Proposal for a SCOR Working Group to identify Ecosystem Essential Ocean Variables for measuring change in the biological properties of marine ecosystems

Rationale

Indicators of marine ecosystem status have been an important focus of discussion for the last two decades, primarily arising from a need to better understand the impacts of fisheries and to develop indicators of when changes to fishing practices may be needed to retain or restore ecosystem health. Until recently, consideration of the effects of fishing assumed that the global oceans retained largely the same levels of productivity at lower trophic levels and that fisheries were the primary driver of long-term change in the sustainable harvest. Understanding has grown that present and expected changes in ocean climate and acidification could result in altered dynamics of marine ecosystems, which, in turn, will need to be considered when making decisions about how to maintain ecosystem health, services and robustness/resilience to future change. 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 cycle is scheduled by end 2014 (the Regular Process for global reporting and assessment of the state of the marine environment, including socieconomic aspects, St. Aimee and Sauvé 2011; see also UNEP 2007). Marine ecosystem indicators will also inform the science for assessment cycles of the emerging Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES - UNEP 2011) as a parallel to the IPCC. However, development of such indicators is not far advanced, particularly whole-ecosystem indicators.

Recent attention to the development of field programs to measure change on large ecosystem scales has recognized 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, Constable and Doust 2009, 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 and 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). Ocean observing systems are expanding worldwide and need assistance in identifying the biological and ecological variables that should be measured.

A SCOR Working Group in collaboration with other international groups, including the IMBER program's Integrating Climate and Ecosystem Dynamics (ICED) project in the Southern Ocean, the Southern Ocean Observing System (SOOS), and the Global Ocean Observing System (GOOS), will provide the best mechanism to bring together the international scientific community to identify the suite of Ecosystem Essential Ocean Variables (eEOVs) that need to be measured to assess status and change in whole marine ecosystems (here, we refer primarily to neritic and open ocean systems and do not include the interface between land and sea *per se*, although the results will benefit from some input from those specialists). Such variables build on the concept of Essential Ocean Variables for sustained monitoring of the ocean that are a part of the Framework for Ocean Observing developed out of the OceanObs'09 conference (Fischer et al. 2010), which has been adopted by GOOS and is being further developed as part of the EC-funded (2012-14) GEOSS interoperability for Weather, Ocean and Water project. This issue will require consideration of key biological attributes of marine ecosystems that underpin structure and function, how those attributes may be summarized and, in particular, the types of cost-effective measurements that will need to be taken simultaneously to capture those properties. As a result, it will require expertise ranging from ocean observations across the different biota of ecosystems to those with a theoretical understanding of the dynamics of ecosystems and the key drivers of their structure and function. Appropriate scientific expertise must be assembled with respect to the different types of global marine ecosystems. Scientists from

developing nations should be included in the Working Group because of their proximity and experience in many important ecosystems, providing for opportunities to build capacity on this topic.

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 and Christensen 2005), which provided foundations for further work on fisheries indicators (e.g., IndiSeas - Shin and Shannon 2010 - and PICES - Perry et al. 2010). Also, SCOR has current working groups considering time series of phytoplankton (Working Group 137) and zooplankton (Working Group 125), 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.

Scientific Background

The development of ecosystem indicators is now fundamentally important to making statements about the state of the marine environment and, in particular, the rate at which marine ecosystems are changing (Millennium Ecosystem Assessment 2005, IPCC 2007, SC-CAMLR 2011). However, many of the indicators currently available for marine ecosystems relate to the physical environment or, for biology, only particular aspects of the ecosystem, most notably on the effects of fishing. In the latter case, biological indicators may range from size-spectra, trophic dominance and composition of fish communities as well as general attributes such as total biomass in a region (see references cited in Shin and Shannon 2010).

Many reviews of ecosystem indicators declare a need for assessments of whether the structure and function of an ecosystem is changing (e.g., Perry et al. 2010, Shin and Shannon 2010, Constable 2011). Such assessments may not require complete knowledge of exactly which elements have changed, but more to provide assessments that change in, say, primary productivity has occurred. This will enable managers to then alter their strategies to achieve sustainability objectives, for example, to adjust fishery strategies to be consistent with the present levels of productivity in the system.

A common difficulty with assessing change in biological components of marine ecosystems is that a sufficiently long time series of measurements is required in order to appropriately differentiate change from natural variability, which could include spatial and temporal variation in the biota of interest, but also in the natural variation associated with food web dynamics over many years. The identification of whole-ecosystem indicators has been a topic of considerable discussion over the last two decades but most indicators have been derived opportunistically from available datasets (e.g., Cury and Christensen 2005, Pauly et al. 2005, Coll et al. 2009, Perry et al. 2010). The utility of indicators for detecting change and the types of data that will be needed for estimating those indicators would ideally be designed so that important change is correctly detected when management action is required (de la Mare 1998, Perry et al. 2010, Constable 2011).

Essential indicators of the physical marine system are well developed, along with the appropriate interpretation and use in the development and application of models of the physical systems (e.g., (Rintoul et al. 2011). Ecosystem Essential Ocean Variables (eEOVs) that indicate status and change in marine habitats and the biotic components of the ecosystem need to be developed in order to establish field programs concomitant to physical programs in order to begin monitoring and measuring change in marine ecosystems as a whole. The definition of eEOVs will need to balance their importance in monitoring ecosystem status and change, with the feasibility of their sustained measurement based on present and emerging observing technology. The readiness of eEOV observations will need to be assessed, to encourage research efforts aimed at a better ability to sustainably monitor ocean ecosystems.

Considerable progress has been achieved in developing individual methods for sampling marine ecosystems (Agnew 1997, Rintoul et al. 2011). Similarly, a large body of experience for assessing change in many marine ecosystems is now available (Perry et al. 2010, Shin and Shannon 2010). Importantly, this experience can be harnessed to develop cost-effective field designs for implementing

methods to provide data on the eEOVs. Tools are now available for assisting with assessing and evaluating the efficacy of indicators and different spatial and temporal sampling approaches, both qualitatively (Dambacher et al. 2009, Melbourne-Thomas et al. submitted) and quantitatively (Fulton et al. 2005). A coherent plan for measuring indicative changes in marine ecosystems can now be developed on the basis of these advances.

Terms of Reference

The proposed Working Group would

1. **Identify composite indices that could be used to detect and track change in the structure and dynamics of marine ecosystems.** These indicators would be based on current understanding of the key drivers of the structure and function of marine ecosystems. Priorities will be considered relative to different types of ecosystem services.
2. **Determine the Ecosystem Essential Ocean Variables (eEOVs) that would need to be monitored on a sustained basis to produce the composite indices identified in the first term of reference**. This determination will be based on an assessment of the importance of the variable in the context of the indices and the feasibility of sustained monitoring.
3. **Provide advice on the technical requirements for measuring these eEOVs**, including identifying available and emerging measurement methods and technologies, assessing the readiness for sustained monitoring, and, based on ecosystem simulation models and analyses of available datasets, specifying the spatial and temporal requirements for field sampling of the eEOVs.
4. **Report on these outcomes through the development of a Web-based report, as well as a set of review papers submitted to the primary scientific literature on each of the three terms of reference above.**

Working Group activities

Each Term of Reference (ToR) will be developed sequentially. The first term of reference (ToR 1) will be developed as case studies for major marine ecosystems around the world, including all the major oceans and subdivisions, as available, many of which have been considered in relation to fisheries impacts on those ecosystems and possible prognoses for impacts. This compilation is envisaged to rely on existing reviews, particularly in relation to indicators that relate to fisheries impacts. ToRs 1and 2 will use qualitative analytical methods (Melbourne-Thomas et al., submitted) to determine eEOVs for each of the major ecosystems that could underpin the development of assessments of change in those ecosystems.

The Working Group will hold its first meeting in 2013, following an initial compilation of material to satisfy ToR 1. This will be in conjunction with a meeting of ICED experts on food web modeling, which is an important part of considering the first term of reference. At this meeting, a work plan will be developed for undertaking a qualitative assessment of candidate eEOVs, including identification of which case studies have sufficient development of structure, function and the drivers of change to undertake such an assessment for that ecosystem. Also, experts will be identified for participation in the qualitative assessment and for participation in a workshop to clarify, test and decide on the best candidate eEOVs for further investigation.

The Workshop to conclude ToR 2 will be held in 2014, involving the WG and, as available, additional experts to consolidate the outcomes of the qualitative assessment and to provide recommendations for continued work on ToR 3. The Workshop will also consider the tools that need to be used to evaluate candidate eEOVs in terms of field sampling and the costs and benefits of the measurement of those eEOVs for estimating whether the structure and function of an ecosystem has changed. In preparation for the workshop, the WG will coordinate the qualitative assessment of the efficacy of different indicators for assessing change in ecosystems and the identification of potential eEOVs to contribute

to those assessments. It will also coordinate the compilation of candidate field methods for measuring eEOVs and the tools (ecosystem models and analytical tools) that may be available for addressing ToR 3 in assessing the value of those methods in measuring change in different ecosystems. A primary outcome of this workshop will be a contribution to the process for UN Global Ocean Assessments, the second phase of which will begin in 2015.

The WG will, by correspondence, begin planning for a symposium to be held early in 2016. The WG will meet in 2015 to consider preliminary results and progress on ToR 3, and to continue the planning for the symposium in 2016.

The symposium early in 2016 will consider the outcomes the first three terms of reference, as well as invite participation through oral and poster presentations on the measurement of status and change in marine ecosystems. Any results on the first 3 ToRs will be made available to participants prior to the symposium to ensure that the greatest input possible to recommending eEOVs and their implementation. The symposium will provide an opportunity to finalize these outcomes amongst the international community as well as for exchanging views on how to integrate ecosystem studies with the long-term measurement and assessment of eEOVs and change in the status and dynamics of these ecosystems. These outcomes will then contribute to the second phase of the Global Ocean Assessment. The outcomes of the symposium will be published in a special issue of a suitable journal, such as *Deep Sea Research II*. The symposium will not use SCOR funds and if other funds cannot be raised for a symposium, the group will publish a small special issue containing only its own work.

The location of each meeting will be dependent on the costs of travel of the working group to a location. Where possible, the meetings will occur in conjunction with other meetings in order to minimise travel costs. The workshop and symposium are proposed to be in Chile and China to facilitate capacity building on these issues in South America and the western Pacific rim. The final locations will be considered at the first meeting of the Working Group and will depend on cost and feasibility.

A tentative schedule for these tasks is:

2013	Meeting 1	TBA	Review of structure and function of marine ecosystems, beginning planning of WG publications, including a short article for (EOS, PICES/ICES newsletter, or whatever venue is appropriate)
2014	Workshop (Meeting 2)	Chile	Consideration of efficacy of eEOVs for different ecosystems
2015	Meeting 3	TBA	Review of progress on evaluating field designs for eEOVs
2016	Symposium, report & publication	China	Final commentary on each primary ToR and recommendations on eEOVs, including cost-effectiveness of implementation

Working Group Membership

The Working Group membership aims to include ecosystem theoreticians and modelers, as well as observational specialists for different biological levels across the different major marine ecosystems in the world. Where possible it will also maintain a balance between gender, age and the capacity and need of each country to participate in this work. The achievement of this balance will be through invitations for participation in particular tasks. A broader involvement of the international community will be achieved through the general invitation to participate in the discussions at the symposium and to give oral or poster presentations on the topic at the symposium.

The Working Group aims to build capacity, in this emerging field, in developing countries through participation in the Working Group by scientists from Chile (1) and China (2). These scientists will provide important linkages to oceanographic and ecosystem research institutions in their respective regions. Further opportunities for capacity building will be available by holding the workshop and

symposium in these countries. We will be approaching SCOR and other funding agencies for funding to assist scientists from developing countries to participate in these events.

The proposed membership is as follows:

Full Members:

Name	Country	Expertise
Sanae Chiba	Japan	North Pacific ecosystems, zooplankton, ecosystem indicators, Continuous Plankton Recorder, SCOR WG 125
Andrew Constable (Co-Chair)[1]	Australia	Southern Ocean, ecosystems, sampling design, pelagic and benthic sampling, CCAMLR Ecosystem Monitoring Program, SOOS, Southern Ocean Sentinel (IMBER ICED)
Dan Costa (Co-Chair)[2]	USA	North Pacific, Southern Ocean, marine mammals and birds, tracking, SOOS
Philippe Cury	France	Fisheries, indicators, SCOR WG 119, European indicators for ecosystem approach to fisheries.
Sophie Fielding	UK	North Atlantic, Southern Ocean, pelagic sampling, acoustics
Beth Fulton	Australia	All regions, ecosystem modelling & synthesis, ecosystem indicators
Sergio Neira	Chile	South-east Pacific, ecosystem ecology & indicators
Oscar Schofield	USA	Southern Ocean, gliders, Northeast United States, remote sensing, SOOS
Yunne Shin	France	IndiSeas project (representative of coordinating group), OSMOSE modelling (lead)
Xianshi Jin	China	Ecosystem and fisheries ecology, PICES Fishery Science Committee, Yellow Sea/Bohai Sea Large Marine Ecosystem

Co-Chairs:

[1] Dr. Andrew Constable
Leader, Southern Ocean Ecosystems Program, Australian Antarctic Division, Kingston, Australia; &
Leader, Ecosystem Impacts Program, Antarctic Climate and Ecosystems Cooperative Research Centre, Hobart, Australia.
Contact: andrew.constable@aad.gov.au

[2] Dr Daniel Costa
Distinguished Professor of Ecology and Evolutionary Biology, Ida Benson Chair in Ocean Health, Director Marine Vertebrate Physiological Ecology Group, University of California Santa Cruz, CA.
Contact: costa@ucsc.edu

Associate Members:

Name	Country	Expertise
Julia Blanchard	UK	Size-based indicators (lead), IndiSeas, QUEST-Fish
Antje Boetius	Germany	Microbial ecologist, GOOS - Deep Ocean Observing Strategy.
Katja Fennel	Canada	Food web and biogechemical modeling, biological data assimilation techniques
Eileen Hofmann	USA	Atlantic, Southern Ocean, ecosystems, IMBER ICED project (co-leader)

Simon Jennings	UK	Marine ecosystems & fisheries ecology and management, indicators
Rudy Kloser	Australia	Bio-acoustic monitoring, Australian Integrated Marine Observing System, ecosystem indicators.
Jason Link	USA	Atlantic, pelagic biota, indicators
Pat Livingston	USA	Ecosystem ecology and fisheries indicators
Olivier Maury	France	All regions, ecosystems, indicators, IMBER CLIOTOP project
Eugene Murphy	UK	Southern Ocean, ecosystems, IMBER ICED project (co-leader)
Todd O'Brien	USA	SCOR WG 125, 137, data management & synthesis
Tony Smith	Australia	Marine ecosystems, fisheries ecology and management, indicators
Xianyong Zhao	China	North Pacific, Southern Ocean, acoustics, SCOR-China

References

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

Coll, M., L. J. Shannon, D. Yemane, J. S. Link, H. Ojaveer, S. Neira, D. Jouffre, P. Labrosse, J. J. Heymans, E. A. Fulton, and Y.-J. Shin. 2009. Ranking the ecological relative status of exploited marine ecosystems. ICES Journal of 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:DOI: 10.1111/j.1467-2979.2011.00410.x.

Constable, A. J., and S. Doust. 2009. Southern Ocean Sentinel - an international program to asses climate change impacts on marine ecosystems: report of an international workshop, Hobart, April 2009. ACE CRC, Commonwealth of Australia & WWF-Australia.

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

Dambacher, J. M., D. J. Gaughan, M.-J. Rochet, P. A. Rossignol, and V. M. Trenkel. 2009. Qualitative modelling and indicators of exploited ecosystems. Fish and Fisheries **10**:305-322.

de la Mare, W. K. 1998. Tidier fisheries management requires a new MOP (management-oriented paradigm). Reviews in Fish Biology and Fisheries **8**:349-356.

Fischer, A. S., J. Hall, D. E. Harrison, D. Stammer, and J. Benveniste. 2010. Conference Summary - Ocean information for society: sustaining the benefits, realizing the potential. In: Proceedings of OceanObs'09: sustained Ocean Observations and Information for Society (Vol. 1), Venice Italy 21-25 September 2009. ESA Publication WPP-306. doi:10.5270/OceanObs09.Summary.

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

IPCC. 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment. Report of the Intergovernmental Panel on Climate Change. Eds: M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, C.E. Hanson. Cambridge University Press., Cambridge, UK.

Jamieson, G., P. Livingston, and C.-I. Zhang, editors. 2010. Report of Working Group 19 on Ecosystem-based Management Science and its Application to the North Pacific. PICES Scientific Report No. 37. North Pacific Marine Science Organization (PICES), Sidney, BC, Canada.

Melbourne-Thomas, J., S. Wotherspoon, B. Raymond, and A. Constable. submitted. Comprehensive evaluation of model uncertainty in qualitative network analyses.

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

Murphy, E. J., R. D. Cavanagh, N. M. Johnston, K. Reid, and E. E. Hofmann, editors. 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.

Pauly, D., R. Watson, and J. Alder. 2005. Global trends in world fisheries: impacts on marine ecosystems and food security. Philosophical Transactions of the Royal Society B-Biological Sciences **360**:5-12.

Perry, R. I., P. Livingston, and E. A. Fulton. 2010. Ecosystem Indicators. Pages 83-89 *in* G. Jamieson, P. Livingston, and C.-I. Zhang, editors. Report of Working Group 19 on Ecosystem-based Management Science and its Application to the North Pacific. PICES Scientific Report No. 37. North Pacific Marine Science Organization (PICES), Sidney, BC, Canada.

Rintoul, S. R., M. Sparrow, M. P. Meredith, V. Wadley, K. Speer, E. Hofmann, C. Summerhayes, E. Urban, and R. Bellerby, editors. 2011. The Southern Ocean Observing System: Initial Science and Implementation Strategy. SCAR, Cambridge, UK.

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. CCAMLR, Hobart, Australia.

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

St. Aimee, D. K., and R. Sauvé. 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, New York, USA.

UNEP. 2007. Global Marine Assessments: A survey of global and regional assessments and related activities of the marine environment. UNEP/UNESCO-IOC/UNEP-WCMC, Cambridge, UK.

UNEP. 2011. Decisions adopted by the twenty-sixth session of the Governing Council/Global Ministerial Environment Forum. Nairobi, 21-24 February 2011.