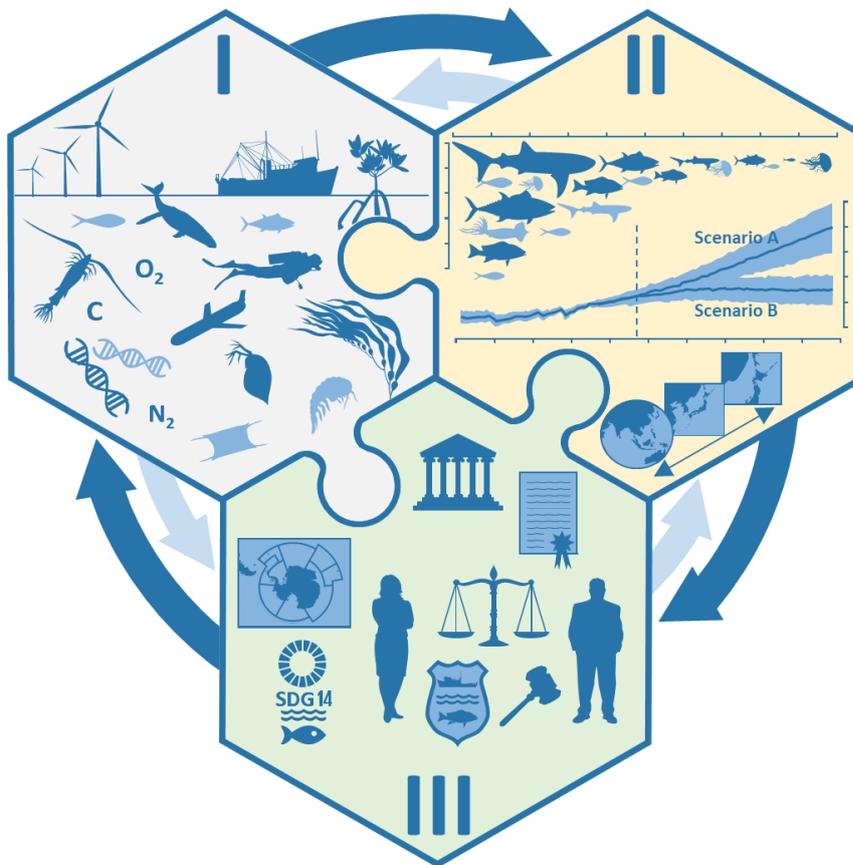


**Annual Report to SCOR
2020 – 2021**



**Ocean Sustainability under Global Change
for the Benefit of Society**

Table of contents

A.	IMBeR STRUCTURE and OPERATIONS	1
B.	SELECTED SCIENCE HIGHLIGHTS in 2020-2021	4
C.	ACHIEVEMENTS and ACTIVITIES 2020-2021.....	7
---	Implementation of the IMBeR Science Plan and Implementation Strategy.....	7
---	Additional IMBeR activities.....	15
D.	SCIENTIFIC STEERING COMMITTEE	15
E.	COLLABORATIVE PARTNERS	17
F.	IMBeR INTERNATIONAL PROJECT OFFICES	18
G.	PUBLICATION SUMMARY	18
H.	SUPPORT from SCOR	18
I.	BUDGET	19
J.	APPENDICES	21

A. IMBeR STRUCTURE and OPERATIONS

Integrated Marine Biosphere Research (IMBeR) is a marine global change research project that is intentionally broad and interdisciplinary. IMBeR is co-sponsored by the Scientific Committee on Oceanic Research (SCOR) and Future Earth.

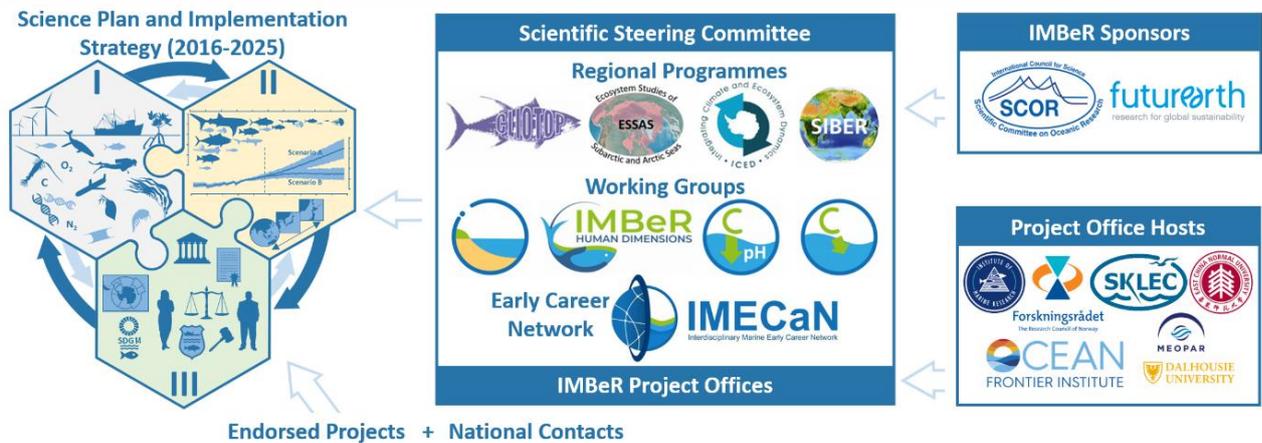


Figure 1. Schematic overview of IMBeR's structure and operations.

All IMBeR activities, initiatives and events correspond to IMBeR's **Science Plan and Implementation Strategy 2016-2025 (SPIS)**. The SPIS was developed in consultation with the IMBeR community, and outlines IMBeR's vision of *"Ocean sustainability under global change for the benefit of society"* and its goal to *"Understand, quantify and compare historic and present structure and functioning of linked ocean and human systems to predict options for securing or transitioning towards ocean sustainability"*.

The SPIS is built around three interacting **Grand Challenges (GCs)**:

- **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. ([GCI Fact Sheet 2019](#))

- **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. ([GCII Fact Sheet 2019](#))

- **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. ([GCIII Fact Sheet 2019](#))

The GCs are supported by **Innovation Challenges (ICs)**, research topics chosen to be prioritised for three to five years, and mainstreamed into the GCs once deliverables have been completed. There are four current ICs:

- **Innovation Challenge 3:** advancing understanding of ecological feedbacks in the Earth System;
- **Innovation Challenge 4:** advancing and improving the use of social science data for ocean management, decision making and policy development;
- **Innovation Challenge 5:** interventions to change the course of climate impacts;
- **Innovation Challenge 6:** sustainable management of Blue Carbon ecosystems.

The Scientific Steering Committee (SSC) provides strategic oversight of IMBeR and ensures progress of the SPIS (more details on SSC in section D). Over the past year, the science outlined in the SPIS has been advanced through:

four **Regional Programmes:**

- **Climate Impacts on Oceanic Top Predators (CLIOTOP)** and its [task teams](#);
- **Ecosystem Studies of Subarctic and Arctic Seas (ESSAS)** and its [working groups](#), [national](#) and [multinational programs](#), and [endorsed projects](#);
- **Integrating Climate and Ecosystem Dynamics (ICED)**; and see [factsheet](#), co-sponsored by the Scientific Committee on Antarctic Research ([SCAR](#)); and
- **Sustained Indian Ocean Biogeochemistry and Ecosystem Research (SIBER)**, co-sponsored by the Indian Ocean Global Ocean Observing System ([IOGOOS](#));

four **Working Groups:**

- **Continental Margins Working Group (CMWG)**, a joint working group with [Future Earth Coasts](#);
- **Human Dimensions Working Group (HDWG)**;
- **Integrated Ocean Carbon Research (IOC-R)**, a joint working group involving IMBeR, the Intergovernmental Oceanic Commission – International Ocean Carbon Coordination Project ([IOCCP](#)), the World Climate Research Programme ([WCRP](#))/Climate and Ocean - Variability, Predictability, and Change ([CLIVAR](#)), the Surface Ocean – Lower Atmosphere Study ([SOLAS](#)), and the Global Carbon Project ([GCP](#));
- **SOLAS-IMBeR Ocean Acidification (SIOA)**, a joint working group with SOLAS;

the **Interdisciplinary Marine Early Career Network (IMECaN)**, with over 700 members from almost 90 countries;

and 12 **Endorsed Projects:**

- **Atlantic Meridional Transect (AMT)**
- **Collaborative Research and Education Project in Southeast Asia for Sustainable Use of Marine Ecosystems (CREPSUM)**

- Gulf of Trieste – Time-series ([GoTTs](#))
- Integrated Arctic Observation System ([INTAROS](#))
- Mechanisms of Marine Carbon Storage and Coupled Carbon, Nitrogen and Sulphur cycles in response to global change ([MCS-CNS](#))
- Marine Ecosystem-based Management Progress Evaluation Group: tracking the global progress of EBM ([MEBM-PEG](#))
- Marine Ecosystem Modeling and Forecasting System in the China Seas and Northwestern Pacific ([MEMFiS](#))
- Negotiating Ocean Conflicts among Rivals for Sustainable and Equitable Solutions ([NoCRISES](#))
- Importance of Physico-Chemical cycling of nutrients and carbon in Marine Transitional Zones ([NUTS&BOLTS](#))
- Processes and Approaches of Coastal Ecosystem Carbon Sequestration ([PACECS](#))
- The Study of Kuroshio Ecosystem Dynamics for Sustainable Fisheries ([SKED](#))
- Ocean Acidification and Biogeochemistry: variability, trends and vulnerability ([VOCAB](#))

The administration of the IMBeR project is carried out by the two **International Project Offices** (IPOs), one in Halifax, Canada, hosted by the [Ocean Frontier Institute](#), [Dalhousie University](#), and [MEOPAR](#), and the other in Shanghai, China, hosted by the [State Key Laboratory of Estuarine and Coastal Research \(SKLEC\)](#), [East China Normal University \(ECNU\)](#). The IPOs also interact with the IMBeR community via the [website](#), an [IMBeR eNews](#) bulletin which is published every second week in English, an [IMBeR newsletter](#) published every month in English and Chinese, Twitter ([@imber_ipo](#) with 1774 followers) and [IMBeR WeChat](#) (with over 19,000 reads).

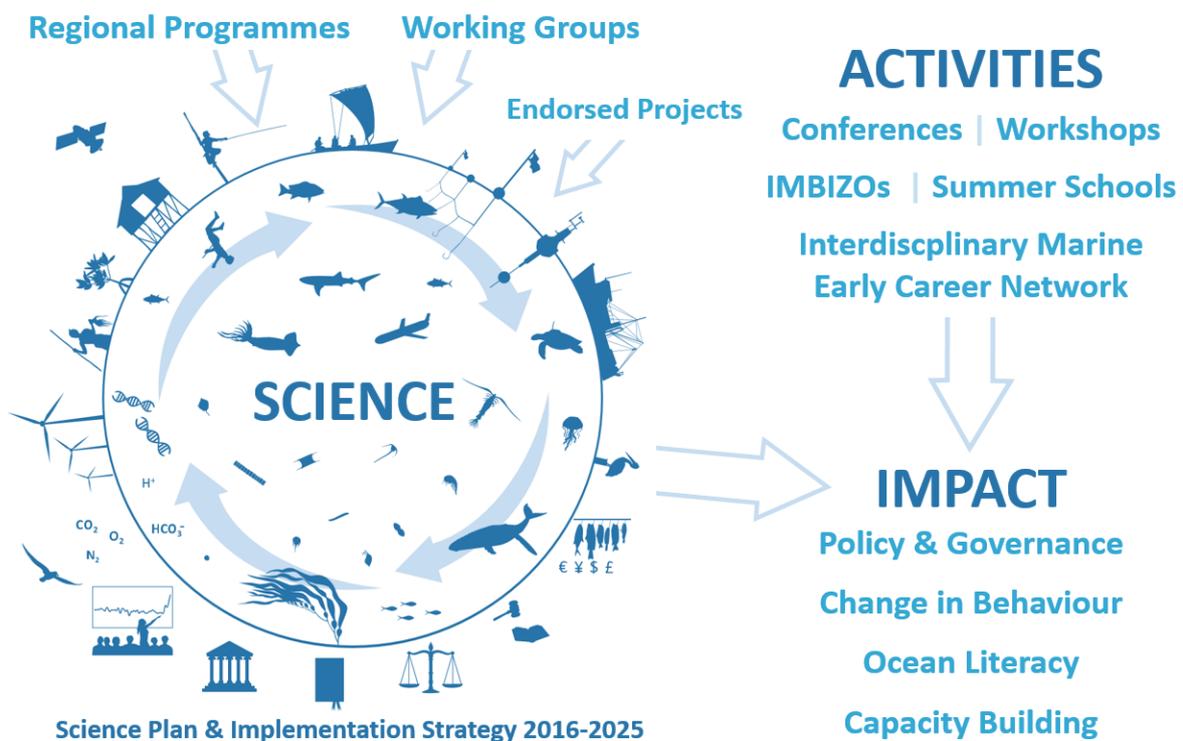


Figure 2. Contribution of the Regional Programmes, Working Groups, Endorsed Projects, Interdisciplinary Marine Early Career Network, and IMBeR activities towards addressing the Grand and Innovation Challenges.

B. SELECTED SCIENCE HIGHLIGHTS in 2020-2021

Integrated Ocean Carbon Research: A Summary of Ocean Carbon Knowledge and a Vision for Coordinated Ocean Carbon Research and Observations for the Next Decade

In 2021, IOC-R published a summary and a vision of coordinated ocean carbon research and observations for the next decade as a contribution to the UN Decade of Ocean Science for Sustainable Development (Aricò et al., 2021). The report sets out to accomplish the vital task of studying the evolution of CO₂ uptake. It presents a synthesis of the state of knowledge about the ocean's role in the carbon cycle and points to the way ahead. Its objective is to provide decision-makers with the knowledge needed to develop climate change mitigation and adaptation policies for the coming decade. The report also emphasizes the importance of scientific knowledge to the taking of informed decisions within the United Nations Framework Convention on Climate Change in order to achieve the goals of the Paris Agreement and build more resilient societies. The report highlights the role of the ocean since the industrial revolution as a sink for carbon generated by human activity. Indeed, without ocean and land sinks, atmospheric CO₂ levels would be close to 600 ppm (parts per million), 50% higher than the 410 ppm recorded in 2019, which is already well above the agreed target of limiting global warming to two degrees Celsius. But there is a danger that this process will be reversed. Instead of absorbing carbon, the ocean could contribute to the warming greenhouse effect of CO₂ emissions. The report thus examines available observations and research to determine whether the ocean will continue to “help” humanity or whether it will turn against it, making mitigation and adaptation to warming more difficult. The broader question is how humanity is altering the ocean carbon cycle, including through carbon dioxide removal schemes, and how this impacts marine ecosystems. The report proposes an innovative joint programme of medium- and long-term integrated ocean carbon research to fill the gaps in this field.



Figure 3. Cover of Aricò et al. (2021).

Role of Antarctic krill in the carbon cycle

Antarctic krill play an important role in biogeochemical cycles and potentially generate high particulate organic carbon (POC) fluxes to the deep ocean. Krill also have an unusual trait of moulting continuously throughout their life-cycle. Manno et al. (2020) determined the krill seasonal contribution to POC flux in terms of faecal pellets (FP), exuviae and carcasses from sediment trap samples collected in the Southern Ocean. They found that krill moulting generated an exuviae flux of similar order to that of FP, together accounting for 87% of an annual POC flux ($22.8 \text{ g C m}^{-2} \text{ y}^{-1}$). Using an inverse modelling approach, the authors determined the krill population size necessary to generate this flux peaked at 261 g m^{-2} . This study shows the important role of krill exuviae as a vector for POC flux. Since krill moulting cycle depends on temperature, the results highlight the sensitivity of POC flux to rapid regional environmental change.

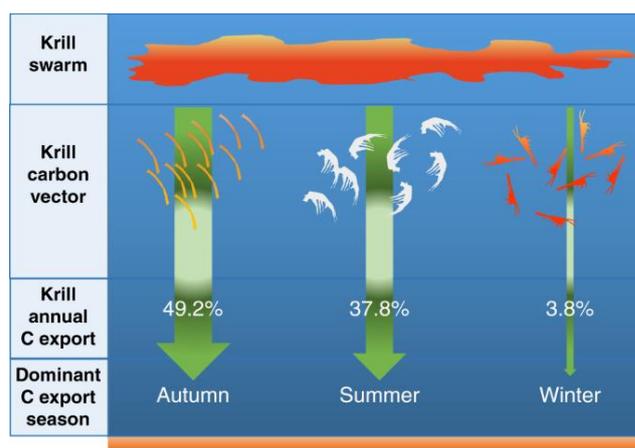


Figure 4. Schematic showing the average annual proportional contribution (%) of krill derived carbon (faecal pellets, exuviae and carcasses respectively) to annual particulate organic carbon (POC) flux and the dominant export season for each vector (Manno et al., 2020).

The quilt of sustainable ocean governance: patterns for practitioners

To address the challenge of full-spectrum sustainability, [Stephenson et al. \(2021\)](#) identified 13 objectives from the literature, Sustainable Development Goals and international agreements, and evaluated how these diverse considerations are included in six sustainability-related concepts (social-ecological systems approach, ecosystem-based management, integrated management, marine spatial planning, participatory co-management and the precautionary approach). The publication arose from the ‘[Designing the quilt of sustainable ocean governance](#)’ session held at the IMBeR Open Science Conference – Future Oceans₂ in Brest, France, 2019.

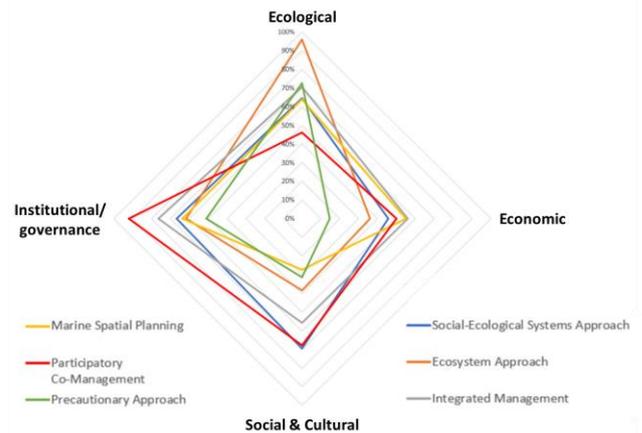


Figure 5. Relative emphasis of concepts related to full-spectrum sustainability, derived from scores of 17 co-authors. Each axis shows the percentage of the possible maximum score that could have been obtained from scoring by all objectives in each group for each concept by 17 co-authors. ([Stephenson et al., 2021](#))

Integrating sociocultural values into marine spatial planning

In most cases, marine spatial planning (MSP) seems to be driven primarily by economic interests rather than by sociocultural interests or by the goals of underrepresented groups. [Pennino et al. \(2021\)](#) discuss how integrating these missing sociocultural layers into MSP can help to reduce governance rigidity, promote adaptability in decision-making, support environmental justice, and improve MSP acceptance and uptake. In particular, the authors focus on identifying possible points of connection between MSP and frameworks based on social-ecological system theory, including co-management and other democratic and empowering alternatives. They conclude by proposing a new definition of the MSP process that is more inclusive, and mindful of users' rights and sociocultural objectives. If the gap between the dominant economic rhetoric and a de facto sociocultural-ecological system approach are bridged, it is likely to improve the chances of the MSP process succeeding on both the human and nature fronts. The publication was an output from IMECaN's 3-day [virtual MSP workshop](#) held in 2020.

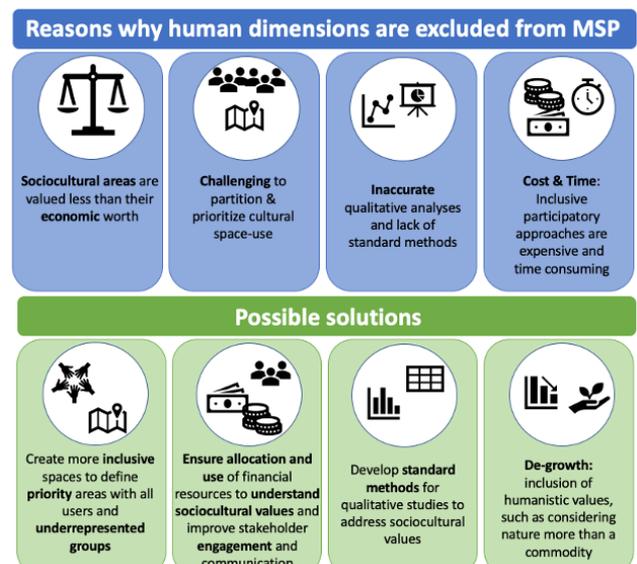


Figure 6. Reasons why human dimensions are excluded from the marine spatial planning process and potential solutions ([Pennino et al., 2021](#)).

Special Issues: The Second International Indian Ocean Expedition (IIOE-2): Motivating New Exploration in a Poorly Understood Ocean Basin (Volumes 3 and 4)

The [third](#) and [fourth](#) volumes from SIBER's collaboration with the Second International Indian Ocean Expedition (IIOE-2) have been published in Deep-Sea Research Part II (13 and 6 articles, respectively). The special issues highlight the broad range of IIOE-2 research. [Polikarpov et al., \(2020\)](#) describe the increasing occurrence of harmful algal blooms and fish mortality events in Kuwait's waters, and concluded that the long-term variability in occurrence and composition of phytoplankton blooms was largely governed by the N:P ratio. By using a novel detection algorithm, [Torterotot et al., \(2020\)](#) show that Antarctic and pygmy blue whales have very different spatial and seasonal distributions in the southern Indian Ocean. [Dalabeharaa and Sarma \(2021\)](#) demonstrate that models based on remote sensing data significantly underestimate primary production in the Indian Ocean. By using satellite observations, [Huang and Feng \(2020\)](#) reveal that diurnal sea surface temperature amplitude in the Northwest shelf of Australia is modulated by surface wind, and that El Niño suppresses Madden-Julian Oscillation activities.

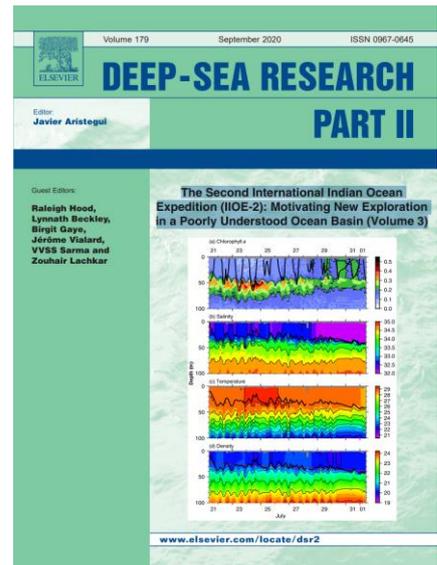


Figure 7. Cover of IIOE-2 special issue [volume 3](#).

Comparative research on ocean top predators by CLIOTOP: Understanding shifts in oceanic biodiversity under climate change

[Evans et al. \(2020\)](#) outline the recent advances that CLIOTOP has made in understanding oceanic top predators, the marine ecosystems that support them and the socio-economic systems that depend upon them. Research conducted under CLIOTOP has focused on how climate change is affecting the pelagic ocean, with a range of impacts detected or predicted for open ocean biology, and provision of ecosystem services such as food. Research has also focused on exploring the socio-economic consequences of oceanic change, and in some cases, evaluating the adaptation options that can reduce the vulnerability to climate change. CLIOTOP has helped describe new frameworks and approaches for understanding the population and spatial dynamics, trophodynamics, future distributions of a range of species as well as identifying individual drivers of change and future risks to populations, the trophic linkages between prey and predators and the pathways through which the environment can influence predators. Research conducted through collaborations facilitated by CLIOTOP align with several of the goals set out under the 2030 Agenda for Sustainable Development and a number of the challenges identified as needing to be addressed in order to achieve the societal outcomes of the UN Decade of Ocean Science for Sustainable Development 2021–2030. Evans et al. (2020) conclude that setting future research directions that maximise the potential of the network of scientists contributing to CLIOTOP will assist in

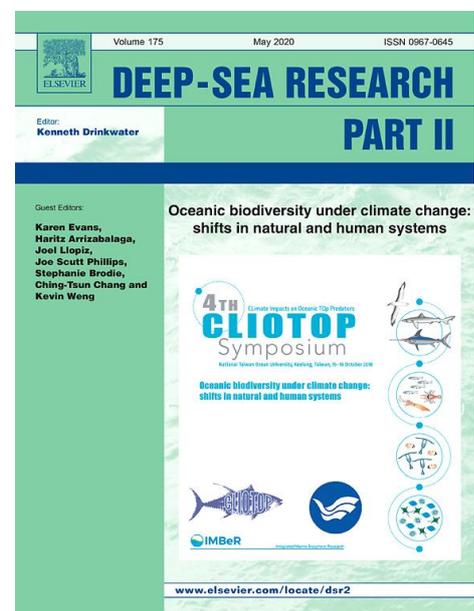


Figure 8. Cover of [CLIOTOP special issue](#).

progressing the science required for achieving a sustainable future. The article is the editorial of the [CLIOTOP special issue](#) developed from the [4th CLIOTOP Symposium](#) in 2018.

Anthropogenic impacts on nutrient variability in the lower Yellow River

Chinese continental margins are characterized by the river-influenced marine environment in the Northwest Pacific Ocean and are important sites for the accumulation of terrigenous organic carbon and high primary productivity fuelled by riverine nutrients discharged from various sources and coastal and river basin erosion. The fluxes and composition of riverine nutrients discharged into the sea has been greatly modified by climate change (here termed as natural), and anthropogenic activities, particularly in the last 20 years. As a part of the CMWG’s work, [Wu et al., \(2021\)](#) were able to quantify the amount of riverine nutrient discharge and changes in nutrient ratios caused by global change and anthropogenic activities occurring in the Yellow River from 2001 to 2018. They quantified the fluxes and composition of macronutrients (N, P, Si) to the Yellow River emitted from three distinct sources; natural, anthropogenic and socio-industrial activities including the impacts of dams, urbanization, and consequential sewage discharges as shown in Figure 9. Their approach should stimulate similar studies in other river-influenced continental margins around the world to better estimate riverine fluxes of nutrients to the sea.

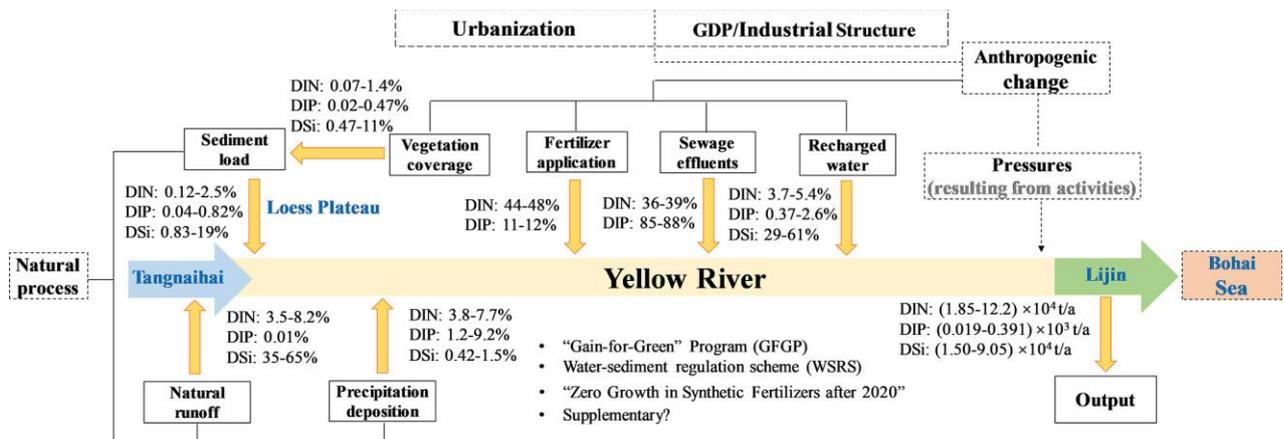


Figure 9. Graphical abstract [Wu et al. \(2021\)](#).

C. ACHIEVEMENTS and ACTIVITIES 2020-2021

--- Implementation of the IMBeR Science Plan and Implementation Strategy

Although COVID-19 made in-person meetings, research cruises, and field work difficult over the period of this report, IMBeR was able to make progress towards achieving the objectives of the Grand and Innovation Challenges. This progress is outlined below:

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

ESSAS

The Resilience and Adaptive Capacity of Arctic marine ecosystems (**RACArctic**) project has submitted four synthesis papers to the ICES Journal of Marine Science which are currently undergoing revision.

The **ESSAS Annual Science Meeting** was held virtually in June 2021 under the theme of “*Linking past and present marine ecosystems to inform future fisheries and aquaculture*”. There were a total of 37 presentations including some collaborative, interdisciplinary studies involving natural, economic and social sciences, a public lecture, and a stakeholder meeting.

ESSAS-endorsed national projects provide observations of essential ocean variables (EOVs) in high-latitude marine ecosystems. E.g., the Arctic Marine Biological Observation Network ([AMBON](#)), is developing a long-term observing program in the Chukchi Sea to monitor EOVs and biodiversity at all trophic levels, from microbes to whales. Similarly, several Japanese programs routinely contribute to sampling standard transect lines in the northern Bering Sea and Chukchi Sea that together form the 'Distributed Biological Observatory' ([DBO](#)).

ESSAS members are active in the development of 'Integrated Ecosystem Assessments' (**IEAs**) for at least three Arctic and Subarctic regions. Former ESSAS co-chair Sei-Ichi Saitoh and current co-chair Franz Mueter participate in a joint PICES/ICES/PAME (Protection of the Arctic Marine Environment) Working Group focused on developing an IEA for the Central Arctic Ocean. Franz Mueter and several AMBON researchers took part in initial meetings of a new PICES/ICES Working Group on Integrated Ecosystem Assessment for the Northern Bering Sea - Chukchi Sea (WG 44) and continue to be involved as members of (or observers to) the Working Group which met virtually in April 2021. Co-chair Benjamin Planque is involved in the ICES IEA groups for the Norwegian and Barents Seas, which report on the ecological status of these two regions annually. Benjamin Planque is also co-chairing the ICES working group on integrated trend analyses and the ICES/PICES working group on common ecological reference points.

George Hunt (former ESSAS Co-Chair) recently led a [Special Issue for Deep-Sea Research II](#) that focused on the rapidly changing Northern Bering Sea region and involved contributions from, among others, researchers from Japan, Korea, Russia and the US. Several of the authors were invited to contribute based on research presentations at ESSAS sponsored activities.

CLIOTOP

Two of the three additional manuscripts published this year in the CLIOTOP special issue in Deep-Sea Research Part II (20 articles in total) contribute to GCI: [Chiang et al. \(2020\)](#) found that the feeding ecology and trophic position of black marlin off eastern Taiwan varies across life-history stages and seasons, possibly reflecting seasonal movements in surrounding pelagic ecosystems; and [Wu et al. \(2020\)](#) concluded that decadal climate indices affect the regional distributions of yellow fin tuna and their long-term availability to fisheries, possibly affecting their overall abundance.

ICED

ICED scientists have been involved in a range of studies examining **the role of krill** ([Manno et al., 2020](#)) and **mesopelagic fish** ([Freer et al., 2020](#) and [Belcher et al., 2020](#)) in Southern Ocean ecosystem structure and functioning, including carbon cycling. ICED scientists contributed understanding of the impacts of climate change on Southern Ocean ecosystems, such as decreased sea ice in a study by Turner et al. (2020), examining past decreases of summer sea ice extent in the Weddell Sea region.

ICED continued its work to campaign and plan for a focus on sea ice ecosystems, including a multi-year, multidisciplinary field work effort. Plans are underway to work with the Scientific Committee on Antarctic Research (SCAR) to progress this initiative. Plans were also presented at the [UK Antarctic Science Conference 2021](#) Scoping Session proposing a UK contribution to this effort.

The Marine Ecosystem Assessment of the Southern Ocean ([MEASO](#)) produced several articles on key species and drivers to support scenarios, projections and governance in the [MEASO Special Issue](#) of *Frontiers in Marine Science*, with several more articles in review.

The ICED community has made strong links with relevant SCAR groups, including 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

(ICED-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 will continue to be involved in SOOS's efforts in assessing physical and biological states through the MEASO initiative.

As a Co-Sponsored Programme of SCAR, ICED has continued to develop links with SCAR's Antarctic Thresholds - Ecosystem Resilience and Adaptation (**Ant-ERA**) and State of the Antarctic Ecosystem (**AntEco**) programmes - both of which ended in March 2021. More recently ICED has been highlighting the need to continue research into the role of metabolic diversity and evolution in marine biogeochemical cycling and ocean ecosystem processes under the new SCAR programme **Ant-ICON**. Omics is not an area in which ICED has invested strongly, yet in addition to helping us understand biodiversity, structure and functioning of Southern Ocean ecosystems and their response to change, it will be key to informing the wider ecological debate about the nature of stability and change in ecosystems.

SIBER

Grand Challenge I continues to be a central SIBER objective - to improve understanding of the Indian Ocean's role in global biogeochemical cycles and the interaction between these cycles and marine ecosystem dynamics. IIOE-2's Eastern and Western Indian Ocean Upwelling Regime Initiatives (**EOURI** and **WIORI**, respectively), numerous individual projects (such as the [SOLSTICE-WIO](#) programme) and national IIOE-2-related programmes and research cruises (India, Australia, France, South Africa, Germany, Japan, Indonesia etc.) all contribute to GC I. As a specific example, using ROVs and eDNA, the IIOE-2 endorsed RV *Falkor* voyage to the **Ningaloo Canyons** was the first to document the biodiversity of this deep water system in March 2020.

The **14th International Conference on Copepoda** (Skukuza, South Africa) with a special session on '[Marine Copepods of the Indian Ocean: A contribution to the IIOE-2](#)', was held virtually in June 2021.

SIBER contributed to the [decadal review](#) process for the Indian Ocean Observing System (IndOOS).

SKED

In autumn 2020, SKED conducted its final cruise along the Kuroshio axis. Multidisciplinary observations of physical, chemical and biological oceanography and microplastics were carried out. SKED ended in March 2021. A summary report has been prepared, and further papers are in preparation.

AMT

[Larkin et al. \(2021\)](#) present 971 globally distributed surface ocean metagenomes collected at high spatio-temporal resolution. Their low-cost metagenomic sequencing protocol produced 3.65 terabases of data, where the median number of base pairs per sample was 3.41 billion. This dataset is expected to help answer questions about the link between microbial communities and biogeochemical fluxes in a changing ocean.

MCS-CNS

[Liu et al. \(2020\)](#) demonstrate that anaerobic oxidation of methane (AOM) can serve as a dominant biogeochemical process through incorporation of methane-derived carbon into dissolved and solid inorganic carbon phases, significantly influencing the cycling of dissolved inorganic carbon within the shallow sediments of the Haima cold seep area.

PACECS

A new solar-powered, air-lifted artificial upwelling (AU) system was applied to study the potential effect on regional carbon removal. [Fan et al. \(2020\)](#) concluded that seaweed growth was stimulated by AU, and that this process has the potential to remove a further 14.8 thousand tons of carbon in Chinese coastal waters.

[Shen et al. 2020](#) demonstrate that laterally transported particles (including sinking and suspended particles) serve as a major energy source for the dark ocean, and that these particles provide organic carbon directly and enhance new organic carbon production by dark carbon fixation, reconciling the mismatch in the regional carbon budget.

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

ESSAS

The ESSAS-led **RACArctic** project focused on developing plausible scenarios for anticipated changes in high-latitude marine ecosystems, and in particular the consequences of these changes for fish populations and fisheries. The work was based on a review of available literature, including qualitative predictions and available projections.

Ongoing activities in the **Norwegian Nansen Legacy** project (2018-2023) aim to provide integrated scientific knowledge on the rapidly changing Barents Sea climate and ecosystem to support sustainable management through the 21st century. Benjamin Planque is involved in the research focus ‘the future Barents Sea’ which includes the development of forecasting and scenarios for climate and ecosystem.

ICED

ICED have 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. ICED used its understanding of the drivers and impacts of climate change (under GCI) in the Southern Ocean to further its work on developing scenarios of key drivers and projections of ecological change. Examples of publications and outputs include:

- **Joint research interests with other programmes and initiatives:** ICED continues to work with other key programmes and initiatives to outline future collaborations/links to improve scenarios and projections of Southern Ocean ecosystems, including with CCAMLR (see [Cavanagh et al., 2021](#)) and SCAR’s new Scientific Research Programmes [Ant-ICON](#) and [AntClim^{now}](#).
- **New EU Horizon 2020 programme:** In December 2020 ICED scientists were notified of their successful EU Horizon2020 bid, ‘Polar Regions in the Earth System: the Role of Local and Regional Polar Processes in Changing the Polar Climate and the Global Climate System’ (PolarRES). Using understanding and data on the abundance and distribution of key species in the Southern (and Arctic) Ocean, PolarRES will generate future projections of their dynamics using outputs from high resolution physical models of the polar regions.
- **ICED scenarios and projection:** ICED continues to develop work on projections. Following ICED’s influence and involvement on the IPCC’s 2019 Special Report on the Ocean and Cryosphere in a Changing Climate ([SROCC, 2019](#)), a group of scientists (including ICED scientists, SROCC report authors, and other international scientists), summarised the SROCC findings that have specific relevance to CCAMLR, focusing on harvested species and associated and dependent species ([Cavanagh et al., 2021](#)). These findings will be useful for informing CCAMLR’s discussions about research, monitoring and management actions. ICED scientists were also involved in an assessment of climate driven changes in Southern Ocean ecosystems and their potential futures ([Rogers et al., 2020](#)) and circumpolar projections for Antarctic krill growth ([Veytia et al., 2020](#)).

- **ICED krill modelling workshop 2021:** ICED established and early career researchers and Bettina Meyer from the SCAR Action Group on Antarctic Krill, organised a virtual [ICED Antarctic krill Modelling Workshop](#) which aimed to unite the research community (ECRs) engaged in modelling Antarctic krill and its application to understanding their ecology, links and feedbacks with Southern Ocean and Earth System processes, and input to conservation and management options.
- **SCAR Krill Action Group (SKAG):** ICED scientists contributed to [Meyer et al. \(2020\)](#) on the inclusion of uncertainties in the ecosystem-based management of Antarctic krill.
- **ICED-MEASO:** ICED scientists have published and submitted several papers to the MEASO Special Issue to support future projections ([Morley et al. 2020](#), [Cavanagh et al. 2021](#)), with several more in review.

CMWG

A **workshop** was held in February 2021 to agree on **earth system model downscaling protocols** across the range of regional and local modelling approaches. A paper is being developed to document the protocol.

INTAROS

INTAROS established an integrated Arctic Observation System (iAOS), including [data catalogue](#), portal for accessing data, cloud platform with analysis tools, and Geostatistical library. Based on a suite of NorCPM (Norwegian Climate Prediction Model) retrospective forecasts, [Dai et al. \(2020\)](#) show that seasonal prediction of pan-Arctic sea ice extent is skillful at lead times up to 12 months, which outperforms the anomaly persistence forecast.

MCS-CNS

A physical-ecological coupling model has been developed to simulate the interaction process between the microbial carbon pump and the biological pump in the northern South China Sea.

MEMFiS

The high-resolution marine ecosystem forecasting system of the China Seas and Northwestern Pacific has been built in the National Marine Environmental Forecast Center.

-- **Grand Challenge III: Improving and achieving sustainable ocean governance**

ICED

ICED has worked with stakeholders to ensure that science undertaken within GCI and GCII is incorporated into adaptation, mitigation and sustainable management and conservation procedures by improving communications and understanding between science, policy, and society.

- **Antarctic Treaty System:** ICED is continuing its work with the Antarctic Treaty Commission via 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 CCAMLR. ICED is also continuing to work with other international environmental treaties and organisations, conservation groups, and international committees, including the International Whaling Committee (IWC).
 - o **CCAMLR:** During 2020, the CCAMLR Working Groups, Scientific Committee and Commission meetings all took place virtually and as such the agendas were more limited than in previous years. Key topics included krill management strategies and climate change. A summary paper based on the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) was submitted to the CCAMLR Working Groups (WG-EMM and WG-FSA, July 2020), see above, ([Cavanagh et al., 2021](#)) which acknowledges the significant contributions by ICED in this area. Furthermore, a Working Paper on climate change was submitted to the Scientific Committee by a number of Delegations (SC-CAMLR-39/03) and this included specific recognition of the contributions ICED has made on this

topic to date, and a recommendation that CCAMLR continues to actively engage with ICED in this regard. CCAMLR meetings in 2021 are being held virtually, again with a restricted agenda. The focus will be on krill management strategies with important contributions from ICED scientists

- **Conservation Groups:** ICED scientists continue to co-lead a science-policy initiative between the British Antarctic Survey and the Cambridge Conservation Initiative based in Cambridge, UK that relates to this objective (see IC4 for details)
- **ICED-MEASO:** MEASO is an ICED initiative focused on generating an assessment of the status and trends of Southern Ocean ecosystems with an emphasis on input to policy and aims to provide a quantitative assessment of the status of Southern Ocean ecosystems that will enable managers to achieve consensus in adapting their management strategies to change. Two papers have been published in this Special Issue regarding challenges and potential solutions for policymakers ([Press, 2020](#); [Cavanagh et al., 2021](#)) with several more in review.
- **United Nations Decade of Ocean Science for Sustainable Development (2021-2030):** ICED has continued to contribute to a Southern Ocean Action Plan as part of the UN Ocean Decade, regarding ways to improve sustainable governance of Southern Ocean ecosystems.

SIBER

Central objectives of **IIOE-2** are to improve scientific knowledge transfer to wider segments of society and regional governments, and to create educational and capacity development opportunities. These efforts all contribute directly to GCIII - improving and achieving sustainable ocean governance.

The ongoing [SOLSTICE-WIO](#) programme (co-led by SIBER SSC 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.

Using an emblematic seamount located in the ABNJ, South of Madagascar, [Marsac et al. \(2020\)](#) discuss how it could become a fully protected space. Guidelines are proposed to encourage dedicated seamount governance under a new legal framework under UNCLOS, in a regional seas organization under UNEP, the Nairobi Convention, which has a management competence over this region.

CLIOTOP

CLIOTOP Co-Chair, Karen Evans was part of the Group of Experts for the United Nations [Second World Ocean](#) Assessment launched in April 2021, and the National Focal Point for Australia. Karen Evans also served on the Decade Executive Planning Group (2018-2020) for the [UN Decade of Ocean Science for Sustainable Development](#), and currently serves on the Interim Decade Advisory Board.

HDWG

Arising from work within the HDWG and the 'Designing the quilt of sustainable ocean governance' session held at the IMBeR Open Science Conference – Future Oceans2 in Brest, France, 2019, [Stephenson et al. \(2021\)](#) compared the relative strengths and weaknesses of a range of governance concepts to provide practitioners with the 'best practice' basis for a coherent approach (See more in section B 'Selected scientific highlights in 2020-2021').

[van Putten et al. \(2021\)](#) used IMBeR as a case study to understand the contribution of interdisciplinary global research networks to solving complex marine socio-ecological challenges. Event attendees were predominantly from western Europe, North America, and East Asia. Overall, in the global network, there

was growing participation by females, students, early career researchers, and social scientists, thus assisting in moving toward interdisciplinarity in IMBeR research.

CMWG

A series of **stakeholder workshops** have been held in March-May 2021 across the NE Atlantic, Black Sea, Mediterranean, and South America to initiate co-production of ecosystem service targeted case studies. An integrated workshop is planned to compare global experiences.

IMECaN

In August 2020, IMECaN held a virtual workshop '[Marine Spatial Planning Workshop: Balancing social, economic, cultural, and ecological objectives](#)'. The workshop was attended by 681 ECRs and early career professionals from 82 countries. One of the outcomes of this workshop was a paper from [Pennino et al. \(2021\)](#) who discuss the importance of integrating these missing sociocultural layers into MSP for successful outcomes for both people and nature. [For more details see section B 'Selected scientific highlights 2020-2021'.]

Partners and Endorsed Projects

A major strategy of GCIII scientists has been to pursue further funding, which has led to the start of four large multi-case projects with a focus on ocean governance. These projects bring together the global community to address GCIII and will accelerate progress over the next few years.

- **Vulnerability to Viability (V2V): Global Partnership** conducts transdisciplinary, community engaged research with small-scale fishing communities in six Asian and six African countries using the I-ADApT management tool developed within the IMBeR Human Dimensions Working Group ([Bundy et al., 2016](#)). V2V have remained active throughout COVID-19 restrictions, launching the 'V2V Thematic Webinar Series' and the 'V2V Learners Series' online.
- **Negotiating Ocean Conflicts among Rivals for Sustainable and Equitable Solutions (NoCRISES)** focuses on ocean conflict hotspots in regions with diverse income levels and which are characterised by rapid ecological and/or social change.
- **A Sea of Connections: Contextualizing Fisheries in the South Pacific Region (SOCPacific)** aims to understand the social value of places and resources, links and tensions between fishing and conservation interests, and to develop the integration of fisheries and management tools for marine spatial planning.
- **Marine Ecosystem-based Management Progress Evaluation Group: tracking the global progress of EBM (MEBM-PEG)** systematically tracks progress towards EBM, communicates its benefits, and identifies where remaining impediments to implementing EBM persist, with suggested solutions for achieving further implementation of EBM.

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

Work continues towards the development of a paper from the '[Ecological Feedbacks in the Earth System](#)' session held at the IMBeR 2019 Open Science Conference in Brest, France.

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

IC4 Task Team

To assist in progressing IC4, a task team has been established from IMBeR SSC members, representatives from Regional Programmes and Working Groups, and the broader IMBeR research community.

ESSAS

Alan Haynie (NOAA, USA), chair of the ESSAS Human Dimensions Working Group, continues to be active at the national and international levels to develop better approaches to using economic data for supporting decision making in fishery management. Activities include:

- Participation in the **Climate Fisheries Initiative**, which is working to plan how NOAA and partners couple ocean modeling and fisheries management over the coming decade.
- Co-PI of the **Alaska Climate Integrated Modeling (ACLIM)** Project, an effort that partners NOAA and university partners to make fisheries management in the North Pacific 'climate ready'.

-- **Innovation Challenge 5:** Interventions to change the course of climate impacts

This innovation challenge focuses on potential ecological interventions to maintain biodiversity i.e. interventions at the species, habitat and human behaviour level. Activities being planned include a workshop with SOLAS (who focus on carbon dioxide removal strategies) and collaboration with WCRP. Two of the workshops planned for IMBIZO 6 '[Exploring potential marine options for climate intervention](#)' and '[Ocean governance and climate adaptation: comparing responses, charting future courses](#)' address aspects of IC5.

-- **Innovation Challenge 6:** Sustainable management of Blue Carbon ecosystems

The IC6 task team has met twice to discuss and refine the objectives and implementation plan and held a session at ASLO in June 2021. Activities being planned include a EuroMarine Foresight funded workshop in September 2021.

-- **Capacity building and outreach**

IMBeR SSC

Global science networks were disrupted by COVID-19 restrictions. However, rather than wait for a return to normal, [Hobday et al. \(2020\)](#) proposed four areas that can ensure a productive and collaborative future for marine science: (1) adapt scientific activities for a physically distanced world; (2) create opportunities to build and strengthen global networks; (3) minimize the impact of lost opportunities; and (4) create a global community based on a desirable future.

HDWG

The HDWG is changing its terms of reference to focus more on capacity building of interdisciplinary skills (i.e. survey development, women's engagement, etc.) targeting managers, policy makers, and NGOs. COVID-19 prevented planned activities over the last year. Members of the HDWG are also engaged with the V2V project and IMBeR endorsed project NOCRISES which both have capacity building at their core.

IMECaN

IMECaN is integral to the planning of the [ClimEco 7](#) summer school and the [IMBIZO 6](#) conference which will both be held virtually in 2021. IMBIZO 6 will hold an ECR day and each workshop includes at least one ECR co-convener.

ICED

[UK Polar Horizons 2021](#) event in Feb 2021 aimed to build capacity of currently underrepresented groups, particularly BAME, LGBTQ+ and Disabled through developing connections and collaborations with the UK

Polar Science community.

To investigate the benefits to ECRs from involvement in research initiatives such as large international projects, [Brasier et al. \(2020\)](#) discuss the experiences of ECRs directly involved in the Marine Ecosystem Assessment for the Southern Ocean (MEASO). They outline the obstacles that may become barriers to ECRs in scientific research and suggest potential actions to overcome these at the individual, institutional and scientific community level.

CREPSUM

CREPSUM scientists published a 'Field Guide to the Commercially-Important Mollusks of Panay, Philippines' ([Norte-Campos et al., 2020](#)), a 'Field Guide to the Jellyfish of Western Pacific' (Eds: [Hwai et al., 2021](#)), a 'Reef and Shore Fishes of Bidong Island off east coast of Malay Peninsula' ([Motomura et al., 2021](#)), and an online training course "Marine Science from Basic to Future Research" was held in May 2021.

INTAROS

INTAROS held the [2020 summer research school cruise - Useful Arctic Knowledge](#) near Svalbard. The summer school was led by the Nansen Environmental and Remote Sensing Center and attended by 10 MSc students. INTAROS organised and led a seminar for a broad range of Norwegian stakeholders from management and industry in January 2021 to present outcomes and solicit comments and feedback ([Report available](#)).

- - - Additional IMBeR activities

Research topics in Frontiers in Marine Science

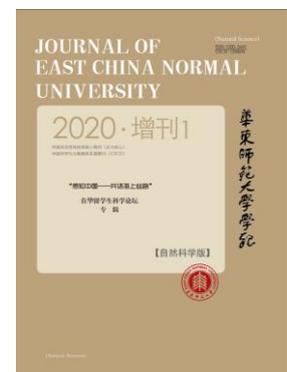
Future Oceans₂ (IMBeR's 2nd Open Science Conference, Brest, France, 2019) led to the development of two research topics in Frontiers in Marine Science:

- Research Topic 1 - [Integrated Marine Biosphere Research: Ocean Sustainability, Under Global Change, for the Benefit of Society](#) – 23 articles have been published so far.
- Research Topic 2 - [Solving Complex Ocean Challenges Through Interdisciplinary Research: Advances from Early Career Marine Scientists](#) – 29 articles have been published so far.

This research topic was developed by IMBeR's Interdisciplinary Marine Early Career Network (IMECaN). Every article required at least one ECR author.

Special issue from the Dialogue on the Maritime Silk Road, Doctoral Forum

- A [special issue](#) arising from the *Dialogue on the Maritime Silk Road, Doctoral Forum* held in 2019 was published with 40 articles in the Journal of East China Normal University.



D. SCIENTIFIC STEERING COMMITTEE

The 2021 Scientific Steering Committee consists of a chair, Carol Robinson (F, UK), three vice-chairs: GCI Alice Newton (F, Portugal), GCII Eugene Murphy (M, UK), GCIII Marion Glaser (F, Germany) and 14 members (5 male and 9 female). Four new members joined the SSC in January 2021: Micaela Trimble (F, Uruguay),

Nireka Weeratunge Starkloff (F, Sri Lanka), Thorsten Blenckner (M, Sweden), and Andrea Belgrano (M, Sweden).



At the end of 2021, Carol Robinson, Eugene Murphy, Ingrid van Putten, and Ying Wu will rotate off the SSC. In order to have a systematic approach for identifying expertise/skills gaps on the SSC, the IPOs conduct a survey of current SSC members. This survey assesses how well the SPIS is covered by SSC members' self-declared expertise. With four members rotating off the SSC at the end of the year, the survey identified that expertise covers the SPIS broadly, with small gaps around elements of GCI, GCII and IC3 (see Appendices for further details). IMBeR will therefore tailor recruitment of new members according to the gaps identified and areas of the SPIS prioritised in the immediate future, while also ensuring gender and geographical balance.

The current Chair's term will come to an end this year and a call for nominations for a new Chair (or Co-Chairs) was launched earlier in 2021. A selection committee of past and present SSC members has been established.

The 2021 IMBeR SSC meeting was held virtually, with two 3-hour plenary sessions separated by a period of 5 weeks during which time was spent working on common tasks:

- **Tasks 1-3.** For each of the 3 Grand Challenges (1) draft a high level summary of achievements since the start of the current SPIS, with some examples of significant outputs and measures of impact; (2) define 3-5 science objectives to be achieved by 2024 with the route by which they will be achieved; (3) Update the GC factsheets.
- **Task 4.** For Innovation Challenge 4, develop a list of tasks, plans to complete the tasks, and measures of success to understand when IC4 is 'completed' and can be rolled back into GC3.

- **Task 5 & 6.** For Innovation Challenge 5 and 6, finalise: (1) the text defining the overall objectives, (2) list of tasks, (3) plans for how tasks will be completed, and (4) measures of success to know when the IC can be ‘mainstreamed’ back into the GCs.
- **Task 7.** Revisit IMBeR’s strategy towards engagement with the UN Decade of Ocean Science for Sustainable Development.
- **Task 8.** Future science strategy - review and future planning
- **Task 9.** Integrating activities across the IMBeR regional programme
- **Task 10.** Finance strategy review and future planning
- **Task 11.** Review endorsement process
- **Task 12.** Review and update SSC terms of reference
- **Task 13.** West Pacific Symposium planning
- **Task 14.** Capacity building planning
- **Task 15.** Classify all publications since 2016 into class 1, 2, and 3.

E. COLLABORATIVE PARTNERS

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

IMBeR continues to have long standing collaborations with the SCOR and Future Earth global research projects, SOLAS (e.g. SIOA working group) and Future Earth Coasts (e.g. CMWG).

The IOC-R working group is a joint initiative involving IMBeR, IOC-UNESCO, IOCCP, WCRP/Climate and Ocean - Variability, Predictability, and Change (CLIVAR), SOLAS, and the Global Carbon Project (GCP).

1. Too Big To Ignore ([TBTI](#))

IMBeR is a partner of the TBTI project that is a global research network focusing on addressing issues and concerns affecting the viability and sustainability of small-scale fisheries. It includes 15 partners, 400 researchers from 45 countries. TBTI conducted 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. Although TBTI was originally scheduled to finish in 2018, the project is still ongoing: holding ‘Small-Scale Fisheries Open House – World Oceans Week 2021’ (June 2-8); publishing [Volume 2](#) of the ‘Blue Justice for Small-Scale Fisheries – A Global Scan’ e-book; and developing a book on ‘Blue Justice’ which is under review.

2. Ocean Carbon Biogeochemistry ([OCB](#))

OCB continues to actively support IMBeR by advertising its activities and events, and by providing financial support for activities. Most recently, OCB has sponsored IMBeR’s upcoming ClimEco7 summer school (2021). IMBeR was also involved in the OCB Summer Workshop, June 2021.

3. World Climate Research Project ([WCRP](#))

CLIVAR, a core project of WCRP, and its Indian Ocean Panel works closely with SIBER. CLIVAR is also part of the Integrated Ocean Carbon Research (IOC-R). WCRP is developing a collaboration agreement with IMBeR.

4. Global Ocean Observing System ([GOOS](#))

SIBER is co-sponsored by the Global Ocean Observing System in the Indian Ocean (IOGOOS) and has strong connections with the Indian Ocean Observing System (IndOOS). CLIOTOP co-chair Karen Evans is a member of the GOOS Biology and Ecosystems Panel.

5. North Pacific Marine Science Organization ([PICES](#))

IMBeR and PICES continue to collaborate, with representatives from both communities attending each other's summer schools and science meetings.

6. Vulnerability to Viability ([V2V](#)): Global Partnership for Building Strong Small-Scale Fisheries Communities

V2V was developed by members of the IMBeR HDWG. IMBeR is a partner on the project which was recently awarded a seven-year Canadian Social Sciences and Humanities Research Council Partnership Grant. The project has 51 listed co-applicants and collaborators and 45 partner institutions, in total representing 24 countries. Among other methods, V2V will use the decision support tool I-ADApT (Assessment based on Description, responses, and Appraisal for a Typology) which was developed within the IMBeR HDWG.

F. IMBeR INTERNATIONAL PROJECT OFFICES

International Project Office (IPO) Canada

John Claydon continues as Executive Director, Lisa Maddison as Deputy, and Tracey Woodhouse as the part-time Executive Assistant to the IPO in Canada. All remain working remotely due to COVID-19.

International Project Office China (formerly IMBeR Regional Project Office)

The IPO in China recruited Gi Hoon Hong as Strategy Director in 2021. Fang Zuo continues as the Deputy Director and Kai Qin as Executive Assistant.

With the assistance of the IMBeR SSC, and co-chairs of the Regional Programmes, Working Groups and IMECaN, the IPOs submitted a mid-term review report (2016-2020) to SCOR and Future Earth in June 2021.

G. PUBLICATION SUMMARY

Since 2016, IMBeR has produced almost 800 publications ([Class 1 and Class 2](#)), and 239 papers were published over the last year (172 Class 1; 67 Class 2). A full list of Class 1 publications (2020-2021) can be found in the Appendices.

IMBeR Publication databases: [since 2016 \(2016-2021\)](#) | [prior to 2016 \(1999-2015\)](#)

H. SUPPORT from SCOR

We greatly appreciate the ongoing support received from SCOR, and the additional support for specific IMBeR activities provided or managed by SCOR from other funding sources. We are especially grateful for the wisdom, advice and assistance from the SCOR Executive Director, Patricia Miloslavich, Financial Officer, Liz Gross, and past Executive Director Ed Urban.

I. BUDGET

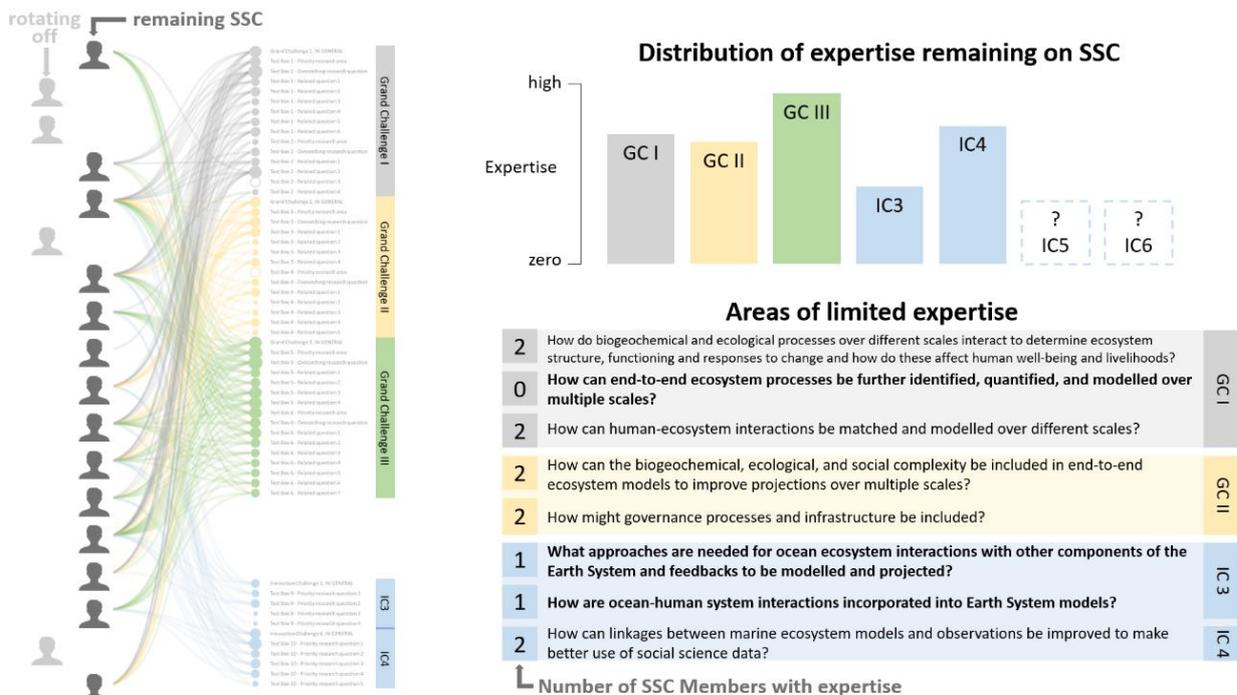
Calendar Year		2020	2021			2022	2023	2024	2025
All values USD		Actual	Budgeted	Actual					
BALANCE from previous year		108,127	172,802	177,686		159,586	125,437	100,307	85,177
INCOME			Budgeted	Current	Predicted				
SCOR (NSF Grants)	(Sept-Aug)	50,000	50,000	0	0	50,000	50,000	50,000	
Future Earth	(from 2021 reduced to Euro 10,000)	16,094	0	0	0	11,870	11,870	11,870	11,870
Meetings registration + sponsorship	IMBeR OSC							315,000	
	ClimEco	0	90,000	400	400	90,000			
	IMBIZO		110,000	0	0		115,000		
	West Pacific Symposium	0	5,000	0	0	125,000			
Miscellaneous		4,884							
Total income		70,978	255,000	400	400	276,870	176,870	376,870	11,870
TOTAL AVAILABLE FUNDS		179,105	377,802	178,086	178,086	436,456	302,307	477,177	97,047
EXPENSES			Budgeted	Current	Predicted				
Meetings	IMBeR SSC	0	32,000	0	0	32,000	32,000	32,000	32,000
	OSC (excl. ECR Day)							285,000	
	OSC - IMECaN ECR Day							20,000	
	OSC contingency							30,000	
	ClimEco	0	90,000	0	5,000	90,000			
	ClimEco contingency	0	17,000	0	0	17,000			
	West Pacific Symposium	0	5,000	0	5,000	125,000			
	West Pacific Symposium contingency	0				17,000			
	IMBIZO		110,000	0	5,000		115,000		
	IMBIZO contingency		10,000	0	0		10,000		
	GC III session at Future Earth's SRI 2021				500				
Subtotal meetings expenses (without contingencies)		0	237,000	0	15,500	247,000	147,000	337,000	32,000
IMECaN		1,419	3,000	0	0	3,000	3,000	3,000	3,000

Working Groups	Carbon WG (IOC-R)	0	2,000	0	0	2,000	2,000	2,000	2,000
	Ocean Acidification	0	7,500	0	0	7,500	7,500	7,500	7,500
	Continental Margins WG	0	5,000	0	0	5,000	5,000	5,000	5,000
	Human Dimensions WG	0	7,500	0	0	7,500	7,500	7,500	7,500
Regional Progs	CLIOTOP	0	15,500	0	0	15,500	7,500	7,500	7,500
	ESSAS	0	8,519	0	0	8,519	7,500	7,500	7,500
	ICED	0	7,500	0	0	7,500	7,500	7,500	7,500
	SIBER	0	7,500	0	0	7,500	7,500	7,500	7,500
Subtotal IMECaN, WGs + RPs expenses		1,419	64,019	0	0	64,019	55,000	55,000	55,000
Sponsorship of other projects		0	0	0	3,000	0	0	0	0
Total EXPENSES		1,419	301,019	0	18,500	311,019	202,000	392,000	87,000
BALANCE at end of year									
	without contingency	177,686	76,783	178,086	159,586	125,437	100,307	85,177	10,047
	including contingency		49,783	178,086	159,586	91,437	90,307	55,177	10,047

J. APPENDICES

IMBeR SSC Expertise Survey

The IMBeR SSC expertise survey is used to identify gaps on the SPIS not covered by SSC members. Example is from May 2021 data, looking at the gaps created when four members rotate off the SSC at the end of their terms. As IC5 and IC6 have been launched after the surveys were conducted, data are not available for these at present.



Class 1 Publications 2020-2021

The publications listed below are ‘Class 1’ - i.e. they have been specifically generated through/by/from/during IMBeR activities (e.g. publications arising from IMBeR conferences, and from the activities of the working groups and regional programmes). Where stated, the activity in question is listed under the publication.

CLIOTOP Publications

Special Issue: Oceanic biodiversity under climate change: shifts in natural and human systems

Wu, Y. L., Lan, K. W., & Tian, Y. (2020). Determining the effect of multiscale climate indices on the global yellowfin tuna (*Thunnus albacares*) population using a time series analysis. *Deep Sea Research Part II: Topical Studies in Oceanography*, 175, 104808.

<https://doi.org/10.1016/j.dsr2.2020.104808>

Class 1; Activity - 4th CLIOTOP Symposium

Chiang, W. C., Chang, C. T., Madigan, D. J., Carlisle, A. B., Musyl, M. K., Chang, Y. C., ... & Tseng, C. T. (2020). Stable isotope analysis reveals feeding ecology and trophic position of black marlin off eastern Taiwan. *Deep Sea Research Part II: Topical Studies in Oceanography*, 175, 104821.

<https://doi.org/10.1016/j.dsr2.2020.104821>

Class 1; Activity - 4th CLIOTOP Symposium

Evans, K., Arrizabalaga, H., Brodie, S., Chang, C. T., Llopiz, J., Phillips, J. S., & Weng, K. (2020). Comparative research on ocean top predators by CLIOTOP: Understanding shifts in oceanic biodiversity under climate change. *Deep Sea Research Part II: Topical Studies in Oceanography*, 175, 104822.

<https://doi.org/10.1016/j.dsr2.2020.104822>

Class 1; Activity - 4th CLIOTOP Symposium

ESSAS Publications

Khasanov, B. F., Fitzhugh, B., Nakamura, T., Okuno, M., Hatfield, V., Krylovich, O. A., ... & Savinetsky, A. B. (2020) New data and synthesis of ΔR estimates from the northern Pacific Ocean. *Quaternary Research*.

<https://doi.org/10.1017/qua.2020.27>

Class 1; Activity - Paleo-Ecology of Sub-Arctic Seas Working Group Special Issue

West, C. F., Etnier, M. A., Barbeaux, S., Partlow, M. A., & Orlov, A. M. (2020) Size distribution of Pacific cod (*Gadus macrocephalus*) in the North Pacific Ocean over 6 millennia. *Quaternary Research*.

<https://doi.org/10.1017/qua.2020.70>

Class 1; Activity - Paleo-Ecology of Sub-Arctic Seas Working Group Special Issue

Special issue in part arising from ESSAS collaborations between Japanese, Russian and US-based researchers

Hirawake, T. and Hunt Jr, G.L., (2020) Impacts of unusually light sea-ice cover in winter 2017-2018 on the northern Bering Sea marine ecosystem—An introduction. *Deep Sea Research Part II: Topical Studies in Oceanography*, 181–182: 104908.

<https://doi.org/10.1016/j.dsr2.2020.104908>

Class 1; Activity - Special issue in part arising from ESSAS collaborations between Japanese, Russian and US-based researchers

ICED Publications

Belcher, A., Cook, K., Bondyale-Juez, D., Stowasser, G., Fielding, S., Saunders, R.A., Mayor, D.J., Tarling, G.A., (2020). Respiration of mesopelagic fish: a comparison of respiratory electron transport system (ETS) measurements and allometrically calculated rates in the Southern Ocean and Benguela Current. *ICES Journal of Marine Science* 77, 1672–1684.

<https://doi.org/10.1093/icesjms/fsaa031>

Class 1

Freer, J.J., Tarling, G.A., Collins, M.A., Partridge, J.C., Genner, M.J., (2020). Estimating circumpolar distributions of lanternfish using 2D and 3D ecological niche models. *Marine Ecology Progress Series* 647, 179–193.

<https://doi.org/10.3354/meps13384>

Class 1

Manno, C., Fielding, S., Stowasser, G., Murphy, E.J., Thorpe, S.E., Tarling, G.A., (2020). Continuous moulting by Antarctic krill drives major pulses of carbon export in the north Scotia Sea, Southern Ocean. *Nature Communications* 11, 6051.

<https://doi.org/10.1038/s41467-020-19956-7>

Class 1

Meyer, B., Atkinson, A., Bernard, K.S., Brierley, A.S., Driscoll, R., Hill, S.L., Marschoff, E., Maschette, D., Perry, F.A., Reiss, C.S., Rombolá, E., Tarling, G.A., Thorpe, S.E., Trathan, P.N., Zhu, G., Kawaguchi, S., (2020). Successful ecosystem-based management of Antarctic krill should address uncertainties in krill recruitment, behaviour and ecological adaptation. *Communications Earth & Environment* 1.

<https://doi.org/10.1038/s43247-020-00026-1>

Class 1

Turner, J., Guarino, M.V., Arnatt, J., Jena, B., Marshall, G.J., Phillips, T., Bajish, C.C., Clem, K., Wang, Z., Andersson, T., Murphy, E.J., Cavanagh, R., (2020). Recent Decrease of Summer Sea Ice in the Weddell Sea, Antarctica. *Geophysical Research Letters* 47, e2020GL087127.

<https://doi.org/10.1029/2020GL087127>

Class 1

Veytia, D., Corney, S., Meiners, K.M., Kawaguchi, S., Murphy, E.J., Bestley, S., (2020). Circumpolar projections of Antarctic krill growth potential. *Nature Climate Change* 10, 568–575.

<https://doi.org/10.1038/s41558-020-0758-4>

Class 1

Zhang, Z., Hofmann, E.E., Dinniman, M.S., Reiss, C., Smith, W.O., Zhou, M., (2020). Linkage of the physical environments in the northern Antarctic Peninsula region to the Southern Annular Mode and the implications for the phytoplankton production. *Progress in Oceanography* 188, 102416.

<https://doi.org/10.1016/j.pocean.2020.102416>

Class 1

Brasier, M.J., Barnes, D.K.A., Bax, N., Brandt, A., Christianson, A.B., Constable, A.J., Downey, R.V., Figuerola, B., Griffiths, H.J., Gutt, J., Lockhart, S.J., Morley, S., Post, A.L., van de Putte, A., Saeedi, H., Stark, J.S., Sumner, M., Waller, C.L., (2021). Responses of Southern Ocean seafloor habitats and communities to global environmental changes. *Front. Mar. Sci.* 8.

<https://doi.org/10.3389/fmars.2021.622721>

Class 1; Activity - ICED-MEASO

ICED-MEASO Frontiers Research Topic: Marine Ecosystem Assessment for the Southern Ocean: Meeting the Challenge for Conserving Earth Ecosystems in the Long Term

Sergi, S., Baudena, A., Cotté, C., Ardyna, M., Blain, S., d'Ovidio, F., (2020). Interaction of the Antarctic Circumpolar Current With Seamounts Fuels Moderate Blooms but Vast Foraging Grounds for Multiple Marine Predators. *Front. Mar. Sci.* 7.

<https://doi.org/10.3389/fmars.2020.00416>

Class 1; Activity - ICED-MEASO

Henley, S.F., Cavan, E.L., Fawcett, S.E., Kerr, R., Monteiro, T., Sherrell, R.M., Bowie, A.R., Boyd, P.W., Barnes, D.K.A., Schloss, I.R., Marshall, T., Flynn, R., Smith, S., (2020). Changing Biogeochemistry of the Southern Ocean and Its Ecosystem Implications. *Front. Mar. Sci.* 7.

<https://doi.org/10.3389/fmars.2020.00581>

Class 1; Activity - ICED-MEASO

Baldry, K., Strutton, P.G., Hill, N.A., Boyd, P.W., (2020). Subsurface Chlorophyll-a Maxima in the Southern Ocean. *Front. Mar. Sci.* 7.

<https://doi.org/10.3389/fmars.2020.00671>

Class 1; Activity - ICED-MEASO

Brasier, M.J., McCormack, S., Bax, N., Caccavo, J.A., Cavan, E., Ericson, J.A., Figuerola, B., Hancock, A., Halfter, S., Hellesey, N., Höfer, J., Puskic, P.S., de Oliveira, C.S., Subramaniam, R.C., Wallis, J., Weldrick, C.K., (2020). Overcoming the Obstacles Faced by Early Career Researchers in Marine Science: Lessons From the Marine Ecosystem Assessment for the Southern Ocean. *Front. Mar. Sci.* 7.

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Cavanagh, R.D., Melbourne-Thomas, J., Grant, S.M., Barnes, D.K.A., Hughes, K.A., Halfter, S., Meredith, M.P., Murphy, E.J., Trebilco, R., Hill, S.L., (2021). Future risk for Southern Ocean ecosystem services under climate change. *Frontiers in Marine Science* 7.

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Class 1; Activity - ICED-MEASO

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Class 1; Activity - ICED-MEASO

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Class 1; Activity - SIBER led or SIBER involvement

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Class 1; Activity - SIBER led or SIBER involvement

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Class 1; Activity - SIBER led or SIBER involvement

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Class 1; Activity - SIBER led or SIBER involvement

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Class 1; Activity - SIBER led or SIBER involvement

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Class 1; Activity - SIBER led or SIBER involvement

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Class 1; Activity - SIBER led or SIBER involvement

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<https://doi.org/10.1016/j.dsr2.2020.104816>

Class 1; Activity - SIBER led or SIBER involvement

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Class 1; Activity - SIBER led or SIBER involvement

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Class 1; Activity - SIBER led or SIBER involvement; IIOE-2

Special Issue: The Second International Indian Ocean Expedition (IIOE-2): Motivating New Exploration in a Poorly Understood Ocean Basin

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Class 1; Activity - SIBER led or SIBER involvement; IIOE-2

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Class 1; Activity - SIBER led or SIBER involvement; IIOE-2

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Class 1; Activity - SIBER led or SIBER involvement; IIOE-2

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Class 1; Activity - SIBER led or SIBER involvement; IIOE-2

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Class 1; Activity - SIBER led or SIBER involvement; IIOE-2

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<https://doi.org/10.1016/j.dsr2.2019.07.010>

Class 1; Activity - SIBER led or SIBER involvement; IIOE-2

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Class 1; Activity - SIBER led or SIBER involvement; IIOE-2

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<https://doi.org/10.1016/j.dsr2.2019.104687>

Class 1; Activity - SIBER led or SIBER involvement; IIOE-2

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<https://doi.org/10.1016/j.dsr2.2020.104810>

Class 1; Activity - SIBER led or SIBER involvement; IIOE-2

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<https://doi.org/10.1016/j.dsr2.2020.104874>

Class 1; Activity - SIBER led or SIBER involvement; IIOE-2

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Class 1; Activity - SIBER led or SIBER involvement; IIOE-2

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Class 1; Activity - SIBER led or SIBER involvement; IIOE-2

Cedras, R.B., Halo, I., Gibbons, M.J., (2020). Biogeography of pelagic calanoid copepods in the Western Indian Ocean. *Deep Sea Research Part II: Topical Studies in Oceanography, The Second International Indian Ocean Expedition (IIOE-2): Motivating New Exploration in a Poorly Understood Ocean Basin Volume 3* 179, 104740.

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Class 1; Activity - SIBER led or SIBER involvement; IIOE-2

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<https://doi.org/10.1016/j.dsr2.2020.104924>

Class 1; Activity - SIBER led or SIBER involvement; IIOE-2

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<https://doi.org/10.1016/j.dsr2.2021.104928>

Class 1; Activity - SIBER led or SIBER involvement; IIOE-2

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<https://doi.org/10.1016/j.dsr2.2021.104926>

Class 1; Activity - SIBER led or SIBER involvement; IIOE-2

Continental Margins Working Group Publications

Song, G., Liu, S., Zhang, J., Zhu, Z., Zhang, G., Marchant, H.K., Kuypers, M.M.M., Lavik, G., (2020). Response of benthic nitrogen cycling to estuarine hypoxia. *Limnology and Oceanography*.

<https://doi.org/10.1002/lno.11630>

Class 1; Activity - IMBeR Open Science Conference 2019

Wu, N., Liu, S.-M., Zhang, G.-L., Zhang, H.-M., (2021). Anthropogenic impacts on nutrient variability in the lower Yellow River. *Science of The Total Environment* 755, 142488.

<https://doi.org/10.1016/j.scitotenv.2020.142488>

Class 1; Activity - IMBeR Open Science Conference 2019

Human Dimensions Working Group Publications

Stephenson, R.L., Hobday, A.J., Allison, E.H., Armitage, D., Brooks, K., Bundy, A., Cvitanovic, C., Dickey-Collas, M., Grilli, N. de M., Gomez, C., Jarre, A., Kaikkonen, L., Kelly, R., López, R., Muhl, E.-K., Pennino, M.G., Tam, J.C., van Putten, I., (2021). The Quilt of Sustainable Ocean Governance: Patterns for Practitioners. *Front. Mar. Sci.* 8.

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Class 1; Activity - IMBeR Open Science Conference 2019

Integrated Ocean Carbon Research

IOC Working Group on Integrated Ocean Carbon Research (IOC-R), Aricò, S., Watson, A.J., Wanninkhof, R., Thomas, H., Shutler, J.D., Schuster, U., Schoo, K.L., Sanders, R., Sabine, C., Robinson, C., Monteiro, P., McKinley, G.A., Jiao, N., Ishii, M., Isensee, K., Gruber, N., Dai, M., Chai, F., Cotrim da Cunha, L., Boyd, P.W., Bakker, D.C.E., Arrieta, J.M., Lauvset, S.K., (2021). Integrated Ocean Carbon Research: A Summary of Ocean Carbon Research, and Vision of Coordinated Ocean Carbon Research and Observations for the Next Decade. UNESCO.

<https://doi.org/10.25607/H0GJ-PQ41>

Class 1

IMECaN Publications

IMECaN Frontiers Research Topic: Solving Complex Ocean Challenges Through Interdisciplinary Research:

Advances from Early Career Marine Scientists

Pennino, M.G., Brodie, S., Frainer, A., Lopes, P.F.M., Lopez, J., Ortega-Cisneros, K., Selim, S.A., Vaidianu, N.M., (2021). The missing layers: integrating sociocultural values into Marine Spatial Planning. *Front. Mar. Sci.* 8.

<https://doi.org/10.3389/fmars.2021.633198>

Class 1; Activity - IMBeR Open Science Conference 2019

Breckwoldt, A., Lopes, P.F.M., Selim, S.A., (2021). Look Who's Asking—Reflections on Participatory and Transdisciplinary Marine Research Approaches. *Front. Mar. Sci.* 8.

<https://doi.org/10.3389/fmars.2021.627502>

Class 1; Activity - IMBeR Open Science Conference 2019

- Ortega-Cisneros, K., Cochrane, K.L., Rivers, N. and Sauer, W.H., (2021). Assessing South Africa's potential to address climate change impacts and adaptation in the fisheries sector. *Front. Mar. Sci.* 8.
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Class 1; Activity - IMBeR Open Science Conference 2019
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- Cosentino, M., Souviron-Priego, L., (2021). Think of the Early career researchers! Saving the oceans through collaborations. *Front. Mar. Sci.* 8.
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Juma, G.A., Magana, A.M., Michael, G.N., Kairo, J.G., (2020). Variation in Seagrass Carbon Stocks Between Tropical Estuarine and Marine Mangrove-Fringed Creeks. *Front. Mar. Sci.* 7.

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Levine, R.M., Fogaren, K.E., Rudzin, J.E., Russoniello, C.J., Soule, D.C., Whitaker, J.M., (2020). Open Data, Collaborative Working Platforms, and Interdisciplinary Collaboration: Building an Early Career Scientist Community of Practice to Leverage Ocean Observatories Initiative Data to Address Critical Questions in Marine Science. *Front. Mar. Sci.* 7.

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Su, Z., Pilo, G.S., Corney, S., Holbrook, N.J., Mori, M., Ziegler, P., (2021). Characterizing Marine Heatwaves in the Kerguelen Plateau Region. *Front. Mar. Sci. 7*.

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Sánchez-Jiménez, A., MacMillan, D., Wolff, M., Schlüter, A., Fujitani, M., (2021). The Importance of Values in Predicting and Encouraging Environmental Behavior: Reflections From a Costa Rican Small-Scale Fishery. *Front. Mar. Sci. 8*.

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Class 1; Activity - IMBeR Open Science Conference 2019

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Adesina, R., Dada, O., Asiwaju-Bello, Y., He, Z., (2020). Erodibility of cohesive sediments along the Nigerian transgressive mud coast: A preliminary experimental study. *Journal of East China Normal University(Natural Science) 2020*, 120.

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