



**Integrated Marine Biosphere Research (IMBeR)**

**Annual Report to SCOR  
2017 - 2018**

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### 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 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 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.

## 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 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 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. During 2017 we mapped the activities of the regional programmes, working groups and innovation challenges on to the objectives of the Grand Challenges and allocated specific members of the scientific steering committee to oversee each of these objectives (Figure 1).

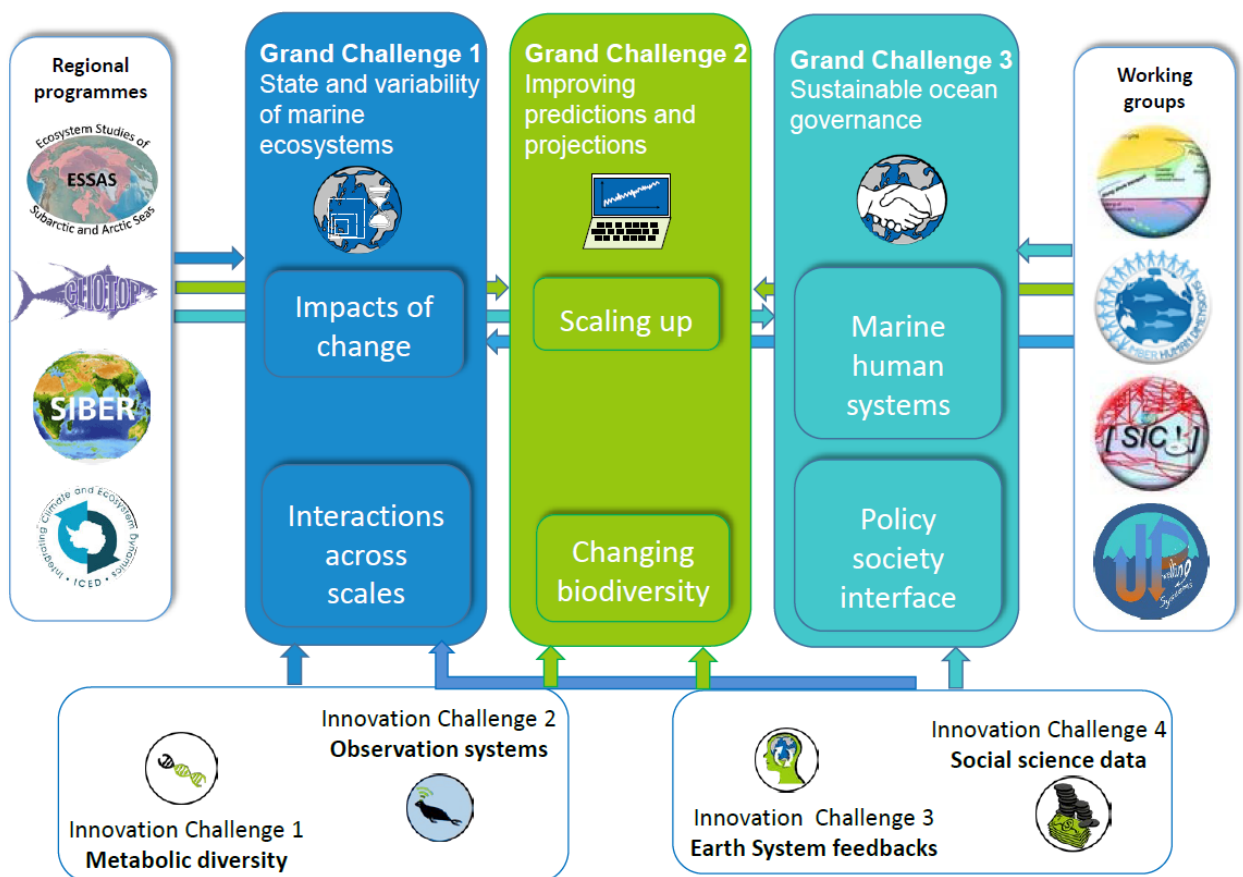


Figure 1. Contribution of the regional programmes, working groups and Innovation Challenges to the objectives of the Grand Challenges

### C. Selected science highlights in 2017

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.

1. ICED scientists led a multidisciplinary study to assess potential climate change impacts on Southern Ocean ecosystems. The study, which was published in *Frontiers in Marine Science* <http://dx.doi.org/10.3389/fmars.2017.00308>, and featured as a research highlight in *Nature Climate Change* <https://www.nature.com/articles/nclimate3408.pdf?origin=ppub> stresses the need for an integrated approach to best use climate-model data for ecological insights. As an example, they consider the implications for Antarctic marine ecosystems of changes in sea-ice.
2. ICED has emphasized the importance of developing quantified understanding of the life cycles of key species such as Antarctic krill (*Euphausia superba*) in Southern Ocean ecosystems. This study developed and applied an empirical relationship of growth rate to assess seasonal spatial variability in the growth of Antarctic krill throughout the Southern Ocean. It showed that over much of the ocean, the potential for growth is limited, and indicated that there are three restricted oceanic regions where seasonal conditions permit high growth rates, and only a few areas around the Scotia Sea and Antarctic Peninsula suitable for growth of the largest krill (>60 mm). The study demonstrated that projections of impacts of future change need to account for spatial and seasonal variability of key ecological processes within ocean ecosystems. Murphy, E.J. et al., (2017) *Scientific Reports* 7, 6963. <http://www.nature.com/articles/s41598-017-07205-9>
3. 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).
4. 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.
5. SIBER has been working to motivate synthesis papers related to the research themes that are articulated in the SIBER Science Plan. The first of these papers on biogeochemical and ecological impacts of boundary currents in the Indian Ocean was published in *Progress in Oceanography* in 2017 (Hood et al. 2017 <https://www.sciencedirect.com/science/article/pii/S0079661117301507>). Evidence from the paleoceanographic record suggests that boundary currents in the Indian

Ocean basin have changed significantly over glacial to interglacial timescales. These changes are explored as a means of providing insight into the potential biogeochemical and ecological impacts of climate change in the Indian Ocean.

6. The SOLAS-IMBeR Ocean Acidification Working Group working through the IAEA Ocean Acidification International Coordination Centre (OA-ICC) has continued efforts to improve the computation of derived variables of the marine carbonate system in earth system models in order to project the impacts of decreasing pH on marine organisms (Kwiatkowski, L., & Orr, J. C. 2018. Diverging seasonal extremes for ocean acidification during the twenty-first century. *Nature Climate Change*, 8(2), 141 <http://www.nature.com/articles/s41558-017-0054-0>). Results suggest that projected seasonality changes will tend to exacerbate impacts during the summer and ameliorate impacts during the winter.
7. The Arctic Ecosystem Integrated Survey (Arctic Eis) in the Pacific Arctic (Northern Bering Sea and Chukchi Sea) is an ESSAS affiliated project which came to an end in 2017. Detailed results can be accessed at <https://web.sfos.uaf.edu/wordpress/arcticeis/> and were published in a special issue of Deep-Sea Research Part II (<http://dx.doi.org/10.1016/j.dsr2.2016.11.005>). A few of the highlights include: (a) High densities of young-of-year Arctic cod (*Boregadus saida*), an ecologically important species in the Arctic that is also of potential commercial interest, were, for the first time, observed in the northeast Chukchi Sea in 2012, 2013, suggesting that this area is an important nursery area for the early life history stages of Arctic cod in the Pacific Arctic. (b) Plankton, fish and invertebrate species of Pacific origin typically dominate demersal and pelagic communities throughout the Chukchi Sea, highlighting the importance of advection of Pacific waters through Bering Strait into the Chukchi Sea. However, distinct Arctic populations of some species are associated with Arctic water masses on the northeast Chukchi Sea shelf, reflecting the intrusion of Arctic water masses from the basin onto the shelf. (c) Fishes and crab consume a large variety of pelagic and benthic prey in the Chukchi Sea and diets typically differ among species, water masses and with predator size. While juveniles and small forage fish rely primarily on zooplankton advected from the Bering Sea, there is an increasing reliance on benthic prey with increasing predator size.

#### **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 third ESSAS Open Science Meeting was held in Tromsø, Norway in June 2017. The title of the meeting was *Moving in, out and across the Subarctic and Arctic marine ecosystems: shifting boundaries of water, ice, flora, fauna, people and institutions*. Nine theme sessions were on Paleo-Ecology; Advection and Mixing; Phenology; Shifting habitats and hotspots; Future Climate and its ecosystem effects; Multiple Stressors; Ocean Acidification; Science, Policy and Management; and a General Open Session. A total of 187 scientists of different disciplines from 11 countries attended the meeting. A special

issue of the *ICES Journal of Marine Science* will be published by the end of 2018 containing some of the papers presented at the ESSAS OSM.

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, with the objective 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 second meeting was held in March 2017, in Juneau, Alaska, USA. It began with a 1-day stakeholder's meeting and was followed by a 2-day meeting of the Principal Investigators and other contributors. The main activity was the development of outlines for scientific papers on future climate scenarios, their ecological impacts and the challenges these represent for management.

ESSAS held its 2018 Annual Science Meeting in Fairbanks, Alaska in June 2018. A primary focus of the meeting was on remote sensing applications in the study of climate change impacts on high-latitude ecosystems. Additional sessions and workshops focused on ocean acidification and other stressors; the biology, ecology and paleoecology of Arctic Gadids, and the use of Integrated Ecosystem Assessments (IEA) as a framework for understanding and managing subarctic and Arctic marine ecosystems.

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

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. [www.iced.ac.uk/index.htm](http://www.iced.ac.uk/index.htm).

ICED scientist Jess Melbourne Thomas was selected as lead author of the Polar Regions Chapter for the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate. The Special Report will build on the work of the IPCC's Fifth Assessment Report (AR5). A report outline was agreed in March 2017 and the report is scheduled to be finalized 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.

The Marine Ecosystem Assessment for the Southern Ocean: Assessing Status and Trends of Habitats, Key Species and Ecosystems in the Southern Ocean (MEASO2018) conference was organized in 2018 by ICED SSC member Andrew Constable. MEASO2018 marks the 10 year anniversary of ICED and provided an important opportunity for the ICED community to present their results. The outcomes of the conference are also expected to provide significant input to the Committee on Environment Protection, the Scientific Committee for the Conservation of Antarctic Marine Living Resources, the International Whaling Commission's Scientific Committee and other organisations interested in the management and conservation of Southern Ocean ecosystems.

## **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 edited and contributed to a special issue of *Reviews in Fish Biology and Fisheries* <https://link.springer.com/journal/11160/27/4/page/1> focused on safeguarding the sustainability of tuna fisheries.

CLIOTOP scientists attended a number of regional and international meetings during 2017 including the VOICE (Variability in the Oxycline and its ImpaCts on the Ecosystem) GO2NE (Global Ocean Oxygen Network) meeting, Regional workshops for the South Pacific and Indian Ocean in support of the second World Ocean Assessment, International Commission for the Conservation of Atlantic Tunas Standing Committee on Research and Statistics sub-committee on ecosystems, XIIIth SCAR Biology Symposium, 6th Biologging Symposium, 22nd Biennial conference on the biology of marine mammals, and the 6th Mediterranean Oceanography Network for the Global Ocean Observing System (MonGOOS) meeting.

CLIOTOP Task team 2016-03 will co-convene a session with the PICES forecasting group at the Fourth International Effects of Climate Change on the World's Oceans symposium in June 2018. CLIOTOP will hold its fourth international symposium in October 2018 at the National Taiwan Ocean University in Keelung, Taiwan.

## **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 2<sup>nd</sup> International Indian Ocean Expedition (IIOE-2) was motivated by SCOR, SIBER, IOGOOS and IOP and has become the main scientific focus of SIBER. SIBER is now leading the development of a Science Plan to guide US participation in IIOE-2. This effort was initiated with a US IIOE-2 Science Planning Workshop, convened at Scripps Institution of Oceanography in September 2017. The draft US IIOE-2 Science Plan is currently undergoing peer-review, with the anticipation that it will be completed by June 2018. SIBER SSC members also helped to organize and participated in a joint South Korea-US workshop in Seoul in December 1, 2017 that was aimed at developing a Science Plan to guide South Korea's participation in IIOE-2.

### **E. Working Groups**

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

The CMWG aims to undertake and compare two socio-ecological case studies, one on the sparsely-populated but rapidly changing Arctic continental margin, and one on the densely populated Chinese marginal seas. A first workshop to plan the Chinese marginal seas case study was convened at the XMAS-III conference in Xiamen, China in early 2017, and the

second is planned to take place during the China/Japan/Korea Symposium to be held in Shanghai in October 2018.

### **Human Dimensions Working Group (HDWG)**

The publication of the I-ADApT Synthesis book *Global Change in Marine Systems: Integrating natural, social and governing responses* was the major activity and output from the HDWG in 2017. The 7th HDWG meeting was held in France in 2017, members of the HDWG led the workshop on *Management Strategy Evaluation: Achieving transparency in natural resource management by quantitatively bridging social and natural science uncertainties* at IMBIZO5 in October 2017, and plan to provide a training course at the CJK symposium in September 2018.

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

In 2017 EBUS submitted a successful proposal to form a SCOR working group #155 with the aim to synthesize existing knowledge on the different physical mechanisms occurring over diurnal, intraseasonal, interannual, decadal, and multidecadal timescales and their implications on water column properties, biogeochemical cycles, biodiversity, ecosystem structure and functioning and the regional climate of EBUS.

In collaboration with the CLIVAR EBUS Research Focus, EBUS organized a Session on EBUS at the 2018 Ocean Sciences Meeting on *Biophysical Dynamics of Eastern Boundary Upwelling Ecosystems in a Changing Ocean: Closing the Gap Between Wind Stress and Ecosystem Productivity*, and a session on *Eastern Boundary Upwelling Systems: diversity, coupled dynamics and sensitivity to climate change* is proposed for the 4th International Symposium on the Effects of Climate Change on the World's Oceans, to be held in June 2018.

EBUS is engaged with the Ocean KAN (Knowledge-Action Network) of the Future Earth Program through the membership of Ruben Escribano on the Development Team. A number of virtual and in-person meetings have taken place through 2017-18.

### **SOLAS IMBeR IOCCP Carbon working group (SIC)**

A new carbon working group with participation of IMBeR, SOLAS, the Global Carbon Project and the SCOR and IOC-UNESCO International Ocean Carbon Coordination project (IOCCP) is being planned. A small group of scientists representing IMBeR, SOLAS, CLIVAR and IOCCP met at the International Carbon Dioxide Conference (ICDC10) in Switzerland in August 2017 and again at the Portland Ocean Sciences meeting in February 2018. A proposal for an integrated ocean carbon working group under the auspices of IOC will be presented to the IOC Executive Council in July 2018, with a first meeting scheduled for early 2019.

Version 6 of the Surface Ocean CO<sub>2</sub> Atlas (SOCAT) was released <https://www.socat.info/> in 2018. SOCAT is a synthesis activity for quality-controlled, surface ocean fCO<sub>2</sub> (fugacity of carbon dioxide) observations by the international marine carbon research community (>100 contributors). The latest SOCAT version (version 6) has 23.4 million observations from 1957 to 2017 for the global oceans and coastal seas. Calibrated sensor data are also available. SOCAT data is publicly



available, discoverable and citable. SOCAT enables quantification of the ocean carbon sink and ocean acidification and evaluation of ocean biogeochemical models.

### **SOLAS-IMBeR Ocean Acidification (SIOA)**

The SOLAS-IMBER Ocean Acidification Working Group provides a key advisory role to the Ocean Acidification International Coordination Centre (OA-ICC), at the International Atomic Energy Agency in Monaco. During 2017, the SIOA has led efforts of the OA-ICC to continue to support the establishment of the Global Ocean Acidification Observing Network (GOA-ON), a worldwide collaborative approach with the goal to expand ocean acidification monitoring and capacity building, especially in areas where there is little or no data, to improve software used by the scientific community working on ocean acidification to calculate carbonate chemistry parameters, and to update and improve best practices guidelines for ocean acidification research.

In June 2017, the OA-ICC co-organized a meeting of the SCOR Working group 149 focused on new best practices guidelines for complex multiple stressor experiments, including ocean acidification. A training workshop using the new tools is planned for October 2018, also in Monaco.

Selected highlights of SIOA 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 (SCS) 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. Three cruises in the SCS have been conducted in the spring 2017, summer 2015 and fall 2014. During these cruises, remote sensing results of altimetry, ocean colour and sea surface temperature and model results of circulation, nutrient-chlorophyll distributions and Lagrangian Coherent Structure were used for planning and guiding survey areas and station locations; measurements and samples of hydrography, nutrients, microbes, plankton and nekton were taken by sensors, water samplers, plankton nets, trawls and acoustic devices at the same or near-same times and locations; and 2 moorings were deployed at the study area for long term observations of hydrography and acoustic backscatter. The results revealed that while the surface ocean of the SCS is classically defined as an oligotrophic ocean with low nutrient and phytoplankton concentrations, there is an active layer of mesopelagic fish living in waters between 50 and 1000 m below the surface.

*Ocean acidification and Biogeochemistry: variability, trends and vulnerability (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 in selected ecosystems, and by studying the larger scale biogeochemistry of ocean waters impinging on those ecosystems. Fine scale sampling will focus 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 April/May 2017. The survey had strong international collaboration with on-board teams from Canada, Germany, the UK, and the USA, and additional support from experts in Denmark and France. All GO-SHIP Level 1 parameters were sampled. Analysis of all biogeochemical samples was carried out on board, with a number of laboratory containers set up on the deck of the ship. The last time the full A02 line was carried out was in June 1997 by WOCE.

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

The goals of OCEAN CERTAIN, which ended in 2017, were 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. Results from the Ocean Certain project showed an enhanced link between temperature and jellyfish abundance after the 1980s. In the Mediterranean, the synergistic effects of climate and commercial fishing have shifted the pelagic food web dynamics to a state of recurrent massive jellyfish bloom events. The massive jellyfish blooms have had dramatic impacts on ecosystem functioning, fisheries and tourism in the Mediterranean. Ocean Certain also developed a user-friendly decision support system (DSS) that allows for an integrated analysis of the environmental and social-economic impacts of changes to the ocean food web under different stressor/policy combinations. This DSS combines scientific knowledge and data with local stakeholder knowledge for the three case studies

(Mediterranean, Barents Sea and Patagonia). The DSS setup files, and documentation will be made available through the Ocean Certain web site ([www.oceancertain.eu](http://www.oceancertain.eu)).

*Processes and Approaches of Coastal Ecosystem Carbon Sequestration (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)*

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)*

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)*

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 will be tackled. Marine ecosystem variability will be addressed at the interface of different systems, parameterizations optimized 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.

*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.

**G. Implementation of the Science Plan in 2017**

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 2017 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.*

Progress towards this challenge is led by IMBeR SSC members Cisco Werner and Alistair Hobday.

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, their variability and response to change across a range of spatial and temporal scales. They have focused detailed work on key species from phytoplankton to whales (Arthur et al 2017, Kaufman et al 2017, Meyer et al 2017), and the structure of food webs (e.g. Saunders et al 2017). They have also examined physical, chemical and biological interactions (e.g Belcher et al 2017, Beekmans 2017) and the effects of past (Tarling et al 2018) and recent variability and change, such as ocean acidification (e.g. Manno et al 2017, Peck et al 2017, Trimbourn et al 2017).

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 2017-01 has been progressing work analysing isotope data from mid-top predators collected across multiple regions and ocean basins and developing methods for integrating multiple trophic assessment methods (isotopes, fatty acids, mercury and ecosystem models) to better understand marine trophodynamics. The task team has grown its membership, expanding the scope of methodologies that the task team uses to understand climate impacts on marine food webs and the regions from which data have been collected. The task team provided a summary of their work for the IMBeR website (<http://www.imber.info/en/news/expanding-marine-predator-isotopework-community-level-metrics-mercury-isotopes-and-data-modellinkages>) and published the following paper: Houssard, P. et al. 2017. Trophic position increases with thermocline depth in yellowfin and bigeye tuna across the Western and Central Pacific Ocean. *Progress in Oceanography*, 154, pp.49-63.

### **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 members Laurent Bopp and Eugene Murphy and was 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 has continued their Model Development Activity 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. Recent work includes: Dinniman et al 2017, Freer et al 2017, Kruger et al 2018, Silber et al 2017, Murphy et al. 2017, Meyer et al, 2018, and Klein et al. 2018.

ICED have continued their work on developing scenarios of key drivers and projections of ecological change in the Southern Ocean. This has included the publication of the community paper Cavanagh et al. 2017 A Synergistic Approach for Evaluating Climate Model Output for Ecological Applications doi:10.3389/fmars.2017.00308 and the organisation in collaboration with the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) of a workshop in April 2018 to further the scenarios and projections work.

### **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.*

This challenge is led by SSC members Marion Glaser, Ingrid van Putten and 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 scientists have been involved in the agreement to establish the world's largest Marine Protected Area (MPA), in Antarctica's Ross Sea, via the Commission for the Conservation of Antarctic Marine Living Resources CCAMLR. This new MPA, came 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.

ICED scientists have also continued to engage with CEP (the Antarctic Treaty's Committee for Environmental Protection) and submitted an Information Paper to the 2017 ATCM (ICED, 2017) outlining the role that ICED can continue to play in providing information on climate change impacts on ecosystems to the Antarctic Treaty.

CLIOTOP Co-chair Karen Evans led the chapter on the South Pacific for the first global integrated marine assessment (produced by the United Nations), providing an assessment on the state of the marine environment throughout the region, key pressures impacting the marine environment and associated ecosystem services, and identifying factors for sustainability throughout the region. Karen also contributed to a series of three technical abstracts developed from the first assessment for use by policy makers focused on (i) the conservation and sustainable use of marine biological diversity in areas beyond national jurisdiction, (ii) the impacts of climate change on the oceans and (iii) the ocean and sustainable development goals under the 2030 Agenda for Sustainable Development. The assessment and technical abstracts were endorsed by the General Assembly of the United Nations and launched at the Oceans Conference in June 2017. The assessment and technical abstracts are available at: [http://www.un.org/Depts/los/global\\_reporting/global\\_reporting.htm](http://www.un.org/Depts/los/global_reporting/global_reporting.htm).

There is a heightened demand from countries to build capacity to report on Target 3 of the UN Sustainable Development Goal 14 that specifically addresses Ocean Acidification. The SIOA and OA-ICC provide coordination, activities, and resources to help Member States address this target. Several SIOA members, GOA-ON, and the OA-ICC are involved in developing methodologies for the SDG14.3.1 indicator (ocean acidity) led by IOC-UNESCO. They attended an expert meeting focused on that topic in January 2018 in Paris. More information can be found at <https://news-oceanacidification-icc.org/2018/02/22/update-to-sdg14-3-voluntary-commitment-enhancing-global-ocean-acidification-monitoring-and-research-by-go-on/>.

**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 was led by SSC members Gerhard Herndl and Tatiana Rynearson. The first activity was a workshop at the IMBIZO5 meeting in October 2017 and the preparation of a synthesis paper describing 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. Future conference sessions are planned, including one at the ASLO meeting in early 2019, and one at the IMBeR Open Science Conference in June 2019.

**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.

IMBeR aims to achieve this challenge through collaboration with ongoing international observing initiatives. One of the most relevant is the Global Ocean Observing System of the IOC-UNESCO (GOOS) through their Biology and Ecosystems Panel whose membership includes two IMBeR SSC members: Dan Costa and Frank Muller-Karger.

Dan Costa and CLIOTOP Co-Chair Kevin Weng participated in the GOOS and the OceanObs Research Coordination Network workshop on **Implementation of Multi-Disciplinary Sustained Ocean Observations** 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.

Dan Costa is a co-author of a SOOS manuscript on the Western Antarctic Peninsula for *Progress in Oceanography*, a contributing author for the IPCC special report for **Oceans and Cryosphere in a Changing Climate** and attended the **Biologging conference** in Germany in September 2017.

Several CLIOTOP members provided feedback on a draft paper on essential ocean variables (EOVs) for fish abundance and distribution, and Dan Costa is drafting the EOV text for marine mammals and seabirds for the GOOS Biology and Ecosystems Panel.

CLIOTOP Task team 2016-04 Operational Oceanography in support of Sustainable Top Predators (OOSTOP) launched their website in late 2017 aimed at improving knowledge transfer between people working on operational oceanography, marine species biology, conservation and management; i.e. improving the ocean observation-science-policy interface. See <https://oostop.wixsite.com/oostop>

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

This challenge is led by SSC members Laurent Bopp and Eugene Murphy, who have prepared a scoping document assessing which Earth System Models enable potential feedbacks to occur and which do not. Following Hense et al. (2017) *Biogeosciences* 14, 403, they reviewed the three major climate feedback loops of atmospheric CO<sub>2</sub> and the biological carbon pump, marine biota and air-sea fluxes of climate forcing agents such as dimethylsulphide and nitrous oxide, and the influence of marine ecosystems on heat transfer and mixing of the oceans. Links with the WCRP Grand Challenge on Carbon Feedbacks in the Earth System, the SOLAS, IMBeR, IOCCP carbon working group, the SCOR IMBeR SOLAS CLIVar EBUS working group and FISH-MIP were identified as potential ways to progress the research questions of this challenge possibly through a workshop at the IMBeR Open Science Conference.

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

This Innovation Challenge is championed by the Human Dimensions Working Group. They have initiated conversations with the Human Dimensions groups of other projects including MSEAS, ICES and PICES about using social science data in ocean management, and are planning to organise a workshop possibly at the IMBeR Open Science Conference to plan the way forward.

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**

### **IMBIZO 5**

The fifth IMBIZO conference ‘Marine biosphere research for a sustainable ocean: Linking ecosystems, future states and resource management’ was held in 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 and Tatiana Rynearson) and 3) Managing Strategy Evaluation: Achieving Transparency in Natural Resource Management by Quantitatively Bridging Social and Natural Science Uncertainties (Ingrid van Putten and Cisco Werner).

### **Early Career Researcher Network**

The Interdisciplinary Marine Early Career Network (IMECaN) was recently established to provide opportunities for the growing network of IMBeR early career researchers and students, to become more involved with IMBeR and to create more networking and collaborative possibilities. Terms of Reference were approved by the IMBeR Executive Committee, and Chris Cvitanovic (Australia) was appointed as the first early career representative on the IMBeR SSC in January 2018.

IMECaN convened a capacity building workshop in Losinj, Croatia in June 2018, to enable EU-based early career marine researchers to operate effectively at the science-policy-society interface. The IMECaN Organising Committee held its first meeting in conjunction with the workshop to plan future events and activities. The next IMECaN event will be a workshop at the IMBeR Future Oceans2 Open Science Conference in June 2019.

### **ClimEco6 summer school August 2018**

The sixth IMBeR ClimEco summer school will be held at the Gadjadara University in Yogyakarta, Indonesia from 1-8 August 2018. Almost 200 applications from 57 countries were received for the 60 available places. The theme of the summer school is “Interdisciplinary approaches for sustainable oceans” and participants will be provided with practical ways to deal with the challenges arising from working across social and natural science disciplines.

IMBeR is very grateful to SCOR for the travel support provided to five participants from developing countries.



## **IMBeR China / Japan / Korea Symposium 2018**

The next CJK symposium will be held in Shanghai in September 2018.

## **IMBeR Open Science Conference 2019**

The next IMBeR OSC will be held in Brest, France in June 2019.

## **International Project Office (IPO, Norway)**

Gro I. van der Meeren resigned as the Executive Officer in June 2017. Lisa Maddison became Acting Executive Officer until June 2018 when John Claydon was appointed as Executive Officer.

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.

## **Regional Project Office (RPO, China)**

Yi Xu resigned from the Deputy Executive Officer post in December 2017 and Fang Zuo became the Acting Deputy Executive Officer. After an international recruitment campaign Fang was appointed to the Deputy Executive Officer post in July 2018. Recruitment is currently underway for an Assistant Administrative Officer for the RPO. 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 hosted the 2017 SSC meeting and will host the 2018 China/Japan/Korea IMBeR symposium.

### **I. Scientific steering committee**

The 2017 scientific steering committee consisted of a chair, Carol Robinson (F, UK), *ex officio* member Eugene Murphy (M, UK) and 15 members (9 male and 6 female). Alida Bundy (*ex officio* F, Canada), Ratana Chuenpagdee (F, Canada), Masao Ischii (M, Japan), Svein Sundby (M, Norway) and Tatiana Rynearson (F, USA) rotate off the SSC at the end of 2017. Ruben Escribano will serve a second term, rotating off at the end of 2020.

An open call for nominations for four new SSC members was advertised in 2017. From 36 applications, four new 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 an early career representative) and Frank Muller Karger (M, USA; as a liaison with GEO BON to contribute to Innovation Challenge 2).

### **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, PAGES, Earth System Governance and bioDiscovery.

*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 hosted and co-sponsored IMBIZO5 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 and SOLAS. 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. Patricia Miloslavich gave a presentation at the IMBeR SSC meeting in 2018, highlighting opportunities for interaction between GOOS and IMBeR. These include a contribution to the specifications for an emerging EOVS on microbes and linking EOVSs to human society. IMBeR were invited to contribute to the draft GOOS 10-year strategy and to be represented at the GOOS Steering Committee meeting in Columbia in June 2018.

*e. ICES*

Collaboration with ICES continues through the membership of Mark Dickey-Collas (ICES) on 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. Cisco Werner is the IMBeR liaison with PICES, Carol Robinson is a member of the ICES/PICES working group on Climate Change and Biologically-driven Ocean Carbon Sequestration (WGCCBOCS) and represented IMBeR on the organizing 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.

## **K. Selected IMBeR Publications**

IMBeR has produced more than 2500 refereed research papers since 2005, with around 150 papers published in 2017-2018.

## **ICED**

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## **L. Support from SCOR**

IMBeR greatly appreciates the ongoing support received from SCOR, and the additional support for specific IMBeR activities provided or managed by SCOR from other funding sources. IMBeR is especially grateful for the advice and assistance from the SCOR Executive Director, Ed Urban, and Financial Officer, Liz Gross.

Together with this report, we submit a request for funding to support students and researchers from developing countries to attend the IMBeR Open Science Conference to be held in Brest, France in June 2019.

## M. Budget

<b>2017 \$</b>	<b>INCOME</b>	<b>Budget agreed SSC April 2016</b>	<b>Actual budget Dec 2017</b>	<b>Comments</b>
	From 2016	64 424	68 750	61546 + misc funds
SCOR NSF	Annual grant	50 000	50 000	
Future Earth	Annual grant	16 000	0	For SSC meeting
Norway, IPO	Salary, travel, expenses	572 000	544 981	
China, RPO	Salary, travel, expenses	65 000	65 000	
IMBIZO 5	Reg fees and sponsorship	90 000	146 165	
	<b>TOTAL INCOME</b>	<b>857 424</b>	<b>874 896</b>	
	<b>EXPENSES</b>			
Norway, IPO	Salary, travel, expenses	572 000	545 981	
China, RPO	Salary, travel, expenses	65 000	65 000	
SSC Meeting	Meeting costs and travel support for SSC	30 000	22 034	Meeting in Shanghai
IMBIZO 5	Meeting costs and travel support	90 000	107 090	
WGs	OA, HDWG, Upwelling, CMWG, Carbon	37 500	31 374	
Regional programmes	ICED, ESSAS, SIBER, CLIOTOP	40 000	28 088	
FEC workshop	Lagoons workshop	0	2 438	Sponsorship from ESA
Sponsorships	PICES	3 000	3 000	Small Pelagics Symposium
	<b>TOTAL EXPENSES</b>	<b>837 500</b>	<b>804 005</b>	
	<b>BALANCE</b>	<b>19 924</b>	<b>70 891</b>	

Please note that blue indicates incomplete income or expenditure

<b>2018 \$</b>	<b>INCOME</b>	<b>Budget agreed SSC April 2018</b>	<b>Actual budget June 2018</b>	<b>Comments</b>
	From 2017	70 891	70 891	
SCOR NSF	Annual grant	50 000	50 000	
Future Earth	Annual grant	16 000	19 538	For SSC meeting in Hobart
Future Earth	Unpaid grant for 2017	16 000	18 527	For SSC meeting in Shanghai
Norway, IPO	Salary, travel, expenses	572 000	572 000	
China, RPO	Salary, travel, expenses	65 000	65 000	
Early career network	Reg fees and sponsorship	30 000	30 700	
ClimEco6	Reg fees and sponsorship	90 000	61 668	Budgeted includes \$10K contingency
	<b>TOTAL INCOME</b>	<b>910 591</b>	<b>888 324</b>	
	<b>EXPENSES</b>			
Norway, IPO	Salary, travel, expenses	572 000	572 000	
China, RPO	Salary, travel, expenses	65 000	65 000	
SSC Meeting	Meeting costs and travel support for SSC	30 000	29 831	SSC meeting in Hobart
Early career network	Science-policy-society workshop	30 671	30 671	

ClimEco6	Meeting costs and travel support	90 000	16 666	Lecturers' flights and hotel
WGs	OA, HDWG, Carbon, CMWG	30 000	11 118	OA costs and flights for HDWG
Regional programmes	ICED, ESSAS, SIBER, CLIOTOP	40 000	32 719	ICED, ESSAS, SIBER
Sponsorship	PICES	3 000	3 000	ECCWO conference support
	<b><u>TOTAL EXPENSES</u></b>	<b><u>860 671</u></b>	<b><u>761 005</u></b>	
	<b><u>BALANCE</u></b>	<b><u>49 920</u></b>	<b><u>127 312</u></b>	