Integrated Marine Biogeochemistry and Ecosystem Research (IMBER)

The Future and Way Forward

(Draft) Position Paper

Developed by the

IMBER Community

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1. INTRODUCTION

Planning for the Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) project was initiated by the International Geosphere-Biosphere Programme (IGBP) and the Scientific Committee on Oceanic Research (SCOR) Ocean Futures Planning Committee in 2001 to "*identify the most important science issues related to biological and chemical aspects of the ocean's role in global change and effects of global change on the ocean, with emphasis on important issues that are not major components of existing international projects*". This resulted in the publication of a science plan and implementation strategy in 2005 (IGBP Report 52), which provided the framework for the IMBER project. The central goal of IMBER is to provide *a comprehensive understanding of, and accurate predictive capacity for, ocean responses to accelerating global change and the consequent effects on the Earth System and human society*. This goal has been pursued through science activities in the open ocean and continental margins by national and regional research programmes, working groups, topical workshops, summer schools, and collaboration with other international global environmental change projects (e.g., Surface Ocean-Lower Atmosphere (SOLAS) project, Land Ocean Interactions in the Coastal Zone (LOICZ) project) and international organisations (e.g., International Council for Exploration of the Sea (ICES), North Pacific Marine Science Organization (PICES)) .

During its first five years the IMBER project progressed in parallel and in collaboration with the Global Ocean Ecosystems Dynamics (GLOBEC) project, sponsored by IGBP, SCOR and the Intergovernmental Oceanographic Commission (IOC). GLOBEC ended in March 2010 (see Barange et al. 2010 for project highlights) and many of its ongoing activities were integrated into IMBER. At this time, IMBER updated its science plan and implementation strategy (IGBP

Report 52A, 2010) to include these activities, as well as guidance on new research directions for the following five years (until 2015).

At the time IMBER was planning this second five-year phase, major changes were being considered for international science coordination, with particular implications for the global environmental change community. Plans were underway to replace/expand the IGBP, the International Human Dimensions Programme (IHDP), DIVERSITAS and the Earth System Science Partnership (ESSP) into a single overarching organisation, Future Earth, a 10-year international research initiative designed to "*develop the knowledge for responding effectively to the risks and opportunities of global environmental change and for supporting transformation towards global sustainability in the coming decades*". The implementation of Future Earth is due to be complete by late 2015, at which time the IGBP will end. The global environmental change core projects currently sponsored by the IGBP, including IMBER, have been invited to transition to Future Earth. This is timely because the IMBER community is currently defining and planning its next 10-year phase of research. It coincides with the development of a community request to SCOR for the extension of IMBER.

The IMBER Open Science Conference, '*Future Oceans – Research for marine sustainability: multiple stressors, drivers, challenges and solutions'* in June 2014, is intended to provide a venue for the larger marine science community to present key findings of IMBER-relevant research. It is also promoting integrated syntheses of IMBER research, and provides the opportunity to update the research agenda to guide future research into marine biogeochemistry, ecosystem structure and functioning, and the human dimensions of global marine change, and the interactions between them. As such it is an important mechanism to gather input about future research directions from the IMBER scientific community.

The objective of this position paper is to outline the key scientific issues and challenges relating to the ocean (open ocean and continental margins) and global environmental change and how IMBER can address these challenges in the next 10 years. This will build upon past successes and expand IMBER science into new areas. IMBER's strong commitment to basic curiosity-driven science remains. However, the environmental issues facing society, particularly those relating to global environmental change, are at the interface between natural and social sciences and humanities, where the understanding provided by curiosity-driven natural science merges with problem-driven, social science research and the many feedbacks from human responses. Understanding the challenges posed by various components and dimensions of global environmental change is central to developing integrated interdisciplinary approaches to deal with the mitigation and adaptation responses of society to changes in the marine realm. The ultimate goal is to foster collaborative, interdisciplinary and integrated research that addresses key ocean science issues and to provide evidence-based guidance for decision makers, managers and communities to help engage them into transitions towards sustainability of the marine realm under global change.

The IMBER community is well poised to take the lead in developing this area of research. Exciting changes and challenges are facing our community and dealing with these in a proactive, forward-thinking manner is key, both for now and the future.

2. IMBER SCIENCE

2.1 IMBER Research Framework

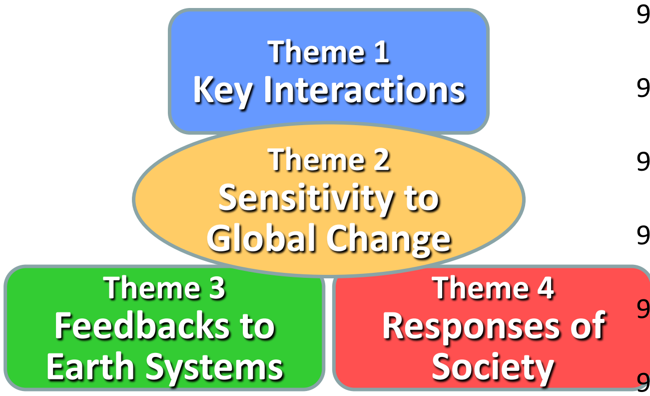

Figure 1. IMBER science themes.

IMBER science focuses around four overarching science themes (Fig. 1, Appendix 1). These research themes are addressed through IMBER's international coordination and networking activities, which are supported by at least 35 national contributions, a series of topical working groups, four regional research programmes, more than 40 endorsed projects, more than 35 national programmes (Fig. 2, Appendices 2 and 3), and several project-wide, integrative activities (IMBIZOs, ClimEco summer schools).

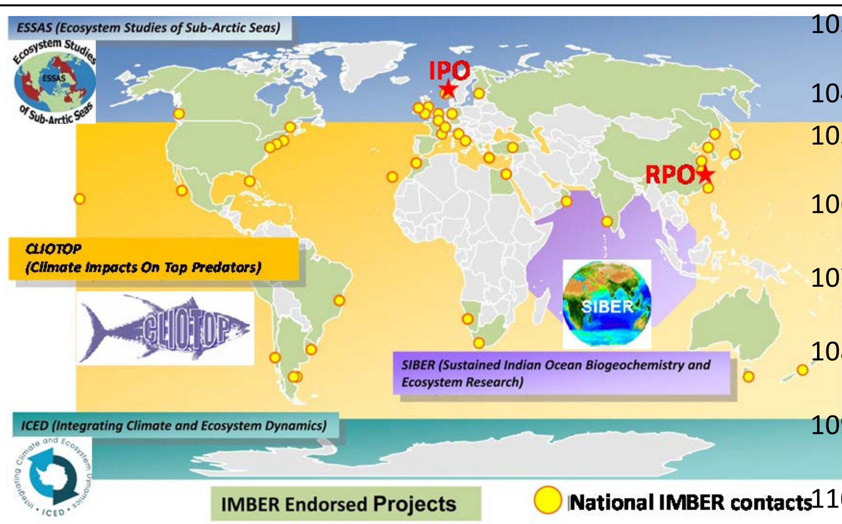

Figure 2. IMBER regional programmes, endorsed projects and national programmes, International Project Office (IPO) and Regional Project Office (RPO).

2.2 IMBER Science Achievements

The science results that accrue from IMBER activities are presented in numerous peer-reviewed articles, special journal issues, and books (www.imber.info/index.php/Products/Publications). IMBER science is also presented to the wider community through numerous special sessions convened at national and international meetings, workshops, symposia, and open science meetings.

2.2.1 Regional programmes

A network of complementary regional research programmes is essential for effective implementation of IMBER. These provide the observations, models, and comparative basis that underpin advances in addressing the IMBER science goals. It is through in-depth regional and topical analyses and comprehensive comparisons of diverse marine ecosystems that new understanding emerges about the potential effects of global environmental changes on biogeochemical cycling and food web dynamics, at multiple scales.

The achievements of the IMBER regional programmes are numerous and have resulted in significant advances for key areas and ecosystems. Many IMBER activities have focused on assessing current understanding, gaps in understanding, and the identification of the science required to address these knowledge gaps. Improved understanding of changes in distribution and abundance of a range of pelagic species at different life stages, and the ecosystem impacts has resulted from the CLimate Impacts on Oceanic Top Predators (CLIOTOP) regional programme. The Ecosystem Studies of Sub-Arctic Seas (ESSAS) programme undertook studies to compare, quantify, and predict the impact of climate variability and global change on productivity and sustainability of these systems. Assessments of change and quantifying and modelling food webs in the Southern Ocean have been the focus for the Integrating Climate and Ecosystem Dynamics (ICED) programme. The Sustained Indian Ocean Biogeochemistry and Ecosystem Research (SIBER) programme has facilitated multidisciplinary research throughout the Indian Ocean region, including significant advances and improvements in biogeochemical measurements.

2.2.2 Working groups

IMBER working groups bring together individuals with particular expertise to provide guidance and synthesis of topics that are timely and relevant to the larger project. IMBER working groups facilitate the integration and synthesis required to answer key science questions, strengthen the IMBER community and its delivery, and foster coordination and cooperation with other international global environmental change projects, such as SOLAS and LOICZ.

IMBER working groups have produced several important products, such as the position paper on sustainability of continental margins resulting from activities of the Continental Margins Working Group. The Surface Ocean CO_2 Atlas (SOCAT) developed by the SOLAS/IMBER Working Group on Surface Ocean Systems is an important synthesis product. The SOLAS/IMBER Working Group on the Interior Ocean Carbon has contributed to the global synthesis of the repeat hydrography initiative, the GLobal Ocean Data Analysis Project (GLODAP), the growing Bio-Argo programme, and to the SCOR working group on sensor calibration. The SOLAS/IMBER Ocean Acidification Working Group coordinates international efforts on ocean acidification research, including the promotion of synthesis products, often co-designed with research end-users. The end-to-end food web working group provided a synthesis of approaches to understanding interactions within and between species and between species and their environment (Moloney et al. 2011).

The establishment of the Human Dimensions Working Group in 2010 was an important development to address IMBER's fourth research goal. This working group has made significant progress in promoting the integration of the human dimension into IMBER science. The development of a decision support tool, IMBER-ADApT (Assessment based on Description, Responses and Appraisal for a Typology), provides an integrated assessment framework and learning platform for global environmental change response.

The Data Management Working Group promotes good data management practices among the IMBER community and published a guide outlining good for data management practices.

The IMBER Capacity Building Working Group undertakes and promotes capacity building activities in several areas that are important to engage students and early career researchers in IMBER science at regional and international levels, with emphasis on developing countries.

2.2.3 Dissemination, outreach and capacity development

The ClimEco summer school series (www.imber.info/index.php/Early-Career/IMBER-Summer-Schools) is an important mechanism to engage graduate students and early career scientists. Recent summer schools have focused on the development of a community of researchers who can work at the interface of human and natural systems. Encouraging young researchers to become interested in pursuing IMBER-related research is important for the continuance of a strong and relevant research agenda.

The IMBIZO meeting series (www.imber.info/index.php/Meetings/IMBIZO) provides a forum for highlighting emerging and important research topics. The special issues and publications resulting from the IMBIZOs provide syntheses of the current state of understanding on these topics as well as highlighting future research needs.

2.2.4 National programmes and endorsed projects

Broad international participation in the IMBER project comes from the development and coordination of related science activities in individual countries (Fig. 2). IMBER science is promoted through the implementation and coordination of research projects funded through international, national, state or local sources. These range from a group of scientists working on a particular IMBER-related research topic to multi-investigator, and multi-institution research projects (Appendix 3).

2.2.5 Partner organisations

IMBER´s science objectives are broad and as such lend themselves to collaboration with other global environmental change projects and organisations. For example, the Climate Variability and Predictability (CLIVAR) project of the World Climate Research Programme (WCRP) has sponsored several of the ClimEco summer schools, and the previous EUR-OCEANS Consortium co-sponsored IMBER IMBIZOs and workshops. The Asia Pacific Network for Global Change Research (APN) recently supported a Capacity Building workshop and is now supporting the ClimEco4 summer school (August 2014, Shanghai, China). PICES has supported many IMBER activities over the recent years. ICES and PICES jointly co-sponsored ESSAS-proposed sessions on comparative studies between North Atlantic and North Pacific ecosystems at their annual science meetings.

CLIVAR and IMBER recently formed a working group, together with SOLAS representatives to investigate biophysical interactions in upwelling regions of the world's oceans. Particular attention is given to the effects of climate change on upwelling and their subsequent effects on fishing and coastal communities.

Recognising the vulnerability of coastal communities to global change, especially those depending on fisheries for food security and livelihoods, IMBER partnered with the global research network, Too Big To Ignore. This aims to address issues related to the social, economic and political marginalisation of small-scale fishing people around the world, through the development of information systems, and research and governance capacity.

An example of future collaboration is the PICES ‘Forecasting and Understanding Trends, Uncertainty and Responses of North Pacific Marine Ecosystems’ (FUTURE) scientific programme. The programme´s three leading goals, resilience and vulnerability to natural and anthropogenic forcing, responses to these, and impacts on societies, are compatible with IMBER research directions. Another example is the 2nd International Indian Ocean Expedition (IIOE-2) which is being developed under the oversight of SCOR and IOC, with partnership between the Indian Ocean Global Ocean Observing System (IOGOOS), IMBER/SIBER and CLIVAR/Indian Ocean Panel (IOP). This endeavour will motivate international collaboration to carry out ocean monitoring, new process studies, summer schools and symposia focused on the Indian Ocean basin.

3. PROJECT THEMES AND FUTURE PRIORITIES

3.1 Developing a new research plan

The ocean plays a key role in the global environment and the sustainability of human populations, particularly through its contribution to climate regulation and its provision of living and non-living resources. The sustainable management of goods and services provided by the marine realm should be based on the knowledge derived from scientific research, which provides methodological approaches to assess and mitigate the impacts of global change and helps governance responses to reduce the vulnerability of marine-dependent communities.

IMBER is first and foremost about the integration of methodological approaches, studies of marine biogeochemical cycles and ecosystems, including humans, and the in-depth understanding of various dimensions and scales of their structure and functions. Significant progress has been made in addressing its four basic research themes, but there is still more to learn, and new research directions have emerged from what has been learned. Inputs from the IMBER Regional Programmes and Working Groups, IMBER scientists, and partner organisations have provided a broad review and perspective of marine-related research that point towards fruitful areas of research in the future. These are described in the following sections.

3.1.1 Continued integration of marine biogeochemistry and ecosystem research

Challenge: To develop end-to-end approaches for predicting the effects of change on marine ecosystems and human societies.

Rationale: Marine biogeochemical cycles and ecosystems are, in the broadest sense, a continuum characterised by the complexity in which their components are both potential drivers of, and solutions to, global change issues. Within this realm, there is still much to be studied, understood and consequently explained for the benefits of end-users, decision-makers and society at large. Biogeochemical processes are fundamental to the structure and functioning of marine ecosystems, yet there are large gaps in our knowledge. IMBER has made significant progress in identifying and filling some of these gaps, but questions remain about the processes that allow coupling of biogeochemical cycles and food webs. Research focused on the surface to deep connections of carbon and nutrients, with particular emphasis on quantifying the magnitude and mechanisms responsible for this transfer of matter and energy, remains important. These processes are key to how the global ocean sink of carbon and nutrient distributions will evolve in the future, and how they might respond to climate variability and change. Similarly, better detection of changes associated with ocean acidification and its impacts on nutrient cycling and ultimately higher trophic levels provides an important link between biogeochemistry and food webs.

Food web structure and functioning are key aspects that can be used in a systems approach to evaluate how the ecosystem as a whole might respond to change. In marine ecosystems this requires an understanding across a range of trophic, spatial, and temporal scales (e.g. from individuals to whole ecosystems, from local to global, and years to centuries). Middle trophic levels (e.g. zooplankton, forage fish) are recognised as critical for the transfer of energy though food webs and feedbacks to biogeochemical cycles. However, sampling and quantification of mid-trophic levels is often insufficient to define these processes and parameterise ecosystem and end-to-end models. Similarly, recent studies have shown that mesoscale and sub-mesoscale processes are potentially important controls of biogeochemical cycling, ecosystem productivity, and variability. Approaches to representing higher trophic levels in end-to-end models are diverse. How these processes and variability will affect current understanding of physical-biogeochemical interactions, how these may change in the future and the importance in large-scale budgets is mostly unknown.

Approach: End-to-end studies of marine ecosystems are already incorporated into IMBER working groups, regional programmes and national programmes. The challenge to predicting change in these complex systems places emphasis on exploring a range of approaches that can be combined to resolve the relative importance of process interactions at different scales. These approaches include comparative studies across many systems that use multi–scale (food web and biogeochemical) models to understand the global operations of marine ecosystems that are coupled with quantitative high-resolution observational methods and platforms (see Salihoglu et al. 2013). In particular, studies focused on the central role of mid-trophic levels in marine ecosystems and linking with higher trophic levels, biogeochemical cycling, mesoscale and sub-mesoscale processes and their role in nutrient and carbon dynamics and food web productivity are needed. Comprehensive yet efficient and effective approaches for representing the diversity of higher trophic levels in end-to-end models also need to be developed.

3.1.2 Impacts of global change and climate variability on marine systems

Challenge: To decipher the multiple interactions between the climate system and the marine realm and their sensitivity to multiple aspects of global environmental change and climate variability to develop predictive understanding of future responses in biogeochemical cycling, food webs and their interactions.

Rationale: The global and climate changes affecting marine ecosystems are not uniform, and therefore produce variable physical and ecological effects. These changes occur simultaneously with those generated by current and past harvesting of marine resources. IMBER science has improved understanding of changes in distribution and abundance of a range of species at different life stages, and ecosystem effects. These findings can now be integrated into models and socio-economic analyses to provide projections of future changes. There is growing evidence that incorporating biological processes into climate models can enable the prediction of different future states because of the feedbacks on the climate system as a result of changes in biology. Understanding these processes and linkages is critical to the next generation of climate models and integral to the development of strategies (adaptation options) to minimise the impacts of climate change on pelagic species.

At regional scales, ecosystems are affected by direct and indirect fluxes of physical and biogeochemical properties, as well as biological organisms. Quantifying these fluxes and documenting and understanding the fate of the properties that currently exist, including natural climate variability, is critical to understanding what will happen in the future under anthropogenic climate change.

Approach: Given the knowledge gaps and uncertainties inherent in studies of change, the use of future scenarios from global and regional climate models is a promising approach to explore drivers and the potential responses to, and consequences of, change. This theme provides a useful introduction to the challenges of providing more meaningful application of climate data and models to ecological change. This theme demands more interdisciplinary research and collaboration and better integration between IMBER and WCRP projects like CLIVAR, or through collaboration with the PICES FUTURE programme. This approach will naturally lead to projections of change and is highly relevant to the requirements of management and policy and to stakeholders.

3.1.3 Role of multiple drivers and stressors, and responses of society

Challenge: To undertake integrated studies of social-ecological-physical systems to consider interactions of multiple drivers and stressors within a given environment, and consider various scenarios for its changes, similar to the Intergovernmental Panel on Climate Change (IPCC) Assessments and what is planned by the Intergovernmental science-policy Platform on Biodiversity and Ecosystem Services (IPBES).

Rationale: Drivers and stressors, and changes do not occur in isolation. Multiple stressors (e.g. ocean acidification, warming, decreases in oceanic oxygen concentrations, fishing, eutrophication) and their complex, multi-scale interactions are creating significant challenges for ocean ecosystems and dependent human communities. From the known processes that may alter marine biogeochemical cycling and ecosystems, better understanding is needed to usefully predict changes due to stresses from warming, acidification, eutrophication and deoxygenation, their interactive effects, and impacts on society. The potential consequences of stresses may exert devastating impacts on marine ecosystem health and functioning, such as spatial and temporal expansion of coastal dead zones, weakening of the CO_2 and microbial carbon pumps, feedbacks to the (i) Earth System through changing elemental cycles, shifts in ecosystem structure and composition, and contractions/disappearance of fish habitats and (ii) human society such as loss of livelihood, changing resource base, and potential population displacement or migration. Distinguishing between influences from anthropogenic stressors and natural fluctuations is often difficult. Prediction of future changes requires mechanistic understanding to attribute cause and effect and to enable effective mitigation and adaptation measures, where possible.

Potential risks may arise from new “frontiers” for exploitation of marine resources, such as expansion of energy extraction, mining and maritime transport activities, including fragile locales like the thawing Arctic. There is a serious need for better assessment of the potential risks before such activities are carried out, but not all risks can be reduced to measurable uncertainties. This is particularly so for activities in regions where understanding of the biogeochemical processes, ecosystem functioning, and responses of society is lacking. In addition, there may be unanticipated synergistic impacts between drivers and stressors related to new uses of marine environments and climate change, e.g., more and increasingly powerful storms and sea level rise.

Approach: Studies (field, experimental, modelling) that are designed from the outset to include the interacting effects of multiple stressors are needed. It is critical to identify which situations and combinations of stressors will produce additive, synergistic, or antagonistic interactions, as these can have important implications on how to manage the stressors and marine ecosystems. Most modelling studies of cumulative effects in marine ecosystems assumed additive interactions, whereas reviews of cumulative effects find that synergistic or antagonistic interactions are more common (Crain et al. 2008).

3.1.4 Integration of marine biodiversity and conservation

Challenge: To provide evidence-based information and development of scenarios that help protect and preserve the marine ecosystems' biodiversity by improving management of marine ecosystem resources and services, limiting human-induced damage to vulnerable marine species, and restoring damaged marine ecosystems.

Rationale: Marine species are sensitive to global environmental change, both in terms of total biomass and community composition. Predicting how marine communities, taxa and individual species will adapt and (eco-)evolve in terms of phenotypic plasticity, natural selection and species sorting, in response to global environmental change drivers and stressors, is a major challenge in the marine realm.

Biodiversity determines resilience and response of the ecosystem to change. Increasing understanding of ecological resistance and resilience to change will be key to informing the wider ecological debate about the nature of stability and change in ecosystems. IMBER is well poised to draw on knowledge of different ecosystems to generate models in which ecological interactions determine responses that are not fixed. The rapid expansion in genetic analyses of marine species and ecosystems is changing our understanding of marine ecosystem productivity and biodiversity. Linking ecological and genetic studies to understand the interplay that determines ecological responses to change is needed.

Approach: Building on the successes of the Census of Marine Life and related initiatives (www.coml.org/census-framework), IMBER should engage with the broad, active research community that has developed over the last few years. Application of rapid genetic assessment methods and tools for species identification will revolutionize marine biology and biodiversity studies over the next 10 years. IMBER must be positioned to adopt and apply these new technologies, and to understand their limitations. Genomic techniques can describe which genes are activated or de-activated through physiological and environmental signals and understanding how this affects the performance and survival of individual organisms and populations will provide new insights into how species respond to their environments. Proactive development of scientific and technical strategies for dealing with the large and complex datasets that will emerge in coming years are needed and can build upon existing data systems (e.g. Ocean Biogeographic Information System, OBIS).

3.1.5 Integration of ocean-human systems

Challenge: To further explore the linkages and interactions between ocean systems and human systems, maintenance of the value and livelihoods for coastal communities and economies dependent on marine resources, and trade-offs with the conservation of ecosystem structure and functioning.

Rationale: Global change issues are typically viewed as environmental issues, but in reality these are social and human issues, wrapped into coupled social-ecological systems. They include issues of marine governance and how knowledge of marine sustainability is acquired, mobilized and made available to marine managers, policy-makers, and end-users. Because humans are both the driver and the recipient of environmental changes, it is necessary to engage humans, as individuals, communities and societies, in charting the way towards a sustainable future. To do so requires mechanisms that enable not only close interaction and cooperation between natural and social scientists, but also effective communication and public engagement. Activities must consider ecosystem-level resources and services management and sustainability assessments, and this will require innovative approaches on several levels. For example, a study of the attributes of successful marine resource co-management found that strong leadership, followed by a harvest quota system, social cohesion, and marine protected areas were the most important attributes of success. Less important conditions included enforcement mechanisms, long-term management policies, and the life histories of the resources being exploited (Gutierrez et al. 2011). Issues of scale, in particular for cross-scale linkages in both the spatial and temporal domains, are also important but difficult issues for decision-making and improving the governance of marine ecosystems and resources.

Focusing on observed human responses to major transitions in harvestable resources in a range of marine environments is only one aspect of ocean-human systems research. Also, of interest are: identifying the spatial and temporal scales of the effects of human responses; determining if alternative management responses and governance systems mitigated or exacerbated human consequences; and quantifying if differences in the local versus distant water fisheries affected human consequences.

Efforts to bring economic and natural scientists together have started through the IMBER Human Dimensions Working Group and expert workshops, such as for the economics of ocean acidification, but this type of synergy needs to be strengthened over the next 10 years and broadened beyond economics to include other social sciences to make scientific research findings more policy relevant.

Approach: Research to support transitions to sustainability must be interdisciplinary and transdisciplinary, and include natural and social scientists, humanities scholars, and representatives from the private and public sectors. Approaches need to include better understanding of how to index the status of marine ecosystems, including the functioning of biogeochemical and food web processes, the valuation of marine resources and services, how to include the human social dimensions, and how to operationalise these indicators. It will also need to consider the further development of an ecosystem approach to managing human interactions with marine ecosystem resources and services, one that includes a broader perspective than just fisheries. While these issues are being also considered by other projects and organisations, IMBER possibly has the broadest perspective and is therefore well-placed to contribute from a whole-ecosystem concept and to lead the development of new partnerships.

Future activities focused on the development of coupled indicators of natural and human social conditions, particularly as early warning systems of potentially significant changes in either sub-system (natural or human social), would provide a mechanism to assess the effects on the performance of the entire coupled system. Development of an ocean-human research agenda to facilitate a dedicated effort on critical, emerging issues, such as resilience of marine ecosystems, small-scale fisheries and vulnerability of the associated communities, is needed. Continued development of frameworks, such as IMBER- ADApT, provide for integrated assessment and learning platforms for marine global change responses.

3.2 Facilitating Research

To deliver the research presented in the above themes, progress is needed in the way the research community is supported, internationally coordinated and networked.

3.2.1 Observation networks

Challenge: To integrate ocean observing networks into all aspects of IMBER science.

Rationale: A rapid expansion is occurring in remote analyses through satellite observations (including counting animals, such as penguins and whales, from space), fixed sensor platforms (e.g. moorings and drifters), use of autonomous vehicles (e.g. gliders with bio-acoustics sensors) and the application of biosensors for animal tracking and activity analyses. This presents major challenges of data communication, storage, management and analysis. There is an urgent need to ensure that the community has the management and analysis systems, and quantitative (e.g. statistical and computational) skills required to fully utilise these data. This presents a major opportunity for the IMBER community develop and deploy innovative new technologies that produce three-dimensional varying views of ocean ecosystem operations.

Approach: Remote sensing satellite measurements are integrated into all aspects of IMBER science. These data will continue to be critical to IMBER science. New satellite missions that will be launched during the next phase of IMBER (e.g. NASA Pre-Aerosol, Cloud, and ocean Ecosystem, PACE) will enhance understanding of climate-carbon and climate-ecological processes and linkages; information that is needed to predict responses to climate and environmental change. Continued promotion of the deployment of biological sensors on physical observational platforms such as moorings, gliders and Argo floats needs to emphasised, along with strategies for collection, quality control and dissemination of the data. Explicit goals and timelines should be set for these efforts. For example, when can the science community anticipate having comparable global coverage from bioArgo floats compared to the present day temperature and salinity measurements? The need to maintain the current Continuous Plankton Recorder (CPR) deployments/transects and the labour intensive analyses of these data must be emphasised, and also the expansion of these transects and data analyses to other areas of the world that are undersampled (e.g., the South Pacific, South Atlantic and the Indian Ocean). Plans should be developed for routine deployment of biogeochemical sensors on coastal and emerging large-scale repeat glider missions. Global coordination and/or synthesis of higher trophic level acoustic surveys and animal-carried instrument deployments should be pursued.

3.2.2 Human networks and capacity building

Challenge: To develop human capacity for successful implementation of international marine scientific research projects.

Rationale: Capacity building activities of international global environmental change research projects, such as IMBER, are often interdisciplinary and aimed at developing a community of young scientists working across traditional disciplinary boundaries, which can complement and extend university education in scientific career development. The key issues identified by a multidisciplinary and international research project are unlikely to overlap completely with the scientific needs of any specific country (e.g., Morrison et al. 2013).. There should be an effort to align the scientific directions of the project to a country's needs, which allows the research project to contribute to capacity development at the national and/or regional level. Discussions about capacity building milestones and then needs of the country are therefore needed throughout the duration of the project. At the international scale, the key issue is to develop capacity to be able to conduct the necessary interdisciplinary research and synthesise the results provided by both natural and social sciences. Complimentary to the educational system of a country, international projects provide an alternative integrated research-based training and education that cuts across disciplinary barriers.

Research capacity (i.e. infrastructure and trained personnel) varies between countries. More advanced countries should assist in building the capacity of developing countries. However, this support must be realistic and appropriate to the research infrastructure available. Of particular importance is the development of expertise to communicate effectively across the natural and social sciences, and to stakeholders and decision makers. To undertake this challenge, there needs to be integration of efforts by different agencies and greater involvement of scientific community from developing countries, and to assure resources to support medium to long-term studies in different ecosystems.

Approach: Globally, mechanisms to participate in capacity building discussion and coordination for IMBER-related research can be used to facilitate and contribute to the creation of a virtual forum for coordination of capacity building activities. Activities that can develop collaborations between international research projects and countries are: 1) use of training activities and summer schools for developing the scientific and technical capacity within the marine science community; 2) establishment of close affiliations between universities and research institutions and Non-Governmental organisations (NGOs) to reduce the barriers of traditional education; 3) promotion at the regional scale of the trans-boundary recognition of university courses and degrees and to overcome political obstacles; 4) identification of mechanisms to facilitate the exchange of students and early-career researchers between institutions, through something like an IMBER-SCOR fellowship and other relevant schemes; and 5) integration of the numerous existing capacity building activities with mature international initiatives to insure global coordination that will facilitate knowledge transfer across regions.

3.2.3 Data management

Challenge: To expand the present level of compliance with IMBER's data and metadata policy to further promote IMBER science and improve IMBER´s visibility throughout the Earth Sciences.

Rationale: Though most of the IMBER programmes and projects follow their own data management rules and policies, and most probably include open data access, simple and direct procedures to link these data with IMBER should implemented.

Approach: Provide the infrastructure to make compliance easy and accessible and promote compliance in current non-compliant countries.

4. IMBER INFRASTRUCTURE

The IMBER International Project Office (IPO) is a critical component of the IMBER project. The IPO, presently located at the Institute of Marine Research, Bergen, Norway, provides coordination and management for the IMBER project at local, national, regional and international levels. The IPO assists with fund-raising activities to support working groups, workshops, conferences and summer schools that further IMBER science. The IPO also assists with dissemination of IMBER science results via its website, social media, newsletters, and publications.

The IMBER Regional Project Office (RPO), based at East China Normal University, State Key Laboratory of Estuarine and Coastal Research (SKLEC), Shanghai, People's Republic of China, facilitates IMBER-related projects in Asian countries and also supports international initiatives. Such regional nodes are critical to the dissemination of IMBER science and the establishment of additional regional nodes would provide for greater impact.

Coordination of IMBER science is via a Scientific Steering Committee (SSC) that is composed of members of the international science community. The rotation of members on this committee reflects the changing emphasis in IMBER science. The composition of the SSC will continue to be updated and modified as needed to best serve IMBER's science goals. Important contributors to the SSC are the representatives from the regional programmes, who serve either as full members of the SSC or as invited ex-officio participants. They provide liaison between the regional programme science committee (SC) and the IMBER SSC.

5. VALUE ADDED OF GLOBAL ENVIRONMENTAL CHANGE PROJECTS AND PROGRAMMES

Science Considerations: Global environmental change projects such as IMBER enable global comparisons and cross-fertilization of new ideas and approaches between countries and regions. These comparisons are essential when addressing complex issues across natural and human systems. IMBER also provides a platform for discussion about prevention, mitigation and adaptation to global environmental change in marine ecosystems, and promotes capacity development to help strengthen research and governance at all levels

Programmatic Considerations: IMBER provides a framework and justification for institutional, national and regional research initiatives, which are focused on understanding the impacts of global environmental change on marine ecosystems. This in turn provides leverage for funding at the institutional, national and regional level. IMBER also provides a mechanism for the synthesis of research results from institutional, national and regional programmes to enable these to contribute to our wider understanding of marine ecosystems and the impacts of global environmental change.

6. FUNDING CONSIDERATIONS

All international science programmes have ongoing efforts to develop a funding base that provides sufficient support for the activities of regional programmes, working groups, and educational and training initiatives. IMBER is no exception. IMBER is fortunate to have strong institutional sponsors in the IGBP and SCOR that recognise the importance of IMBER science and have worked with the project to secure funding for activities that support this science. With the transition to Future Earth and expansion of IMBER basic science, the IMBER project will need to expand its current funding base. It will need to extend to more applied-research and delivery aimed at key end-users such as marine resources managers and policy advisors, while maintaining a strong curiosity-driven research basis and community. IMBER will continue to work with SCOR to develop proposals for funding of basic science.

Activities of regional programmes will continue to be supported at some level through IMBER core funding, although with the inclusion of new initiatives, these funds will be more thinly spread. Continued support from SCOR, national and international funding sources and private foundations is critical to the success of these activities. Opportunities that may provide support for IMBER-related summer schools, conferences and symposia will be identified and proposals will be developed for these funds, including those submitted with SCOR. Continuing support for the activities of working groups and regional programmes will require a proactive approach to identify and secure funding outside IMBER's core funding. The IMBER IPO and RPO will work with regional programmes to identify funding opportunities for activities and to develop proposals for these.

An important contributor to IMBER is the crucial support that is provided for the IMBER IPO and RPO by the national funding agencies and host institutions. Continuation of this

support is critical for the success of IMBER as it moves into its next 10-year phase. The support from the host institutions and national funding agencies (Research Council of Norway) is gratefully acknowledged.

7. WAY FORWARD

The regional programmes and working groups have greatly expanded the science results possible through IMBER, and will continue to do so. The international project office in Norway and the regional project office in China, continuation of the IMBIZO series and ClimEco summer schools, and continued linkages with other international science programmes and partner organisations will ensure that IMBER science is recognised and incorporated into global science initiatives. The next phase of IMBER brings opportunities for many new, exciting and different research directions.

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APPENDICES

Appendix 1. Current IMBER Themes, www.imber.info/index.php/Science/IMBER-Science-Themes/Overview

Appendix 2. IMBER regional programmes (www.imber.info/index.php/Science/Regional-Programmes) and working groups (www.imber.info/index.php/Science/Working-Groups).

Appendix 3. IMBER national programmes (www.imber.info/index.php/Science/National-Network) and IMBER endorsed projects (www.imber.info/index.php/Science/Endorsed-Projects) – will be added later

Appendix 4. Acronyms and websites – will be added later