SCOR Working Group Proposal

Title: **Designing a biological observing system in the Southern Ocean to inform global ocean observing of marine ecosystems.**

Acronym: **SO-eEOV WG**

Summary/Abstract

Sustained biological observing of marine ecosystems is necessary for developing realistic scenarios of change in species, foodwebs and ecosystems and the attribution of change to their causes. This capability is essential for ecosystem-based management and for developing mitigation and/or adaptation strategies in the long-term. Investment in sustained biological observations requires demonstration that those observations are likely to contribute to detection and/or attribution of change. Current work in the Global Ocean Observing System (GOOS) and the Southern Ocean Observing System (SOOS) has identified many candidate 'ecosystem Essential Ocean Variables' (eEOVs) for long term observations. The comparative simplicity of the Southern Ocean ecosystem and the small number of human pressures compared to elsewhere makes this a useful experimental system for informing the development of biological observing for other more impacted and complex regions. This Working Group will significantly contribute to science of marine ecosystems by designing field programs to acquire data necessary to make scenarios of their dynamics realistic. It will do this by developing tools, procedures and experience from the Southern Ocean; specifically it will (1) assess whether candidate eEOVs will correctly indicate dynamics and/or change in ecosystems of the Southern Ocean, taking into account the potential confounding effects of fishing and global change, (2) evaluate the spatial and temporal sampling requirements, and their concomitant costs, of field observations needed to robustly estimate the candidate eEOVs in the Southern Ocean, and (3) disseminate the tools, framework and outcomes for supporting the design of ecosystem observing systems.

Scientific Background and Rationale

Realistic scenarios of change are a major challenge for marine science (see IPCC Working Group II Assessment Review 5, 2014), making it difficult to place research on the ecology of marine ecosystems in a realistic regional and/or global context. Knowledge of the magnitude and rate at which marine ecosystems are changing is fundamentally important for managing human activities that may affect ecosystem services (e.g., Millennium Ecosystem Assessment, 2005), either through short-term tactical adjustments to keep them sustainable, such as in fishing, or in strategic long-term planning for mitigation or adaptation to long-term change, as for managing climate change. Currently available indicators relate to the physical environment or, for biology, only particular aspects of the ecosystem, such as biogeochemistry or foodweb components affected by fishing (Shin and Shannon 2010).

Assessing biological change requires a sufficiently long time series that allows differentiation of change from natural variability. To date ecosystem indicators have been derived opportunistically from available datasets (e.g., Coll *et al.*, 2009; Cury & Christensen, 2005; Perry *et al.*, 2010). This work suggests that indicators need to be better designed for correctly detecting change and that the observation system needs to be capable of detecting change when it occurs (Constable, 2011; Perry *et al.*, 2010).

The development of sustained biological observing programs for marine ecosystems has received much attention since the Ocean Observing conference in 2009 that led to the Framework on Ocean Observing (FOO; Lindstrom *et al.*, 2012), with activities in the Global Ocean Observing System (GOOS)(First Technical Expert Workshop for the GOOS Biology and Ecosystem, and GOOS Biogeochemistry Panels, November 2013, Townsville, Australia), GOOS Deep Ocean Observing System, and Group on Earth Observations Biodiversity Observation Network (GEOBON). These activities and the recent workshop sponsored by the ICSU, SCOR and SCAR and the Southern Ocean Observing System (SOOS) held at Rutgers University in March 2014 (Constable *et al.*, 2014; hereafter termed 'the Rutgers worskhop') have identified biological variables that could be candidates for being 'ecosystem Essential Ocean Variables' as intended under FOO (Constable *et al.*, 2014). A key challenge that has not been resolved by any biological observing system is to demonstrate which candidate eEOVs need to be given priority for investment in the long-term, i.e. that their state of readiness is mature (sensu Lindstrom *et al.*, 2012). It is widely recognised that the state of readiness of many, if not most, biological variables is currently at the conceptual or pilot stage rather than mature.

An important task is to establish observing systems that can detect change. A second task is to establish and identify those observations that will enable attribution of change to specific causes, probably with the assistance of models. In this case, long-term measurements will be needed to make the dynamics of these models realistic, so that the relative importance of different drivers can be correctly interpreted. A third task is to take measurements that help combine historical datasets, thereby facilitating historical reconstructions to better understand current status and trends of key species and the ecosystem overall.

The set of field measurements to be taken in a biological observing system need to contribute to estimating eEOVs that will further these three tasks; eEOVs have been further defined at the Rutgers Workshop as essential biological or ecological quantities that reflect ecosystem properties – primary productivity, food web productivity, abundance, diversity, energy transfer and global and regional human pressures (Constable *et al.*, 2014). How can the maturity of an eEOV be judged in advance of its long-term implementation?

For the first task on 'detecting change', candidate eEOVs need field measurements that enable signals of change to be detectable above the variability of the system and the noise of measurement error. In this case, datasets that indicate spatial and temporal variation in measurements can be used as a foundation for evaluating two attributes of the eEOVs. The first attribute is whether the eEOV is likely to give a clear signal related to the possible drivers of change, such as whether a change in krill predator reproductive performance can be clearly attributed to change in the abundance of krill (de la Mare & Constable, 2000). Current uncertainties in ecosystem structure and dynamics may mean that differences in the eEOV over time may be difficult to interpret. The second attribute is whether the field sampling design is feasible in space and time to unambiguously yield the expected signal above the background variability. The inclusion of a candidate eEOV in the observing system will be contingent on the quality (interpretation) of the signal and the cost of obtaining that signal.

The second task is to provide measurements that will facilitate tuning models to be realistic in order to investigate change in unmeasurable parts of the system and the attribution of change to particular drivers. In this case, eEOVs do not necessarily need to detect change but provide the foundation for ensuring the dynamics of the model, in terms of the ecosystem properties identified above, are realistic. Sufficient representative (not all) eEOVs at critical times and locations will be needed to capture the dynamic properties of the ecosystem, including the covariance of different components of the system.

Historical datasets may include some eEOVs that will enable ecosystem reconstruction from these datasets. The third task, will be to capture the covariance between critical ecosystem properties and such historical datasets. This covariance will enable hindcasting of ecosystem models by estimating the historical ecosystem properties from these historical time series.

For many candidate eEOVs, field data that demonstrate their variability in space and time already exist. These eEOVs could be progressed to maturity if the requirements for the spatial and temporal design of the field measurements can be evaluated and tested. Data for the eEOVs, synoptic data, such as satellite and ocean model data, and ecosystem simulations can be used to determine how well the candidate eEOVs will generate unambiguous signals for ecosystem properties (change, ecosystem dynamics or covariance with historical datasets) and the cost to deliver those signals.

A SCOR Working Group in collaboration with other international groups, including the IMBER program's Integrating Climate and Ecosystem Dynamics (ICED) in the Southern Ocean, the Southern Ocean Observing System (SOOS), and the Global Ocean Observing System (GOOS), will provide an important vehicle to bring together the international scientific community to evaluate the readiness of candidate eEOVs in advance of their implementation, the latter of which will require long-term commitment and investment in sustained biological observations. The relative simplicity of the Southern Ocean ecosystem and the small number of current human pressures compared to elsewhere makes this a useful experimental system for informing the development of biological observing in other more complicated regions. Furthermore, compared to other global oceans, all regional human pressures in the Southern Ocean are reported, measured and managed through the regulatory bodies. Moreover, considerable progress has been achieved in developing individual methods for sampling Southern Ocean ecosystems (Agnew, 1997; Rintoul *et al.*, 2011) and for modelling these ecosystems (Murphy *et al.*, 2012). A large body of experience is available for assessing change in many marine ecosystems (Perry *et al.*, 2010; Shin & Shannon, 2010). Together, this experience can be harnessed to evaluate the readiness of candidate eEOVs (signal and the cost of field implementation) in the Southern Ocean Observing System. The procedures and results of this work can then inform the development of eEOVs in the GOOS and other observing systems, including organisations developing methods to assess the state of marine ecosystems.

Terms of Reference

The proposed Working Group will:

1. Assess whether candidate 'ecosystem Essential Ocean Variables' (eEOVs) will contribute to making ecosystem scenarios realistic by reliably indicating dynamics and/or change in ecosystems of the Southern Ocean, taking into account the potential confounding effects of fishing and global change.
2. Evaluate the sampling requirements in space and time, and their concomitant costs, of field observations needed to robustly estimate the candidate eEOVs in the Southern Ocean.
3. Disseminate the tools, framework and outcomes for supporting the design of ecosystem observing systems.

Working plan

The Terms of References will be achieved between 2015 and 2017, through coordinated modelling work and data analysis, workshops in South Africa (November 2015) and in the Republic of Korea (November 2016), and a larger symposium to be hosted in China to facilitate greater community involvement (September 2017).

Milestone 1: Assessment of the reliability of candidate eEOVs to indicate ecosystem dynamics and/or change in Southern Ocean ecosystems (November 2015).

Prognoses for change in Southern Ocean ecosystems have been summarised in Constable *et al*. (in press) and Nymand-Larsen *et al*. (2014). The IMBER Program ICED has developed models to represent these ecosystems (Murphy *et al.*, 2012) and determined future scenarios for investigating climate change impacts on the Southern Ocean (Cavanagh *et al*., in prep). The models and scenarios will be used to assess the degree to which uncertainty in ecosystem structure and dynamics may affect signals from candidate eEOVs in the future.

Candidate eEOVs will be those derived from the Rutgers Workshop on eEOVs in the Southern Ocean (Constable *et al.*, 2014); approximately 25 eEOVs have been identified, including those related to the CCAMLR Ecosystem Monitoring Program, to measure change in krill and krill predators, and for estimating the dynamics and trends in Southern Ocean food webs under climate change scenarios. eEOVs identified by GOOS will also be considered.

Work to assess the performance of candidate eEOVs will involve fine-tuning the models to achieve this task as well as developing appropriate metrics of ecosystem states and eEOVs, including methods to visualise and simplify potentially complex results, the latter of which are not currently available. The Working Group will monitor progress quarterly and provide feedback to expert teams established for different sectors of the Southern Ocean, in order to account for regional differences in the ecosystem.

Results will be integrated at the 2015 workshop with the aim of establishing which eEOVs could be classed as having *pilot* readiness, i.e. which candidate eEOVs could reliably indicate dynamics and/or change despite uncertainties and/or variability. The Working Group will then publish the tools and experience in the assessment of candidate eEOVs making them available to other researchers developing eEOVs for their marine ecosystems.

Milestone 2: Evaluation of the design and cost of field programs for measuring the pilot eEOVs (November 2017).

Realistic options for field designs will be determined by using existing data to characterise pilot eEOVs, including time series of *in situ* variables (west Antarctic Peninsula, Scotia Sea), satellite products and model re-analyses. These data and statistical analyses will be used to determine alternative spatial and temporal field sampling designs for measurements underpinning those eEOVs. These methods have not yet been developed for foodwebs and will be an important output of this Working Group. The approach will be discussed at the first workshop and will be undertaken over Year 2 of the Working Group.

A realistic design will need to take adequate account of the spatial and temporal variability that is likely to occur with field measurements. This work will identify the tradeoffs between the cost of the field design and the signal derived for the eEOV.

Prior to the next step, the ecosystem models will be refined so that they can report simulated field observations to support the eEOVs at realistic biological, spatial and temporal scales as well as incorporating possible measurement errors given the field conditions and methods. Methods to downscale ecosystem models to the level of field measurements will be developed in Year 2.

Next, ecosystem simulations of the future scenarios will be used to evaluate the performance and cost of the candidate field designs in the long-term. Performance of the eEOV in these simulations will be judged by how well the eEOV (estimated from the simulated measurements) compares to the actual quantity in the simulated ecosystem. This approach is similar to methods used to evaluate fisheries management strategies (Constable, 2011). These simulations will be used to optimise the quality of the signal relative to the cost of the field program for estimating the eEOVs into the future. The results will be used to determine which eEOVs are feasible and whether they could be regarded as mature and thus be included in the biological observing system. This work will be undertaken over Years 2 and 3.

The workshop in November 2016 will review progress and finalise papers from Milestone 1 and the first part of Milestone 2. This workshop will also be a major planning meeting for the symposium in September 2017, which will review all the outcomes of Milestone 2 and disseminate the experience and results.

Milestone 3: Develop an implementation plan for eEOVs determined to be at a mature stage of readiness and disseminate the experience, tools and products from the work of the Working Group (November 2017).

A Symposium on ’eEOVs and the design of biological observing systems’ will be held in September 2017 to share the experience of this Working Group and to finalise an implementation plan for eEOVs for the Southern Ocean Observing System. The state of readiness of the other candidate eEOVs will be reviewed and advice provided on how they might be progressed to maturity. This symposium will have broad participation, which will include presentations on related works, along with a presentation of the candidate eEOVs and the associated design for field implementation of those eEOVs the working group regarded as mature. This symposium is designed to build capacity in biological ocean observing by bringing together experts involved in the work of this Working Group as well as from other national and international marine biological observing initiatives, particularly GOOS.

Deliverables

The third term of reference aims to provide outputs that are useful to other bodies who are also designing marine biological observing systems. These outputs will include:

i) ecosystem models used for evaluating whether signals (dynamics and/or change) arising from eEOVs will be robust to uncertainties in ecosystem structure and function;
ii) statistical methods developed for estimating eEOVs from field observations;
iii) tools and methods for utilising satellite and model data to evaluate the variability in estimates of eEOVs;
iv) methods and routines for downscaling large-scale ecosystem models to report on simulated measurements from the observing system;
v) a final report and consequent scientific publications in an open access journal on the evaluated performance of eEOVs for Southern Ocean ecosystems and their advantages (signal, sampling efficiencies) and disadvantages (cost of sampling, variability/noise); and
vi) an implementation plan for the biological theme of the SOOS.

These products will be made available to GOOS, IMBER, CCAMLR and other organisations interested in developing ecosystem observing systems, as well as to the general scientific community, through the SOOS website (www.soos.aq) and Southern Ocean Knowledge and Information wiki (www.soki.aq). Progress reports and product announcements will also be published regularly through the online SOOS newsletter, to ensure dissemination to the greater ocean observing community.

Capacity Building

An established need in marine ecosystem research is the capability for statistical and dynamic modelling of marine ecosystems. This Working Group will link key expert groups in both Southern Ocean and global ecosystem modelling to enhance existing capability to make ecosystem models realistic and useful for evaluating the design of field programs. The Working Group also has four full Members from developing nations that will provide important opportunities for building capacity in marine ecosystem modelling and approaches to the development of efficient sustained biological observing systems that could be applied to their local situations. In addition to this, the uptake by developing nations of consistent field sampling plans will help their observing efforts gain more leverage internationally, and have greater scientific and societal impact. Both workshops and the Symposium will be held in developing nations, which will further the sharing of skills and building partnerships between research groups in developed and developing nations. The Symposium is also intended to be an open event, and additional funds will be sought to support the attendance of developing country scientists where possible.

The expert groups for each milestone and Southern Ocean region will provide opportunities to build teams of researchers and post-graduate students around each combination of milestone and region. Support for these teams will be provided through ICED, CLIOTOP, SOOS and SCAR. This increased capability will further the objectives of IMBER and the Future Earth program. This Working Group will also contribute to an improved capability for evaluating climate change impacts on ecosystems and will be timely for the sixth assessment review by the IPCC.

SCOR will be approached for extra funding to involve additional developing country scientists in working group activities, beyond those who are Full members of the working group.

Working Group composition

This Working Group requires expertise in observing marine ecosystems, ecosystem modelling and statistics. The Working Group is designed to provide this expertise while achieving the desired discipline, geographical and gender balances. It has an emphasis on building capacity in developing nations in marine ecosystem research and observing.

Full Members

Name	Gender	Place of work	Expertise relevant to proposal
1 Parli Bhaskar	Male	National Center for Antarctic and Ocean Research, India	Microbial ecology, biogeochemistry, Field and Laboratory studies. SOOS
2 Andrew Constable (co-chair)	Male	Australian Antarctic Division, Australia	Modelling, theoretical ecology, field observing. SOOS, ICED, CCAMLR
3 Dan Costa (co-chair)	Male	University of California Santa Cruz, USA	Marine mammal/bird ecology and bioenergetics, field observing measurements. SOOS, ICED, CLIOTOP
4 Katja Fennel	Female	Dalhousie University, Canada	Biogeochemistry, modelling. GOOS, OTN, IMBER
5 Beth Fulton	Female	CSIRO, Australia	End-to-end ecosystem modelling, theoretical ecology, field observing. PICES
6 Eileen Hofmann	Female	Old Dominion University, USA	Biophysical modelling. IMBER, ICED
7 Xianshi Jin	Male	Yellow Sea Fisheries Research Institute, China	Ecosystems/fisheries ecology, Field observing. PICES Fishery Science Committee
8 Olivier Maury	Male	University of Cape Town, South Africa	Ecosystem modelling. ICED, CLIOTOP
9 Monica Muelbert	Female	Universidade Federal do Rio Grande, Brazil	Habitat and population ecology, field observing. IWC, SORP, CLIOTOP
10 Yunne-Jai Shin	Female	Institut de Recherche pour le Développement, France	Ecosystem modelling, ecosystem indicators. IndiSeas Co-convenor

Associate Member

Name	Gender	Place of work	Expertise relevant to proposal
1 Sanae Chiba	Female	Japan Agency for Marine-Earth Science and Technology, Japan	SAHFOS, North Pacific ecosystems
2 Simon Jennings	Male	Centre for Environment, Fisheries and Aquaculture Science, UK	Ecosystem observing, fisheries, macroecology, survey design, indicators, food webs. ICES
3 Bettina Meyer	Female	Alfred Wegner Institute, Germany	Krill observations, systems ecology, Weddell Sea. CCAMLR
4 Eugene Murphy	Male	British Antarctic Survey, UK	Scotia Arc, Ecosystem observing, theoretical ecology, modelling. ICED.
5 Olav Rune Godoe	Male	Institute of Marine Research, Norway	Acoustic observations, ecosystem ecology, Scotia Arc, CCAMLR
6 Ian Salter	Male	University of Bremen, Germany	Microbial ecology, biogeochemical time-series. GOOS-DOOS, SOMLIT
7 Oscar Schofield	Male	Rutgers University, USA	Ecosystem observing, Palmer LTER. SOOS
8 Hung-Chul Shin	Male	KOPRI, Republic of Korea	Southern Ocean ecosystem ecology, CCAMLR
9 Sandy Thomalla	Female	CSIR, Republic of South Africa	Oceanography, Biogeochemistry, ocean observing. SOCCO
10 George Watters	Male	AMLR Program USA	Ecosystem observing, modelling. US AMLR, CCAMLR

Acronyms:

CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources)
CLIOTOP (IMBER - Climate Impacts on Oceanic Top Predators)
GOOS-DOOS (GOOS Deep Ocean Observing System)
ICED (IMBER - Integrating Climate and Ecosystem Dynamics in the Southern Ocean)
ICES (International Council for the Exploration of the Sea)
IMBER (Integrated Marine Biogeochemistry and Ecosystem Research)

IWC (International Whaling Commission)
LTER (Long Term Ecological Research)
OTN (Ocean Tracking Network)
PICES (North Pacific Marine Science Organisation)
SAHFOS CPR (Sir Alistair Hardy Foundation for Ocean Science)
SOCCO (Southern Ocean Carbon and Climate Observatory)
SORP (Southern Ocean Research Partnership of the IWC)
SSC (Science Steering Committee)
US-AMLR (USA program on Antarctic Marine Living Resources)

Working Group contributions

Parli Bhaskar has background in microbial processes and food-web dynamics (especially the microbial loop), in the Indian and Southern Oceans. He will contribute to field standardisation, evaluation and implementation of candidate eEOVs at lower trophic levels.

Andrew Constable (co-chair) is a theoretical ecologist using ecosystem models to assess the effects of climate change and fisheries on Southern Ocean ecosystems and is Vice-chair (Biology) of SOOS SSC. He will use his models and statistics to help standardise and evaluate eEOVs.

Dan Costa (co-chair) has extensive experience on the foraging ecology and movement of top predators in the Southern Ocean and the North Pacific and Bering Sea, is on the SCAR Expert Group on Birds and Marine Mammals, and SOOS, ICED and CLIOTOP SSCs. He has pioneered the use of animals to obtain oceanographic measurements and will provide expertise in obtaining data from animals about their movement and environment.

Katja Fennel has expertise in regional coupled physical-biological modelling and assimilation of biological and biogeochemical data. She will focus on modelling of ecosystem processes at lower trophic levels (i.e. phytoplankton and zooplankton dynamics), assimilation of observations and evaluation of observing system design.

Beth Fulton has extensive global experience in whole-system modelling (developer of Atlantis), leading teams to evaluate management and monitoring/observing strategies in marine ecosystems around the world. She and her team will use end-to-end ecosystem models to test the theoretical performance of different eEOVs and indicators and explore the information costs and benefits of alternative monitoring schemes.

Eileen Hofmann brings experience in modelling physical-biological interactions in marine ecosystems, with particular focus on the Southern Ocean and is Chair of the IMBER SSC and co-convenor of ICED SSC. She will contribute expertise on identifying eEOVs that are needed for development, calibration and evaluation using marine ecosystem models constructed for Southern Ocean systems.

Xianshi Jin is an expert in the ecology of ecosystems, including variability of ecosystem structure and high trophic level dynamics. He will contribute to the standardisation of eEOVs and their measurement, including field evaluations and implementation of eEOVs at high trophic levels.

Olivier Maury is on the CLIOTOP SSC and has worked to assess climate change impacts on top predators, particularly through development of size-based food web models (APECOSM). He will adapt APECOSM to the Southern Ocean to undertake simulation experiments to identify which variables would be critical to observe to characterise ecosystem variability, and to assess eEOVs on whether they properly characterise ecosystem states.

Monica Muelbert is on the SCAR Expert Group on Birds and Marine Mammals and is a key investigator in Brazil on tracking of marine mammals. She will provide the working group with expertise in population dynamics, genetics and tracking of higher predators in South America.

Yunne-Jai Shin is an IndiSeas co-convenor with end-to-end ecosystem modelling expertise (developer of OSMOSE) as well as expertise in the analysis of ecosystem indicators. She will use her ecosystem models to test the theoretical performance of different eEOVs, as well as the development of methods to analyse eEOVs from field data.

Relationship to other international programs and SCOR Working groups

This topic is of fundamental theoretical importance to marine science as well as management, which are key goals for SCOR. SCOR already has experience in providing leadership in the development of indicators through its Working Group 119 (Cury & Christensen, 2005), which provided foundations for further work on fisheries indicators, e.g. IndiSeas (Shin & Shannon, 2010) and PICES (Perry *et al.*, 2010), and Working Group 125, which considered trends in zooplankton. Also, SCOR has current working groups considering time series of phytoplankton (Working Group 137) and methods for developing time series of the chemical environment (Working Group 143), which together will provide important inputs to whole-ecosystem indicators and monitoring. The involvement of SCOR will provide the impetus for engaging with the wider community on this issue, including scientists from academic and government institutions as well as young researchers and those from developing countries.

Marine ecosystem management will require indicators of the underlying status of marine ecosystems and how they may be changing, such as is highlighted by the UN World Oceans Assessment whose first assessment is scheduled to be delivered in 2014 (the Regular Process for global reporting and assessment of the state of the marine environment, including socieconomic aspects, St. Aimee & Sauvé, 2011). Marine ecosystem indicators will also inform the science for assessment cycles of the emerging Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), as a parallel to the IPCC. However, development of such indicators is not far advanced, particularly whole-ecosystem indicators. Experts involved in these panels have become involved in discussions on eEOVs prior to the Rutgers workshop and will be engaged with the process of their evaluation.

Recent attention to the development of field programs to measure change on large ecosystem scales has recognised deficiencies in understanding what biological parameters may be routinely measured to provide effective indication of the trajectories of change of those ecosystems (Murphy *et al.*, 2008; Rintoul *et al.*, 2011). In particular, there is a growing recognition of the need to measure the background state of ecosystems to facilitate interpretation of indicators from fisheries, for example, the IndiSeas Working Group of the Eur-Oceans Network of Excellence (Shin & Shannon, 2010), the North Pacific Marine Science Organization (PICES) assessment of the North Pacific marine ecosystem status (Jamieson *et al.*, 2010), and in the Scientific Committee for the Conservation of Antarctic Marine Living Resources (SC-CAMLR) (SC-CAMLR, 2011). The delivery of biological observing systems and support modelling and statistical tools relevant to these organisations has been a focus of GOOS, GEOBON and SOOS, ICED, SCAR, and IMBER amongst others. Products arising from this Working Group will be provided to all these organisations through the Working Group Members that participate in these respective bodies.

Key References

Agnew D.J. 1997. The CCAMLR ecosystem monitoring programme. Antarctic Science, 9: 235-242.

Coll M., et al. 2009. Ranking the ecological relative status of exploited marine ecosystems. ICES J. Marine Science, 67: 769–786.

Constable A.J. 2011. Lessons from CCAMLR on the implementation of the ecosystem approach to managing fisheries. Fish and Fisheries, 10.1111/j.1467-2979.2011.00410.x.

Constable A.J., et al. 2014. Outcomes and context for future work from the Workshop on ecosystem Essential Ocean Variables (eEOVs) for the Southern Ocean. Rutgers University, New Brunswick, USA, 18-21 March 2014. 31 pp.

Constable A.J., et al. In press. Climate change and Southern Ocean ecosystems I: How changes in physical habitats directly affect marine biota. Global Change Biology.

Cury P.M., Christensen V. 2005. Quantitative Ecosystem Indicators for Fisheries Management. ICES J. Marine Science, 62: 307-310.

de la Mare W.K., Constable A.J. 2000. Utilising data from ecosystem monitoring for managing fisheries: development of statistical summaries of indices arising from the CCAMLR Ecosystem Monitoring Program. CCAMLR Science, 7: 101-117.

Jamieson G., et al. (eds). 2010. Report of Working Group 19 on Ecosystem-based Management Science and its Application to the North Pacific. PICES Scientific Report No. 37, Sidney, BC, Canada.

Lindstrom E., et al. 2012. A Framework for Ocean Observing: prepared by the Task Team for an Integrated Framework for Sustained Ocean Observing (IFSOO). (Report IOC/INF-1284 rev.). pp 28, UNESCO.

Melbourne-Thomas J., et al. 2013. Testing paradigms of ecosystem change under climate warming in Antarctica. PLoS ONE, 8: e55093.

Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-being: Biodiversity Synthesis, World Resources Institute.

Murphy E.J., et al. 2012. Developing integrated models of Southern Ocean food webs: Including ecological complexity, accounting for uncertainty and the importance of scale. Prog. Oceanography, 102: 74-92.

Murphy E.J., et al. 2008. Integrating Climate and Ecosystem Dynamics in the Southern Ocean: A Circumpolar Ecosystem Program: Science Plan and Implementation Strategy. GLOBEC Report No. 26, IMBER Report No. 2.

Nymand-Larsen J., et al. 2014. Chapter 28 Polar Regions. In: Working Group II Contribution to the IPCC Fifth Assessment Report (AR5). (eds Field C, Barros V). San Francisco, USA.

Perry R.I., et al. 2010. Ecosystem Indicators. In: Report of Working Group 19 on Ecosystem-based Management Science and its Application to the North Pacific. PICES Scientific Report No. 37. pp 83-89.

Rintoul S., et al. 2011. The Southern Ocean Observing System: initial science and implementation strategy, SCAR-SCOR.

SC-CAMLR. 2011. Report of the thirtieth meeting of the Scientific Committee (SC-CAMLR XXX), Annex 4, Report of the Working Group on Ecosystem Monitoring and Management. Hobart, Australia.

Shin Y-J, Shannon L.J. 2010. Using indicators for evaluating, comparing and communicating the ecological status of exploited marine ecosystems. 1. The IndiSeas project. ICES J. Marine Science, 67: 686–691.

St. Aimee D.K., Sauvé R. 2011. Report on the work of the Ad Hoc Working Group of the Whole on the Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socio-economic Aspects. 66th Session of the United Nations General Assembly, UN.

Appendix

Parli Bhaskar

BHASKAR P.V. et al. 2011. Identification of non-indigenous phytoplankton species dominated bloom off Goa using inverted microscopy and pigment (HPLC) analysis. Journal of Earth System Sciences, 120: 1145-1154.

BHASKAR P.V., Bhosle N.B. 2008. Bacterial heterotrophic production and ecto-glucosidase activity in a shallow coastal station off Dona Paula Bay. Estuarine Coastal Shelf Sciences, 80: 413-424.

BHASKAR P.V., Grossart H.P., Bhosle N.B., Simon M. 2005. Production of organic macroaggregates from exopolysaccharides of bacterial and diatom origin. FEMS Microbiology Ecology, 53: 255-264.

BHASKAR P.V., Cardozo E., Giriyan A., Garg A., Bhosle N.B. 2000. Sedimentation of particulate matter in the Dona Paula Bay, west coast of India during November to May 1995-97. Estuaries, 23: 722-734.

Andrew Constable

Murphy E.J., Cavanagh R.D., Hofmann E.E., Hill S.L., CONSTABLE A.J., Costa D.P., Pinkerton M.H., Johnston N.M., Trathan P.N., Klinck J.M., Wolf-Gladrow D.A., Daly K.L., Maury O., Doney S.C. 2012. Developing integrated models of Southern Ocean food webs: Including ecological complexity, accounting for uncertainty and the importance of scale. *Progress in Oceanography*, 102: 74-92.

Melbourne-Thomas J., CONSTABLE A., Wotherspoon S., Raymond B. 2013. Testing paradigms of ecosystem change under climate warming in Antarctica. *PLoS ONE,* 8(2): e55093.

Kawaguchi S., Ishida A., King R., Raymond B., Waller N., CONSTABLE A., Nicol S., Wakita M., Ishimatsu A. 2013. Risk maps for Antarctic krill under projected Southern Ocean acidification. *Nature Climate Change*, 10.1038/nclimate1937.

Nymand-Larsen J., Anisomov O.A., CONSTABLE A., Hollowed A., Maynard N., Prestrud P., Prowse T., Stone J. 2014. Chapter 28 Polar Regions, In: Field, C., Barros, V. (eds) Working Group II Contribution to the IPCC Fifth Assessment Report (AR5), IPCC.

CONSTABLE A.J., Melbourne-Thomas J., Corney S.P. *et al*. In press. Climate change and Southern Ocean ecosystems I: How changes in physical habitats directly affect marine biota. *Global Change Biology*.

Dan Costa (co-chair)

Roquet F., Wunsch C., Forget G., Heimbach P., Guinet C., Reverdin G., Charrassin J.-B., Bailleul F., COSTA D.P., Huckstadt L.A., Goetz K.T., Kovacs K.M., Lydersen C., Biuw M., Nøst O.A., Bornemann H., Ploetz J., Bester M.N., McIntyre T., Muelbert M.C., Hindell M.A., McMahon C.R., Williams G., Harcourt R., Field I.C., Chafik L., Nicholls K.W., Boehme L., Fedak M.A. 2013. Estimates of the Southern Ocean general circulation improved by animal-borne instruments. Geophysical Research Letters, 40: 6176-6180.

Hazen E. L., Jorgensen S., Rykaczewski R.R., Bograd S.J., Foley D.G., Jonsen I.D., Shaffer S.A., Dunne J.P., COSTA D.P., Crowder L.B., Block B.A. 2012. Predicted habitat shifts of Pacific top predators in a changing climate. Nature Clim. Change, 3: 234–238. doi:10.1038/nclimate1686.

COSTA D. P., Breed G.A., Robinson P.W. 2012. New Insights into Pelagic Migrations: Implications for Ecology and Conservation. Annual Review of Ecology, Evolution, and Systematics, 43: 73-96.

Steinberg, D.K., Martinson D.G., COSTA D.P. 2012. Two decades of pelagic ecology of the Western Antarctic Peninsula. Oceanography, 25: 56-67.

COSTA, D. P., Huckstadt L.A., Crocker D.E., McDonald B.I., Goebel M.E., Fedak M.A. 2010a. Approaches to Studying Climatic Change and its Role on the Habitat Selection of Antarctic Pinnipeds. Integrative and Comparative Biology, 50: 1018-1030.

Katja Fennel

Ibarra D., FENNEL K., Cullen J. 2014. Coupling 3-D Eulerian bio-physics (ROMS) with individual-based shellfish ecophysiology (SHELL-E): A hybrid model for carrying capacity and environmental impacts of bivalve aquaculture. Ecological Modelling, 273: 63-78.

FENNEL K., Hu J., Laurent A., Marta-Almeida M., Hetland R. 2013. Sensitivity of hypoxia predictions for the Northern Gulf of Mexico to sediment oxygen consumption and model nesting. Journal of Geophysical Research-Oceans, 118: 990-1002. doi:10.1002/jgrc.20077.

Mattern J.P., FENNEL K., Dowd M. 2012. Estimating time-dependent parameters for a biological ocean model using an emulator approach. Journal of Marine Systems, 96-97: 32-47.

Hu J., FENNEL K., Mattern J.P., Wilkin J. 2012. Data Assimilation with a local Ensemble Kalman filter applied to a three-dimensional biological model of the Middle Atlantic Bight. Journal of Marine Systems, 94: 145-156.

Bagniewski W., FENNEL K., Perry M.J., D'Asaro E.A. 2011. Optimizing models of the North Atlantic spring bloom using physical, chemical and bio-optical observations from a Lagrangian float. Biogeosciences, 8: 1291-1307. doi:10.5194/bg-8-1291-2011.

Beth Fulton

FULTON E.A., Smith A.D.M., Punt A.E. 2005. Which ecological indicators can robustly detect effects of fishing? ICES Journal of Marine Science, 62: 540 – 551.

Shin Y.-J., Bundy A., Shannon L., Simier M., Coll M., FULTON E.A., Link J.S., Jouffre D., Ojaveer H., Mackinson S., Heymans J.J., Raid, T. 2010. Can simple be useful and reliable? Using ecological indicators for representing and comparing the states of marine ecosystems. ICES Journal of Marine Science, 67: 717-731.

Smith A.D.M., FULTON E.A., Hobday A.J., Smith D.C., Shoulder P. 2007. Scientific tools to support practical implementation of ecosystem based fisheries management. ICES Journal of Marine Science, 64: 633 – 639.

Branch T.A., Watson R., FULTON E.A., Jennings S., McGilliard C.R., Pablico G.T., Ricard D., Tracey S.R. 2010. The trophic fingerprint of marine fisheries. Nature, 468: 431-435.

Worm B., Hilborn R., Baum J., Branch T., Collie J., Costello C., Fogarty M., FULTON E.A., Hutchings J., Jennings S., Jensen O., Lotze H., Mace P., McClanahan T., Minto C., Palumbi S., Parma A., Ricard D., Rosenberg A., Watson R., Zeller D. 2009. Rebuilding global fisheries. Science, 325: 578-585.

Eileen Hofmann

Murphy E.J., Cavanagh R.D., HOFMANN E.E., *et al*. 2012. Developing integrated models of Southern Ocean food webs: including ecological complexity, accounting for uncertainty and the importance of scale. Progress in Oceanography, 102: 74-92.

Murphy E.J., HOFMANN E.E., Watkins J.L., Johnston N.M., Piñones A., Ballerini T., Hill S.L., Trathan P.N., Tarling G.A., Cavanagh R.A., Young E.F., Thorpe S., Fretwell P. 2013. Comparison of the structure and function of Southern Ocean regional ecosystems: the Antarctic Peninsula and South Georgia, Journal of Marine Systems, 109-110: 22-42.

Piñones A., HOFMANN E.E., Daly K.L., Dinniman M.S., Klinck J.M. 2013. Modeling the remote and local connectivity of Antarctic krill (*Euphausia superba*) populations along the western Antarctic Peninsula. Marine Ecology Progress Series, 481: 69-92.

Piñones A., HOFMANN E.E., Daly K.L., Dinniman M.S., Klinck J.M. 2013. Modeling early life stages of Antarctic krill (*Euphausia superba*) in continental shelf environments on the west Antarctic Peninsula. Deep-Sea Research *I*, 82: 17-31.

Ballerini T., HOFMANN E.E., Ainley D.G., Daly K., Marrari M., Ribic C., Smith Jr. W.O., Steele J.H. 2014. The marine food web of the western Antarctic Peninsula continental shelf – Structure and dynamics. Progress in Oceanography, 122: 10-29.

Xianshi Jin

JIN X. 2004. Long-term changes in fish community structure in the Bohai Sea, China. Estuarine Coastal and Shelf Science, 59(1): 163-171.

Xu, B., Jin X. 2005. Variations in fish community structure during winter in the southern Yellow Sea over the period 1985-2002. Fisheries Research, 71(1): 79-91.

JIN X., Zhang B., Xue Y. 2010. The response of the diets of four carnivorous fishes to variations in the Yellow Sea ecosystem. Deep Sea Research II, 57: 996-1000.

Jin X.S., Shan X.J., Li X.S., *et al.* 2013. Long-term changes in the fishery ecosystem structure of Laizhou Bay, China. Sci China Earth Sci, 56(3): 366-374.

Shan X., Sun P., Jin X., Li X., Dai F. 2013. Long-Term Changes in Fish Assemblage Structure in the Yellow River Estuary Ecosystem, China. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 5(1): 65-78.

Olivier Maury

Dueri S, Bopp L., MAURY O. 2014. Projecting the impacts of climate change on skipjack tuna abundance and spatial distribution. Global Change Biology, DOI: 10.1111/gcb.12460.

MAURY O., Poggiale J.-C. 2013. From individuals to populations to communities: a Dynamic Energy Budget model of marine ecosystem size-spectrum including life history diversity. Journal of Theoretical Biology, 324: 52–71.

Handegard N.O., du Buisson L., Brehmer P., Chalmers S. J., De Robertis A., Huse G., Kloser R., Macaulay G., MAURY O., Ressler P. H., Stenseth N. C., Godø O. R. 2013. Towards an acoustic-based coupled observation and modelling system for monitoring and predicting ecosystem dynamics of the open ocean. Fish and Fisheries 14: 605-615.

Dueri S., Faugeras B., MAURY O. 2012. Modelling the skipjack tuna dynamics in the Indian Ocean with APECOSM-E: Part 1. Model formulation. Ecological Modelling, 245: 41-54.

MAURY O. 2010. An overview of APECOSM, a Spatialized Mass Balanced “Apex Predators ECOSystem Model” to Study Physiologically Structured Tuna Population Dynamics in their Ecosystem. In: Parameterisation of Trophic Interactions in Ecosystem Modelling, M. St John, P. Monfray (eds). Prog. Oceanogr. 2010, 84: 113-117.

Monica Muelbert

Roquet F., Wunsch C., Forget G., Heimbach P., Guinet C., Reverdin G., Charrassin J-B, Bailleul F., Costa D.P., Huckstadt L.A., Goetz K.T., Kovacs K.M., Lydersen C., Biuw M., Nøst O.A., Bornemann H., Ploetz J., Bester M.N., McIntyre T., MUELBERT M.C., Hindell M.A., McMahon C.R., Williams G., Harcourt R., Field, I.C., Chafik L., Nicholls K.W., Boehme L., Fedak M.A. 2013. Estimates of the Southern Ocean general circulation improved by animal-borne instruments. Geophysical Research Letters, 40: 6176-6180.

MUELBERT M.C., de Souza R.B., Lewis M.N., Hindell M.A. 2012. Foraging habitats of southern elephant seals, Mirounga leonina, from the Northern Antarctic Peninsula. Deep-Sea Research. Part 2. Tropical Studies in Oceanography, 88-89: 47-60.

Boehme L., Kovacs K., Lydersen C., Nøst O.A., Biuw M., Charrassin J.-B., Roquet F., Guinet C., Meredith M., Nicholls K., Thorpe S., Costa D.P., Block B., Hammill M., Stenson G., MUELBERT M., Bester M.N., Plötz J., Bornemann H., Hindell M., Rintoul S., Lovell P., Fedak M.A. 2010. Biologging in the Global Ocean Observing System In: OceanObs'09 Ocean information for society: sustaining the benefits, realizing the potential, 2010, Veneza. OceanObs09.

Botta S., Secchi E.R. , MUELBERT M.M.C., Danilewicz D., Negri M.F., Cappozzo H.L., Hohn A.A. 2010. Age and growth of franciscana dolphins, Pontoporia blainvillei (Cetacea: Pontoporiidae) incidentally caught off southern Brazil and northern Argentina. Journal of the Marine Biological Association of the United Kingdom, 90: 1493-1500.

Oliveira L.R., Hoffman E., Hingst-Zaher E., Majluf P., MUELBERT M.M.C., Morgante J.S., Amos W. 2008. Morphological and genetic evidence for two evolutionarily significant units (ESUs) in the South American fur seal, *Arctocephalus gazella*. Conservation Genetics, 1: 1.

Yunne-Jai Shin

Shannon L.J., Coll M., Bundy A., Gascuel D., Heymans J.J., Kleisner K., Lynam C.P., Piroddi C., Tam J., Travers M., SHIN Y.-J. 2014. Trophic level-based indicators to track fishing impacts across marine ecosystems. MEPS, in Press.

Travers-Trolet M., SHIN Y.-J., Shannon L.J., Moloney C.L., Field J.G. 2014. Combined fishing and climate forcing in the southern Benguela upwelling ecosystem: an end-to-end modelling approach reveals dampened effects. Plos One, 9(4): e94286.

Bundy A., Coll M., Shannon L.J., SHIN Y.-J. 2012. Global assessments of the status of marine exploited ecosystems and their management: what more is needed? Current Opinion in Environmental Sustainability, 4: 292-299.

SHIN Y.-J., Bundy A., Shannon L.J., Blanchard J.L., Chuenpagdee R., Coll M., Knight B., Lynam C., Piet, G., Richardson A.J., the IndiSeas Working Group 2012. Global in scope and regionally rich: an IndiSeas workshop helps shape the future of marine ecosystem indicators. Reviews in Fish Biology and Fisheries, 22(3): 835-845.

Smith A.D.M., Brown C.J., Bulman C.M., Fulton E.A., Johnson P., Kaplan I.C., Lozano-Montes H., Mackinson S., Marzloff M., Shannon L.J., SHIN Y-J, Tam J. 2011. Impacts of low-trophic level species on marine ecosystems. Science, 333: 1147-1150.