

Appendix 5
Integrated Marine Biosphere Research (IMBeR) Project



Annual Report to SCOR 2018 - 2019

A. Introduction

The Integrated Marine Biosphere Research project (IMBeR) is a global environmental change research initiative co-sponsored by the Scientific Committee on Oceanic Research (SCOR) and Future Earth.

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 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 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 regional programmes, working groups and endorsed projects, and is facilitated through focussed workshops (IMBIZOs), conferences and symposia, and the training of early career researchers at biennial Climate-Ecosystem (ClimEco) summer schools. [Further details at <http://www.imber.info>.]

B. IMBeR Science Plan and Implementation Strategy (2016-2025)

<http://www.imber.info/resources/images/prosjekter/imber/IMBeR-Science-Plan-and-Implementation-Strategy-2017.pdf>

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 bases 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 and emerging topics. Specific members of the scientific steering committee are designated as “Challenge Champions” to oversee progress towards the

objectives of the Grand Challenges made by the Regional Programmes, Working Groups, Endorsed Projects, and IMBeR meetings and other activities (Figure 1).

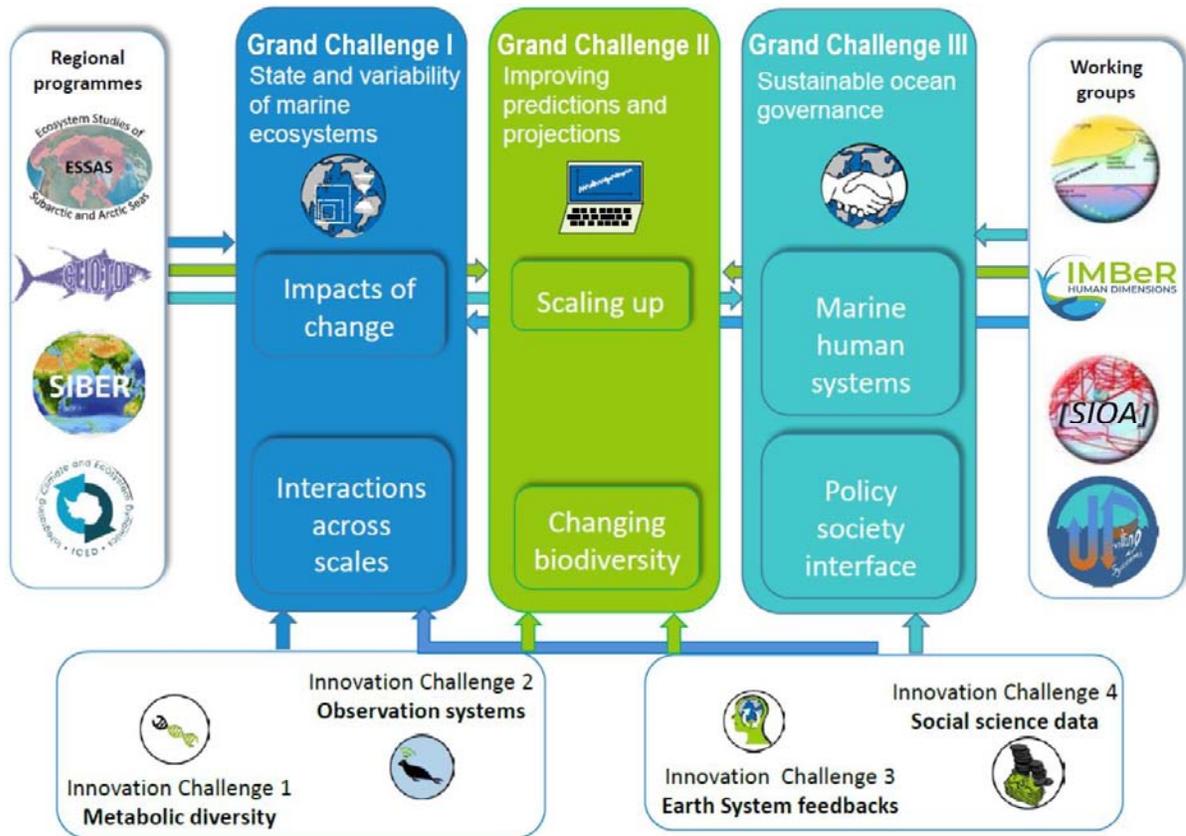
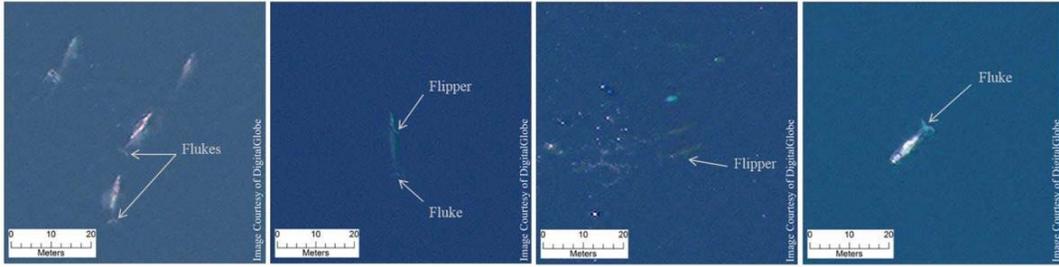


Figure 1. Contribution of the Regional Programmes, Working Groups and Innovation Challenges to the objectives of the Grand Challenges

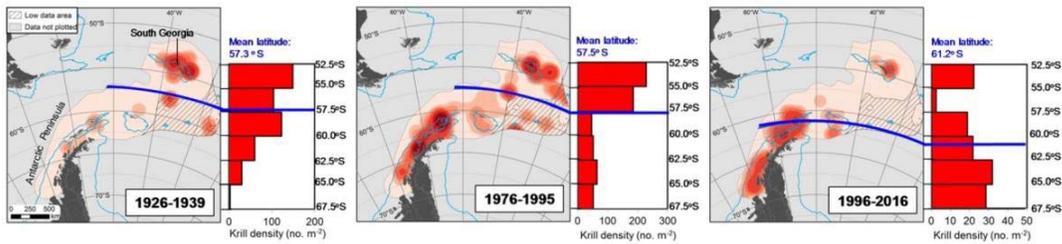
C. Selected science highlights in 2018-2019

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 and activities where IMBeR has contributed to the progression of fundamental knowledge in marine interdisciplinary science [For details of the figures presented, please refer to the original publication referenced]

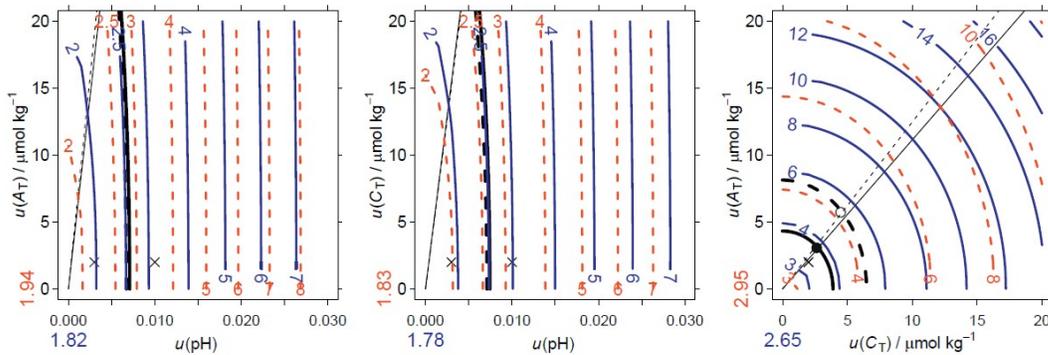
1. **Cubaynes et al (2019)** [British Antarctic Survey / ICED (IMBeR regional programme ICED – Integrating Climate and Ecosystem Dynamics)] demonstrated that advances in the resolution of satellite imagery now allow baleen whales to be identified definitively from satellite imagery. They used imagery from the WorldView-3 satellite to manually identify and count four different mysticete species: fin whales (*Balaenoptera physalus*) in the Ligurian Sea, humpback whales (*Megaptera novaeangliae*) off Hawaii, southern right whales (*Eubalaena australis*) off Peninsula Valdés, and gray whales (*Eschrichtius robustus*) in Laguna San Ignacio. The study demonstrated that high resolution satellite imagery can be used to monitor great whales.



2. **Atkinson et al (2019)** (IMBeR regional programme ICED – Integrating Climate and Ecosystem Dynamics) have observed major shifts in the distribution of krill: over the last 90 years, **krill (*Euphausia superba*) have moved and contracted southwards in response to warming seas**. Along with changing their geographic distribution, there have also been major changes in the size of krill, their densities, and the levels of recruitment. As a keystone species in the Antarctic, these changes have major implications for the species that feed on krill, and therefore food web structure and biogeochemical cycling. These findings are invaluable for the management of both the globally important fisheries of the Antarctic and its iconic biodiversity.

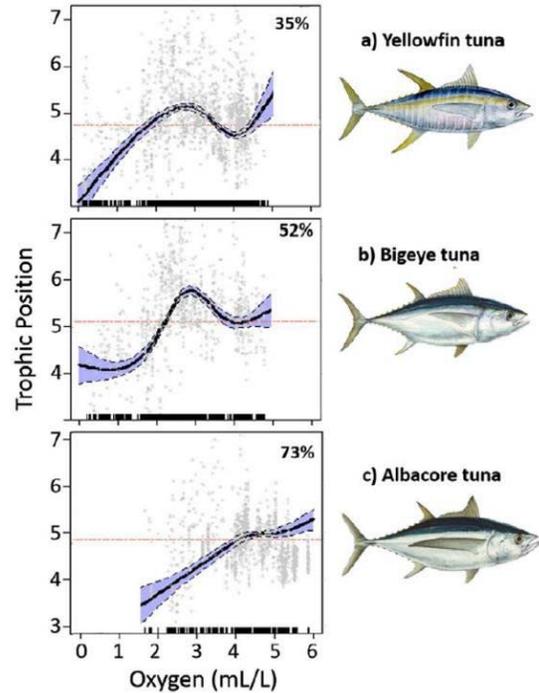


3. **Orr et al (2018)** (SOLAS-IMBeR Ocean Acidification Working Group - SIOA) developed **new tools for estimating uncertainties for calculated ocean acidification variables**. Previously, such uncertainties were seldom reported. These authors created software to propagate uncertainties and provided it as add-ons to four commonly used public packages that compute marine carbonate chemistry [CO2SYS-Excel (Visual Basic), CO2SYS-MATLAB (MATLAB), seacarb (R), and mocsy (Fortran)]. These tools along with a new type of diagram to visualise the uncertainties should allow propagating uncertainties to become standard practice for calculations of marine CO₂ system variables.

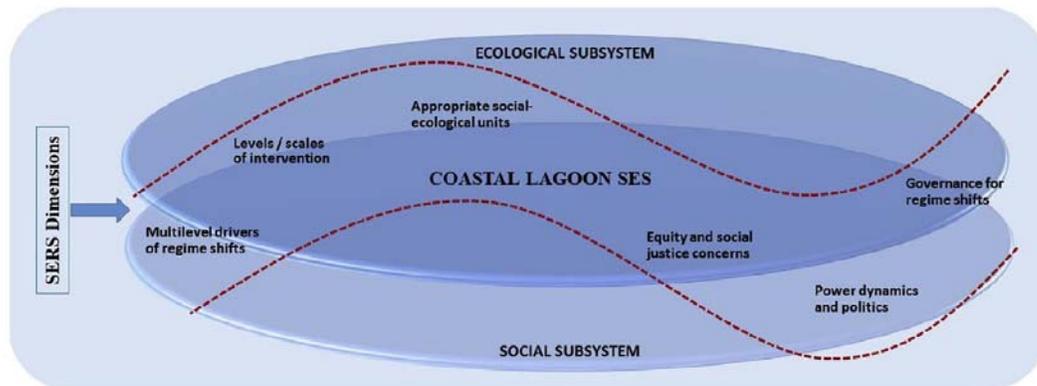


- In one of the first global studies of its kind, using stable isotopes **Pethybridge et al (2018)** identified previously unknown **effects of warming oceans on marine top predators and their food webs**.

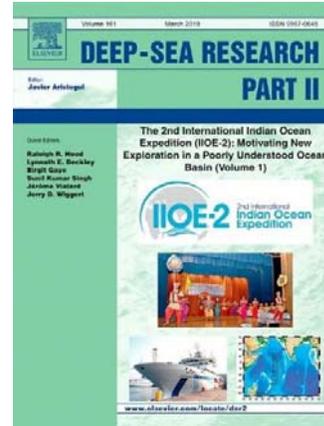
Through the network created by CLIOTOP (Climate Impacts on Oceanic Top Predators, IMBeR Regional Programme), they were able to collate samples of three species of tuna collected over a 16- year period by multiple research programmes. They found that the oxygen minimum zones – areas starved of oxygen – have a large effect on the food chain, and in the foraging behaviour of top predators, and that patterns were consistent across different regions. Because deoxygenation is a direct effect of climate change, these low oxygen zones are predicted to expand. The findings have broad implications and improve our ability to model the effects of climate change on ocean ecosystems.



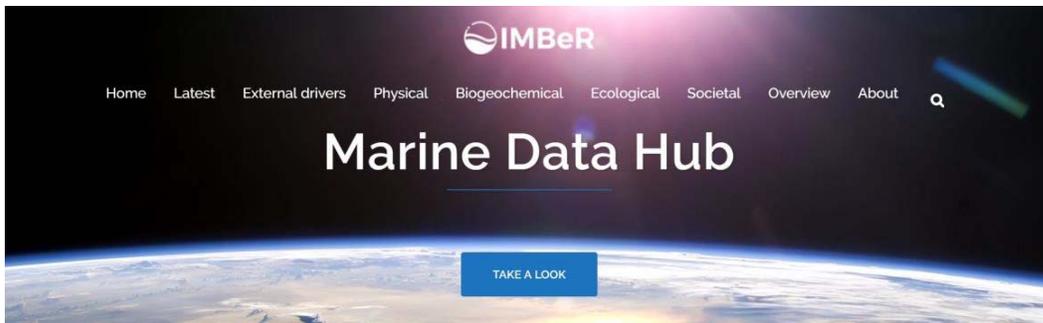
- Marine social-ecological systems are dynamic and involve many different groups of people, all with different understandings of the system, different priorities, and different visions about the future. While they all share a need to anticipate future changes, especially in the context of accelerated global change, it is difficult to combine these different actors effectively in the same process. To address this, and using the Barents Sea as a case study, **Planque et al (2019)** developed a widely applicable ‘**participatory scenario method**’ where actors develop scenarios jointly and can effectively explore the future of marine social-ecological systems.
- In global change science, the term ‘regime shift’ is typically restricted in its use to refer to the dramatic changes in a system from one ecological state to another. However, **Nayak and Armitage (2018)** have shown that this concept needs to be broadened to include social processes. Thus, considering ‘**social-ecological regime shifts**’ helps to identify suitable management interventions and approaches to governance. The study is a further example of the growing importance of interdisciplinary research to address global change.



- The IMBeR regional programme SIBER (Sustained Indian Ocean Biogeochemistry and Ecosystem Research) led the development of the first **Special Issue on the Second International Indian Ocean Expedition (IIOE-2)** for publication in **Deep-Sea Research II – The 2nd International Indian Ocean Expedition (IIOE-2): Motivating New Exploration in a Poorly Understood Basin, Volume 1**. This is the first compendium of scientific papers to emerge from IIOE-2 and three of the editors are/were SIBER SSC members. A second volume is in preparation and is scheduled to be published later in 2019, with contributions from SIBER SSC members.



- The IMBeR **Marine Data Hub** was launched (<https://ccdatahub.ipsl.fr/>). The Marine Data Hub is a product arising from the IMBeR IMBIZO 5 *Critical Constraints on Future Projections of Marine Systems* workshop. The hub links ecological, physical, biogeochemical and societal data sets for global models. It raises awareness of high quality data products, and encourages exchange.

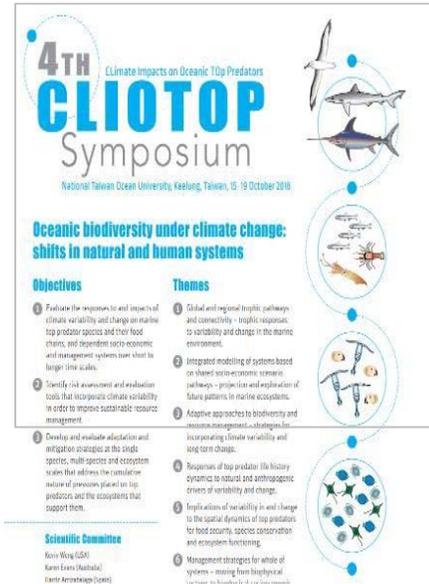


- Future Oceans2** – the 2nd IMBeR Open Science Conference (OSC) – was held in Brest, France, 17-21 June 2019. The meeting was attended by 553 delegates, with 27 Sessions and 10 Workshops, 549 Oral Presentations, 194 Posters, and an Early Career Researcher Day during which IMECaN (the IMBeR Interdisciplinary Marine Early Career Network) was launched.



10. The **Fourth CLIOTOP Symposium – Oceanic biodiversity under climate change: shifts in natural and human systems** – was successfully held in Keelung, Taiwan, 15-19 October 2018. This was attended by most CLIOTOP SSC members and the IMBeR International Project Office staff and drew good attendance, particularly from across Asia, a regional area where CLIOTOP has been working on expanding its network of collaborators. The conference was especially well attended by early career researchers and students.

11. **ClimEco6** (IMBeR Summer School) was held at the Gadjah Mada University in Yogyakarta, Indonesia, 1-8 August 2018. The theme of the summer school was “**Interdisciplinary approaches for sustainable oceans**” and participants were provided with practical ways to deal with the challenges arising from working across social and natural science disciplines. There were 59 participants from 19 countries.



12. Regional Programmes

Brief descriptions of the Regional Programmes and their major activities over the last year are presented below. Further details on their activities can be found in Section G. *Implementation of the IMBeR Science Plan*.

Ecosystem Studies of Subarctic and Arctic Seas (ESSAS)

<https://essas.arc.hokudai.ac.jp/>

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 (<https://essas.arc.hokudai.ac.jp/>).

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. RACArctic held its 3rd stakeholder meeting in Tromsø, Norway, 19 March 2019.

ESSAS was very involved in the IMBeR *Future Oceans2* OSC (17-21 June 2019): ESSAS convened the Session ‘Arctic marine ecosystems in a changing climate’ (28 oral presentations and 15 posters) to better understand recent variability and changes in the Arctic. ESSAS workshops: (1) The Bioenergetics working group (WG) organised a workshop on ‘Bioenergetics and survival trajectories of Arctic fish in response to environmental stressors’, and (2) the AnalogueART WG (Natural Analogues of an Arctic in Rapid Transition) convened a workshop on ‘Using natural analogues to investigate the effects of climate change and ocean acidification on northern ecosystems’.

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

www.iced.ac.uk/index.htm

The ICED regional programme aims to better understand climate interactions in the Southern Ocean, the implications for ecosystem dynamics, the impacts on biogeochemical cycles, and the development of sustainable management procedures. ICED is co-sponsored by SCAR (Scientific Committee on Antarctic Research).

ICED scientists in the USA (including Eileen Hofmann and Walker Smith) convened a Town Hall meeting at the fall AGU meeting in Washington, DC, USA in December 2018 with the aim of leveraging funding for a multidisciplinary, multinational effort in the Ross Sea to study the entire food web (end-to-end analyses), as well as a winter study involving novel technologies, and a study to investigate the initiation of the spring phytoplankton bloom. National Science Foundation and international representatives were present. An additional meeting was held in early 2019 in order to facilitate additional community input to address these critical scientific issues at circumpolar scales.

ICED contributed to the IMBeR *Future Oceans2* OSC, convening the session ‘Managing the effects of change on Southern Ocean ecosystems: Understanding, challenges, and solutions’. This was linked to ‘Southern Ocean ecosystems: a workshop on the Marine Ecosystem Assessment for the region (MEASO)’. The aim of the session was to reflect on the past decade of ICED science and apply insights to improve research on understanding and projecting changes in Southern Ocean ecosystems so that it is relevant to conservation and management decisions. The session focussed on: (i) Southern Ocean species and ecosystems; (ii) Modelling and projections of ecological change; (iii) Policy implications and decision-making (with a focus on integrated understanding of natural and human systems interactions). The workshop explored and discussed (i) the merits of different methods for assessing the status and trends of ecosystems, (ii) the respective utilities of the results for making management decisions on mitigating or adapting to prognoses of change, and (iii) how best to communicate the results to end-users. The workshop was attended by natural and social scientists.

CLimate Impacts on Oceanic TOP Predators (CLIOTOP)

<http://imber.info/science/regional-programmes/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.

The very successful Fourth CLIOTOP Symposium was held in Keelung, Taiwan, 15-19 October 2018.

Karen Evans, co-chair of CLIOTOP, was nominated to the Executive Planning Group for the UN Decade of Ocean Science for Sustainable Development. In this role, Evans provides a direct link between IMBeR and planning for the Decade.

Sustained Indian Ocean Biogeochemistry and Ecosystem Research (SIBER)

<https://incois.gov.in/portal/siber/index.jsp>

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.

There have been multiple Indian Ocean research activities motivated by or directly associated with SIBER. Notable among these are activities of the *Eastern Indian Ocean Upwelling Research Initiative* (EIOURI), and the activities associated with the new SOLSTICE-WIO programme which most recently included the *Agulhas Bank Ecosystem Study* cruise with the South African RV *Ellen Khuzwayo* (March 2019), and the May-June 2019 cruise with Australia’s new RV *Investigator* (May/June 2019). The track repeats that of a cruise that was part of the original IIOE, almost 60 years ago. Other significant SIBER-associated research has been conducted through the *African Coelacanth Ecosystem Programme* (ACEP, with a cruise in May 2019).

SIBER convened a session at *Future Oceans2* ‘The Second International Indian Ocean Expedition (IIOE-2): Motivating New Exploration in a Poorly Understood Basin’. The session brought together observationalists and modellers to exchange information and understanding on the current ‘state-of-knowledge’, gaps, challenges, and future directions in observing and modelling the complex physical, biogeochemical and ecological processes in the Indian Ocean in the context of anthropogenic influences and climate change.

13. Working Groups

Brief descriptions of the Working Groups are presented below. Further details on their activities can be found in Section *G. Implementation of the IMBeR Science Plan*.

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

<http://www.imber.info/en/projects/imber/science/working-groups-1/cmwg>

The CMWG aims to compare a sparsely-populated northern Arctic shelf region with a shelf in a heavily-populated Southeast Asian region. The CMWG is a collaboration between IMBeR and Future Earth Coasts. The CMWG convened a session at *Future Oceans2* titled ‘Ecosystem-social interactions in marginal seas’. The session aimed to improve understanding of marginal social-ecological systems, guiding sustainable development of resources and advising governance regimes to facilitate sustainable governance, facilitating equitable sharing of margin resources, and evaluating alternative research approaches and partnerships that address major margin challenges.

Human Dimensions Working Group (HDWG) <http://www.imber.info/en/projects/imber/science/working-groups-1/human-dimensions-working-group-hdwg>

The HDWG has continued to develop systems understanding of the human dimensions of marine resource use and interactions with global oceans. In particular, work by members of the group is pivotal to guiding and informing IMBeR Grand Challenges II and III. Achieving sustainable ocean governance is a rapidly developing field of research potentially heightened by a global focus on blue growth/economy.

At the IMBeR *Future Oceans2*, the HDWG convened a workshop and three sessions. The workshop ‘Visioning Global Ocean Futures’ explored how the *Nature Futures Framework* of IPBES resonates for the Oceans, contributing to iterative cycles of visioning, stakeholder co-creation, and modelling at global, regional and local scales that are supported by the IPBES Scenarios and Models Expert Group. The sessions – (i) ‘Modelling social-ecological systems: methods and tools for scenario development and prediction’, (ii) ‘Designing the quilt of sustainable ocean governance’, and (iii) ‘But why won’t they use my science? Improving the impact of marine science on policy; advances in theory and practice’ – explored and promoted the integration of human dimensions and governance into IMBeR-related science.

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

<http://www.imber.info/en/projects/imber/science/working-groups-1/eastern-boundary-upwelling-systems-ebus>

EBUS focuses on the potential effects of climate change on the intensity, seasonality and geography of upwelling systems and their ecological and socio-economical consequences. The WG promotes the understanding of biogeochemical, biological, fish and fisheries processes and trends on the four major coastal upwelling regions, i.e. California, Humboldt, Canary and Benguela, and their socio-economical impacts. In 2017 EBUS submitted a successful proposal to SCOR to form a SCOR working group co- chaired by IMBeR SSC member Ruben Escribano.

The EBUS SCOR WG met on 9 December 2018 in Washington DC. The group discussed issues relevant to modelling predictions and projections in EBUS and decided on the following actions: (1) Explore the opportunity to collaborate with the US CLIVAR Working Group ‘Changing Width of the Tropical Belt’, (2) Form a task team specifically focussed on this cross-shore wind stress comparison, (3) Planning for a summer school will continue via conference calls in winter and spring, and (4) Review and register comments on the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC; specifically the box on upwelling systems). R Escribano provides the link between this WG and IMBeR.

Integrated Ocean Carbon Research IOC-R

Collaboration between SOLAS, IMBeR, the Intergovernmental Oceanographic Commission - International Ocean Carbon Coordination Project (IOC-IOCCP), Global Carbon Project, World Climate Research Programme (WCRP) and CLIVAR

Following the disbandment of the SOLAS-IMBeR Carbon Working Group in 2017 (with the exception of SIOA), it was recognised that there was an important void to fill by the ocean carbon community. In July 2018, the IOC Secretariat agreed to the establishment of the Integrated Ocean Carbon Research working group (IOC-R). IOC-R is still in an early stage of development. The scientific committee includes IMBeR members Laurent Bopp, Niki Gruber and Carol Robinson and the first meeting will be held in October 2019.

SOLAS-IMBeR Ocean Acidification (SIOA)

<https://www.iaea.org/ocean-acidification>

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, providing 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 (above).

14. Endorsed projects

Atlantic Meridional Transect (AMT)

<https://www.amt-uk.org/>

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). Over 300 scientific papers have been published, and the long-term nature of the data (>20 years) continues to be useful in analysing trends and forecasting future outcomes.

Gulf of Trieste Time series (GoTTs)

http://nettuno.ogs.trieste.it/ilter/GoTTs/en_index.html

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.

Ocean acidification and Biogeochemistry: variability, trends and vulnerability (VOCAB)

<http://www.imber.info/en/projects/imber/science/endorsed-projects/vocab>

This project aims to address some of the gaps in our current knowledge of the vulnerability of selected marine ecosystems in Irish waters to ocean acidification (OA), by exploring some of the complex biogeochemical processes occurring at fine scales, and by studying the larger scale biogeochemistry of ocean waters impinging on those ecosystems. Fine scale sampling focuses on three areas, one of direct commercial interest (shellfish aquaculture) and two of wider importance (kelp beds and deep water coral ecosystems). NUI Galway and the Marine Institute led the GO-SHIP A02 survey in 2017 and the report has now been completed. Since then, several new systems have been installed on the RV *Celtic Voyager* that have enabled the collection of a variety of surface water and atmospheric samples. Surveys and fieldwork are continuing.

Processes and Approaches of Coastal Ecosystem Carbon Sequestration (PACECS)

<http://www.imber.info/en/projects/imber/science/endorsed-projects/pacecs>

The aim of PACECS is 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)

<http://snf.fra.affrc.go.jp/html/english/index.html>

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.

Mechanisms of Marine Carbon Storage and Coupled Carbon, Nitrogen and Sulphur cycles in response to global change (MCS-CNS) <http://www.imber.info/en/projects/imber/science/endorsed-projects/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.

Marine Ecosystem Modelling and Forecasting System in the China Seas and Northwestern Pacific (MEMFiS)

<http://imber.info/en/science/endorsed-projects/memfis>

Focusing on the ecology of the Bohai, Yellow, East and South China Seas, and the Northwestern Pacific, the MEMFiS project aims to develop an integrated modelling and forecasting framework, using high-resolution physical-ecosystem models and data from multiple sources. By investigating ecosystem variability at different temporal and spatial scales, several key scientific questions are being tackled. Marine ecosystem variability is addressed at the interface of different systems, parameterizations optimised for biogeochemical processes in different regions, data assimilation and ecosystem forecasting using multiple observations, not only from moorings, buoys and ships, but also from bio-Argo, gliders and high-resolution satellite imagery.

Integrated Arctic Observation System (INTAROS)

<http://www.intaros.eu/>

INTAROS is developing 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), to strengthen the societal and economic role of the Arctic region.

15. Implementation of the IMBeR Science Plan

The IMBeR regional programmes and working groups are working towards the research goal outlined in the SPIS (2016-2025). Progress towards achieving the objectives of the SPIS Challenges during the 2018-2019 period 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.

SIBER - Grand Challenge I

SIBER was instrumental in fostering the development of both the 2nd International Indian Ocean Expedition (IIOE-2) and the Eastern Indian Ocean Upwelling Research Initiative (EIOURI), both of which are dedicated to understanding and quantifying the state and variability of marine ecosystems and also, importantly, the physical forcing that drives this variability. The IIOE-2 has become a major international research programme in the Indian Ocean with an active international steering committee and joint programme offices (located in Hyderabad, India and Perth, Australia). National IIOE-2 committees have also been established in India, Australia, Germany, France, South Africa, UK and USA. Current and former SIBER Scientific Steering Committee (SSC) members have been instrumental in establishing IIOE-2 National Committees in all of these countries. Most recently, SIBER SSC members Mike Roberts and Jenny Hugget launched the UK/South African SOLSTICE-WIO project (<https://www.solstice-wio.org/>). Francis Marsac initiated a French research programme in the Western Indian Ocean - an important new component of IIOE-2.

ICED - Grand Challenge I

ICED has continued to develop whole ecosystem level understanding of the structure and functioning of Southern Ocean ecosystems, their variability and response to change across a range of spatial and temporal scales. ICED conducted detailed work on key species from phytoplankton to higher predators (e.g. Costa et al. 2019; Cubaynes et al. 2018; Kaufman et al. 2018; Saunders et al. 2018; Thorpe et al. 2019; Young et al. 2018; Xavier et al. 2018), and the structure of food webs (e.g. Dimitrijević et al. 2018; Krüger et al. 2018; Sequeira et al. 2018). Work also continued on physical, chemical and biological interactions (e.g. Belcher et al. 2019; Manno et al., 2018; Peck et al. 2018) and the effects of past (e.g. Tarling et al. 2018) and recent variability and change, such as ocean acidification (e.g. Atkinson et al. 2018; Freer et al. 2018; Klein et al. 2018; Kruger et al. 2018b; Trathan et al. 2018). Work in these areas is pivotal to guiding and informing ICED's work under GC II and GC III.

ESSAS - Grand Challenge I

Understanding variability in high-latitude marine ecosystems in response to climate variability and change is a central goal of ESSAS. A major initiative by ESSAS to further this goal was the Resilience and Adaptive Capacity of Arctic marine ecosystems (RACArctic) project. The project is nearing its end and a 3rd stakeholder meeting was held in Tromsø, Norway, 19 March 2019 (following two earlier stakeholder meetings in Hakodate, Japan, and Juneau, Alaska, USA). Meeting participants included industry representatives and scientists. This project aims to synthesise expected effects of climate change on high-latitude marine ecosystems, including their consequences for fisheries and fisheries management.

A number of national programmes endorsed by ESSAS monitor marine ecosystems and conduct research in both the Pacific Arctic and Atlantic Arctic, in particular the northern Bering Sea / Chukchi Sea (Japan, USA, Korea), the Barents Sea / Fram Strait (Norway, Russia), the waters around Iceland, and the Northwest Atlantic (Canada, Greenland).

To foster a better understanding of high-latitude changes within the IMBeR community, ESSAS organised a scientific session on 'Arctic marine ecosystems in a changing climate' (28 oral presentations and 15 posters) at the IMBeR Open Science Conference (OSC) to better understand recent variability and changes in the Arctic.

CLIOTOP - Grand Challenge I

CLIOTOP Task Team 2016-04 participated in the FAO led Fish Forum. This forum had the objective of "Bringing together the wider community of scientists and experts working on fisheries and the marine environment in the Mediterranean and Black Sea in order to build a lasting network, discuss advancements in research, integrate scientific knowledge in support of decision-making and identify research priorities for the coming decade". The task team participated in a workshop on operational fisheries oceanography where it was agreed that such a network should focus on 5 specific goals or challenges:

- a. Better identification and understanding of the environmental drivers affecting key species and ecological processes
- b. Adequate parameterisation of the environmental drivers identified (by definition of appropriate indicators)
- c. Development of best practices for integrating indicators into current assessment models
- d. Fostering capacity building
- e. Identifying successful case studies and promoting new ones

Task Team 2016-06 continued developing movement models for inferring behaviour- environment relationships in top predators, with a first case study of southern elephant seals.

A major focus has been the development of a model using Template Model Builder for the first time. This model is detailed in a publication in *Ecology* (Jonsen et al. 2018). The task team has also been developing movement models for the vertical dimension that enables inference at the scale of individual dives, as well as longer-term inference over many dives, at the scale of days and weeks. *In situ* and modelled oceanographic covariates are associated with seal dives to understand the relationship between environmental features and behavioural switches that manifest at biologically relevant time scales. An R package *foieGras* has also been developed by the team and has been published on CRAN (<https://cran.r-project.org/web/packages/foieGras/vignettes/foiegras-basics.html>). This focuses on Argos location filtering, a necessary step prior to analysis and simulation of movement behaviour in an environmental context.

Task Team 2017-01 attended a workshop on community-level metrics, mercury isotopes, and data-model linkages and has been wrapping up a number of publications that have either been published (Álvarez-Berastegui et al. 2018, Dhurmeea et al. 2018, Houssard et al. 2019, Pethybridge et al. 2018, and Regelo et al. 2018), are currently in review or in the final stages of preparation. These have focussed on improving 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.

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.

ESSAS - Grand Challenge II

As part of the RACArctic project (see above), ESSAS has focused on developing plausible scenarios for anticipated changes in high-latitude marine ecosystems, and in particular the consequences for fish populations and fisheries, based on a review of available literature, including qualitative predictions and available projections. Three manuscripts are in preparation, as well as an information sheet for stakeholders. ESSAS focuses on comparative analyses among Arctic marine ecosystems and works to initiate and facilitate such comparisons by bringing scientists from around the circumpolar North together at workshops and scientific sessions such as the IMBeR OSC.

ICED - Grand Challenge II

ICED has continued 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 is to advance end-to-end ecosystem modelling approaches that integrate physical, chemical and biological processes and generate projections of Southern Ocean ecosystems. Recent work in this area includes Freer et al. 2018; Klein et al. 2018; Kruger et al. 2018b; and Murphy et al. 2018 -CCAMLR).

ICED has used its understanding of the drivers and impacts of climate change (under GC I in the Southern Ocean to further work on developing scenarios of key drivers and projections of ecological change. For example, an ICED Projections workshop was held in April 2018, in collaboration with the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), to further the scenarios and projections work (Murphy et al. 2018).

CLIOTOP - Grand Challenge II

CLIOTOP Task Team 2016-06 has been working on movement models for humpback whale populations and extracting and compiling CMIP5 output into environmental fields suitable for such models. Current models being tested relate movement to sea ice, ocean temperature and phytoplankton and carbon for the last decade of the historical run using the NorESM1-ME earth system model (selected as it performs well in representing the seasonal sea ice cycle) and setting up a simulation framework using the equivalent fields for the last decade (2091-2100) of the RCP8.5 run.

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.

SIBER - Grand Challenge III

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 has developed full operational details to guide the Expedition. This steering committee is chaired by high-level representatives from the Indian Ocean GOOS (IOGOOS) program, the Scientific Committee for Oceanic Research (SCOR) and UNESCO's Intergovernmental Oceanographic Commission (IOC). A key aspiration of this committee is to leave a lasting legacy throughout the Indian Ocean region, as did the original IIOE. This is being 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. These efforts all contribute directly to IMBeR's goal of improving and achieving sustainable ocean governance. As previously stated, SIBER has been instrumental in establishing IIOE-2 and its governance structure. Further, the Sustainable Oceans, Livelihoods and food Security Through Increased Capacity in Ecosystem research in the Western Indian Ocean (SOLSTICE- WIO) program (co-led by SIBER SCC member Mike Roberts), is focused on fisheries and food security in the western Indian Ocean, and combines environmental and socio- economic research with state-of-the art techniques and knowledge transfer, to develop policies for sustainable and resilient fisheries.

ICED - Grand Challenge III

ICED continues to work with the Antarctic Treaty Commission via the Scientific Committee for Antarctic Research (SCAR, within which ICED is a 'Co-Sponsored Programme'), and with a number of Antarctic Treaty agreements including the Committee for Environmental Protection (CEP) and the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). ICED also continues to work with other international environmental treaties and organisations, conservation groups, and international committees, including the International Whaling Committee.

Antarctic Treaty System: ICED provides input to the Antarctic Treaty System via SCAR and builds on collaborations with a number of treaty agreements, particularly the CEP and CCAMLR. The Antarctic Treaty System recognises the role that ICED can play in providing external and valuable input on climate change impacts on Southern Ocean ecosystems to their work, that otherwise would not be available.

SCAR: SCAR is tasked with providing scientific advice to the Antarctic Treaty via reports and representation at the annual Antarctic Treaty Consultative Meetings (ATCMs). ICED contributes to SCAR's annual scientific reports. This includes highlighting ICED science under GC's I, II and those that specifically address GC III. ICED provided input for SCAR's Annual Report to the Scientific Committee of CCAMLR (SC CCAMLR), summarising the 2018 work relating to fishery management and policy.

CEP: ICED scientists engage with CEP by providing information on climate change impacts on ecosystems to the Antarctic Treaty, e.g. ICED works with the CEP on their Climate Change Response Work Programme.

CCAMLR: ICED continues its work with CCAMLR to ensure that ICED science is relevant to CCAMLR and that scientific results are translated appropriately into messages that resonate with policy makers.

- A working group paper on the preliminary results of the ICED-CCAMLR Projections workshop (June 2018, Cambridge, UK) was submitted (Murphy et al. 2018a), followed by a background paper detailing the full results of the workshop, including recommendations to CCAMLR (Murphy et al. 2018b).
- ICED scientists attended the CCAMLR Workshop on Spatial Management in June 2018, Cambridge, UK (WS-SM-18). The potential for ICED and CCAMLR to work together on spatial management issues was noted. This includes, but is not limited to, joint ICED-CCAMLR activities on projections of change, together with ICED research focussed on understanding the structure and functioning of Southern Ocean ecosystems and their variability and response to change across a range of spatial and temporal scales. Currently, this has particular relevance to the future research and monitoring plan for the "Domain 1" MPA proposal for the Antarctic Peninsula region. ICED will continue to develop activities to support the work of CCAMLR and ensure this links with

CCAMLR's ongoing work on spatial management.

- A number of publications have been submitted by ICED scientists to CCAMLR in support of fisheries management and development of future MPA's.

Conservation Groups: ICED scientists continue to lead a science-policy initiative based in Cambridge, UK that relates to this objective (see IC 4 for details) and science-policy fora as part of the MEASO2018 Conference (see IC 4).

Other international organisations:

IPCC: ICED scientist, Jess Melbourne-Thomas (AAD and ACE CRC, Australia) was selected as lead author of the Polar Regions chapter of the IPCC Special Report on the *Ocean and Cryosphere in a Changing Climate*. This Report will build on the work of the IPCC's Fifth Assessment Report (AR5). It is scheduled to be finalised in September 2019. Other ICED scientists (including Dan Costa, ICED SSC) have been involved as contributing authors to the *Changing Ocean, Marine Ecosystems, and Dependent Communities* chapter.

IPBES: ICED scientists have expressed concern over the exclusion of the Southern Ocean in its remit both directly to IPBES and through the external reviewer process of the IPBES global assessment of biodiversity.

CLIOTOP - Grand Challenge III

Members of Task Team 2016-04 are now contributing to the European Union-funded PANDORA project. This project aims to:

1. Create more realistic assessments and projections of changes in fisheries resources by utilising new biological knowledge including, for the first time, proprietary data sampled by pelagic fishers.
2. Advice on how to secure long-term sustainability of EU fish stocks and elucidate trade-offs between profitability and number of jobs in their fisheries fleets. Provide recommendations on how to stabilise the long-term profitability of European fisheries.
3. Develop a public, internet-based resource tool box, including assessment modelling and stock projections code, economic models, and region- and species-specific decision support tools; increase ownership and contribution opportunities of the industry to the fish stock assessment process through involvement in data sampling and training in data collection, processing and ecosystem-based fisheries management.

CLIOTOP Co-chair Karen Evans, as well as being a member of the Group of Experts coordinating the second World Ocean Assessment is leading the writing of a chapter in the assessment on cumulative impacts and is contributing to chapters relating to management approaches. These chapters will provide an overview of current processes for the assessment of cumulative impacts and varying management approaches, including an assessment of pros and cons. She is also leading the writing of a manuscript for the special issue associated with OceanObs'19 discussing how the world ocean assessment provides links between ocean observations and policy across multiple scales.

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

A recent publication in *Trends in Ecology and Evolution* by Baltar et al. (2019) entitled '*Towards Integrating Evolution, Metabolism, and Climate Change Studies of Marine Ecosystems*' is a product from the working group from '*Workshop 2: Metabolic diversity and evolution in marine biogeochemical cycling and ocean ecosystem processes*' of the IMBeR IMBIZO 5 meeting, Woods Hole Oceanographic Institution, October 2017.

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.

SIBER – Innovation Challenge 2

This IMBeR Challenge represents one of the central goals of SIBER. SIBER emerged as a result of the potential opportunity to leverage the CLIVAR/GOOS Indian Ocean mooring array (RAMA/IndOOS) and associated measurements and cruises for doing biogeochemical and ecological research. SIBER provides the biogeochemical and ecosystem research focus and counterpart for IndOOS and the IORP. This opportunity is being realised through the deployment of biogeochemical sensors on the RAMA mooring array and the deployment of bio-Argo floats in the northern and southwestern Indian Ocean. An Australia/India 4-year BioArgo collaboration (Nick Hardmann-Mountford [CSIRO], and former SIBER SSC members Wajih Naqvi [NIO] and Ravichandran [INCOIS]) was launched in 2014 and recently completed, generating a large amount of unprecedented and valuable data; <http://biogeochemical-argo.org/key-areas-projects-io-bio-argo.php>. Plans are being developed for the deployment of many more biogeochemical sensors in the Indian Ocean as part of IIOE-2 and the second phase of IndOOS. These efforts are all focussed on measuring biogeochemical EOVs that contribute to the development of a global ecosystem observational and modelling network.

ICED – Innovation Challenge 2

The ICED community has made strong links with relevant SCAR groups, the SCAR- SCOR Southern Ocean Observing System (SOOS) and the CCAMLR Ecosystem Monitoring Program to progress integrated ecosystem observing. These, together with ICED's Marine Ecosystem Assessment of the Southern Ocean (MEASO) will (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. ICED scientists involved in SOOS have been involved in progressing its development of 5 regional working groups: West Antarctic Peninsula and Scotia Arc, the Weddell Sea and Dronning Maud Land, Southern Ocean Indian Sector, Ross Sea, and the Bellingshausen- Amundsen Sea working groups. It has also established a task team on ecosystem Essential Ocean Variables in support of the Marine Ecosystem Assessment for the Southern Ocean. These groups are directly aligned with activities in ICED and will contribute to sustained observations to support ICED modelling efforts. Also, there is consideration of circumpolar ecosystem field research activities that will support future activities of ICED in understanding key processes, such as in the sea ice zone. A further activity that will have synergies with ICED modelling activities is the Capability Working Group on designing the observing system.

ESSAS – Innovation Challenge 2

Many of the ESSAS-endorsed national projects provide observations of EOVs in high- latitude marine ecosystems. For example, the Arctic Marine Biological Observation Network (AMBON), an ESSAS endorsed project, is developing a long-term observing programme in the Chukchi Sea to monitor EOVs and biodiversity at all trophic levels, from microbes to whales. Several Japanese programmes routinely contribute to sampling standard transect lines in the northern Bering Sea and Chukchi Sea that together form the 'Distributed Biological Observatory'.

Former ESSAS co-chair and SSC member S.-I. Saitoh and current co-chair F. Mueter were involved in the development of an 'Integrated Ecosystem Assessments (IEA)' for the Central Arctic Ocean. F. Mueter is working with the PAME Ecosystem Approach to Management group to develop an IEA for the Chukchi Sea. Co-chair B. Planque is involved in IEAs for the Norwegian and Barents Seas.

ESSAS organised a workshop in 2018 on Integrated Ecosystem Assessments for the Subarctic and Arctic that helped inform the development of plans for a new Chukchi Sea IEA.

CLIOTOP – Innovation Challenge 2

Task Team 2016-04 participated in the 2018 conference of the Mediterranean Operational Network for the Global Ocean Observing System (MONGOOS) to further the development of the MONGOOS science and strategy plan. The plan can be accessed at [http://www.mongoos.eu/documents/11176/135008/MonGOOS+Science+and+Strategy+Plan+Document+\(Lower+Resolution\)](http://www.mongoos.eu/documents/11176/135008/MonGOOS+Science+and+Strategy+Plan+Document+(Lower+Resolution)).

Collaboration with GOOS – Innovation Challenge 2
IMBeR SSC members are involved in drafting the specification for an emerging GOOS EO2 on microbial biomass and diversity.

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

ICED – Innovation Challenge 3

An evaluation of regional ocean acidification from observations and CMIP5 models, species and functional group responses to OA and other stressors, ecological change and a review of marine biogeochemical feedbacks resulting from plankton community stoichiometry changes to ocean acidification and climate change has been undertaken as part of the SCAR Ocean Acidification review and led by ICED SSC member Richard Bellerby. In his IMBeR SSC role, Eugene Murphy, with Laurent Bopp, developed a session at *Future Oceans2* on ecological feedbacks.

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

SIBER – Innovation Challenge 4

An example of emerging SIBER-driven projects that address this IMBeR challenge is the SOLSTICE-WIO project (co-led by SIBER SCC member Mike Roberts). It involves case studies of threatened, emerging and collapsed fisheries, in Tanzania, Kenya and South Africa, respectively, including socio-economic as well as environmental research through to outreach and briefs to stakeholders and policy makers (<https://www.solstice-wio.org/>).

ESSAS – Innovation Challenge 4

Alan Haynie (NOAA, USA), chair of the ESSAS working group on Human Dimensions, is active at national and international levels to develop better approaches to using economic data for supporting decision making in fishery management.

ICED – Innovation Challenge 4

ICED scientists have been developing studies to expand analyses of ecosystems to consider human social and economic system interactions. Following a workshop convened by ICED scientists Eugene Murphy, Stuart Corney and Jess Melbourne-Thomas at IMBIZO IV, (which emphasised that ecological models are now sufficiently advanced that they are useful for decision-making) ICED continues to develop activities aimed at integrating human dimensions into marine ecosystem models. Eugene Murphy presented a talk on this topic at the MEASO2018 meeting held in Hobart, Australia in April 2018, considering how modelling can be developed to help robust decision making. ICED scientists have also been working on understanding stakeholder perspectives on ecosystem-based management of the Antarctic krill fishery. This has been well received within CCAMLR and discussions of follow-up work in this area are underway. Work has also continued on ecosystem services in the Southern Ocean. The use of social science data in decision-making is an area ICED is keen to develop with other relevant groups (e.g. IWC and Centre for Science and Policy, University of Cambridge, CSaP) and two workshops, held in Cambridge were led by ICED scientists Rachel Cavanagh and Susie Grant. The second of these was “Ocean Plastics: Challenges and Solutions” (Cambridge, Mar 2018). These form part of a series on Science-Policy Challenges in Polar Conservation and Management in collaboration with the Cambridge Conservation Initiative (a collaboration between the University of Cambridge and 9 leading international biodiversity conservation organisations).

16. Other IMBeR activities

Future Oceans2

<http://imber.info/en/events/osc/2019>

The 2nd IMBeR Open Science Conference – *Future Oceans2* – was held in Brest, France, 17-21 June 2019 (workshops held 15-16 June 2019)

553 Attendees • 27 Sessions • 10 Workshops • 549 Oral Presentations • 194 Posters • Early Career Researcher Day

4th CLIOTOP Symposium

<http://imber.info/events/imber-working-groups-program-events/4th-cliotop-symposium> The 4th CLIOTOP Symposium was held at the National Taiwan Ocean University, Keelung, Taiwan, 15-19 October 2019
>100 Attendees • 6 Sessions • 40 Oral Presentations • 15 Posters

Interdisciplinary Marine Early Career Network (IMECaN) <http://www.imber.info/science/imecan--interdisciplinary-marine-early-career-network> IMECaN was officially launched at *Future Oceans2* on 16 June 2019. Stephanie Brodie will take over as Chair of IMECaN from Chris Cvitanovic on 1 January 2020.

IMECaN Early Career Researcher Day

<http://imber.info/en/events/osc/2019/early-career-day>

IMECaN held an Early Career Day (16 June 2019) prior to *Future Oceans2*. The workshop focused on career development paths for marine researchers, and using infographics in research outputs. Attended by >200 Early Career Researchers and students.

ClimEco6 Summer School

<http://www.imber.info/en/events/climeco-imber-summer-schools/interdisciplinary-approaches-for-sustainable-oceans>

ClimEco6 was held at the Gadjadara University in Yogyakarta, Indonesia, 1-8 August 2018. The theme of the summer school was “Interdisciplinary approaches for sustainable oceans” and participants were provided with practical ways to deal with the challenges arising from working across social and natural science disciplines.

About 60 participants attended.

8th IMBeR China / Japan / Korea Symposium

<http://imber.info/en/events/china-japan-korea-imber-symposia/cjk8>

The 8th IMBeR China / Japan / Korea Symposium was held at the East China Normal University, Shanghai, China, 17-19 September 2018

>100 Attendees • 3 Sessions • 1 Workshop • 47 Oral Presentations • 35 Posters

The next symposium in the series will be the first *IMBeR West Pacific Symposium* and will be held in Thailand in August 2020.

Inaugural Continental Margins Working Group Workshop

The inaugural Continental Margins Working Group workshop was hosted by the State Key Laboratory for Estuarine and Coastal Research (SKLEC), East China Normal University (ECNU), Shanghai, China, 20-21 September 2018.

I. IMBeR Project Offices

International Project Office (IPO, Norway)

The current IPO hosting arrangement with the Institute of Marine Research, Bergen, Norway, will come to an end in April 2020. The IPO is in the process of finalising its move to a new host institution and is in discussions with a consortium of institutions from Halifax, Canada, and with SKLEC, East China Normal University, Shanghai, China to grow the IMBeR Regional Project Office into an IPO. The possibility of having two IPOs is being discussed, with the current Bergen IPO Director and Deputy Director moving to Halifax.

Regional Project Office (RPO, China)

Xiaona Wang was recruited as Project Assistant.

Funding is available for the RPO from the State Key Laboratory for Estuarine and Coastal research (SKLEC) at the East China Normal University (ECNU) until 2020. SKLEC is in discussions for the RPO to become an IPO led by Deputy Director Fang Zuo (see above).

J. Scientific Steering Committee (SSC)

An open call for nominations for four new SSC members was advertised in 2017. From 36 applications, four new 2018 SSC members were proposed and accepted by SCOR and Future Earth – Oscar Iribane (M, Argentina), Alice Newton (F, Portugal), Suvaluck Satumanatpan (F, Thailand) and David VanderZwaag (M,

Canada). We also appointed *ex officio* members Olav Kjesbu (M, Norway; to act as an IMR liaison), Chris Cvitanovic (M, Australia; as the early career representative) and Frank Muller Karger (M, USA; as the liaison with GEO BON to contribute to Innovation Challenge 2). At the end of 2018, Daniel Costa (M, USA) and Cisco Werner (M, USA) rotated off the SSC as did *ex officio* member Ken Drinkwater (M, Norway), and Jeomshik Hwang (M, South Korea) was proposed and accepted as an SSC member in 2019.

Details of the current IMBeR SSC members are listed in the Appendix.

K. 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, PAGES, Earth System Governance and bioDiscovery.

1. 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.

2. Ocean Carbon Biogeochemistry (OCB)

OCB continues to actively support IMBeR by advertising its activities and events, and by providing financial support for activities.

3. 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. CLIVAR is also part of the newly established Integrated Ocean Carbon Research (IOC-R).

4. GOOS

SIBER has strong connections with the Global Ocean Observing System in the Indian Ocean – IOGOOS.

5. ICES

Collaboration with ICES continues through the membership of Mark Dickey-Collas (ICES) on the IMBeR Scientific Steering Committee.

6. PICES

IMBeR and PICES continue to collaborate, with representatives from both communities attending and funding each other's summer schools and science meetings. Carol Robinson was a member of the ICES/PICES working group on Climate Change and Biologically-driven Ocean Carbon Sequestration (WGCCBOCS) which ended in 2018 and represented IMBeR on the organising committee of the PICES International Symposium The Effects of Climate Change on the World's Oceans (ECCWO) to be held in Washington in June 2018. PICES co-sponsored ClimEco5 in August 2018 and *Future Oceans2* in June 2019.

L. Selected IMBeR Publications

IMBeR has produced more than 2,500 refereed research papers since 2005, with around 150 papers published in 2018-2019.

IMBeR General

Baltar F, Bayer, B, Bednarsek N, Deppeler S, Escribano R, Gonzalez CE, Hansman RL, Mishra RK, Moran MA, Repeta DJ, Robinson R, Sintés E, Tamburini C, Valentin LE, Herndl GJ (2019) Towards Integrating Evolution, Metabolism, and Climate Change Studies of Marine Ecosystems. *Trends in Ecology &*

ICED Publications

Management and Policy related reports and papers to CCAMLR, IWC, ACAP etc

- Atkinson, A., Hill, S.L., Pakhomov, E.A., Siegel, V., Reiss, C.S., Loeb, V., Steinberg, D.K., Schmidt, K., Tarling, G.A., Gerrish, L. & Sailley, S.F. 2019. Krill (*Euphausia superba*) distribution contracts southward during rapid regional warming. *Nature Climate Change*, 9:142-147 DOI: 10.1038/s41558-018-0370-z
- Cubaynes, Hannah C., Peter T. Fretwell, Connor Bamford, Laura Gerrish, Jennifer A. Jackson. 2018. Whales from space: four mysticete species described using new VHR satellite imagery. *Marine Mammal Science* 35 (466-491). <https://doi.org/10.1111/mms.12544>
- Dinniman, M.S., Klinck, J.M., Hofmann, E.E. & Smith, W.O. 2018 Effects of Projected Changes in Wind, Atmospheric Temperature, and Freshwater Inflow on the Ross Sea. *Journal of Climate*, 31, 1619-1635. doi:10.1175/jcli-d-17-0351.1
- Krüger, L., Ramos, J.A., Xavier, J.C., Grémillet, D., González-Solís, J., Petry, M.V., Phillips, R.A., Wanless, R.M. & Paiva, V.H. (2018). Projected distributions of Southern Ocean albatrosses, petrels and fisheries as a consequence of climatic change. *Ecography* 41: 195- 208 DOI: 10.1111/ecog.02590
- Saunders, R.A., Collins, M.A., Shreeve, R., Ward, P., Stowasser, G., Hill, S.L., Tarling, G.A. 2018. Seasonal variation in the predatory impact of myctophids on zooplankton in the Scotia Sea (Southern Ocean). *Progress in Oceanography*, 168, 123-144. <https://doi.org/10.1016/j.pocean.2018.09.017>
- Thorpe SE, Tarling GA, Murphy EJ (2019) Circumpolar patterns in Antarctic krill larval recruitment: an environmentally-driven model. *Mar Ecol Prog Ser* 613:77-96 doi: 10.3354/meps12887
- Capurro A, Santos MM, Cavanagh RD, Grant SM. 2018. The identification of scientific reference areas in the wider context of Marine Protected Area planning. CCAMLR WS-SM-18/17
- Murphy, E.J., Johnston, N.M., Corney, S. P., and Reid, K. (2018). Integrating Climate and Ecosystem Dynamics in the Southern Ocean (ICED) programme: Preliminary report of the ICED-CCAMLR Projections Workshop, 5-7 Apr 2018. WG-EMM-18-09.
- Murphy, E, Johnston, N, Corney, S and Reid, K including workshop participants and contributors Atkinson, A, Belchier, M, Bellerby, R, Bindoff, N, Cavanagh, R, Constable, A, Costa, D, Eddy, T, Emmerson, L, Grant, S, Groeneveld, J, Hill, S, Hobbs, W, Hofmann, E, Jackson, J, Kawaguchi, S, Korczak-Abshire, M, Lenton, A, Meijers, A, Melbourne-Thomas, J, Newman, L, Nicol, S, Piñones, A, Reiss, C, Santos, M, Tarling, G, Trathan, P, Trebilco, R, Watters, G, Welsford, D, Zhu, G. (Submitted). Integrating Climate and Ecosystem Dynamics in the Southern Ocean (ICED) programme: Report of the ICED-CCAMLR Projections Workshop, 5-7 Apr 2018. SC-CAMLR XXXVII.

Other papers to CCAMLR Working Group on Ecosystem Monitoring and Management 2018 can be found at <https://www.ccamlr.org/en/wg-emm-18>

Scientific publications

- Atkinson, A., Hill, S.L., Pakhomov, E.A., Siegel, V., Reiss, C.S., Loeb, V., Steinberg, D.K., Schmidt, K., Tarling, G.A., Gerrish, L. & Sailley, S.F. 2019. Krill (*Euphausia superba*) distribution contracts southward during rapid regional warming. *Nature Climate Change*, 9:142-147 DOI: 10.1038/s41558-018-0370-z
- Bagchi, A., A. J. Batten, M. Levin, K. N. Allen, M. L. Fitzgerald, L. A. Huckstadt, D. P. Costa, E.S. Buys, and A. G. Hindle. 2018. Intrinsic anti-inflammatory properties in the serum of two species of deep-diving seal. *Journal of Experimental Biology* 221.
- Brault, E. K., P. L. Koch, D. P. Costa, M. D. McCarthy, L. A. Huckstadt, K. T. Goetz, K. W. McMahon, M. E. Goebel, O. Karlsson, J. Teilmann, T. Harkonen, and K. C. Harding. 2019. Trophic position and foraging ecology of Ross, Weddell, and crabeater seals revealed by compound-specific isotope analysis. *Marine Ecology Progress Series* 611:1-18.
- Constable, A.J. & Kawaguchi, S. 2018 Modelling growth and reproduction of Antarctic krill, *Euphausia superba*, based on temperature, food and resource allocation amongst life history functions. *Ices Journal of Marine Science*, 75, 738-750. (doi:10.1093/icesjms/fsx190).
- Costa, D. P., L. A. Huckstadt, L. Schwarz, A. Friedlaender, B. Mate, A. Zerbini, A. Kennedy, and N. J. Gales. 2018. Assessing the Potential Exposure of Migratory Animals to Disturbance. *Integrative and Comparative Biology* 58:E44-E44.
- Costa, D. P., S. S. Kienle, S. J. Trumble, S. Kanatous, M. E. Goebel, and D. Krause. 2019. Foraging Ecology of the Leopard Seal. *Integrative and Comparative Biology* 59:E43-E43.
- Dimitrijević D, Paiva VH, Ramos JA, Seco J, Ceia FR, Chipev N, Valente T, Barbosa A, Xavier JC (2018) Isotopic niches of sympatric Gentoo and Chinstrap Penguins: evidence of competition for Antarctic krill?

- Polar Biology 41: 1655-1669 <https://doi.org/10.1007/s00300-018-2306-5>
- Dinniman, M.S., J.M. Klinck, E.E. Hofmann, and W.O. Smith, Jr. 2018. Effects of projected changes in wind, atmospheric temperature and freshwater inflow on the Ross Sea. *J. Climate* 31: 1619-1635.
- Frazer, E. K., P. J. Langhorne, M. J. M. Williams, K. T. Goetz, and D. P. Costa. 2018. A method for correcting seal-borne oceanographic data and application to the estimation of regional sea ice thickness. *Journal of Marine Systems* 187:250-259.
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