Appendix 6
Integrated Marine Biogeochemistry and Ecosystem Research (IMBER)

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Annual Report to SCOR
May 2016

A. Introduction

Integrated Marine Biogeochemistry and Ecosystem Research (IMBER, www.imber.info) is an international global environmental change research project, co-sponsored by the Scientific Committee on Oceanic Research (SCOR) and, the International Geosphere-Biosphere Programme (IGBP) until it ended in December 2015, and now Future Earth. IMBER's International Project Office (IPO) in Bergen, Norway is sponsored by the Institute of Marine Research (IMR) and the Norwegian Research Council, and its Regional Project Office (RPO) in Shanghai is hosted and supported by the State Key Laboratory of Estuarine and Coastal Research (SKLEC) and the East China Normal University (ECNU).

IMBER's goal has been to develop 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, as outlined in the 2005 IMBER Science Plan and Implementation Strategy (SPIS) and the 2010 supplementary update. Now, after 10 years, IMBER has a new vision: *ocean sustainability for the benefit of society*, and aims 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.* A new SPIS providing the basis for the next decade of IMBER research is under review by SCOR and Future Earth. The current structure of IMBER (Fig. 1) provides the starting point for implementation of the SPIS.

IMBER's strong commitment to curiosity-driven science provides its foundation. However, the environmental issues facing society, particularly those relating to global environmental change, are issues that challenge natural and social sciences and humanities. Integration of the understanding provided by curiosity-driven natural science and the problem-driven, societally relevant science requires research that crosses the interfaces between these disciplinses (transdisciplinary research). A clear message from the 2014 IMBER Open Science Conference (OSC) and community consultation in 2015 associated with development of the SPIS, was that transdisciplinay research must be part of the future research agenda. This is underscored by the recent science highlights presented in the next section.

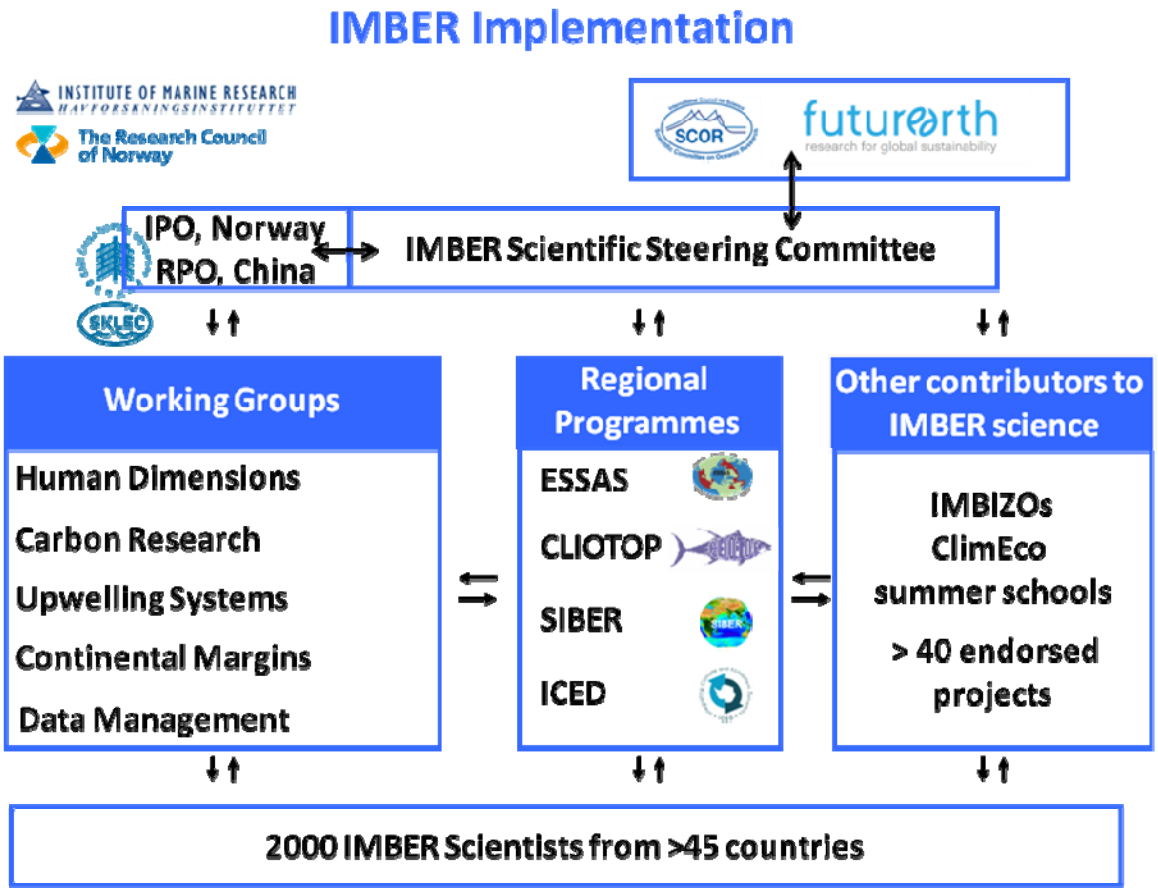

Figure 1. Structure of IMBER.

B. Selected IMBER discoveries and highlights

- IMBER advanced understanding of climate effects on marine ecosystems in the Anthropocene
- IMBER advanced understanding of natural-human science interactions in marine systems
- IMBER is developing a social-ecological decision support framework for marine systems
- IMBER promoted and undertook capacity building and knowledge transfer activiites
- IMBER research informs sustainable use of marine ecosystems

Selected discoveries and highlights in 2015-16 from IMBER regional programmes, working groups and endorsed research projects. Special relevance to societal issues are marked in red.
From: Ecosystem Studies of Sub-arctic and Arctic Seas (ESSAS):

1. A new hypothesis has been proposed suggesting that the shift in Atlantic mackerel distribution from the Norwegian Sea was a result of reduced food production due to the declining nutrient concentrations (Si) along the northern European continental slope, forcing the mackerel stock to seek new feeding grounds in the nutrient richer waters farther north and west, i.e. around Iceland and east Greenland. *(Pacariz et al., submitted 2016).*

2. A critical review of harvest control rules for fisheries management was undertaken. This includes their historical and institutional development, recent cases and potential harvest control rules for future fisheries management, in terms of both ideal and realistic developments. *(Kvamsdal et al, submitted 2016).*

3. Special Issue of Progress in Oceanography titled "Combining Modeling and Observations to Better Understand Marine Ecosystem Dynamics" *(eds. Curchister et al. 2015)* contains 19 papers on modeling marine ecosystems. The papers focus on approaches to investigate the mechanisms linking environmental

influences to biological responses. An integral component is the use of observational data to ensure the credibility and appropriate interpretation of model results.

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

4. Quantifying the strength of biological feedbacks in Southern Ocean air-sea CO_2 flux is important to understanding the effects of climate change. Several global biogeochemical models under climate change to the end of the century were compared, with a focus on vertical carbon flux and changes in plankton community structure. Although there was no agreement on physical changes in the Southern Ocean, the models did agree that the biological carbon pump will be responsible for increased CO_2 uptake in a future, less well-buffered ocean. *(Hauck et al. 2015)*

5. Understanding the key drivers of population connectivity is essential for effective management of natural marine resources. A 'seascape genetics' approach combining oceanographic modeling and microsatellite analyses was used to investigate the influences on the genetic structure of two populations of Antarctic fishes with contrasting life histories. Inter-annual variability in oceanographic flows strongly influenced the projected genetic structure, suggesting that shifts in circulation patterns due to climate change are likely to impact future genetic connectivity and opportunities for local adaptation, resilience and recovery from perturbations. *(Young et al. 2015)*

6. The uptake of anthropogenic CO_2 is altering the carbonate chemistry and pH of the oceans, and the polar oceans are predicted to be the most severely affected. This study carried out ocean acidification (OA) manipulations of natural Arctic and Southern Ocean pelagic communities. Many responses to OA varied between environments but there was a consistent response with regards to copepods always preferring to graze dinoflagellates compared to other phytoplankton species when in elevated pCO_2 conditions. This demonstrates that changes in food quality and altered grazing selectivity may be a major consequence of the predicted chemical changes to the polar oceans. Such altered trophodynamic interactions will impact how carbon is channelled through polar foodwebs, and the extent to which future anthropogenic CO_2 emissions can be absorbed. *(Tarling et al, 2016)*

7. Jackson et al., 2015 summarises the findings of over a decade of work to reconstruct the population trajectories and assess the recovery status of all Southern Hemisphere humpback whale populations. The study also details methodological advances and the significant challenges overcome during the assessment, and identifies key data gaps and avenues for future work. *(Jackson et al 2015)*

8. From the 137-year long record of the El Niño-Southern Oscillation (ENSO), no significant trend can be detected, and the recent multi-decadal variability is similar to earlier decades. ENSO has not fundamentally changed over the period of large increase in atmospheric CO_2, and the potential of predicting the future states of the fisheries and ecosystems are quite limited. *(Harrison and Chiodi, 2015)*

9. Major uncertainties in modeling frameworks are broadly categorised into those associated with (i) insufficient knowledge about the interactions of climate and ocean dynamics with marine organisms and ecosystems; (ii) lack of observations to assess and advance modeling efforts and (iii) an inability to predict with confidence natural ecosystem variability and longer term changes due to external drivers (e.g. greenhouse gases, fishing effort) and the consequences for marine ecosystems. As a result of these uncertainties and intrinsic differences in the structure and parameterisation of models, users are faced with considerable challenges associated with making appropriate choices on which models to use. A key research direction is the development of management systems that are robust to this unavoidable uncertainty. *(Evans et al., 2015)*

10. Zooplankton faecal pellet production is a key control of the efficiency of deep carbon transfer in the Scotia Sea. This region contains the largest seasonal uptake of atmospheric CO_2 yet measured in the Southern Ocean (*Manno, et al., 2015)*.

11. IMBER/ICED scientists contributed to a Southern Ocean biogeographic atlas, www.biodiversity.aq.

From: Sustained Indian Ocean Biogeochemistry and Ecosystem Research (SIBER):

12. From a biogeochemical sensor at the 80E RAMA mooring, striking chlorophyll "spikes" were observed at the Equator during the fall Wyrtki Jets. These appear to be related to entrainment pulses and/or Yanai waves. *(Strutton et al., 2015)*

13. A Special Issue of Exchanges, Celebrating 50 Years of Indian Ocean Research, initiated by SIBER and the CLIVAR Indian Ocean Regional Panel was published at the launch of the Second International Indian Ocean Expedition (IIOE-2) at the International Symposium on the Indian Ocean, 30 November - 4 December 2015, at the National Institute of Oceanography (NIO), Goa, India (see below) *(Valiard et al., 2015).*

From: Climate Impacts on Ocean Top Predators (CLIOTOP):

14. Using longline catch data from six tuna species in the Pacific, Atlantic and Indian Oceans, a global, comparative perspective of habitat preferences for these species was developed based on a common dataset and consistent approaches. Results confirmed that tropical tunas prefer warm, low oxygen, stratified waters, while temperate tunas tolerate a wider range of environmental conditions, the widest demonstrated by Atlantic bluefin tuna (*Thunnus thynnus*). This view of preferred habitats will be useful for spatial approaches to management and better predictions of the impacts of changing climate on populations and associated fisheries. *(Arrizabalaga et al., 2015).*

15. Trials on yellowfin tuna identified increased hatch times and reduced larval growth under varying levels of increased pCO_2, with varying impacts on larval survivability. Technical challenges during experiments, and limitations on the range of pCO_2 levels used limited the assessment of potential impacts. *(Bromhead et al., 2015).*

16. New projections of the features of the western warm pool in the Pacific Ocean suggest that while its edge is projected to warm, it is likely to remain within 10º of its present longitude. This is in stark contrast to the large projected eastward displacements of the isotherms that are usually used to define the edge. *(Brown et al., 2015)*

17. The southwest Pacific has been identified as an area of particularly rapid warming and this trend is expected to continue. Understanding the effects of increased warming on the distribution of fisheries in the region, and management responses, is essential for the sustainable management of these fisheries. Projections from a high resolution ocean model were used to condition a catch distribution model examining potential changes in the catches of yellowfin tuna off the east coast of Australia. Results suggest that by 2060 the core area fished by the longline fleet in the region will shift both poleward and offshore relative to existing areas. Such shifts may require modification of current fishing behaviours, which in turn may require social and economic adjustments to the fishery. *(Dell et al., 2015).*

18. Interactions between warming, acidification and deoxygenation and their effects on the aerobic scope of yellowfin tuna were investigated using a physiology-based habitat suitability model. The model indicated positive non-linear interactions between temperature and acidification effects, with the largest impacts on aerobic scope occurring under conditions of high oxygen partial pressure, low temperature and low CO_2 partial pressure. Overall, the model suggests that the vertical habitat for yellowfin tuna in the eastern tropical Pacific will contract vertically and that the species will need to rely on adaptations allowing them to utilize less hospitable environments to greater extents. *(Del Raye and Weng, 2015).*

19. Some of the most important development goals for the countries and territories of the Western and Central Pacific Ocean involve the sustainable management of their fisheries in light of environmental, economic and social uncertainties. Research priorities include: (i) improved resolution of processes driving ecosystem model components via the incorporation of higher resolution climate models; (ii) development of seasonal and inter-annual forecasting tools enabling management responses to short-term variability in tuna distributions and abundances; (iii) improved understanding of the population dynamics of, and the energy transfer efficiencies between, food web components; (iv) assessment of the optimal value of access rights and overall fishery value under multiple scenarios of tuna distribution and abundance and influences on decision making by fisheries managers and fleets and (v) utilisation of management strategy evaluation frameworks for testing fishery management procedures to help prioritize research directions and investment. *(Evans et al., 2015).*

20. Finding a balance between ensuring food security, economic health, fishery sustainability, biodiversity conservation and ecosystem function in marine systems is a challenge. Climate change may make this balancing act more difficult, as ranges and productivity of species change in time and space and will require careful and informed development of policy for managing natural resources. Insights into several conflicts and trade-offs associated with the harvesting of pelagic species, including (i) maximizing future food production given the depleted state of some stocks; (ii) minimizing bycatch of non-target species, (iii) setting ecosystem allocation rules for non-target top predators, such as seabirds, and (iv) maximizing value and livelihoods for local economies are identified. Resolving these conflicts is achievable with current approaches and technologies. *(Hobday et al., 2015).*

21. Comparison of parameters from a eutrophic micro-/nanophytoplankton dominated ecosystem showed that systems with small primary producers (such as the oligotrophic western Pacific) have longer food chains than those with large primary producers (such as the eutrophic California Current System). Current projections of ocean ecosystems suggest reductions in net primary productivity and increased contributions of picoplankton size classes associated with warming of surface waters and increased stratifcation. The response of food webs to such changes may be dependent on their linkage structure with ecosystems with longer food chains more resilient and capable of adaptation than those with shorter food chains. *(Hunt et al., 2015).*

22. The end-to-end ecosystem model SEAPODYM was used to investigate the influence of environmental change and fishing on albacore abundance and distribution on past catches and on future catches under climate change scenarios. Projections suggest a decrease in biomass until 2035, stabilization and then growth after 2080 associated with the establishment of a new spawning ground in the Tasman Sea. Simulations identified particular sensitivity of the model to dissolved oxygen concentrations, projections of which include large uncertainty in the tropics. Outputs should help in developing policies for fisheries management robust to a changing environment and identify understanding of changes to oxygen availability as a key priority. *(Lehodey et al., 2015).*

23. An investigation of larval scombrids (e.g. mackerel, tuna) from around the world in relation to water column and sea surface properties found that feeding success was distinctly different between regions, varying from 100% in the Straits of Florida and the Mediterranean Sea to as little as 40% in the Gulf of California and off north-west Australia. The number of prey species consumed was typically low and usually similar for a given scombrid taxon among regions. Larval habitat conditions were often similar, but variability among regions highlighted the potential for region-specific mechanisms regulating larval survival and, ultimately, levels of adult recruitment. This has implications for how recruitment indices are incorporated into global tuna population models. *(Llopiz and Hobday, 2015).*

24. δ15N values across multiple trophic levels and over a large spatial scale were determined in two pelagic marine ecosystems to investigate (i) if isotopic baselines could be determined from a primary consumer rather than more traditonally sampled, but more logistically challenging, primary producers and (ii) how differing methods of baseline assessment might influence estimates of trophic position in the predator yellowfin tuna. Spatial variations of δ15N from particulate organic matter, barnacles and yellowfin tuna showed similar patterns across the two ecosystems suggesting that they all can effectively reflect δ15N isoscapes. Further they suggest that variations in the isotopic composition at the base of the food web, rather than differences in diet, were the main contributors to isotopic variability. The study reinforced the importance of considering isotopic baseline variations, and provided new insights into methods that can be applied to generate nitrogen isoscapes for worldwide comparisons of marine ecosystems. *(Lorrain et al., 2015)*

25. Many climate models describe a decrease in nutrient upwelling in the western Pacific warm pool as a result of increased stratification, leading to projections of lower surface primary production and an overall decrease in net primary productivity. Examination of high-resolution projections suggests, however, that increased mixing due to changes in currents (not fully resolved in lower resolution models), results in increased subsurface primary production. This is expected to result in almost no change in overall net primary production within the warm pool, suggesting that climate change may not have substantive impacts on marine ecosystems within the region. *(Matear et al. 2015).*

26. Although time series of fish catches are the core of many assessments, these time series have largely been underutilised with respect to investigating variability in ecosystems. An extensive time series of drift gillnet survey data from the western North Pacific was used to analyse spatio-temporal variations in the higher

trophic level community structure, revealing clear spatial and temporal patterns. Both longitudinal and latitudinal gradients in metrics calculated were evident, while temporal trends varied between metrics. Co-occurring changes in survey methods, however, prevent causal relationships from being concluded, highlighting the importance of standardized methods for the collection of time series. *(Okuda et al., 2015).*

27. Animal daily routines represent a compromise between maximizing foraging success and optimizing physiological performance, while minimizing the risk of predation. For ectothermic predators, ambient temperature may also influence daily routines through its effects on physiological performance. Using a combination of electronic tags deployed on blacktip reef sharks (*Carcharhinus melanopterus*) and bite rates in herbivorous reef fishes, the activity rates of these predators and their prey was quantified. Activity rates varied in relation to diel cycles of temperature, with predators being most active during cooling periods, when their greater thermal mass would result in their body temperatures being higher than those of their prey. This body temperature difference likely results in an advantage for the predators. *(Papastamatiou et al. 2015).*

28. Biochemical composition of the muscle tissues of predators provide information on dietary histories across much longer time scales than traditional investigations of stomach contents and can therefore be used to investigate longer term variability in the trophodynamics of predators. Using signature fatty acids, spatial variability in the trophic position of albacore and skipjack tuna (*Katsuwonus pelamis*) from the southwestern Pacific Ocean and underlying trophic and physiological reasons for variability were investigated. Latitudinal variability was particularly evident in albacore tuna and was attributed to differences at the base of the food web between temperate and tropical regions. The study identified that signature fatty acids could potentially be used as indicators of thermal change in regions such as the 'tropicalisation' of subtropical and temperate waters. Latitudinal gradients in concentrations of health-benefitting omega-3 fatty acids suggest that such tropicalisation could potentially reduce the lipid quality of albacore tuna for human consumers. *(Parrish et al., 2015).*

29. Increasing water temperature has been associated with range shifts in a number of marine species. While the direction and increase in rates of range shifts have been noted, identification of drivers of variation in range shifts within species and across regions within a species range in areas of intense warming, is lacking. Projected shifts in the core habitat of a number of pelagic species off the east coast of Australia were compared at varying spatial and temporal scales to investigate variability in the rate of shifts and their association with spatial gradients in temperature. Projections across all scenarios showed consistent southern (poleward) shifts in the core habitats of all species. Notably, the trailing edges of habitats shifted faster than their leading edges, due to weaker spatial gradients in water temperatures associated with (northward) trailing edges, in conjunction with relatively constant rates of warming across latitudes. This suggests that spatial gradients in temperature may be important in determining spatial variability in range shifts within species. *(Robinson et al., 2015).*

30. The speed at which the ocean is warming and associated isotherms are moving varies considerably both temporally and spatially. Projections under *business as usual* emission scenarios suggest that the speed at which isotherms migrate will be up to seven times faster in the 21st century compared to the last century, and speeds during summer will be greater than those in winter across most oceanic regions. In response, the thermal ranges of species will undergo sudden, rapid shifts rather than exhibiting gradual uniform movement. Such rapid shifts are likely to present challenges both in data collection and management responses. *(Sen Gupta et al. 2015).*

31. Dynamic optimal foraging theory predicts that foraging efficiency increases with body temperature, maximising energy harvest rates, and that therefore, vertical migrations demonstrated by species such as bigeye tuna are thermoregulatory in nature. The observed behaviour of bigeye tuna was examined to determine if vertical migrations were quantitatively consistent with predictions from dynamic optimal foraging theory using a simple dynamic programming model. Modeled behaviour was found to be consistent with observed data on vertical movement, with small individuals displaying constant-depth strategies and large tuna displaying vertical migrations. The analysis supports the hypothesis that bigeye tuna behaves in such a way as to maximize its energy gains. The model developed provides insight into the processes underlying observed behavioural patterns and allows the generation of predictions of foraging behaviour in unobserved environments. *(Thygesen et al., In Press).*

32. Common oceanic sunfish (*Mola mola*) frequently occur as bycatch in fisheries worldwide and comprise the greatest portion of the bycatch in California's large-mesh drift gillnet fishery. Little is known of their

movements, oceanic drivers of movements or the habitats utilised by individuals. Using data derived from electronic tag deployments, sunfish were observed to undertake seasonal movements between the southern California Bight and adjacent waters off northern and central Baja California. Association with upwelling fronts and surface slicks indicated convergent circulation. Zooplankton sampling in the region suggest sunfish were associating with areas of dense concentrations of salps, a common food item. The study suggests that bio-physical interactions in coastal upwelling fronts create a favourable foraging habitat for this species. *(Thys et al., 2015).*

33. Biologging instruments allow the simultaneous measurement of the fine-scale foraging behaviours of predators and their environment, revealing characterisation of foraging environments and insights into the distributions of their prey. Using such instruments, the relationship between prey encounter events by southern elephant seals and water temperature, light and depth was investigated. Foraging environments were found to be structured by the main frontal systems of the Southern Ocean. Large physical and/or spatial differences in these environments suggest that differing prey communities are targeted by the seals depending on their location, highlighting the dietary flexibility of the species and potentially it's adaptability to future environments. *(Vacquié-Garcia et al., 2015)*.

34. Fishery resource managers and policy makers in Pacific Island countries and territories will be increasingly challenged by the need to ensure food security and resource sustainability within the context of a changing climate. Pelagic fish resources available to the region, challenges to development, capacity and climate change and science needs for identifying and addressing changes to resources and potential conflicts with development goals are outlined. Key to responding to climate change will be investments aimed at expanding the capacity for research, management and sustainable fisheries management within these countries and territories, which could be facilitated through collaboration between PICTs, RFMOs, and scientific centers of excellence. *(Weng et al., 2015).*

35. Extinction risk is closely tied to body size, home range, and species distribution, so quantifying these features is important for conservation, to enable the use of concepts such as 'umbrella species', whose conservation protects other species due to shared habitat. A multi-year study of the home range of humphead wrasse in the central tropical Pacific was conducted to determine the value of this species as an umbrella species for coral reef conservation. Home ranges varied substantially and changed with ontogeny. Females had relatively large home ranges, indicating value as an umbrella species for coral reefs. The home range of the species was then compared to the size distribution of tropical marine protected areas (MPAs), and the MPA length necessary to retain humphead wrasse was estimated. It was determined that most MPAs are too small to effectively protect the humphead wrasse, so small reserves are unlikely to be an effective management tool. *(Weng et al., 2015).*

36. Little is known of the movements and diet of albacore tuna in the South Pacific Ocean, or how variability in both might influence the vulnerability of albacore tuna to fisheries across their range. Using electronic tagging and stomach samples, the diving behaviour and diet of albacore tuna in three locations were investigated. Albacore tuna in tropical regions demonstrated a distinct diel pattern in vertical habitat and consumed significantly more deepwater prey species than those in temperate regions which tended to be limited to shallow waters above the mixed layer. This latitudinal variability in diving behaviour and diet suggests that future changes in the vertical structure of temperate waters might influence the vertical distribution of albacore tuna and, therefore their vulnerability to oceanic fisheries. *(Williams et al., 2015).*

37. Human pressures have resulted in declines in populations of leatherback turtles (*Dermochelys coriacea*) in the eastern Pacific Ocean. How climate change might impact these already threatened populations is not well understood. Using habitat models derived from data collected from electronic tag deployments on turtles and future ocean state derived from climate models, changes to the core habitats of leatherback turtles were investigated. Results suggest that the core pelagic habitat of the eastern Pacific leatherback turtle population will decline by approximately 15% within the next century, compounding recent declines in abundance. This reduction in available habitat may result in distributional shifts, behavioural changes, or even extinction. To ensure resilience of the population to potential habitat modification associated with climate change, existing stressors on the population such as fishing and anthropogenic impacts on nesting beaches need to be reduced *(Willis-Norton et al., 2015).*

38. Time series of commercial fishery catches and scientific survey data of the diet of northern fur seals (*Callorhinus ursinus*) from the waters off northeastern Japan spanning 60 years were examined to investigate potential long-term changes in the marine ecosystem. Variability in both datasets highlighted the

many environmental factors influencing the observed trends and with neither dataset supporting the 'fishing down the food web' postulated for many fisheries in other regions. Inconsistencies in trends observed in the two datasets highlighted the need to use multiple datasets when investigating ecosystem variability, and also careful interpretation of results based on individual environmental time series. *(Yonezaki et al., 2015).*

39. Classical diet studies have provided most of the historical information on trophic pathways in pelagic ecosystems, but biochemical methods (stable isotopes, fatty acid signatures) are allowing new questions to be addressed. Progress on understanding the spatial and temporal variability in the trophodynamics of marine predators was reviewed, and impacts of ocean warming on marine ecosystems from both top-down and bottom-up trophic perspectives were examined. Impacts identified included alterations to energy transfer efficiency, decreased productivity, shifts in biodiversity hotspots, shifts and restrictions in population abundances and distributions and alterations in species assemblages, which can influence food availability for higher predators. For a comprehensive understanding of the trophodynamics of marine top predators, a combination of methodologies is needed. *(Young et al., 2015).*

From: SOLAS/IMBER Carbon (SIC) Working Group:

40. An article on the Ocean Acidification International Coordination Centre (OA-ICC) **data compilation on the biological response to ocean acidification (**https://www.iaea.org/ocean-acidification/page.php?page=2203) was published in the journal ***Earth System Science Data*** in February 2016. The data compilation is maintained in cooperation with the State Key Laboratory of Marine Environmental Science, Xiamen University (China) and the German data publisher PANGAEA. It currently offers access to data sets from nearly 700 scientific papers.

41. The Surface Ocean CO_2 Atlas (SOCAT, www.socat.info), compiled by the international marine carbon community, provides access to quality-controlled surface CO_2 data (Fig. 3). The first two versions were released in 2011 and 2013, respectively. Version 2 contains 10.1 million quality-controlled, surface ocean fCO_2 (fugacity of CO_2) values from 1968 to 2011 for the global oceans and coastal seas. Version 3 of the Atlas was released on 7 September 2015 *(Pfeil et al. 2015)*

42. Scientific applications of SOCAT include: 1) quantification of the ocean carbon sink and 2) ocean acidification and their temporal and spatial variation, 3) validation of ocean carbon models and coupled climate carbon models, and 4) provision of constraints for atmospheric inverse models used to estimate land carbon sink (*Lauvset, et al., 2015, Bakker et al., 2015)*

43. SOCAT synthesis products represent an impressive achievement in coordinating international researchers to deliver publicly accessible and uniformly quality-controlled data for marine carbon and ocean acidification research that can be used for research and to inform international policy and climate negotiations.

From: Capacity Building Task Team:

44. IMBER is proactive in building and strengthening the scientific capacity of early to mid-career researchers, and scientists from developing countries. A major activity in facilitating capacity building is the biannual international, transdisciplinary ClimEco (Climate and Ecosystems) summer school. To date, more than 300 students and early career researchers, many from developing countries, have attended the four summer schools organized by IMBER *(Hofmann et al.,2015)*.

45. The legacy and perspective document on IMBER capacity building aims to assess these activities, and outline a way forward for sustainable capacity development within the IMBER research community as it prepares for the next 10 years of marine biogeochemistry and ecosystem research. *(IMBER Capacity Building Task Team (2016).IMBER Report No. 9, IMBER Regional Project Office /IMBER International Project Office, Shanghai, China. 30pp).*

From: Human Dimensions Working Group (HDWG):

46. I(MBER)-ADApT (Assessment based on Description, Responses and Appraisal for a Typology) developed by the HDWG, is an integrated assessment framework built on knowledge learned from past responses to global change issues. It will enable decision makers, researchers, managers and local stakeholders to make more efficient decisions for marine sustainability, and to evaluate most effectively where resources should be allocated to reduce vulnerability and enhance resilience of coastal people and communities to global

change (*Bundy, et al., 2015*; http://www.imber.info/index.php/eng/Science/Working-Groups/Human-Dimensions/IMBER-ADApT).

From: Continental Margins Working Group:

47. The quest for resources is driving exploration and exploitation on continental margins, including the Arctic margins. Disasters, such as the 2010 BP-Deepwater Horizon oil spill, are likely to occur with increasing frequency and exacerbate on-going threats, such as coastal hypoxia. The IMBER-Future Earth Coasts Continental Margins Working Group (CMWG) found that the prevailing Law of the Sea promotes exploitation but with insufficient responsibility and accountability to stem unsustainable development. Recommendations from CMWG activities focus on reforms based on better understanding of the social-ecological systems (*Levin, et al., 2015*), assessment of risks associated with development, and effective governance (*Glavovic, et al., 2015*).

From Endorsed projects:

SWAtlantic (SACC-IAI)

48. Shelf-deep ocean exchanges and their variability are key to understand the processes that control retention of planktonic species, and therefore abundance and biodiversity over a wide range of trophic food webs, and may have a strong impact on the carbon budget of continental margins. Satellite-derived surface temperature, salinity and currents combined with in-situ observations and numerical simulations reveal intense shelf-deep ocean exchanges in the western South Atlantic. *(Strub et al., 2015, Guerrero et al., 2014, Matano et al., 2014).*

49. Upwelling is the main process sustaining plant growth in the open ocean. Though the most effective upwelling ecosystems are wind-forced (e.g. mid-latitude eastern boundary currents), other productive marine ecosystems, such as the Patagonia continental shelf in the SW South Atlantic must rely on other upwelling mechanisms. Theory predicts that the interaction of western boundary currents of subpolar origin with the ocean bottom lead to strong shelf break upwelling. *Franco et al., 2015, Matano et al., 2014, Pisoni et al., 2014, Valla and Piola 2015.*

GALATHEA

50. It is expected that ocean warming will lead to increased bacterial activity and faster remineralisation of particulate organic carbon (POC) in the surface layers, which increase POC export to to deep waters, potentially decreasing the strength of the biological pump. This temperature sensitivity of remineralisation in the global ocean has now been quantified and is an important input for modelling of the ocean carbon cycle (*Bendtsen, et al., 2015).*

PERSEUS

51. An overview of the pressures impacting the Southern European Seas (SES) and their roles in altering the environmental status was undertaken. Additional knowledge and improved understanding is needed to undertake a scientific Good Environmental Status (GES) evaluation. Some of the indicators for the *Marine Strategy Framework Directive* (MSFD) are almost impossible to evaluate for operational purposes (e.g. those related to biodiversity, food web structure, marine litter and microplastics, underwater noise and energy). Additional targeted scientific priorities were identified for the SES to help reduce uncertainties and gaps in data and knowledge *(Crise et al., 2015)*

52. The swarms of Portuguese Man-of-War (*Physalia physalis*) that appeared in summer 2010 in the Mediterranean Sea had dramatic consequences, including the region's first recorded human fatality attributed to a jellyfish sting. Analyses of the meteorological and oceanographic conditions of the Northeast Atlantic Ocean in the months prior to the appearance of *P. physalis* and simulation of the probable drift of Atlantic populations into the Mediterranean basin suggested that the swarms resulted from an unusual combination of meteorological and oceanographic conditions the previous winter, and was not a permanent invasion due to favourable climatic changes *(Prieto et al., 2015).*

53. Trawls in the coastal areas of the Eastern Mediterranean and Black Sea found up to 1211 items of litter per km^2. Plastics were the most abundant (mostly bags and bottles) litter, up to 95% of the total, in all study areas. More than half of marine litter items were of medium size: 10 × 10 cm, <20 × 20 cm. The results are

presented in a recent report, supporting the Marine Strategy Framework Directive (MSFD) implementation, as well as efforts to discourage plastic carrier bag use *(Ioakeimidis et al., 2015)*.

54. A visual census of marine litter on the seafloor of the Saronikos Gulf (Greece) was combined with environmental education in a novel two-day research cruise, in which schoolchildren actively participated in using a Remotely Operated Vehicle (ROV). Marine litter proved to be an ideal theme to enhance the environmental awareness of schoolchildren *(Ioakeimidis, et al., in press).*

CATARINA

55. The first observation-based acidification trends in the water masses of the Atlantic basin over the past two decades were compared with climate model results. Observations and model output confirm that pH changes in surface layers are dominated by the anthropogenic component. In mode and intermediate waters, the anthropogenic and natural components are of the same order of magnitude and sign (about -0.002 yr^{-1}). Large changes in the natural component of newly formed mode and intermediate waters are associated with latitudinal shifts of these water masses caused by the Southern Annular Mode in the South Atlantic and by changes in the rates of water mass formation in the North Atlantic *(Aida et al., 2015)*.

CARBOCHANGE

56. Several studies have suggested that the carbon sink in the Southern Ocean—the ocean's strongest region for the uptake of anthropogenic CO_2—has weakened in recent decades. We demonstrated, on the basis of multidecadal analyses of surface ocean CO_2-observations, that this weakening trend stopped around 2002, and by 2012 the Southern Ocean had regained its expected strength based on the growth of atmospheric CO_2. The large decadal variations in the Southern Ocean carbon sink suggest a rather dynamic ocean carbon cycle that varies more than previously recognized. *(Landschutzer et al., 2015)*

57. For the year 2014, CO_2 emissions from fossil-fuel combustion and cement production grew to 9.8 ± 0.5 GtC yr^{-1}, 0.6% above 2013, continuing the growth trend in these emissions, albeit at a slower rate compared to the average growth of 2.2%yr^{-1} that took place during 2005–2014. Cumulative emissions of CO_2 will reach about 555 ± 55 GtC for 1870–2015, whereof about 75% from fossil fuel and cement production, and 25% from change in land use. *(Le Quéré et al., 2015).*

58. Century-scale trends and seasonality in pH and temperature for shallow zones of the Bering Sea show a long-term decline of 0.08 ± 0.01 pH units between the end of the 19th and 20th century, which is consistent with atmospheric CO_2 records. Additionally, a strong seasonal cycle (~0.22 pH units) is observed and interpreted as episodic annual pH increases caused by the consumption of CO_2 during strong algal (kelp) growth in spring and summer. The rate of acidification intensifies from –0.006 ± 0.007 pH units per decade (between 1920s and 1960s) to –0.019 ± 0.009 pH units per decade (between 1960s and 1990s), and the episodic pH increases show a continuous shift to earlier times of the year throughout the centennial record. This is indicative of ecosystem shifts in shallow water algal productivity in this high-latitude habitat resulting from warming and acidification. *(Fietzkeet al., 2015)*

Too Big To Ignore (TBTI, http://toobigtoignore.net/)

59. To address the marginalization of small-scale fisheries in policy and governance, an Information System (ISSF, http://issf.toobigtoignore.net/), containing information such as fishing area, gear type, targeted species and catch fate, has been developed. As of March 2015, ISSF contained 1,740 records contributed by 400 individuals from 140 countries. This extensive and comprehensive information system makes possible for the first time the development of evidence-based descriptions of the existence and importance of small-scale fisheries around the world (Jentoft and Chuenpagdee, 2015).

AMT

60. The Atlantic Meridional Transect (AMT) is a multidisciplinary programme since 1995 (http://www.amt-uk.org/) which undertakes biological, chemical and physical oceanographic research during an annual voyage between the UK and destinations in the South Atlantic. The annual transect crosses a range of ecosystems from sub-polar to tropical and from euphotic shelf seas and upwelling systems to oligotrophic mid-ocean gyres. AMT informs on trends and variability in biodiversity and function of the Atlantic ecosystem during this period of rapid change to our climate and biosphere.

C. Activities of IMBER Regional Programmes

Ecosystem Studies of Subarctic and Arctic Seas (ESSAS) Regional Programme

As ESSAS research is expanding to include the Arctic, at last year´s SSC meeting the name was changed (but retaining the same acronym) to include Arctic seas.

ESSAS Annual Science Meeting on The Role of Ice in the Sea was held in Seattle, Washington, in June, 2015 with 51 oral presentations and 13 poster presentations. Four themes were explored: Humans, Ice and the Sea in the Subarctic and Arctic Past, the Role of Sea Ice in the Arctic and Subarctic, the Ecological Role of Tidewater Glaciers, and Social Science Investigations of Changing Sea Ice Conditions. Over 100 scientists attended from 11 countries. This was the largest ESSAS ASM and by all indications one of the most successful.

The ESSAS RACArctic (Resilience and Adaptive Capacity of ARCTIC marine systems under a changing climate) Project funded by the Belmont Forum began with fall meetings in 2015 in each of the co-sponsoring countries, Japan, the US and Norway. The first international meeting was held 1-3 March 2016 in Hakodate, Japan, beginning with a stakeholders' meeting. The aim of the project is to synthesize information from completed and ongoing regional studies on how climate variability and change in the Subarctic to Arctic transition zones may affect future marine ecosystems of the Pacific and Atlantic Arctic. In particular, it will examine how fish populations and their prey are able to adapt or respond to natural and anthropogenic changes in the Arctic and how these are expected to affect existing and future fisheries, subsistence harvests, and the socio-economic systems that depend upon them.

The ESSAS 3rd Open Science Meeting is planned for June 2017 in Tromsø, Norway – "Moving in and out and across the Subarctic and Arctic – shifting boundaries of water, ice, flora, fauna, people and institutions".

A Special Issue by the ESSAS WG on Modelling Marine Ecosystems entitled Combining Modeling and Observations to Better Understand Marine Ecosystem Dynamics and dedicated to the late Bern Megrey was published in November 2015 with 19 papers. The idea for this special issue was formulated at the ESSAS Open Science Meeting in Seattle during 2011 and was edited by Enrique Curchitser, Ken Rose, Shin-ichi Ito, Myron Peck and Michio Kishi.

ESSAS will continue with its current structure. There are currently four working groups:
WG: Modelling ecosystem response – published a special issue on modelling and observational approaches.
WG: Arctic-Subarctic interactions, had a session at the 2016 ASLO Ocean Sciences meeting.
WG: Human dimensions, has organised a session at the ESSAS Annual Science Meeting 2015 in Washington.
WG: Comparative Paleo-ecology in Sub-Arctic seas (a longer term assessment of the mechanisms linking climate, oceanography, ecology and human system relationships).

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

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

Highlights from ICED science over the past year are in section B. In addition, ICED scientists were involved in the following international events:

International workshop on Pteropod and Ocean Acidification, British Antarctic Survey, June 2015. The outcomes from the workshop were submitted to Biological Review and will be presented at the High CO_2 Symposium in May 2016. A further output may be the preparation of a paper by the joint OSPAR/ICES Ocean Acidification Study Group on the potential of pteropods as an ocean acidification bio-indicator species.

Scientific Committee on Antarctic Research (SCAR) Cross-Program Workshop on Interactions between Biological and Environmental Processes in the Antarctic, Institut de Ciències del Mar, 16-18 September 2015, Barcelona, Spain. ICED links with SCAR, in particular AnT-ERA, were strengthened through our involvement in this interdisciplinary activity which followed directly on from and complemented the ICED Workshop on *Southern Ocean Food webs and Scenarios of Change, British Antarctic Survey.* The ICED workshop focused on the pelagic food web in exploring the use of climate models and data in scenarios and projections of change.The SCAR workshop focused on the benthic food web with ICED scientists providing the link between the two towards a more complete picture of changing Southern Ocean ecosystems.

IMBER IMBIZO IV, 26-30 October 2015, Trieste, Italy. ICED scientists convened one of the workshops *Integrated modelling to support assessment and management of marine social-ecological systems in the face of global change.* This brought together natural and social scientists from the modelling community, as well as experts in policy and the human dimensions related to the marine environment to consider approaches to integrate modelling efforts to address societal questions on marine social-ecological system change and management. ICED scientists had a leading role in developing and leading the workshop, which generated a stimulating discussion and a series of new insights. A number of outputs from the workshop are in development, including a short high profile paper and a more detailed paper on future directions. A theme section/special issue is under consideration.

EURO-MARINE Consortium General Assembly, 28-29 January 2016, Portugal. The EURO-MARINE Network is a FP7 Coordination and Support Action, launched in June 2014, and represents the merger of three former FP6 Networks of Excellence that have involved ICED Scientists (EUR-OCEANS- ICED scientists led the Southern Ocean System, MarBEF - marine biodiversity, and Marine Genomics Europe - high throughput approaches for marine biology), as well as their follow-up legacy structures the EUR-OCEANS Consortium (involving ICED scientists) and the MarBEF+ Association. EURO-MARINE represents 'a bottom-up organisation and the voice of the European marine scientific community supporting and promoting initial development of emerging science topics'. ICED scientists from the British Antarctic Survey (a paying member of EURO-MARINE) attended this year's General Assembly meeting, ensuring links between ICED and the shared vision of this European network whilst building on the legacy of EUR-OCEANS in developing the ICED network and science strategy. For further information see http://www.euromarinenetwork.eu/.

ICED scientists also presented at conferences, for example: American Geophysical Union Fall Meeting, 12-16 December 2015, San Francisco, USA; World Seabird Conference 26-30 October 2015, Cape Town, South Africa.

In addition ICED contributed to the annual SCAR report and Science Highlights for the Antarctic Treaty Consultative Meeting 2015; to the SCAR Cross-Program Workshop; and Richard Bellerby has led the development of a major SCAR report on ocean acidification and potential impacts in the Southern Ocean. This has involved input from a range of ICED scientists and the report is due to be formally completed in early 2016. ICED has continued its close partnership with SOOS with members of ICED also on the SOOS SSC. Collaborations are ongoing and most recently include SOOS's request for ICED to contribute to the development of a Southern Ocean database and map of field activities.

As ICED is a regional programme of IMBER, it has benefited from SCOR's financial support for various programme activities. We also appreciate SCORs work in developing science themes and capacity building.

ICED contributes to the development of the EU-PolarNet Consortium: In September ICED scientists submitted a contribution to the newly formed EU-PolarNet Consortium's (2015-2020, see www.eu-polarnet.eu) future series of white papers addressing urgent polar research questions. ICED's contribution focused on the need to advance knowledge of polar marine ecosystems and their influence on global cycles by coordinating strategic comparative research activities on both the Arctic and the Antarctic. The EU-PolarNet Consortium will transmit science priorities and a strategic framework to the European Polar Board, which then gives advice to the European Commission and other international bodies to strengthen polar research, optimise infrastructure and provide tangible benefits to society.

ICED and ESSAS scientists have undertaken a series of joint activities. A joint programme paper on advection (led by George Hunt) is in review in Progress in Oceanography and one on Antarctic and Arctic biodiversity and ecosystem functioning (led by Eugene Murphy) is also in review. We intend to build on and develop these links and are currently investigating possible mechanisms for doing this (e.g. COST Action).

ICED are continuing its work with CCAMLR to ensure that ICED science is relevant to CCAMLR and that scientific results are translated appropriately into messages that resonate with policy makers. ICED will be represented at the second Joint Workshop of the CCAMLR Scientific Committee and the Antarctic Treaty's Committee on Environmental Protection (CEP), to be held 19-20th May 2016 in Punta Arenas, Chile.

ICED scientists have also been involved in key International Whaling Commission work including the completion of the Southern Hemisphere humpback whale assessment led by Jen Jackson.

CLimate Impacts on Oceanic TOp Predators (CLIOTOP) Regional Programme

CLIOTOP is an international research network open to researchers, managers, and policy makers involved in research related to large marine species. Network participants organise large-scale comparative efforts to elucidate key processes involved in the interaction between climate variability and change and human use of the ocean on the structure of pelagic ecosystems and large marine species. CLIOTOP seeks to develop predictive capability for these socio-ecological systems and evaluate adaptation options to ensure future sustainability. www.imber.info/CLIOTOP.html.

During the 18 months since the last report to the IMBER SSC, the regional program CLIOTOP finalized activities associated with its second phase (2011-2015) and transitioned to its third phase (2016-2020) as part of IMBER under the Future Earth program. In association, CLIOTOP held its third symposium in September 2015 where activities conducted under its second phase were presented and discussions regarding its third phase occurred.

Interaction between the CLIOTOP leadership team has been through a "semi-monthly" update from the co-chairs, conference sessions and working group meetings. Every member of CLIOTOP is a volunteer, and we appreciate the efforts of all over the last 18 months. The CLIOTOP SSC met face-to-face just prior to the symposium and largely focused on development of the framework for the third phase of CLIOTOP.

Funding for CLIOTOP activities, such as workshops remains an ongoing issue, as for all the regional programs. Most activities conducted by the CLIOTOP working groups were opportunistic and largely planned in synchrony with conferences where reasonable numbers of working group members were already attending. Several working groups have sought funds via varying avenues, but there have been few successes to date. Remaining activities (such as writing of publications) have been coordinated remotely.

Working groups have generated a number of publications either through a special issue of the journal Deep Sea Research II associated with the previous CLIOTOP symposium and published in May 2015, or individually through activities associated with working groups.

At the third CLIOTOP symposium Alistair Hobday stepped down as co-chair of the SSC after six years as co-chair. Karen Evans (CSIRO, Australia) has formally replaced Alistair as co-chair. Osamo Abe and Robert Cowen retired from the SSC during 2015 and were formally thanked for their contributions to the SSC by the outgoing co-chair Alistair Hobday. A number of candidates to join the SSC were identified during the SSC meeting and these will be followed up by the co-chairs.

Under the third phase of CLIOTOP, the SSC has agreed on a re-working of the structure for CLIOTOP. Rather than the SSC setting the science directions of working groups, with working group chairs then developing science initiatives, the SSC and the CLIOTOP community will work together to develop a series of task teams. These task teams will be cross-disciplinary, problem solving and output oriented, with varying life times (e.g. 6 months to 2 years). They will bring together experts from domains needed to resolve overarching questions orientated around the goals of CLIOTOP and be consistent with the Grand Challenges and Innovative Challenges of IMBER (www.imber.info) and in turn, the focus of Future Earth.Task teams may be led by individuals or groups, tasks may be simple (e.g. writing a paper) or complex (developing new approaches to addressing a problem) and they may be seed funded by CLIOTOP or unfunded, but either aligned to CLIOTOP or conducting science that is consistent with CLIOTOP's objectives.

In early November 2015, the first call for task team proposals was sent out to the CLIOTOP community with eight proposals submitted to the SSC. The SSC through online discussions has since decided on those proposals that will form the first tranche of teams in Phase 3 of CLIOTOP. The next step in getting teams operational will be to work with the IMBER IPO in dispersing funds allocated to CLIOTOP to teams. The first tranche of teams is expected to be in place and operational before summer of 2016. Formal reporting systems for task teams will require teams to report on their activities at the end of each calendar year for inclusion in CLIOTOP reports to IMBER.

Sustained Indian Ocean Biogeochemistry and Ecosystem Research (SIBER) Regional Programme

SIBER is a basin-wide research initiative sponsored by IMBER and the Indian Ocean GOOS (IOGOOS) Programme with close ties to CLIVAR's Indian Ocean Panel (IOP). It focuses on understanding climate change and anthropogenic forcing on biogeochemical cycles and ecosystems in the Indian Ocean, to predict the impacts

of climate change, eutrophication and harvesting (www.imber.info/index.php/Science/Regional-Programmes/SIBER and www.incois.gov.in/Incois/siber).

Launch of the 2nd International Indian Ocean expedition (IIOE-2): This expedition was motivated by SCOR, SIBER, IOP and IOGOOS and it is sponsored by SCOR, IOC and IOGOOS. The IIOE-2 has become the main focus of SIBER.

Completion/publications of the IIOE-2 Science Plan (Hood et al., 2015): The IIOE-2 Science Plan was commissioned by SCOR and developed by the SCOR IIOE-2 Science Plan Development Committee beginning in April/May 2014. The development was based on several IOC-sponsored "Reference Group" planning meetings and national meetings. A progress report was delivered to SCOR in Bremen in September 2014. The first draft was completed in February 2015. The final peer-reviewed and revised draft was delivered to the IOC Interim Planning Committee in April 2015 and accepted. The plan was finalized and printed for the Goa Symposium in November 2015.

Completion/publication of the IIOE-2 Implementation Strategy (IPC, 2015): In June/July 2014 the IOC establish (through Resolution EC-XLVII.1) the IOC IIOE-2 Interim Planning Committee (IPC). The IPC was tasked to propose to the IIOE-2 sponsoring organizations (IOC, SCOR and IOGOOS) the establishment of committees to oversee the planning and implementation of IIOE-2. The IOC Executive Secretary coordinated the establishment of the IPC (through a call via IOC Circular Letter No. 2541, in September 2014). The IPC met four times by teleconference and twice in person in 2015 to undertake these assigned tasks. The IIOE-2 Implementation strategy was finalized and printed for the Goa Symposium in November, 2015.

Goa IIOE 50th Anniversary Symposium and Launch of the IIOE-2: The symposium was convened at NIO in Goa, November 30 through December 4, 2015. Special sessions followed the IIOE-2 Science Plan research themes. The first cruise of IIOE-2 was launched on the last day of the symposium. The symposium was followed by the SCOR general assembly and the joint SIBER/IOP/IOGOOS/IRF meetings.

Launch of the Eastern Indian Ocean Upwelling Research Initiative (EIOURI): EIOURI is a major SIBER research initiative under IIOE-2. Planning for EIOURI is at an advanced stage. The main foci of this initiative is on the upwelling regions that develop seasonally off Java, Sumatra, and northwestern Australia. The Science Plan for EIOURI has also been completed (Yu et al., 2016).

Development of the Western Indian Ocean Upwelling Research Initiative (WIOURI) (Roberts et al., in preparation): In addition to EIOURI, planning efforts have been initiated to develop a complementary upwelling research initiative under IIOE-2 on the western side of the basin.

SIBER has strong collaborations with various regional organizations (e.g., Indian Ocean Panel of CLIVAR and IOGOOS). This collaboration provides a model for successful CLIVAR-IMBER collaboration.

D. Activities of IMBER Working Groups and Task Teams

SOLAS-IMBER Carbon (SIC!) Working Group

IMBER currently has three joint SOLAS-IMBER carbon (SIC!) working groups that consider carbon in the surface ocean systems (SOS), carbon in the interior ocean (IOC) and ocean acidification (SIOA).

Surface Ocean Systems (SIC!-SOS)

The Surface Ocean CO_2 Atlas (SOCAT) includes more than 100 contributors, and has assembled surface ocean carbon dioxide (CO_2) data in a uniform, quality-controlled format. Version 1 was made public in 2011 at the IMBER-SOLAS Carbon conference in Paris. Version 3 was released just before the SOLAS Open Science Conference 2015 in Kiel, Germany.

SOCAT Version 3 provides surface water fCO_2 (fugacity of CO_2) values from 1957 to 2014 (i.e., 58 years) for the global oceans and coastal seas with 14.5 million unique data points (4.4 million data points more than Version 2), from over 3,600 datasets. The SOCAT synthesis and gridded data products can be interrogated via interactive online viewers or downloaded in a variety of formats from the SOCAT website (www.socat.info). The quality control criteria have been adapted for Version 3 to accommodate calibrated CO_2 data from new sensors and alternative platforms. Data submitted before the end of January 2016 will be quality-controlled and

made public in SOCAT version 4 on 30 June 2016. Applications of the SOCAT Atlas include process studies, quantification of the ocean carbon sink, seasonal to year-to-year variation, and ocean carbon cycle modelling. The Global Carbon Budget (www.globalcarbonproject.org/carbonbudget/) uses SOCAT for quantification of the annual ocean carbon sink.

The Surface Ocean pCO_2 Mapping intercomparison (SOCOM) is a recent initiative that compares a total of 14 surface ocean CO_2 gridded products, derived by a variety of methods, many of them based on SOCAT.

Interior Ocean Carbon (SIC!-IOC)

Recent activities focused on analysing the carbon data from hydrographic surveys to determine change in the oceans' anthropogenic CO_2 content since the 1990s. The preliminary results from the first decade of GO-SHIP were presented in a review paper. The WG will finalize the results on the basis of GLODAPv2, the quality-controlled database released in January 2016 for CO_2-relevant biogeochemical and physical parameters from 724 scientific cruises covering the global ocean.

IOC also contributed to the joint GO-SHIP/Argo/IOCCP "Sustained ocean observing for the next decade" meeting in Galway, Ireland http://www.gaic2015.org. They continue to support the development and application of biogeochemical sensors on Argo floats. Recently, they contributed to the draft BGC-Argo Implementation Plan and reported on it to the Argo steering team in March 2016. IOC is likely to engage fully in the data synthesis and integration on a global/basin-scale.

SOLAS-IMBER Ocean Acidification (SIOA)

The SIOA working group coordinates international efforts and synthesis activities for ocean acidification research. Within a single decade ocean acidification has gone from a research area of limited interest to one that is now considered to be a priority for ecology and environmental sciences. This rapid expansion has made it difficult for experts to share information and train new scientists from different countries.

The SIOA was instrumental in the development of the OA International Coordination Centre (OA-ICC) and in co-design and co-production with a range of stakeholders. OA-ICC is mainly driven by the SIOA. The Centre aims to foster scientific collaboration at the international level, promote best practices, improve observational capacities and databases, and facilitate communication and outreach. The OA-ICC is supervised by a science coordinator (SIOA's current chair). The OA-ICC advisory board includes all SIOA members, the IMBER SSC Chair and is chaired by a SIOA member.

The 4th Ocean in a High-CO_2 World Symposium was held in Hobart, Australia, 3 - 6 May 2016. SIOA organised several side events at the IPCC *Our Common Future Under Climate Change* conference in Paris in July 2015, and produced a variety of outreach material.

Continental Margins Working Group (CMWG)

With the tragic death of past CMWG co-chair Konkee (K.K.) Liu, and the re-organisation of LOICZ as Future Earth Coasts (FEC), the CMWG has been semi-quiescent this year. However, Karin Limburg has now been appointed as the IMBER CMWG co-Chair and Don Forbes her FEC counterpart. New activities are being planned to progress the ideas developed by the CMWG in the previous three years. The priority areas identified in Glavovic et al. (2015) map well onto the IMBER Grand Challenges. Because these are somewhat general, it is necessary to refine and test them with case studies. Accordingly, it is suggested that two good test areas would be: 1) a densely populated part of the world, where severe pollution/hypoxia/etc. is in conflict with fisheries, aquaculture, and other consumptive activities, e.g. southern Asia, and 2) a sparsely populated part of the world, e.g. the Arctic, where climate warming is driving an increase in economic activities and exploitation in fragile, largely pristine continental margins. New CMWG members are being selected according to expertise relevant to the case studies.

A proposal to fund a workshop to organize the first case study was submitted to the Asia Pacific Network (APN), however unfortunately it was rejected. The Arctic case study has yet to be developed and connections with the IMBER ESSAS programmes and ESA are being made. Both IMBER and FEC succesfully applied for IGBP/ESA funds to support a workshop on the Arctic focus within the CMWG, and the planning for this is underway.

Data Management Committee (DMC)

The current Data Management Committee (DMC) has achieved what it set out to do. If the group is to continue, new members with expertise in social science data, and maybe in animal tracking, GOOS, etc. need to be appointed and new Terms of Reference developed.

The Data Management Cookbook (http://imber.info/index.php/Science/Working-Groups/Data Management/Cookbook) remains an important and significant product of the DMC. Data management workshops have been organised at the IMBIZOs and the OSC. At IMBIZO IV in October 2015 the DMC provided advice and guidance on all data-related issues.

Capacity Building Task Team (CBTT)

At the last IMBER SSC meeting it was agreed that the Capacity Building Task Team has done an excellent job, and has fulfilled its mandate. As capacity building is now included in all IMBER activities and events, once the IMBER capacity building legacy document is published, the members will be thanked and the Task Team disbanded. IMBER will ensure that the recommendations in the legacy document are properly considered/ fulfilled.

Human Dimensions Working Group (HDWG)

The group is finalising a book comprising 19 chapters related to I(MBER)-ADApT (Assessment based on Description, Responses and Appraisal for a Typology, http://www.imber.info/Science/Working-Groups/Human-Dimensions/I-MBER-ADApT) and has published a special issue (February 2016) in *Regional Environmental Change*. They will also convene a session at the World Fisheries Congress in Korea in May 2016 together with ICES and PICES. It is hoped this might lead to better linkages with natural and social sciences, including governance. The HDWG focuses on the interactions between human and ocean systems, and aims to create an integrated and interactive natural-social science marine research community within IMBER. One of its major achievments has been the development of the I(MBER)-ADApT decision support tool.

Four new members have agreed to join the HDWG next year, including van Putten, thus ensuring a continued HDWG-SSC link when Bundy and Chuenpagdee rotate off.

I-ADApT has been published and is now being tested with an increasing number of case studies. The goal is to include about 100 cases.

On a longer term the intention is to develop a database of global case studies as an open-access web site to help decision makers, researchers and stakeholders decide how to respond when faced with difficult choices and trade-offs. There is an open invitation and template to supply case-studies to the I-ADApt system. Because of the complex interactions and feedbacks between humans and the ocean, the case study template includes questions about the natural, social and governing systems, the stressors that affect them, their response and an appraisal of that response.

IMBER-CLIVAR Upwelling Working Group

There have been two major events on upwelling since the last IMBER SSC meeting in June 2015. Enrique Curchitser, leader of the Research Focus (RF) group, organized a workshop in Ankara, Turkey, in October 2015 to further plan the work of the Upwelling WG. It was held following a CLIVAR summer school. A total of 18 participants were involved representing several disciplines: physical oceanography models and observations, atmospheric sciences, biogeochemistry, climate modelers, and fisheries scientists. Reuben Escribano was the IMBER representative although a number of other IMBER scientists such as Colleen Maloney, also attended. The discussion centered primarily on Eastern Boundary Upwelling Systems (EBUS). Particular attention was paid to global climate model biases resulting from the lack of resolution in EBUS.

Some of the major points of the discussion included:

- There is need to design proper metrics for climate models. Significant work is needed on the atmospheric and coupled atmosphere/ocean dynamics in EBUS.
- What observations are needed, e.g. glider lines, etc.? Oxygen Minimum Zones (OMZs) and their interaction within upwelling regions were discussed.

- More information is needed on the origin and destination of the upwelled waters.
- The definition of an EBUS needs to be refined and comparison between different systems need to be highlighted
- The role of the meso- and sub-mesoscale processes in determining characteristics of EBUS needs to be elucidated.
- Detailed resolution of coastal winds in upwelling zones is required.
- It was recognized that fisheries in upwelling areas need to be addressed and a plan was drafted regarding the use of models to understand the impacts of climate variability on EBUS Schematics of EBUS processes in a coupled atmosphere/ocean system were drawn up.

The second major event was the Upwelling Workshop at IMBIZO IV in Trieste, Italy led by Francisco Chevez, Eddy Allen and Nina Bednarsek. The main objectives of the workshop were to:

1. Determine how integrated and coordinated projects can be developed so that the relative roles of natural climate variability, anthropogenic climate change, broader global change and human responses can be elucidated and predicted.
2. Integrate perspectives from a broad range of disciplines, including oceanographers, ecologists, economists, political scientists and others with interests in coastal systems and their dependent human populations.
3. Prepare a white paper/synthesis paper incorporating novel ideas generated during the sessions

E. Other IMBER activities

Development of the new IMBER Science Plan and Implementation Strategy (SPIS)

Developing the new SPIS (2016-2025) "IMBER into the Future" wasa major task for the SSC Chair and the IPO.The SPIS includes a new vision and research goal for IMBER, and is developed around three Grand Challenges (GC) and four Innovation Challenges (IC). Specific research questions relating to the GCs and ICs are intended to provide the basis for implementation of research programs. The SPIS was submitted to SCOR and Future Earth (FE) in November 2015 for joint review, and about 10 reviewers (selected by SCOR and FE) have delivered their reviews. Based on this SCOR and FE are producing a joint document suggesting improvements/changes for IMBER to consider before making the final version openly available.

IMBER will maintain its focus on fundamental biogeochemisy and ecosystem reseach but will expand to include aspects of sustainable oceans, human well being, biodiversity conservation, and making science relevant to society. Another issue is to ensure that IMBER science is available in a form that can be used to influence decision-making that will safeguard marine ecosystems and their dependent human societies. Achieving this will require the involvement of a diverse science community that is drawn from a range of different disciplines, including quantitative global change social science, international relations, and ocean geopolitics. IMBER will also engage in activities that enhance integration among and between IMBER's regional programmes, working groups and endorsed projects.

Preparing for the ClimEco5 Summer School

IMBER ClimEco Summer Schools are held every two years and are a successful capacity building mechanism for engaging students and early-career scientists. The planning for the summer school to be held in August in Natal, Brazil is on schedule. The theme is *Towards more resilient oceans: Predicting and projecting future changes in the ocean and their impacts on human societies*. We have had > 200 applicants, approved about 90 from more than 30 different countries and expect about 10% to drop out. There is some concern regarding the zika virus outbreak, and all approved candidates has been thoroughly notified and given links to important websites.

IMBIZO IV & V

The IMBIZO IV (held in Trieste, Italy 26-30 October 2015), co-convened by Xavier Arístegui and Ingrid van Putten, was very successful. There were four concurrent workshops instead of the usual three. Presentations during the workshops showed the state of the art of the science in the four themes, and there was discussion regarding the way forward and IMBER´s role.

Before the start of the IMBIZO, early career workshops were held on how to write a good publication, and how to write a good grant proposal.

Each workshop will produce a synthesis paper or special issue.

An article on the IMBIZO was published in the April edition of the OCB newsletter.

IMBIZO V will be held in 2017 in Woods Hole, most probably at the beginning of October, and it was suggested that the next IMBER SSC meeting should be held in conjunction with IMBIZO V, to involve more SSC members.

Based on the IMBER SSC decision to use the workshops to specifically progress implementation of the SPIS, potential topics for IMBIZO V are:

IMBIZO V – Overall theme: Sustainable Oceans in the 21st Century

1. Metabolic diversity and adaptation (Herndl/Rynearson)
2. IMBER scenarios/projections and their applications (Bopp and FISHMip)
3. Putting human behaviour into models (MSE) (van Putten/ Werner)

IMBER contributions to IGBP synthesis and celebration at AGU

The IMBER manuscript to the IGBP synthesis special issue of *Anthropocene* was accepted and published in late 2015.

A final IGBP celebration was held at the Fall Meeting of the American Geophysical Union in San Francisco, 14-18 December 2015. An IGBP-IMBER session was convened at the meeting, where Hofmann presented results from the four workshops of IMBIZO IV and a summary statement.

IMBER and Future Earth (FE)

IGBP ended in December 2015 and a transition document (TD) to Future Earth (FE) was developed (lead by Hofmann) being a formal request by IMBER to become a core project of FE. Reviews of the TD have been very positive this far, so the process is essentially a formality. The signing of a FE-SCOR-IMBER Memorandum of Understanding (MoU), outlining how they will work together, will be the final formality.

The IMBER chair and IPO is actively taking part in the development of Future Earth, in particular delivering inputs to several Knowledge Action Networks (KAN) with a focus on the OCEAN KAN. We will participate in aFE Core Project meeting in Bern in June 2016, and the IPO is involved in the FE/IPBES fast track initiative.

Status of the International Project Office (IPO, Norway) and the Regional Project Office (RPO, China)

IPO

The present IPO funding from IMR and the Norwegian Research Council (NRC) runs out at the end of March 2017. Meetings have been held with the IMR leadergroup and several NRC directors, resulting in a "promise" for cofunding for another three years (until end of March 2020). An IPO project proposal has been sent to NRC on this, and the final decision is expected mid June 2016.

Since the present IPO director is getting close to retirement, a process is underway for his replacement. The IMR leadergroup decided this would happen via an internal advertisement process at IMR, and IMBER will have key IMBER people in the evaluation committee.

The IPO also planned and executed (in late November 2015) a Sweden-IMBER workshop in Stockholm on "Effects of ocean acidification on ecosystems and human societies" which recuited about 40 new "members" to the IMBER community. At the same time the IPO took part and presented IMBER at the opening of the Stockholm Future Earth Hub.

The IPO organised the IMBER SSC meeting in New Orleans in February 2016 alongside the ASLO/AGU/TOS Ocean Science Meeting.

The IPO director is part of the Science and Technology Advisory Board for the European Copernicus Marine Environment Monitoring Service (CMEMS) having about two meetings per year. CMEMS is looking for more users of their services related to marine ecosystems, and this may be a source for IMBER to use.
In March 2016 the IPO attended the Future Earth/IPBES indicator workshop in Switzerland.

The IPO is struggling with getting the new web site up to a quality ready for release,

RPO

The present RPO funding from the East China Normal University in Shanghai ends in 2016. An active process is ongoing to renew the funding.

The leader of the RPO, Yi Xu represented IMBER at the successful 7th China/Japan/Korea (CJK) IMBER symposium at the KIOST Jeju centre. The results from the symposium will soon be presented in an IMBER newsletter.

Xu also participated in the IOC/WESTPAC-CorReCAP Workshop which was held at SKLEC, ECNU. Under the leadership of Dr. Jing Zhang, the RPO will produce a book synthesizing the anthropogenic impact on Coral Reefs in the West Pacific region, and they are applying for funds from IOC/WESTPAC to run a summer training course about the influence of ocean acidification on Coral Reefs.

F. IMBER SSC member nominations

Hofmann ended her term as SSC Chair at the end of 2015. There is no call for nominations with regard to the Chair. Rather, the Executive Committee identifies individuals who is/has been involved with IMBER. The Executive Committee suggested Carol Robinson (University of East Anglia, UK and former IMBER SSC member), and she took over from the beginning of 2016. Hofmann remains as *ex officio* Past Chair in 2016.

Three new SSC members are needed and a call for nominations went out in April 2016. In relation to the existing and outgoing expertise we search for scientists with skills in:

- marine sustainability science
- marine policy/governance science
- integrated modelling of social and marine ecological systems
- biodiversity/adaptation science
- communication (ocean literacy)

Nominations are still being received with a deadline in late May 2016.

G. IMBER cooperation

IMBER has been closely collaborating for many years with SOLAS (see SIC!) and LOICZ (now Future Earth Coast, see CMWG above) and recently with CLIVAR, and with other projects and organizations.

a. Too Big To Ignore (TBTI)
IMBER is a partner of the TBTI project. TBTI has reached its midpoint and now includes over 200 scientists from 45 countries. TBTI is conducting a global analysis, based on information systems, to better understand small-scale fisheries (SSF). IMBER information that might relate to SSF can be added at issf.toobigtoignore.net, and this can be used for case studies for I-ADApT. There was collaboration at IMBIZO IV. A TBTI Fellowship (3-4 month placement or Postdoc) will soon be launched. Chuenpagdee recommended that IMBER-relevant organisations with mutual interests should be encouraged to consider hosting a TBTI-IMBER Fellow

b. Ocean Carbon Biogeochemistry (OCB)
OCB continues to actively support IMBER by advertising its activities and events, and by providing financial support for activities. OCB provided travel support for five participants from the USA to attend IMBIZO IV. IMBER has always had a SSC member on the OCB SSC. Hofmann rotated off and is replaced by Mike Roman (IMBER Vice-Chair 2006-2012).
In the interests of raising IMBER's profile in the USA, Hofmann has suggested a session proposal for the OCB summer workshop in 2017.

c. WCRP

CLIVAR, a core project of WCRP and its Indian Ocean panel works closely with SIBER. CLIVAR will hold an OSC from 19-23 September 2016 in Qingdao, China and several IMBER-related sessions will be convened as this conference. A Joint Upwelling WG is established, now represented with Escribano from the IMBER SSC.

d. GOOS/Copernicus

SIBER has strong connections with IO-GOOS, and IMR is involved with EURO-GOOS through Copernicus (European Programme to establish European capacity for Earth Observation). Also the SOLAS-IMBER Carbon WG have good links to GOOS. Increased alignment with GOOS will help IMBER deal with the challenge of ocean data. Links have been established with Eric Lindstrom (co-chair of GOOS). IMBER responded to the recent GOOS Biology Panel survey for metadata.

e. ICES

The IMBER IPO had an information booth at the ICES Annual Science Conference in Copenhagen, Denmark in September 2015. In addition to having more than 100 WGs on IMBER-relevant science, ICES provides official management advice (for the north Atlantic) with strong interaction with stakeholders. The management advisory processes have very strict quality assurance procedures, which are beyond IMBER´s capacity. ICES is funded by member countries and has a secretariat of more than 50 people and arranges annual science conferences (ASC) with about 700 participants including several IMBER scientists. Next ASC will be in Riga, Latvia 19-23 September 2016, and next year in Fort Lauderdale, US 18-21 September 2017.

f. IOC

IOC agreed to support two participants from developing countries to attend the Upwelling workshop at IMBIZO IV and to support participants for the CLIOTOP Symposium.

g. Hjort Centre

The Hjort Centre for Marine Ecosystem Dynamics is an active research cluster in Bergen with similar goals to IMBER. The Hjort Centre administration is collocated with the IMBER IPO at the Institute of Marine Research in Bergen with effective exchange of information between the two research communities

h. PICES

IMBER and PICES continue to collaborate, with representatives from both communities attending and funding each others activities, such as summer schools and science meetings. PICES will hold their 25th Annual Meeting in November 2016

H. Selected IMBER Publications

IMBER has produced more than 1000 refereed research papers since its implementation; about 150 papers were published in 2015-2016.

Publications related to recent discoveries and highlights

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Communication and Outreach

IMBER's main communication tool is the project website (www.imber.info) which has an average of about 250 visitors each day. A new IMBER website is being developed and soon ready for release and hosted at IMR. Software changes by the internet service provider in France were such that the existing IMBER website could no longer be supported. This transition has caused disruptions in availability of the IMBER website, and the transfer has taken much longer than anticipated. Once the new site at IMR is launched, it will have a new more regularly updated news section, and the community will be encourged to regularly send news items or articles to be featured on the website. The new IMBER website will also be accessible from a range of devices such as mobile phones and iPads.

The *IMBER Update Newsletter*, www.imber.info/index.php/News/Newsletters, is emailed to ~2000 scientists three times a year, and re-directed through multiple channels to about 10,000 researchers:

- ***Issue n°30*** – April 2016. The IMBER IMBIZO IV that was held in Trieste, Italy last year provides the impetus for this issue of the IMBER Update. IMBIZOs are IMBER´s flagship 'gatherings' (this is the meaning the Zulu word 'IMBIZO'). They are held every second year and bring together about 120 mutlidisciplinary scientists to discuss and synthesise the current state of knowledge about marine and human systems and their linkages, and to consider key research questions for the IMBER community to address going forward. The overall theme of IMBIZO IV was *Marine and human systems: Addressing multiple scales and multiple stressors*.
- ***Issue n°29*** – December 2015, is dedicated mostly to articles pertaining to the CLImate Impacts On Top Oceanic Predators (CLIOTOP) Regional Programme. They held their 3rd Symposium, titled "Future of oceanic animals in a changing ocean", in Spain in September. In addition to highlighting some of the excellent work that CLIOTOP working groups and individual scientists have done in the years since the last symposium in New Caledonia, this gathering also provided the opportunity to get community input about the direction that the programme should go in its next phase.
- ***Issue n°28*** - June 2015, included articles about a new ESSAS Arctic project, Canadian research in the North, a generic concept for the vertical behaviour of fish eggs in the world oceans, observing changes in the surface ocean carbon, and a world wide evaluation of the use of ecosystem drivers of stock production in tactical fisheries management.

An electronic IMBER *eNews Bulletin* is published monthly, which provides information about IMBER and IMBER-relevant activities and events. Calls for funding proposals, job opportunities, workshops and conference announcements are also included.

The IMBER contact database is continually updated with information for about 2,300 marine researchers. Finally, the IPO and RPO staff and several IMBER researchers have presented more than a dozen IMBER poster and oral presentations at national and international meetings during 2015.

I. Support from SCOR

IMBER greatly appreciates the ongoing support received from SCOR, and the additional support for specific IMBER activities provided or managed by SCOR from other funding sources. In addition, IMBER welcomes the advice, assistance and information received from the SCOR President and secretariat, especially its Executive Director, Ed Urban, and Financial Officer, Liz Gross.

Funding request

We are requesting funding to support students and researchers from developing countries to attend the IMBIZO V that will be held in Woods Hole in early October 2017.

Amount requested: 10 000 USD

J. Strategic development

IMBER is entering into its second decadal period based on the new IMBER SPIS and involving Future Earth instead of IGBP

IMBER has a history of connecting natural and social sciences and promoting integration across disciplines and communities. Many of IMBER's coordination and networking activities match the integrated approaches desired by FE. As a result, IMBER is well placed to take the lead in developing marine-focused efforts under FE. The transition to a combined SCOR-FE core project should not require modifications to IMBER science goals or implementation strategy.

As with SCOR, the new SPIS forms the basis for FE's incorporation of IMBER as a core project. The transition document (TD) includes a description of what IMBER can bring to FE in terms of science and as an international network of researchers. The TD also includes what IMBER expects from FE, such as support for SSC meetings and integrated activities, funding at the same level as provided by SCOR, and specific assistance with fund raising, outreach, communication and engagement of stakeholders.

The IMBER SSC met in February 2016, and proposed the following strategic actions for IMBER:

1. To work towards better integration between the regional programmes and working groups, focusing particularly on the priority research areas.
2. IMBIZO workshops will be targeted towards implementation of the SPIS.
3. Link to experts on governance, maintain social science expertise on the SSC
4. Delegate members of the SSC as "champions" to lead the progress of the different SPIS challenges
5. Create stronger links to organisations dealing with global observations
6. Implement an action plan to raise the profile of IMBER
7. Revamp the Data Management Committee to better deal with both natural and social science data,
8. Decide whether to change the name of IMBER and if so, create a strategy to communicate the new name
9. Make a strong contribution to the FE Oceans KAN
10. Start preparing for the 2nd IMBER open science conference in 2019
11. Find ways to better measure success
12. Find more funding

K. Budget

The SCOR omnibus grant from the National Science Foundation, which provides support for IMBER, was last year funded for three years. Support for the SSC meeting was also achieved from Future Earth. In addition leftover money from IGBP and IGBP/ESA were received making 2016 a quite good financial year. If no extra funds are achieved for 2017, the IMBER program and WG activities must be reduced significantly. A proposal through SCOR was sent to NASA for a new grant that supports activities of the HDWG, ESSAS and the SIOA, + extra support to the IMBER/CLIVAR Upwelling Group. There are signals that the NASA proposal will be approved. A European Cost Action proposal is planned to be submitted in 2016. Ideally an additional 100K USD per annum sponsorship would enable us to do all the new things, as well as continuing the on-going work. There are currently no funds available to allow us to increase IMBER's visibility, so activities to raise the profile of IMBER have to be cost-neutral for the time being.

Some activities may be reduced in 2016, and related funds are requested to be transferred to 2017.