. An e-newsletter is distributed weekly, the front page of the upgraded www.IMBeR.info website gives regular news highlights and @imber_ipo twitter account is frequently used to relay information to its 500 followers.

Regional Project Office (RPO, China)

Yi Xu and Fang Zuo successfully applied for a further three years of funding (2017-2020) for the RPO from the East China Normal University (ECNU). Carol Robinson and Gro I. van der Meeren visited Shanghai in October 2016 to sign the Memorandum of Understanding with the Director of the State Key Laboratory for Estuarine and Coastal research (SKLEC) and the Vice-president of ECNU.

SKLEC hosted the 2017 SSC meeting and will host the 2018 China/Japan/Korea IMBeR conference.

Yi Xu represented IMBeR at the 3rd Xiamen Symposium on Marine Environmental Sciences (XMAS III), the SCOR China meeting in Qingdao and the annual Future Earth Asia Workshop in Tokyo, Japan.

I. Scientific steering committee

The 2016 scientific steering committee consisted of a chair, Carol Robinson, *ex officio* Past Chair Eileen Hofmann and 14 members (8 male and 6 female). Edward Allison (M, USA), Alida Bundy (F, Canada) and Katrin Rehdanz (F, Germany) rotate off the SSC at the end of 2016. Eugene Murphy (M, UK) agreed to continue as an *ex officio* member of the SSC and Vice Chair of the Executive Committee.

An open call for nominations for three new SSC members was advertised in April 2016, requesting expertise in marine sustainability science, marine policy and governance science, integrated modelling of social and marine ecological systems, biodiversity and climate adaptation science and ocean literacy. From more than 30 applications, three new members were proposed and accepted by SCOR and Future Earth - Mark Dickey-Collas M, Denmark), Marion Glaser (F, Germany) and Alistair Hobday (M, Australia).

J. Collaborative partners

IMBeR science is strengthened and its impacts extended through on-going and new partnerships and collaborations with international and national organisations, including the International Council for Science (ICSU), the Scientific Committee on Oceanic Research (SCOR), Future Earth, the World Climate Research Programme (WCRP), and the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO) which sponsors the Global Ocean Observing System (GOOS) and the International Ocean Carbon Coordination Project (IOCCP).

IMBeR continues to have long standing collaborations with the SCOR and Future Earth global research projects SOLAS, Future Earth Coasts and PAGES. Further collaboration with the Earth System Governance, bioDiscovery and bioGENESIS projects are envisaged through implementation of the IMBeR Scien Plan and development of a Future Earth Ocean Knowledge-Action Network.

a. *Too Big To Ignore (TBTI)*

IMBeR is a partner of the TBTI project which includes 15 partners, 62 scientists from 27 countries. TBTI is conducting a global analysis, based on information systems, to better understand small-scale fisheries and to develop research and governance capacity to address global fisheries challenges.

b. *Ocean Carbon Biogeochemistry (OCB)*

OCB continues to actively support IMBeR by advertising its activities and events, and by providing financial support for activities. OCB are hosting and co-sponsoring IMBIZO 5 at Woods Hole in October 2017.

c. *World Climate Research Project (WCRP)*

CLIVAR, a core project of WCRP, and its Indian Ocean panel works closely with SIBER. The IMBeR Eastern Boundary Upwelling working group is co-sponsored by CLIVAR. A representative from the China CLIVAR office

attended the IMBeR SSC meeting in Shanghai in April 2017, and discussions are ongoing for a CLIVAR contribution to a newly formulated SOLAS IMBeR IOCCP carbon working group.

d. GOOS

SIBER has strong connections with the Global Ocean Observing System in the Indian Ocean – IOGOOS. Eric Lindstrom, GOOS co-Chair attended the 2016 IMBeR SSC meeting in New Orleans.

e. ICES

Collaboration with ICES will be developed through the appointment of Mark Dickey-Collas (ICES) to the IMBeR scientific steering committee.

f. PICES

IMBeR and PICES continue to collaborate, with representatives from both communities attending and funding each other's summer schools and science meetings. Gro van der Meeren, Cisco Werner, Ken Drinkwater and Masao Ishii attended the PICES 25th Annual Meeting in the USA in November 2016.

K. Selected IMBeR Publications

IMBeR has produced more than 1000 refereed research papers since 2005, with around 150 papers published in 2016-2017.

ICED

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We are requesting funding to support students and researchers from developing countries to attend the ClimEco 6 Summer School that will be held in Accra, Ghana in August 2018.

Amount requested: 7 500 USD