IOC/GOOS-Biol-1/1
Paris, July 2014
Original: English

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION
(of UNESCO)

Report of the First Workshop of Technical Experts for the Global Ocean Observing System (GOOS) Biology and Ecosystems Panel: Identifying Ecosystem Essential Ocean Variables (EOVs)

Held at the Australian Institute of Marine Science (AIMS) Laboratories at Cape Cleveland, Townsville, Australia

13 - 15 November 2013
www.ioc-goos.org/GOOSBio2013

SPONSORS:
European Commission FP7 GEOWOW Project; Australian Institute of Marine Science (AIMS), IOC-UNESCO and the GOOS

GOOS Report No. 207

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1. EXECUTIVE SUMMARY

A group of marine experts was brought together for the ***First Workshop on the Identification of Ecosystem Essential Ocean Variables (EOVs)*** (13-15 November 2013, Townsville, Australia), jointly with the International Ocean Carbon Coordination Project (IOCCP) and their focus on biogeochemical EOVs. The Workshop, co-sponsored by the European Commission FP7 Project 'GEOSS Interoperability for Weather, Ocean and Water (GEOWOW)'; the Australian Institute for Marine Science (AIMS) and the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO) contributed jointly to the goals of the new Global Ocean Observing System (GOOS) Panel's for 'Biology and Ecosystems', and 'Biogeochemistry', and GEOWOW.

Identifying and defining ecosystem Essential Ocean Variables (eEOVs) builds on the work underway for defining and monitoring EOVs within the ocean physics and biogeochemistry fields, guided by the principles within the *Framework for Ocean Observing* (FOO). A significant portion of the present day changes in marine biology and ecosystems are occurring as a direct result of changes in physics and biogeochemistry. Therefore, whilst the Biology and Ecosystem, Biogeochemistry and Physics Panels have their own focus, overlapping questions and observing strategies are evident and therefore EOVs should not be considered as mutually exclusive from each other.

Workshop aims were to solicit advice in the identification of:

- major scientific and societal challenges that require sustained ocean biology and ecosystem variable observations;
- candidate ecosystem EOVs (e EOVs);
- the role of GOOS in regional co-ordination of data collection; and
- monitoring activities & projects to practically implement the biological and, biogeochemistry recommendations in the *The Framework for Ocean Observing (FOO)* and the *Panel for Integrated Coastal Observation (PICO) Plan.*

This report summarises the outcomes from the GOOS Biology and Ecosystems discussions. From initial identification of eEOVs, 43 were prioritised from which 10 were selected for high impact / high feasibility status (as guided by the concept of 'Readiness' outlined in the *FOO*). These were grouped into 4 themes relating to various drivers that influence the health of marine ecosystems, including: productivity; biodiversity, ecosystem services, and human activities. Candidate 'pilot' and 'concept' projects for monitoring eEOVs were proposed, considering the availability and 'Readiness' of known monitoring systems and datasets, feasibility of continued or new monitoring infrastructure, and potential availability of funds to support the activities. Of these, 7 were prioritised, relating to all 4 themes. The concept for Essential Ocean Samples (EOS) was raised and requires further discussion. Understanding the critical eEOVs to assist modelling ecosystem state (present and future) also requires further discussion to influence the prioritization of eEOVs and the design of ocean observation infrastructure for operational monitoring of biological components in ocean observing systems.

Six Working Groups were suggested to continue detailed discussions in the process of defining eEOVs, explore the potential for EOS, understand modeling requirements and in particular to instigate the commencement of the prioritized pilot/concept projects. Through the work of the full GOOS Biology and Ecosystems Panel (once formed) and the proposed Working Groups, the goal is for at least 6 eEOVs to fully defined and being monitored within 5 years.

The major challenge is identifying human and financial resources to support a credible and strategic work plan for a GOOS Biology and Ecosystems Panel, so that it can be communicated to relevant stakeholders, and implemented.

A corresponding report detailing the outputs from the GOOS Biogeochemistry EOV discussions is available separately.

2. INTRODUCTION

The First Workshop of Technical Experts for the Identification of Ecosystem Essential Ocean Variables (EOVs) took place from 13-15 November 2013 in Townsville, Australia. The experts were invited to assist both the Global Ocean Observing System (GOOS) Steering Committee and the European Commission funded 'GEOSS Interoperability for Weather, Ocean and Water' (GEOWOW) Program to identify and prioritise ecosystem Essential Ocean Variables (eEOVs).

Following the model successfully employed by GOOS to develop and coordinate global ocean physics observations over the last two decades, the GOOS Steering Committee is in the process of forming two new Panels - GOOS Biology and Ecosystems (entirely new), and GOOS Biogeochemistry (led by the SCOR-IOC International Ocean Carbon Coordination Project IOCCP). The role of these panels will be guiding extension of global ocean observation systems to include essential biological, ecosystem and biogeochemistry variables. An enhanced information base of these Essential Ocean Variables (EOVs) is required to support critical policy development and management decisions on ocean and coastal resource sustainability and health.

Complementary to this effort, the IOC-UNESCO – through leading the Ocean Ecosystem component of the GEOWOW Project – seeks to identify and gather data on eEOVs, forming the basis for new marine ecosystem data registered as GEOSS DataCORE, and useful for informing global, regional and local marine policy decisions.

As GOOS develops the two new Panels and as GEOWOW progresses the ocean ecosystems work, advice was sought from technical experts at the Workshop to assist with:

- identification of major scientific and societal challenges that require sustained ocean biology and ecosystem variable observations;
- identification of candidate ecosystem, biological and biogeochemical EOVs;
- clarification of the role of GOOS in developing consensus requirements, coordinating observing networks, and promoting development of a data management system;
- monitoring activities and projects to practically implement the biological, ecosystem and biogeochemistry recommendations in the GOOS Framework for Ocean Observing (FOO) and the Panel for Integrated Coastal Observation (PICO) Plan.

The concept of EOVs adopted by GOOS as a lens for viewing and evaluating the observing system identifies those sustained observations with high impact in the delivery of societal and scientific value, balanced with the feasibility of their sustained monitoring. Identifying the EOVs associated with ocean ecosystem-related societal issues, and in particular identifying the biological / ecosystem EOVs, will assist in evaluating the status of the ocean 'health' and in monitoring any future changes. This has been prioritized for action by the FOO and at the last two Sessions of the GOOS Steering Committee. The Technical Workshop was the first opportunity to bring together leading global experts to work towards this goal and the complementary goal within GEOWOW. A discussion of potential candidates for these new GOOS Panels also formed part of the Workshop.

3. BACKGROUND – THE NEED FOR ECOSYSTEM ESSENTIAL OCEAN VARIABLES

3a. A FRAMEWORK FOR OCEAN OBSERVING (FOO)

Monitoring ocean ecosystems and services will assist our understanding of them, and hence improve their management, for societal benefit, through a proactive approach. This requires an understanding of the holistic 'marine ecosystem' –with observations of oceanic variables beyond the traditional physical measurements and integrating across the physics, biogeochemistry and biology.

A Framework for Ocean Observing (FOO) (2012) [1] sets out the principles for the co-ordinated and sustained effort to observe and monitor the world's ocean, with free and open data exchange. Recognising that monitoring is already underway globally, and mostly for physical ocean variables, it states that it is impossible practically and financially to monitor everything in the ocean. Consequently, there is a need to establish what is necessary or 'essential' to observe, dependant on the societal benefit of improved understanding of any given ocean 'variable' and also considering the scale of maturity or 'Readiness' of an observing system. Determining the 'Readiness' is driven by the societal requirements and negotiated with the feasibility of monitoring, as demonstrated in the following diagram:

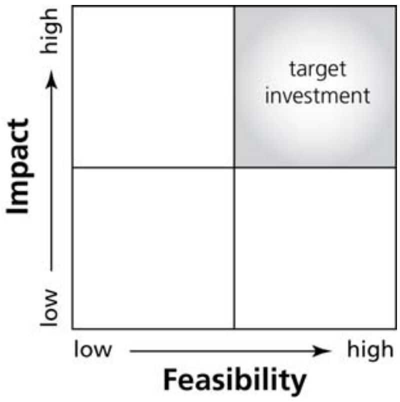


Figure 1: Conceptual model used to determine priority observations based on the impact of the observation (in terms of societal benefit) and the feasibility of monitoring (in terms of infrastructure and funding). The higher the impact, and the higher the feasibility of monitoring increase the 'Readiness'. [*Source: GOOS 2013*]

In addition, determining the 'Readiness' from concept phase to mature (highest level of readiness) is outlined in the FOO, as shown in Figure 2. Part of this process includes examining the end-to-end system, moving through a spectrum from societal requirements, required observations to data information management. Using this as a guide, the ocean science community is able to organize an approach to determining the essential ocean variables to monitor, and how to do so. This process guided discussions at the Workshop to identify and define eEOVs and to test their 'readiness' to inform the known and predicted state of the marine ecosystem.

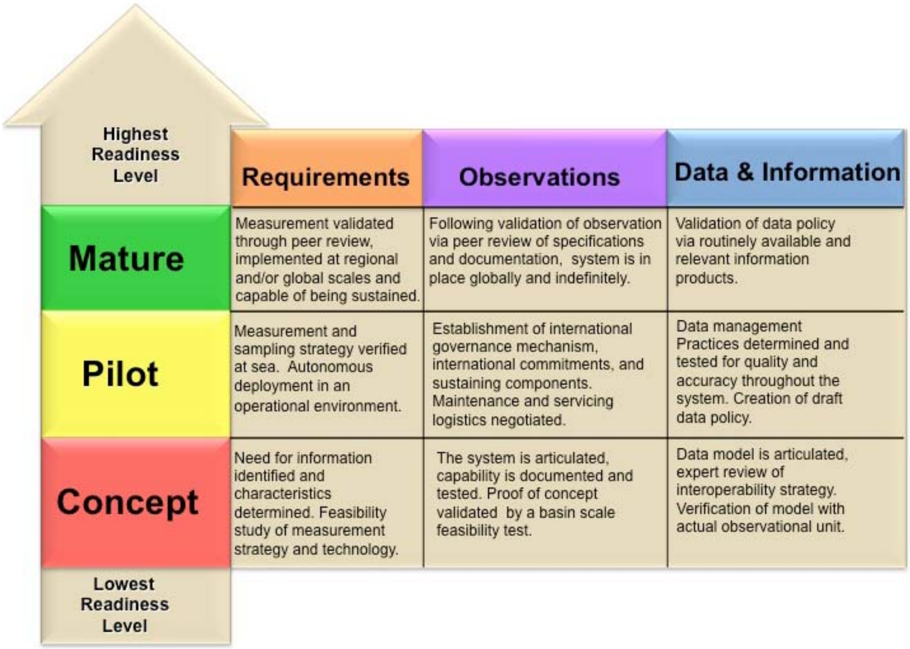


Figure 2: Framework Processes and Readiness Levels

Each eEOV will require rigorous review, vetting and approval by the community before reaching the highest level of readiness. This process will allow for innovation while protecting the system from inadequate or duplicative solutions. [*Source: FOO (2012): 10)*]

3b. WHAT IS AN ECOSYSTEM ESSENTIAL OCEAN VARIABLE (eEOV)?

Adopted by the GOOS and the FOO (2012), an Essential Ocean Variable (EOV) is a concept to organise and describe ocean variables that have both a high impact in responding to known scientific and societal issues and a high feasibility of sustained observation. The concept has been summarised in both the FOO (2012) and the GEOWOW Report **WP6-IOU-16.1.1** *"Definition of Ecosystem Essential Ocean Variables"* [2]. Notably, ecosystem EOVs were adopted from a concept already in use by the weather, climate and biodiversity monitoring communities, as shown in the following diagram:

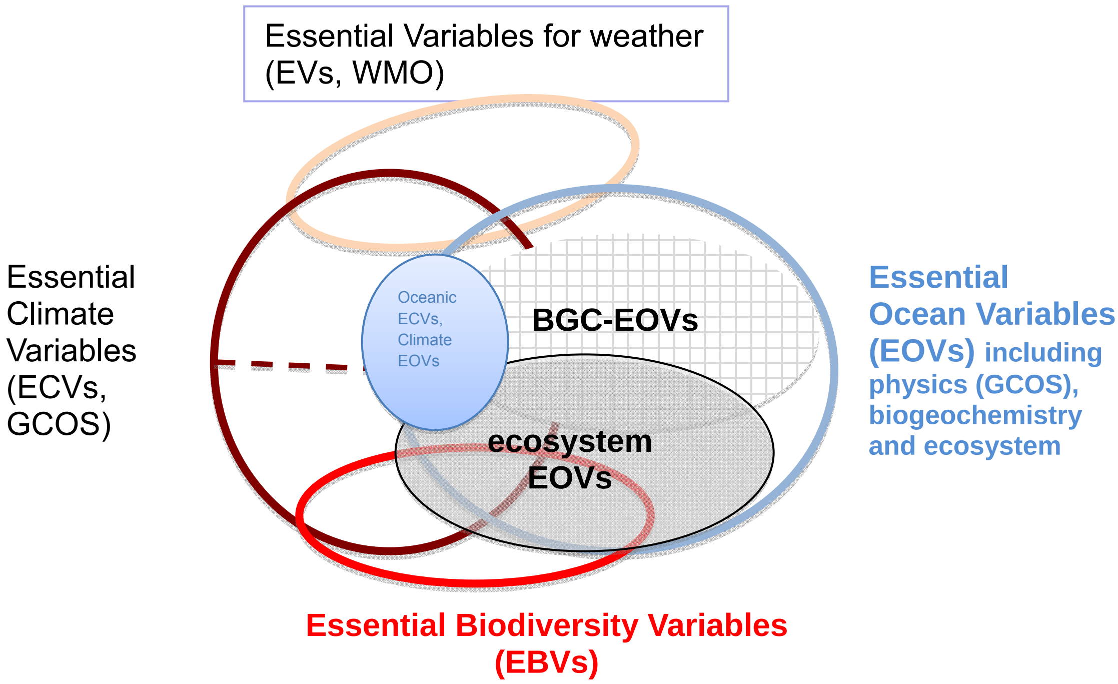


Figure 3: A Conceptual Overlap of Essential Ocean Variables (EOVs), including the physics, ecosystem and biogeochemistry EOVs, related to other Essential Variables (climate, weather and biodiversity).
Essential Variables defined by the WMO for Weather Forecasting inspired the Essential Climate Variables later

defined by GCOS. The concept has been adopted for Essential Biodiversity Variables on land by GEOBON. [*Source: FOO (2012:7)*]

Through the FOO (2012), EOVs have been further subdivided by attributes (e.g. physical, chemical, biogeochemical and ecosystem). Being at various stages of development (eg – definition and monitoring of physical EOVS are the most advanced), this report outlines the results of discussions focused on the identification and prioritization of ecosystem (especially biological) EOVs – for which little is currently known. Ecosystem EOVS (eEOVs), as the name suggests, focusses on the EOVs that will indicate the state of marine ecosystem – mostly linked to biological variables, but not exclusively as they can also include the drivers of ecosystem change. Taking an ecosystem-based approach improves the understanding of the state of the marine ecosystem. Ensuring sustained observations of the 'essential' variables provides a mechanism to monitor changes to the ecosystem and services.

A preliminary review of the known literature and information regarding eEOVs, was gathered prior to the Workshop (McKinnon 2013) [3] and is attached in Appendix 3. This provided a backbone for the discussions to identify and prioritize eEOVs. Part of this review included an analysis of the preliminary list and table of eEOVS, as identified by GEOWOW (2012) and shown in Appendix 4. These are a composite of information drawn from several sources including discussions from the:

- May 2010 Workshop on *'Attaining Operational Marine Biodiversity Observations: A Workshop to Determine the Status of Current Abilities and Scope Future Solutions'*, funded by the US Government [4]
- Panel for Integrated Coastal Observations (PICO) synthesised into a report: *The Requirements for Global Implementation of the Strategic of the Panel for Integrated Coastal Observations (PICO) (2012)* [5];
- May 2012 Workshop in Yeosu (Korea) co-ordinated by the UNESCO-IOC to discuss the *FOO (2012)* and candidate ecosystem EOVs.

These discussions set the groundwork for definition of eEOVs and the need to integrate biological and biogeochemical ocean data with the acquisition of physical data. The GEOWOW Report defines several categories of variables (eg physical, chemical, biological) that are essential to monitor for the improved understanding of marine ecosystems and their services to society. They are organized around the Societal Benefit Areas (SBAs) as defined by the Group on Earth Observations (GEO). The SBAs relate to specific themes by which the Global Earth Observation System of Systems (GEOSS) concentrates observing efforts. There is no specific marine SBA. However since the GEOWOW Report was written, a new GEO Task 'Blue Planet' acknowledges that marine observations bring societal benefit across the 9 SBAs.

Recently, and also using the SBA categories, the GEO Biodiversity Observation Network (GEOBON) have been defining Essential Biodiversity Variables (EBVs), within which there is a dedicated marine task. In tandem to these processes, the Canadian Government has progressed identifying eEOVs for the Arctic Ocean (see www. Caff.is/marine; and www.dfo-mpo.gc.ca/science/oceanography-oceanographie/cbmp-psbc/index-eng.html). Currently, the Southern Ocean Observing System (SOOS) via the SCOR (Scientific Committee on Oceanic Research) is also carrying out a similar initiative for eEOVs in the Southern Ocean (www.soos.aq/). Representatives from each of these initiatives were invited to the Workshop.

It is clear from McKinnon's review and the other initiatives that the definition of eEOVs for biological and ecological observations are more complex and less well understood and observed than for the physics and chemical properties. McKinnon suggests eEOVs could be arranged around biological variables that relate to direct sample of size structure (within trophic level); taxonomic diversity and biogeographic boundaries. Also clear is that the marine observing communities are at the beginning of a complex process to define and prioritize eEOVS, and should collaborate to ensure their strong development and understanding without duplication of efforts. The GOOS Biology and Ecosystems Panel has a pivotal role in ensuring collaboration.

3c. DRIVING NEEDS: CONVENTIONS

In addition to the recent push from the scientific community to understand the state of the marine ecosystems, there are numerous legal instruments, conventions and/or policy guides that 'call' for a need to understand, monitor and maintain healthy marine ecosystems to ensure sustainable development of the world's population. Some (but not all) are listed in Appendix 5. Consistency with these legal frameworks and principles is crucial when considering the identification of feasible and relevant eEOVs to ensure both the practicality of monitoring, and the potential to attract funding.

Recommendation: The GOOS Biology and Ecosystems Panel should investigate the relevant conventions/frameworks that provide the basis for developing eEOVs. With this knowledge, it will be possible to design an observing system that supports the assessment tools/management aims of the various frameworks.

4. DEFINING REQUIREMENTS AND NEEDS

As prescribed by the FOO (2012), the GOOS Biology and Ecosystems Panel recognised that a first step in this process was to define the major societal challenges and scientific questions requiring sustained global observations of ocean biological and ecosystem variables. Some work has already been carried out in the PICO Plan (2012) and GEOWOW Report (2012) to help define some of these societal benefit areas, organised around the GEO SBAs. These should also be considered in combination with the Convention on Biological Diversity (CBD) 2020 Biodiversity Aichi Targets and the Report written by GEOBON investigating the adequacy of observations to support the Targets [6].

Further to this, several points were raised at the Workshop to focus discussion on EOV definition:

- Is the Group interested in only societal pressures?
- How will the Group prioritise when there are multiple questions to answer and multiple measures?
- How will success be measured for GOOS Biology and Ecosystem observations?

Some key questions to drive the Group's method to identify eEOVs were raised:

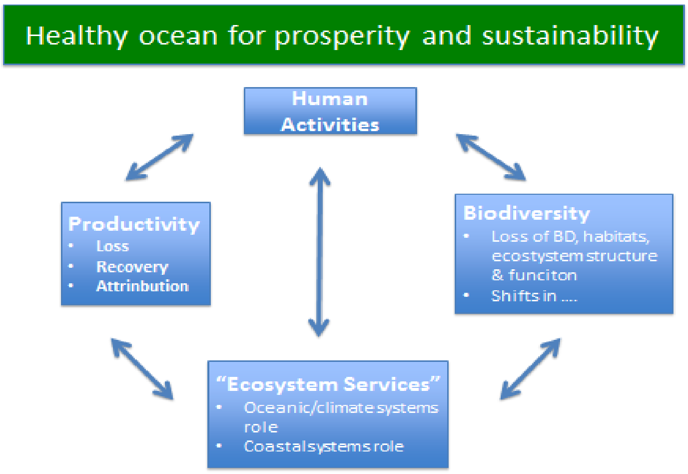
What is a healthy ocean? This overarching question is a significant motivator for understanding marine ecosystems and establishing sustainable use of them. However, it was recognised that any definition of a 'healthy ocean' is subjective and that there is no globally 'accepted' term. For the Workshop, this question was a determining factor for defining and prioritising eEOVs.

In defining a healthy ocean, participants agreed with the first three paragraphs of the *Ocean's Compact (2013)* [7] (see Appendix 6), where it is emphasised that 'the world's oceans are key to sustaining life on the planet', however impact of human activities is a serious threat to these ecosystems, resulting in a 'loss of biodiversity, decreased abundance of species, damage to habitats and loss of ecological functions' (Ban Ki Moon 2013:1). The Workshop added loss of ocean productivity and loss of ecosystem services to this list. Reversing these threats and rapid losses is only possible with a deeper understanding of the marine ecosystem, through sustained monitoring. As outlined in the *FOO* (2012), sustained monitoring of marine ecosystems is an urgent but mammoth task at a global scale. As such, the concept of monitoring those variables of the marine ecosystem that are 'essential' to understand and feasible to monitor, provide the starting point for establishing a priority list of eEOVs. Another consideration, which requires further exploration, is how to measure the success of monitoring an eEOV – and importantly, its role in contributing to a 'healthy ocean'.

It was agreed that an accepted 'Statement of Ocean Health' was required for the GOOS Biology and Ecosystems Panel to help define requirements for eEOVs.

Recommendation: The GOOS Biology and Ecosystems Panel agrees on an interpretation of 'Ocean Health' (including an indication of the needs of society) that will help define requirements for EOVs, measure their success (eg maintaining ocean productivity) and attract funding.

With the notion that society wants a 'healthy /productive ocean' now and in the future, participants devised the following **vision** to guide the identification of sustained ocean ecosystems and services required for this, and which also guided the selection of eEOVs at the Workshop:



Four Themes were considered to comprise a 'healthy and productive ocean' for human needs: Productivity, Biodiversity, Ecosystem Services, Human Activities and Pressures.

4a. PRODUCTIVITY

A 'productive' ocean is one that can provide humans with the food security required now and in the long-term. This was linked directly to the Food and Agricultural Organisation of the United Nations (FAO) targets for ensuring sustainable productive global fisheries, as an example. Measurements of productivity might be through 'loss of…'; 'recovery of…' indicator species and habitats. Attribution was also considered an important variable to measure, that is: attributing a change in a productive ecosystem to a particular cause (eg anthropogenic and/or natural).

Several key questions in relation to measuring ocean productivity were considered by the Workshop:

1. **Can we determine whether ocean productivity (and its distribution) is changing and if so, in which direction?**

   In particular, changes in primary productivity can be measured through time (eg seasonality, annual, decadal) and via functional groups distribution (e.g. microbial/phytoplankton/plants). The IPCC Report (2013) [8] noted that half the productivity of world is from phytoplankton, a large proportion of which is in the world ocean. Production of protein and sequestration of carbon should also be considered.

2. **How do changes in productivity influence changes in the structure of food webs? And can these eventual changes influence the human use of ocean resources (including impacts of fishing across the food chain)?**
3. **What is the impact of habitat modification on primary, secondary and tertiary productivity?**
4. **How can humans boost ocean and food productivity whilst keeping the ocean 'healthy'?**

   (Related to this question, participants also asked whether determining that this goal was met was possible with observation systems in place?)

5. **What is the influence of decreasing oxygen and increasing carbon on ocean productivity?**
6. **A Reverse Question to No.2: How will the changes in food web structure influence (global? primary?) ocean productivity?** (Potentially a question to consider with the GOOS Biogeochemistry Panel)

For the purpose of identifying ecosystem EOVs, importance was placed on productivity (primary) and carbon flows through the food web.

4b. BIODIVERSITY

Biodiversity in the ocean is considered an important contributor to a productive and healthy marine state, essential to define ecosystems structure and a warranty to maintain the services they provide to humans. Within the frameworks of the CBD and the 2020 Aichi Biodiversity Target and the Intergovernmental science-policy Platform on Biodiversity and Ecosystem Services (IPBES), there is global recognition that biodiversity and ecosystem services must be conserved for their sustainable use by humans in the future. Currently, 'loss of' and 'shifts in' marine biodiversity, ecosystem structure and function, and habitats threaten their resilience to and increase their vulnerability to human impact. However, it is also possible that present and future climate impacts may increase biodiversity but decrease productivity (e.g. for fisheries). The situation is complex and for the moment, not well understood. Considering these factors and the need to monitor biodiversity EOVs, the Group raised the critical question: ***'How is marine biodiversity changing (globally and regionally)?'***. Without a simple answer, the Group noted that rates of change (natural or anthropogenically induced) at global and regional scales (e.g. extinctions, invasions, population decline, habitat loss/shift and community structure); and range of changes (especially due to impacts from climate change) are critical variables for understanding, monitoring and maintaining optimum marine biodiversity.

Several other major questions of concern for maintaining marine biodiversity and ecosystems structure for a 'healthy and productive ocean' were raised:

1. **How do we measure biodiversity/quantify biodiversity especially when so little is known? Will there be lost opportunities from lack of knowledge? How do we measure what we don't know?**
2. **What is the relationship between species biodiversity and functional biodiversity?**
3. **What is meant by community structure[1]? How can this be measured?**
4. **What is the relationship between biodiversity and resilience? Why do we care about biodiversity? Can we define and measure resilience?**
5. **What is the scope for genetic/behavioural adaptation?**

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[1] Noting the complexities of 'Community structure' where:

- Community has a function
- Assemblage has a structure
- There are Functional groups
- Sentinel / indicator species exist; and
- The species 'pool' can change over space and time

6. **Why does society appreciate biodiversity? (GOOS needs to be able to respond to this) [e.g. through food security, decline of bio-resources is detrimental to human society, decline in genetic diversity].**

Whilst these questions were noted as important, they fell short of highlighting the significant ongoing research and observations around these issues that will over time inform the eEOV selection. Further investigation is required by the Panel.

4c. ECOSYSTEM SERVICES

Ecosystem Services are defined as those attributes of an ecosystem that provides, directly or indirectly, a valued 'service' or benefit for society. Examples in the marine environment include ecosystems that provide physical protection for human populations living on the coast (e.g. mangrove and coral reef ecosystems), the ocean's role in sequestration of carbon and food productivity (e.g. fisheries). Given the societal need to maintain a 'productive ocean' – with full use of marine ecosystem services, it is clearly important to consider the sustained maintenance of these services as essential for humans. This can range from protection and/or to exploitation of marine ecosystem services. Establishing the ecosystem base-line 'health' or functioning productivity of these services will require monitoring selected eEOVs, and will be intricately linked to monitoring biodiversity, productivity and climate change impacts. Also, a main effort should be addressed to maintain and/or increase observations in the coastal areas, given that 44% of the world population lives within 150km of the coast [9].

The Group identified several ecosystem services other than food, and raised questions to help determine how to identify the eEOVs required for monitoring the 'health' of marine ecosystem services and their eventual changes:

1. **Particulate Carbon, Nutrients and Oxygen** (overlaps with the GOOS Biogeochemistry Panel)

- What is the likely impact of rates of change of these parameters on Ecosystem Services?
- What is the capability of the system to deal with pollution (limits to bioremediation – space and time dimension)?
- How does increased nutrient availability and particulate carbon levels modulate ecosystem services?

2. **Genetics**

- What are genetic resources from the ocean?
- What are the spatial and temporal variations in genetic resources?
- What are the realised and potential values of genetic resources?

3. **Coastal Protection and Habitat Loss**

- What is the role of coastal habitat communities (e.g. saltmarshes/mangroves)?
- Can roles and resilience services provided by coastal habitats be improved (and quantified)?

4. **Bioproducts**

- What are the spatial and temporal variations in bio-resources of the ocean?
- What is the realised and potential value of the ocean's bio-resource?

5. **Recreation/Tourism/Cultural values**

- What are the threats to the high value coastal tourism assets?
- What is the impact of tourism on the ocean ecosystem? [linked to pressures]

4d. HUMAN ACTIVITIES AND PRESSURES

Human impact and pressures on the marine ecosystem state is a theme that requires special attention. Pressures on the ecosystem result from interference with the natural functioning state of the ocean.

Mostly, these are the result of direct human impact and can be cumulative. Building on Halpern et al (2008) [10] participants identified the following key pressures/human activities:

- Climate change related (e.g. ocean acidification, warming, de-oxygenation);
- Fishing (pelagic/demersal, artisanal/industrial, illegal);
- Pollution
  - Micro and macro plastics, noise, shipping; fishnets; inorganic, non-point organic (oil), nutrient input
  - Freshwater runoff (river input, damming, land-use changes, environmental flows, agriculture, eutrophication)
- Structures (e.g. physical alteration, mining platforms, benthic structures, sustainable energy/development, dredging);
- Species invasion;
- Human population growth;
- Bio-prospecting;
- Transportation (e.g. shipping, ballast water discharge)
- Recreational use; and
- Aquaculture.

4e. OTHER

National *State of the Environment Reports* (e.g. in Australia, New Zealand) may form a basis for locating further information on the pressures on marine ecosystems under national jurisdiction. Additionally, the *World Ocean Assessment* is currently underway with expected completion at the end of 2014. The Assessment is investigating the range of pressures on the marine ecosystem with a view to making a statement on the current health of the global ocean. Beyond this Workshop, it is worth the GOOS Biology and Ecosystems Panel contacting the lead co-ordinators to discuss any relevant data required for collection to inform societal issues, and help identify and refine the relevant eEOVs required.

Recommendation: A sub panel of GOOS Biology and Ecosystems Panel to peruse known National State of Environment Reports, and contact the facilitators of the World Ocean Assessment and other international initiatives e.g. Blue Planet, GEO BON to discuss the relevant data already collected (and still required) to inform societal issues and their monitoring needs.

4f. MEASURABLE TRAITS

Determining the relevant eEOVs for these four themes involves identifying the factors essential for their measurement and for establishing a baseline 'health' against which changes can be detected. Ecosystem EOVs may vary in type, spanning from individual variables (e.g. for measuring a change in an ecosystems service) to suites of variables that in sum, or through integration with other information, may provide 'indicators' as a measure of health. Related to some of the questions above, much thought is still required to determine how measurements can be made for the following:

- Change in key Societal Benefit Areas (SBAs);
- Rates of change in community structure;
- Protection and exploitation of ecosystem services (considering multiple drivers and impacts); and
- Pressures (especially cumulative stress); and
- The reversibility of negative marine ecosystem changes.

Further consideration needs to be given to the science questions that can inform these measurements.

Recommendation: Determining the measurable traits and how they can be measured needs serious consideration in the definition process, beyond the realms of the Workshop.

5. MODELLING NEEDS

Data extracted from observed eEOVs are most likely to be used by models for indicating trends in the state of particular ocean variables and/or ecosystems now and in the future. Additionally, models are able to pproduce a global diagnostic (forecast and hind-cast for gaps in observations in the past) and connect disparate data from different observation systems (integrating and interpolating across elements). Even if models are imperfect, and measuring dynamic relationships can be complex, models can indicate useful trends. As well, reporting on model uncertainties is also very useful to frame the predictions. This supports the idea in the FOO (2012) that we cannot measure everything; however, 'essential' ocean variables can inform trends via models that may show if elements in an ecosystem are changing. Given this, it is particularly important to understand the needs of the modelling community so that eEOVs are identified for the collection of data that is both adequate and suitable for developing the most accurate ecosystem models possible. Critically, modellers need data for the 'present state' modelling, to inform the 'future state models'

For the biological and ecosystem models, a useful approach is to use 'end to end' ecosystem models, which test hypotheses about the interactions between habitats (especially connectivity and forcings between the physical and biological components); productivity (especially nutrient imports, recycling and export); and functional qualities (including spatial scale). For habitat modelling, there is a need to relate physical and biological variables, and in some cases, habitats can be simulated if certain variables are known. Ecosystem and habitat modelling can inform the priority areas of change in a marine ecosystem, and subsequently, may prove an important signal for pursuing other monitoring needs. Currently, many ocean observation systems are not set up to measure variables that will demonstrate connectivity within the ecosystem. Understanding the observational requirements, indicators and eEOVs required for the modellers to successfully model ecosystem state now and in the future is a critical task for the GOOS Biology and Ecosystems Panel. For example, ecosystem models are more accurate with system state variables, rather than estimated rates. Additionally, Constable (2013) demonstrated at the Workshop the key measures for biological models:

Table 1. Key Measures Required for Biological Models

	Scale *- Time [Space]	Size Composition	functional composition
Microbes (phytoplankton)	Intra-annual [Satellite – regional/basin to global scales]	Cell size	Class
Secondary producers	Annual [habitat/ regional/basin to global scales]	Mass	Order
Mesopelagic	2-5 years [habitat]	Mass	Family
Top predators	10 years [foraging areas]	Mass	Dominant prey type (Family)!
* [relative] Abundance measured at scales identified			

! diet is used to integrate this data	

Source: Andrew Constable, *Australian Antarctic Division Ecosystems Program, ACE CRC* [11]

Along with these measures, discussions elaborated that seasonal cycle may influence models. As well, when modelling food webs, it is useful to know the species/functional group pool, so that it can be switched 'on' and 'off' within modelling parameters to test potential future ecosystem states according to a given scenario. With advice from the modelling community, the GOOS Biology and Ecosystems Panel should be able to select the key variables to measure when describing e.g. food webs, ecosystems structure and function and showing drivers of change. For this, it will be important to know the functional groups that characterize the system locally and regionally. To test the strength of this type of modelling, a clear concept on the extent to which a system is open ended, with clear inputs and outputs (interactions) is required.

Based on the development of eEOVs for the Southern Ocean Observing System, modellers are using the SOKI (Southern Ocean Knowledge and Information wiki www.soki.aq) as a tool to organise and access disparate eEOV data for modelling the Southern Ocean ecosystem.

Recommendation: SOKI wiki is a useful tool for the GOOS Biology and Ecosystems Panel to guide ideas for developing global eEOVs.

Whilst further discussion is required to understand how the essential variables will be useful for modelling ocean ecosystem state, it is clear that the design of the observation infrastructure for the GOOS Biology and Ecosystem EOVs should be influenced by modelling needs. Gaps in observation data can be reduced if the relevant observation systems are set up as soon as possible, to provide data for the best possible models. As well, as time series increases so does confidence in a model using the time series data. Observation systems need to be adaptive to accommodate the changing variables required for various ecosystem models.

It was also emphasised that models can be an important communication tool for scientists to inform policy guidance and decision makers, especially in the politically sensitive topic of managing predicted future marine ecosystem changes. For the development of eEOVs and expanding the GOOS with biological and ecosystem observations, model trends will be crucial to convince potential funders to support the initiative.

Recommendation: The GOOS Biology and Ecosystems Panel in collaboration with the modelling community should identify a short list of 'backbone' measurable ecosystem indicators that be incorporated into regional and global models. Additionally, it would be useful for the GOOS Biology and Ecosystems Panel to encourage the GOOS Regional Alliances (GRAs) and National Ocean Observing Systems to consider the needs for modellers when designing ocean observation infrastructure for monitoring marine ecosystem state.

6. DEFINING eEOVs

Having agreed on the need for EOVs, the Workshop participants discussed criteria that could be used to identify a list of potential eEOVs. For each of the four themes (productivity, biodiversity, ecosystem services and human impacts) and their key questions, participants prioritized the questions and discussed potential eEOVs. The process for identifying potential eEOVs was guided by the concept of 'Readiness' levels outlined in *A Framework for Ocean Observing (FOO) (UNESCO 2012*) including what datasets and/or observation platforms already existed (eg a high maturity in 'Readiness'); to eEOVs that provided a good signal of information in a 'noisy system'; and eEOVS that would be simple to implement at a global level whilst being cost efficient. Generally, eEOVs were categorized via biological issues or 'phenomena' that drive the perceived 'health' of the ocean (following a similar method to the PICO Plan, GEOWOW and GEOBON EBVs) rather than being species' specific (unless warranted, for example an 'indicator' species). Keeping in mind the CBD Aichi Targets, eEOVs related to food security for humans were also given attention. Taking these into account and the expertise present in the room, for the four themes, 49 eEOVs were listed, demonstrating the complexity of the biological system. These were further condensed to **43 eEOVs** through grouping some with similar attributes:

Table 2. List of 43 Potential eEOVS Defined at the Workshop

eEOVs – PRODUCTIVITY
eEOVs – PRIMARY PRODUCTIVITY
Chlorophyll (signaling global change in primary productivity in the ocean surface)
Mangrove Area
Salt Marshes
Seagrass (Kelp and Macroalgae)
eEOVs – FOOD WEB
Zooplankton: • Biomass/Abundance (including sub-set of populations, or size spectrum) • Species (Key) • Groups (e.g. copepods) • Ranging from Ichthyoplankton to Species Level (100s of species or just key commercial species; and a proxy for adult fish abundance) • Krill • Jellyfish • Pteropods
Abundance and Distribution of Apex Predators
Nitrogen/Carbon Stable Isotope (an indicator of shifts in Trophic Level)
Higher Trophic Level Abundance / Biomass (Predators as an integrator of Productivity)
Copepod Indicator (important exploitable species relevant to fisheries - restricted to temperate and tropical environments).
Average Trophic Level
Biomass of *K Strategists*
Age Spawning and Length of Maturity of Top Predators.
Movement patterns / hotspots / habitat use of Top Predators + Species of Value (e.g. whales) via Tags and Tracking

eEOVS – BIODIVERSITY
Coral Cover
Genetic Composition
Extinctions/endangered species
Community Structure and Changes Over Time (as an indication of species composition)

Charismatic Species (eg marine mammals) – Quantifying their Change in Global Abundance as an important indicator of Health and Biodiversity ('integrated ocean health')
Abundance, Distribution and Size of Upper Trophic Levels (e.g. Large Marine Vertebrates)
Habitat Loss (especially Key Living Benthic Habitats e.g. Seagrass; Mangroves)[2]
Habitat Loss (Structural e.g. Rocky Shore, Coral Reef etc)[3]
Deep Sea Benthic Habitat Loss
Changes in Pelagic Habitat defined by Oceanographic Boundaries

eEOVS – ECOSYSTEM SERVICES
Impacts of Nutrients / Sediment etc on Coastal Water Quality[4] : - Pathogens (including E.coli bacteria, HABs, Vibrio) - Jellyfish Abundance Area - Eutrophication indicators (eg Oxygen depletion areas)
Coastal: - Corals - Seagrasses - Macroalgae biomass
Open Ocean: Tracking the shifts in the structure of the food web (pico- and nanoplankton)
De-calcification for Bivalves and Mollusks Ocean Acidification – an indicator of ocean acidification

eEOVS – HUMAN ACTIVITIES
Plastics Density/Biomass (in both space and time)
Soundscape (ideally measuring the sound spectrum every 15 minutes[5])
Footprint of Fishing (especially Benthic, 'Swept Area' x 'Time' / Longline /Purse Seine /Dynamite Area)
Dredge Area (in cubic metres)
Impacts of Oil and Gas Wells & Pipelines
Seabed Mining Footprint
Hardened Coastlines (measured in kilometres)
Mercury Levels in Apex Predators (Change over Time)
Commercial Shipping Route Destiny
Coastal Aquaculture Footprint

[2] See PICO Plan (2012) for more information

[3] See PICO Plan (2012) for more information

[4] Potential connection to biogeochemical EOVs

[5] The US NMFS-NOAA *Soundscape Initiative* could be used to help inform development of this eEOV. See also [12].

Desalinization Plant Number and Capacity
Freshwater Input/Budget
Sustainable Energy Structures 'Footprint' (Wind/Tide/Wave/Current)

The concept for Essential Ocean Samples (EOS)—collecting and preserving the present state of the ocean through water samples to create raw material for future analytic techniques (such as meta-genomic techniques) to detect change from today's baselines—was raised and requires further discussion.

Workshop participants did an initial ranking of the impact and feasibility of monitoring each eEOV using a scale of 1-10. Results, whilst not statistically viable and hence should only be considered as a very preliminary assessment, indicate the majority of eEOVs were viewed to have medium to high feasibility and impact (with a mean score greater than 5) (see Appendix 7). Ten eEOVs were considered to be both high impact and high feasibility (with a mean score greater than 7) (Table 3). The workshop noted that the 'Human Impact/Pressures' theme was not represented in the ten however it relates to first 3 themes in some aspect.

Table 3: Priority List of 10 eEOVs Defined at the Workshop

Potential eEOV	eEOV Theme
1. Chlorophyll	A. Productivity (Primary) D. Human/Climate impacts
2. Coral Cover	B. Biodiversity C. Ecosystem Services (food supply for human populations in tropical latitudes, ecological buffer) D. Human/Climate impacts
3. Mangrove Area	A. Productivity (Primary) C. ES (Carbon sequestration, ecological buffer-flooding) D. Human/Climate impacts
4. Harmful Algal Blooms (HABs)	C. Ecosystem Services D. Human/Climate impacts
5. Zooplankton (biomass/abundance)	A. Productivity (Food Web) D. Human/Climate impacts
6. Salt Marsh Area	A. Productivity (Primary) C. ES (ecological buffer) D. Human/Climate impacts
7. Large marine vertebrates: abundance/distribution	B. Biodiversity D. Human/Climate impacts
8. Seagrass Area	A. Productivity (Primary) D. Human/Climate impacts
9. Tags and Tracking of species of value/large marine vertebrates	A. Productivity (Food Web) C- Ecosystem Services (related to fisheries) D. Human/Climate impacts
10. Zooplankton (Krill)	A. Productivity Food Web D. Human/Climate impacts

7. POTENTIAL PILOT PROJECTS

A candidate 'pilot project' was defined by an opportunity to create a 'project' that develops an eEOV through the following criteria:

- 1-2 years to develop;
- Local to regional scale but with an opportunity to expand to the global scale;
- Potentially led by 3 countries (encouraging global collaboration).

Potential pilot projects were also categorized into 'concept' or 'pilot' projects (Figure 4) using the concept of 'Readiness' Levels outlined in *A Framework for Ocean Observing (FOO) (UNESCO 2012*).

FRAMEWORK PROCESSES BY READINESS LEVELS

Readiness Levels	Requirements Processes	Coordination of Observational Elements	Data Management & Information Products
Mature			
Level 9 "Sustained"	Essential Ocean Variable: • Adequate sampling specifications • Quality specifications	System in Place: • Globally • Sustained indefinitely • Periodic review	Information Products Routinely Available: • Product generation standardized • User groups routinely consulted
Level 8 "Mission qualified"	Requirements "Mission Qualified:" • Longevity/stability • Fully scalable	System "Mission Qualified:" • Regional implementation • Fully scalable • Available specifications and documentation	Data Availability: • Globally available • Evaluation of utility
Level 7 "Fitness for purpose"	Validation of Requirements: • Consensus on observation impact • Satisfaction of multiple user needs • Ongoing international community support	Fitness-for-Purpose of Observation: • Full-range of operational environments • Meet quality specifications • Peer review certified	Validation of Data Policy • Management • Distribution
Pilot			
Level 6 "Operational"	Requirement Refined: • Operational environment • Platform and sensor constraints	Implementation Plans Developed: • Maintenance schedule • Servicing logistics	Demonstrate: • System-wide availability • System-wide use • Interoperability
Level 5 "Verification"	Sampling Strategy Verified: • Spatial • Temporal	Establish: • International commitments and governance • Define standardized components	Verify and Validate Management Practices: • Draft data policy • Archival plan
Level 4 "Trial"	Measurement Strategy Verified at Sea	Pilot project in an operational environment	Agree to Management Practices: • Quality control • Quality assurance • Calibration • Provenance
Concept			
Level 3 "Proof of concept"	Proof of Concept via Feasibility Study: • Measurement strategy • Technology	Proof of Concept Validated: • Technical review • Concept of operations • Scalability (ocean basin)	Verification of Data Model with Actual Observational Unit
Level 2 "Documentation"	Measurement Strategy Described • Sensors • Sensitivity • Dependencies	Proof of Concept: • Technical capability • Feasibility testing • Documentation • Preliminary design	Socialization of Data Model • Interoperability strategy • Expert review
Level 1 "Idea"	Environment Information Need and Characteristics Identified: • Physical • Chemical • Biological	System Formulation: • Sensors • Platforms • Candidate technologies • Innovative approaches	Specify Data Model • Entities, Standards • Delivery latency • Processing flow

Figure 4: Framework Processes By Readiness Levels [*Source: FOO (2012): 11)*]

A **preliminary set of candidate pilot projects** were drafted, considering the availability of known monitoring systems and datasets, feasibility of continued or new monitoring infrastructure, and potential availability of funds to execute the projects. The full listing is in Appendix 8. Additional Projects were also identified that may inform the design of the GOOS Biology System (also in Appendix 8). The Workshop undertook a preliminary prioritisation of the projects for further consideration noting the need to ensure at least one project related to each of the 4 eEOV themes. An extra 2 were selected based on the ability to start immediately with a mature system and little funds required (Table 4).

Table 4: Priority List of 7 Candidate Pilot/Concept Projects for eEOVs

Candidate Pilot Project	eEOV Theme/s	eEOV	FOO Readiness	Platforms
Developing syntheses of abundance and distribution of Large Marine Vertebrates as a signal of the health of the marine ecosystem (via tagging and tracking techniques)	A. Productivity (Food Web) B. Biodiversity. D. Human / Climate impacts	Movement patterns / hotspots / habitat use of Top Predators + Species of Value (eg whales)	Mature	Tags and Tracking

Standardizing Cal/Val for chlorophyll and primary productivity through coordination of the Chlorophyll / ocean colour community	A. Productivity (Primary) D. Human / Climate Impacts	Chlorophyll	Mature	Satellite *in situ* sampling for calibration and fluorometric measurements at existing permanent mooring sites.
Developing a synthesis product of Continuous Plankton Recorder (CPR) records to produce eEOV time series for ocean biomes (zooplankton); as well as developing zooplankton sampling using standardized emerging genetic technologies	A. Productivity (Food Web) D. Human / Climate Impacts	Zooplankton *Potential EOS	Feasible within 2-3 years?	CPRs + genetic techniques + optical and classic taxonomy identification
Developing purpose built environment DNA system for EOVs in collaboration with biodiversity observation networks (e.g. USA: MarineBON) [longer time horizon]	B. Biodiversity.	*Potential EOS	Feasible within maybe >5 years?	Ship sampling
Human activity data for oceanographers: develop an operating basis for making this information widely available for research.	D. Human / Climate impacts	?	Feasible within 2-3 years?	
Promoting universality/integration of the tagging/tracking/historic archive (already underway in Southern Ocean)	A. Productivity (Food Web) B. Biodiversity.	Tags and Tracking + Species of Value (eg whales) and Top Predators	Mature	Tags and Tracking
<u>Using an area with 60 years of high-resolution data to ask: Can we invert the CALCOFI ? e.g. if we had</u> to re-construct it, what variables would we target? Perhaps some indicator species rather than all fish indicators? (given the known 60 years of data)	A. Productivity (Food Web) C. Ecosystem Services D. Human / Climate impacts	?	?	?

The proposed projects will need to be advanced with support and direction from the GOOS Biology and Ecosystems Panel once it is constituted. Noting that technical expertise relevant to each of the eEOV themes will be required to progress the projects and that the overall list of eEOVs covers several 'groupings' of expertise, 6 Working Groups were proposed and Workshop participants identified potential experts who may be interested in participating in a working group:

- **Trophic – Primary Producers**
- **Trophic – Zooplankton**
- **Trophic - Large Marine Vertebrates**
- **Habitats**
- **Human Impacts**
- **Water Quality**

It is envisaged that the Working Groups will progress the process of defining eEOVs and facilitate the implementation of pilot and concept projects. Working Groups will report to the GOOS Biology and Ecosystems Panel. Further expectations on the Working Groups are listed in the recommendations at the end of the report.

8. SCIENTIFIC SYNERGIES WITH THE GOOS BIOGEOCHEMISTRY PANEL

Throughout the Workshop, GOOS Biology and Ecosystems and Biogeochemistry Panel cross-cutting issues were identified and there were some preliminary discussions about them in joint sessions of the two panels. Both Panels agreed these require further discussion and integration to ensure synthesis between the two groups. This is especially the case with definition and monitoring of eEOVs associated with ‘ecosystem services’ and ‘habitats’. Some topics for joint discussion were identified and include ‘will changes in the ocean impact on habitats/trophic levels in general, or impact on the physiology of species?’ It would also be useful to facilitate collaboration between the Panels through some of the Candidate Pilot Projects.

In terms of modelling, the challenge for the GOOS Biology and Ecosystems Panel is to contribute the relevant biological variables for the Biogeochemistry models. In the past, with little biological information at hand, this has not been satisfactory for biogeochemistry models. There is the possibility that biological data may help better regionalise/localise the closure term for biogeochemistry models. However, the overall question remains for modellers to close the gaps between the requirements for both the biology and biogeochemistry needs. How this will be accomplished needs further discussion with the modelling community and representatives from both GOOS Biology and Ecosystems and Biogeochemistry Panels.

9. FUNDING OPPORTUNITIES

Funding is required to advance the development and monitoring of the proposed eEOVs and candidate pilot/concept projects, and to progress the activities of the GOOS Biology and Ecosystems Panel. One suggestion was to establish a sub-committee within the GOOS Biology and Ecosystems Panel to focus on communicating the benefits of developing and monitoring EOVs, and as well to secure the funds necessary to support these activities. However, in the interim, strategic suggestions by participants included:

- Define some eEOVs with explicit questions that relate to climate change impacts on ocean health, or anthropogenic (e.g. ocean acidification) impacts on ocean health.
- Investigate the potential for the development of eEOVs to be ‘branded’ or linked to the GEO Blue Planet initiative, which may identify opportunities involving the GEOSS, GEO and GOOS.
- That the GOOS Biology and Ecosystems Panel and Working Groups should collaborate closely with GEOBON, in their development of marine EBVs, in order to reduce duplication of effort in developing eEOVs and join forces in funding proposals.
- The GOOS Biology and Ecosystems Panel and Working Groups should consider seriously the key modelling needs for the development and monitoring of eEOVs, and subsequently use the modelling ‘products’ to communicate any ecosystem changes, thereby promoting the use of eEOV data acquisition specifically relevant to national governments and/or international agencies.
- Target national (eg Australian IMOS, US IOOS) and GRA observing networks (eg EuroGOOS) to learn of any opportunities that may assist the development of eEOVs and observation platforms specific to a country or region.
- Investigate opportunities to assist ecosystem monitoring and improved marine management in regions of developing countries.
- Consider the priorities in the European Commission Funds in the upcoming round of Horizon 2020.

10. POTENTIAL CANDIDATES FOR THE GOOS BIOLOGY AND ECOSYSTEMS PANEL

Participants discussed the potential candidature requirements for the full GOOS Biology and Ecosystems Panel. A selection of skills was suggested, falling into various categories that, in combination, will comprise a strong team of people prepared to progress the expansion of the biological component of GOOS. Representatives with the following expertise were suggested:

- Molecular genetics;
- Already connected to existing programs (eg CALCOFI, GEOBON, GRAs, National Observation Systems such as IMOS, US IOOS, and major conventions such as CBD) to integrate all the experience;
- Data / Information Systems;
- One person connected across the other two GOOS panels;
- The Chair from each of the 6 proposed Working Groups;
- Ecosystem modeling capability (for both science and policy development);
- Statistician;
- Chair of the Sub-Committee on Technology;
- Citizen Science;
- Chair from Sub-Committee on Funding/Communications;
- International Community Representatives (including a disciplinary mix e.g. from fisheries, benthos, large marine vertebrates, plankton and remote sensing [e.g. Chair International Ocean Colour Coordinating Group (IOCCG)]);
- Social Science;
- Coastal and oceanic expertise;
- Policy – Science Integrated experience

The suggestion was also made to consider the use of Sub – Committees within the GOOS Biology and Ecosystems Panel including:

1. **Technology and Instrumentation:** To address setting up the relevant technological marine biological instruments required for expanding the GOOS Biology and Ecosystems observations component, and filling the gaps in observation and data requirements. Representatives might include technical and instrumentation experts in:
   - In-situ
   - Bio-optics;
   - Remote sensing
   - IOCCG (eg Chair) ; and
   - Modeler

2. **Communications and Funding:** To focus on the communication efforts to promote the goal of the GOOS Biology and Ecosystems Panel and as well, secure funding for the proposed activities. Representatives might be from/include:
   - GRAs
   - National Observation Systems (e.g. IMOS/US IOOS)
   - Social Scientist
   - Someone with expertise in the major conventions (e.g. CBD)

11. CONCLUSION

This Report sets out the results of discussions from *The First Workshop of Technical Experts for the Identification of Ecosystem Essential Ocean Variables (EOVs)*. It is clear that the definition of eEOVs is in an early phase and requires further consideration and development. This Workshop built on known efforts and refined the identification of eEOVs to help strengthen and expand the GOOS for monitoring marine ecosystems. The results of the Workshop will be used to progress the formation of the GOOS Biology and Ecosystems Panel to guide continued development of eEOVs critical for the maintenance and sustained development of a healthy and productive ocean. The GOOS Biology and Ecosystems Panel will work in collaboration with the other GOOS Panels to achieve this.

12. IMPLEMENTATION – RECOMMENDED NEXT STEPS

Subject to the available resources it is recommended that:

- A 1 – 2 year vision and work plan for the GOOS Biology and Ecosystems Panel is developed.
- Nominations for a full GOOS Biology and Ecosystems Panel occur immediately and once formed it will implement the work plan and advise the date for a Panel meeting in 2014.
- Six Working Groups, with the Chair of each a member of the GOOS Biology and Ecosystems Panel, are formed to continue detailed discussions in the process of defining eEOVs, and in particular to instigate the commencement of the prioritized pilot projects:
    - **Trophic – primary producers**
    - **Trophic – Zooplankton**
    - **Trophic - Large Marine Vertebrates**
    - **Habitats**
    - **Human Impacts**
    - **Water Quality**

- The GOOS Biology and Ecosystems Executive will develop the Terms of References for each Working Group which could include:
    - Working Groups to seriously consider the measurable traits of an eEOV;
    - Working Groups to determine the most critical eEOVs required for modellers to model changes to ecosystem, and determine if these eEOVs are feasible with the known observations infrastructure in place.
- Through the work of the full GOOS Biology and Ecosystems Panel (once formed) and the Working Groups, the goal is for at least 6 eEOVs to be underway (fully defined and being monitored) within 5 years.
- The GOOS Biology and Ecosystems Panel (which should include modelling representatives), devise a list of 'backbone' measurements in general, and when feasible, useful for indicators and able to be synthesised and fed into regional models, and which could be fed into global models. For each eEOV, it would be useful to devise a list of the most important measurements that would inform biological observations (e.g.'collect at any cost' or 'absolutely fundamental measurements').
- *The issue of "backbone measurements" is critical to any GOOS biology. The GOOS Biology Panel should come up with a list of the most important measurements that would inform biological observations. This would be the collect at any cost or absolutely fundamental measurements. Something that is required for all eEOVs.*
- The GOOS Biology and Ecosystems Panel consults with the GRA Chair and National Observing System representatives to discuss longer-term design of observation infrastructure, taking into account eEOV data required for modelling ocean ecosystem state/change.
- Once formed the GOOS Biology and Ecosystems Panel should consider:
    - Dates are selected for writing workshops (for funding applications and pilot projects)
    - A Review of Pilot Projects is conducted in 2-3 years.
    - The development of an eEOV Template in alignment with the templates being prepared for the GOOS Physics and Biogeochemistry Panels.

    - How to link with and collaborate with the relevant activities of PICO, GEOWOW, GEOBON (marine EBVs), SOOS (for Southern Ocean eEOVs) and also the Canadian Government (for Arctic EOVs), and the investigation by GEOBON on the adequacy of observation systems to support the CBD Aichi 2020 Targets [6]. Collaboration with these initiatives will strengthen the imperatives to set up relevant ecosystem EOV monitoring infrastructure, reduce duplication of effort and improve opportunities for funding.
    - Collaborate with IODE/OBIS in establishing open access data system infrastructures, and developing standards, guidelines/best practices and training in data management (collection, processing, describing, quality control, storing and redistribution/publishing/sharing).
    - Investigate the relevant conventions/frameworks that provide the basis for developing eEOVs. With this knowledge, target specific funding avenues that may support the development of particular eEOVs.
    - A sub panel of GOOS Biology and Ecosystems Panel to peruse known National State of Environment Reports, and contact the facilitators of the World Ocean Assessment to discuss the relevant data already collected (and still required) to inform societal issues.
- The GOOS Biology and Ecosystems Panel Chair maintains close communication with the Chairs of the GOOS Physics and Biogeochemistry Panels to ensure harmonized development of eEOVs and an integrated observing system.

APPENDIX 1: WORKSHOP AGENDA

JOINT WORKSHOP OF TECHNICAL EXPERTS FOR THE IDENTIFICATION OF ECOSYSTEM ESSENTIAL OCEAN VARIABLES

SPONSORS: GEOWOW & GOOS (BIOLOGY AND BIOGEOCHEMISTRY PANELS)

Wednesday to Friday, November 13 -15, 2013

At the Australian Institute of Marine Science (AIMS) Laboratories at Cape Cleveland

Townsville, Australia

Optional Extra: Fieldtrip to the Great Barrier Reef, Saturday November 16, 2013.

This Workshop is jointly funded by the European Commission's FP7 GEOWOW Project, IOC/UNESCO and the Australian Government.

Wednesday, 13 November

08:00 – 10:30 Opening - Joint Session

- **INTRODUCTION/ WELCOME / EXPECTATIONS** [Albert Fischer (GOOS Secretariat/ GEOWOW); Toste Tanhua (Chair, GOOS Biogeochem Panel) and, Ian Poiner (Chair GOOS Biology and Ecosystems)]
- **CONTEXT - SETTING THE SCENE** [John Gunn – Co-Chair, GOOS Steering Committee; and Albert Fischer] :
  - GOOS/ FOO/ OOPC/ EOVs/ Readiness/ New GOOS Biology and Ecosystems and Biogeochemistry Panels / Pilot Projects + GOOS Regional Alliances / Coastal and Open Ocean/ PICO Plan /International Conventions and Assessments needing sustained ocean observations/ Modelling Needs / GEOWOW, GEO and GEOSS.
- **INTRODUCTION FROM EACH PARTICIPANT** – their role, their research and how it may fit in

10:30 – 11:00 Coffee Break

11:00 – 12:30 Joint Discussion Items

- **CONTEXT – INTRODUCING THE KEY CONCEPTS UNDERPINNING THE WORKSHOP** (which will be explored further in separate Panel sessions)
  - Essential Climate Variables/ Essential Biodiversity Variables – Introduce the concept of requirement driven design of the observing system, guiding the selection of EOVs. [John Gunn / OOPC?]
  - Biology Ecosystem Synthesis Report – brief summary of findings [Dave McKinnon, AIMS]
  - Biogeochemistry Synthesis Report – brief summary of findings [Maciej Telszewski, IOCCP]
  - What are the main scientific questions (or answers) that will provide significant scientific benefit / address societal challenges (that require sustained global ocean observations of biogeochemical and biological variables?) [As background for each Panel to devise a list of requirements eg societal or science driven questions that need sustained monitoring of EOVs to answer].
  - What long term global biology, biogeochemistry and observation systems are already in place, what variables do they measure and why do we need these variables? [keeping in mind the question – **why do we need a time series on EOVs ?**]
  - Global, regional and local existing data systems and information products.

12:30 – 13:30 Lunch [+ National Sea Simulator (Group 1)]

13:30 – 15.30 BGC Panel Separate Session 1 - Defining Requirements / Needs

- Define the **societal needs** for ocean biogeochemical observations (motivate why we should spend time and money on measuring these variables for decades), e.g. climate change, fisheries , health of ecosystems, healthy ocean, tourism, transport etc.
- Define the **science needs** for ocean biogeochemical observations.
- Define requirements for EOVs based on societal and science needs. Come up with a list of requirements, i.e. societal or science driven questions that needs sustained monitoring of biogeochemical variables to answer.

13:30 – 15.30 Biology Panel Separate Session 1 - Defining Requirements / Needs

- Understanding what we are trying to achieve – planned outcomes from the Workshop:
    - List of major societal challenges and scientific questions requiring sustained global observations of ocean biological variables.
    - Define and prioritise EOVs including measurement requirements (frequency and resolution)
    - Evaluation of 'readiness' of observation systems.
    - For each EOV – what is required to improve current observations?
    - Priority list of potential observation systems for ecosystem EOVs.
    - Candidate pilot projects.

Requirements:

- State of knowledge - Biology Ecosystem Synthesis Report – presentation of findings [Dave McKinnon]
- Define the societal needs for biology/ecosystem observations (why we should spend time and money on measuring these variables for decades), e.g. climate change, fisheries, health of ecosystems, healthy ocean, industry (e.g. tourism, transport etc).
- Define requirements for EOVs based on societal and science needs. Come up with a list of requirements, i.e. societal or science driven questions that needs sustained monitoring of biogeochemical variables to answer.
- What are the types of variables needed for modelling [Andrew Constable ACE CRC]
- What long term global/regional biology observation systems are already in place, what variables do they measure and why?

15:30 – 16:00 Coffee break

16:00 – 18:00 BGC Panel Separate Session 2 - Defining Requirements / Needs - Continued….

16:00 – 18:00 Biology Panel Separate Session 2 - Defining Requirements / Needs - Continued….

- Including initial prioritisation of requirements and define the EOVs that are needed (1st cut)

19:00 Group Dinner – On-site provided by AIMS

Thursday, 14 November 2013

08:00 – 8.30 Recap of Day 1 - Joint Discussion/ Cross-Fertilization

08.30 - 10:30 BGC Panel Separate Session 3 - Defining EOVs 1st Take

- What are the types of variables needed for modelling [Modellers to lead a discussion].
- Go through the requirements and define EOVs that are needed for those.

08.30 - 10:30 Biology Panel Separate Session 3 - Defining EOVs 1st Take

- Priority list of requirements and define the EOVs that are needed taking into consideration:
  - Redundancies; and,
  - Likely spatial and temporal resolution.
- EOV observational requirements and an assessment of existing observing system.
- Review the agreed list of EOVs and define spatial and temporal resolution observational requirements.
  - E.g. Spatial resolution: Surface or interior ocean? Coastal or open ocean? At what spatial resolution in those realms?
  - Temporal resolution: Decadal, annual, seasonal, weekly, diurnal?
  - Accuracy and/or precision requirements.
- Ensure the temporal and spatial resolution needs to be tied to the requirements already defined.
- Existing long term global/regional biology observation systems – can they meet any of the identified requirements?
- Evaluate the 'readiness' to observe each EOV and recommendations for improvement and/or development.

10:30 – 11:00 Coffee Break

11:00 – 12:30 BGC Panel Separate Session 4 – Priority EOVs

- Assess the EOVs identified. Reduce redundant ones. Make sure EOV spatial and temporal resolution requirements are really needed. Produce a slim list of EOVs, without missing important variables capable of monitoring important processes or trends.

11:00 – 12:30 Biology Panel Separate Session 4 - Priority EOVs

- Priority list of requirements and define the EOVs that are needed taking into consideration:
  - Redundancies; and,
  - Likely spatial and temporal resolution.

12:30 – 13:30 Lunch [+ National Sea Simulator (Group 2)]

13:30 – 15:30 BGC Panel Separate Session 5 - EOV Observational Requirements, and assessment of existing observing systems

"Readiness table"

Go through the identified EOVs and define spatial and temporal resolution requirements.

- Spatial resolution: Surface or interior ocean? Coastal or open ocean. At what spatial resolution in those realms?
- Temporal resolution: Decadal, annual, seasonal, weekly, diurnal?
- Accuracy and/or precision requirements.

The temporal and spatial resolution needs to be tied to the requirements already defined.

Draw on already formulated resolution requirements from existing program plans, e.g. GO-SHIP, Oxygen on Argo, SOCAT

13:30 – 15:30 Biology Panel Separate Session 5 –'Readiness'

- EOV observational requirements and an assessment of existing observing system.
- Review the agreed list of EOVs and define spatial and temporal resolution observational requirements.
    - E.g. Spatial resolution: Surface or interior ocean? Coastal or open ocean. At what spatial resolution in those realms?
    - Temporal resolution: Decadal, annual, seasonal, weekly, diurnal?
    - Accuracy and/or precision requirements.
- Ensure the temporal and spatial resolution needs to be tied to the requirements already defined.
- Existing long term global/regional biology observation systems – can they meet any of the identified requirements?
- Evaluate the 'readiness' to observe each EOV and recommendations for improvement and/or development.

15:30 – 16:00 Coffee break

16:00 – 18:00 BGC Panel Separate Session 6 - EOV Observational Requirements, and assessment of existing observing systems – Continued…..

16:00 – 18:00 Biology Panel Separate Session 6 - Review of EOVs, Readiness and existing observing system.

- Finalise the "Readiness table" - for each EOV agree on:
    - the 'readiness' of observation systems
    - what is required to improve current observations.
    - priority list of potential observation systems for ecosystem EOVs

19:00 Group Dinner – On-site provided by AIMS

Friday, 15 November 2013

08:00 – 8.30 Recap of Day 2 - Joint Discussion / Cross-Fertilization

08:30 – 10:30 BGC Panel Separate Session 7 - Reduction of the number of EOVs

- Assess the EOVs identified. Reduce redundant ones. Make sure EOV spatial and temporal resolution requirements are really needed. We want to produce a slim list of EOVs, without missing important variables capable of monitoring important processes or trends.

08:30 – 10:30 Biology Panel Separate Session 7 – Review of EOVs, Readiness and existing observing systems – Continued….

10:30 – 11:00 Coffee Break

11:00 – 12:30 BGC Panel Separate Session 8 – Pilot Projects

- Potential pilot projects – based on the devised list of priority EOVs, what already exists (eg readiness of observation systems, GRA networks) and what monitoring systems could be established if there was funding?
- Selection of proposals based on the priority candidate EOVs and potential pilot projects.

11:00 – 12:30 Biology Panel Separate Session 8 – Pilot Projects

- Potential pilot projects – based on the devised list of priority EOVs, what already exists (eg readiness of observation systems, GRA networks) and what monitoring systems could be established if there was funding?
- Selection of proposals based on the priority candidate EOVs and potential pilot projects.

12:30 – 13:30 Lunch [+ National Sea Simulator (Group 3)]

13:30 – 15.30 Joint Discussions on Identified EOVS from each Panel

- Sharing the list of EOVs between Panels
- Sharing the ideas for Pilot Projects between Panels
- Discussion on overlap, synergy, redundancy etc.

15:30 – 16:00 Coffee break

16:00 – 18:00 Joint Session - Workshop Summary and Further Steps

- Discussion on overlap, synergy, redundancy, feasibility etc.
- Formulate a 10 year plan for the two GOOS Panels (envisioning a 70% cut in funding, or a 500% increase).
- Funding Discussion to implement the proposed Panel activities: what funding is available, and what are the potential funding bodies/rounds to approach for the funding of the potential proposals based on the list of Candidate EOVs and Pilot Projects.
- Writing the Workshop Report – next steps and due date.
- Next Panel Meetings?

19:00 Group Dinner – On-site provided by AIMS

ANTICIPATED WORKSHOP OUTCOME

For GOOS Biogeochemistry Panel

- Define Essential Ocean Variables (EOVs) for biogeochemistry.
- Define societal relevance for ocean biogeochemical observations (motivate why we should spend time and money on measuring these variables for decades).
- Define requirements for frequency and resolution of measurements.
- Present a list of EOVs appropriate for each of the frequency and resolution requirement. These lists can have different EOVs, and specify different accuracy demands.
- Define the state of readiness for EOVs on the various frequency and resolution levels. Matrix of readiness for all EOVs and frequency and resolution; requirements, observations, data streams.
- Recommendation for each EOV / level on how to improve the observational network from the current state.

For GOOS Biology and Ecosystems Panel

- A Report stating:
- List of major societal challenges and scientific questions requiring sustained global observations of ocean biological and biogeochemical variables,
- Priority List of ecosystem EOVs prepared for GEOWOW and GOOS,
- Evaluation of 'readiness' of observation systems
- Priority list of potential observation systems for ecosystem EOVs,
- Candidate pilot projects (at least 3);
- Identified funding opportunities;
- Identified pilot projects for endorsement by the GOOS Steering Committee; and
- Nominations for GOOS Biology and Ecosystems Panel Members / potential Date for a Panel Meeting; and
- Identification of dates for 'writing workshops' for writing the funding proposals for the pilot projects.

FIELDTRIPS

The Workshop will be held at the AIMS in Townsville over 3 days. One afternoon and in between the Agenda items, there will be a **mini tour of the AIMS Laboratories at Cape Cleveland including the recently commissioned National Sea Simulator.** In addition, for those staying beyond the Workshop, there will be an optional **tour to the Great Barrier Reef on Saturday November 16 (weather dependent).**

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APPENDIX 3: EOV LITERATURE SUMMARY (MCKINNON 2013)

CANDIDATE ESSENTIAL OCEAN VARIABLES

FOR GOOS *BIOLOGY AND ECOSYSTEMS*

AND GOOS *BIOGEOCHEMISTRY*

A discussion paper

for the

First Joint Workshop of Technical Experts

For the Identification of Ecosystem Ocean Variables

13-15 November 2013

Townsville

Australia

David McKinnon

Australian Institute of Marine Science

5 November 2013

About this document

This document is an attempt to collate what has already been done to help participants address the following:

Problem: The degradation of coastal habitats, pollution, over-exploitation of fisheries, biodiversity decline, bleached and dying coral reefs, receding polar ice sheets, sea level rise, and ocean acidification are all raising awareness and concern among the public and policymakers, and threaten the well-being of the great numbers of the human population (over 40%) that live in coastal areas worldwide. There is a growing need for more systematic ocean information at local, national, regional, and global scales to support efforts to manage our relationship with the ocean. (Lindstrom et al. 2012)

Vision: Provision of routine and sustained global information on the marine environment sufficient to meet society's needs for describing, understanding and forecasting ***marine variability*** *(including physical, biogeochemical, ecosystems and* ***living marine resources****), weather, seasonal to decadal climate variability, climate change,* ***sustainable management of living marine resources****, and assessment of* ***longer term trends****.* (from The OceanObs'09 conference vision)

Goal: To identify candidate ecosystem and biogeochemical Essential Ocean Variables (EOVs)

These will include essential biological variables, essential ecosystem variables, and essential biogeochemistry variables.

Method: Potential EOV's should be evaluated on the basis of the GOOS Framework for Ocean Observing (**FOO**) http://www.oceanobs09.net/foo/ (Lindstrom et al. 2012)

Welcome to a Pantheon of Acronyms!

The FOO document lists 82 acronyms, but here are the ones you need to get started:

GEOWOW: Group on Earth Observations (GEO) started implementing the Global Earth Observation System of Systems (GEOSS). GEOWOW, is short for "GEOSS interoperability for Weather, Ocean and Water".

PICO: Panel for Integrated Coastal Observations, part of the GOOS Scientific Steering Committee.

GEOBON: Group on Earth Observations (GEO) Biodiversity Observation Network (BON) **.**

IOCCP: International Ocean Carbon Coordination Project.

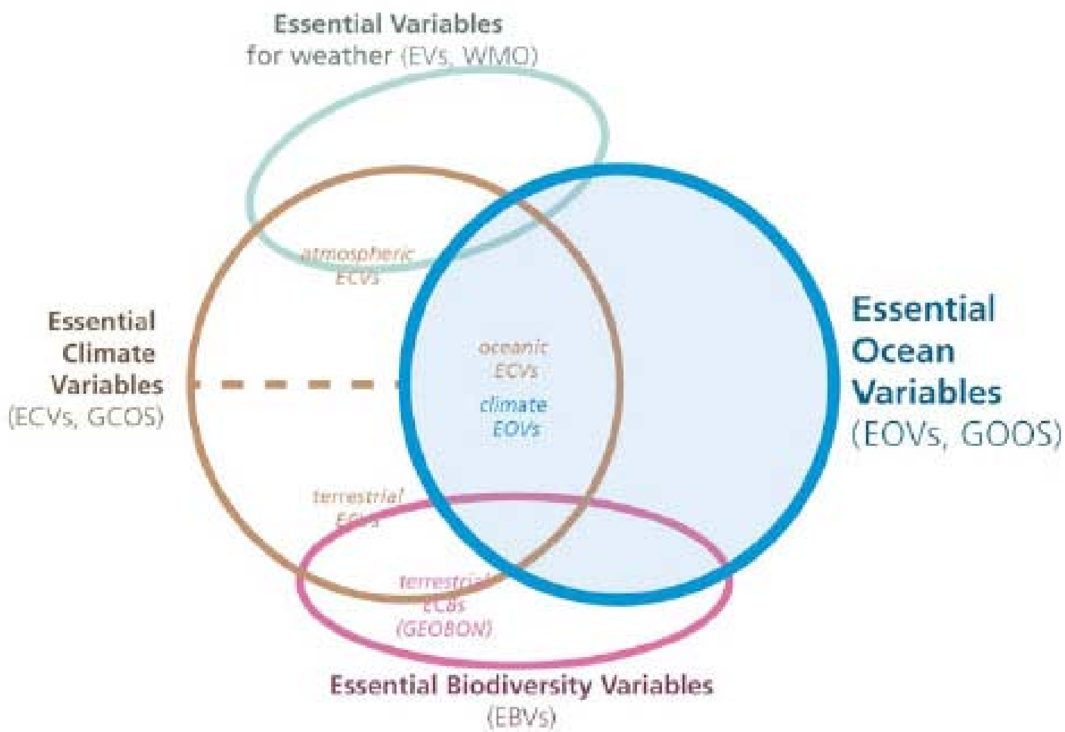
Table of Contents

What is an Essential Ocean Variable?

GEOWOW-WP6-IOU-16.1.1 *"Definition of ecosystem Essential Ocean Variables"* lays the framework for identification of EOV's, summarised below:

An **Essential Ocean Variable** (EOV) is a concept adopted by the **Global Ocean Observing System** (GOOS) to organize and describe ocean variables that have a high feasibility of sustained observation, and high impact in responding to stated scientific and societal issues.

EOV's overlap with Essential weather variables, essential climate variables, and essential biodiversity variables as shown in the following diagram (from GEOWOW-WP6-IOU-16.1.1):



EOV's Physical include water temperature/ocean heat content, water temperature stratification, sea ice, salinity, currents, surface wave height and direction, absolute sea level, shoreline position, bathymetry, total suspended matter, seamounts.

EOV's Chemical includes dissolved inorganic nutrient concentration, dissolved oxygen, pH, fCO2 & total alkalinity, coloured dissolved organic matter.

Societal Benefit Areas

The Framework for Ocean Observing emphasises that EOV's should be selected on the basis of scientific and societal issues.

GEOWOW identified the following GEO **Societal Benefit Areas**, here tabulated with respect to their relevance to different ocean biomes.

SBA's	Coastal	Pelagic Ocean	Benthic Ocean
Coastal eutrophication and hypoxia	x	x	
Human exposure to water-borne infections and microbes	x		
Toxic Harmful algal blooms	x	?	
Loss and modification of biologically structured benthic habitats	x		x
Distribution and condition of calcareous organisms affected by ocean acidification	x	x	?
Abundance of exploitable fish stocks related to food security	x	x	x
Understanding the impact of anthropogenic global change on ocean ecosystems and ecosystem services	x	x	x
Management and policy responses	x	x	x

GEOWOW Biological EOV’s

GEOWOW 16.1.1* “Definition of ecosystem essential ocean variables” presented a full interpretation of societal needs and of the process for the identification of these based on the intersection of ocean domains and human systems. In that document, Biological EOV’s, were tabulated by relevance to open ocean or coastal, and to **GEO Societal Benefit Areas** (SBA’s):

- Eutrophication and hypoxia (Ecosystems, agriculture and biodiversity)
- human exposure to pathogens (health)
- harmful algal blooms (health)
- habitat loss and modification (ecosystems and biodiversity)
- vulnerability to coastal flooding (disaster)
- ocean acidification (ecosystems and biodiversity)
- food security (agriculture)
- understanding impact of anthropogenic change on ecosystem services (ecosystems, biodiversity, agriculture, climate)

The Candidate EOV’s Biological were:

1. Phytoplankton (pigments and size)
2. Primary productivity / phytoplankton biomass (chl-a)
3. Toxic phytoplankton abundance
4. Calcareous phytoplankton abundance
5. Diatoms/non-diatom ratio
6. Abundance of copepod indicator species
7. Abundance of waterborne pathogens
8. Bacterial communities
9. Zooplankton (abundance, size structure, composition and timing)
10. Extent of living benthic habitats
11. Species diversity of communites associated with living benthic habitats
12. Coral skeletal density
13. Abundance of eggs, larvae and size classes of exploited fish stocks
14. Fish stocks
15. Bycatch
16. Diet of exploitable fish species
17. Abundance and size of apex predators
18. Food webs and trophic changes
19. Geographic distribution of taxa (biodiversity)

*http://www.geowow.eu/resources/deliverables/GEOWOW-WP6-IOU-I6.1.1-v1.0.pdf

Panel for Integrated Coastal Ocean Observations (PICO) EOV's

Ecosystem-based approaches (EBA's) to sustainable development require:

1. frequent, routine and integrated ecosystem assessment (IEAs)
2. continuous provision of data and information on meteorological, geophysical, biogeochemical and biological states (indicators) needed for timely IEAs that inform decision makers.

Priority indicators of ecosystem states (health):

1. Surface phytoplankton biomass and subsurface oxygen fields
2. Distribution and abundance of waterborne pathogens and toxic phytoplankton,
3. Spatial extent of living benthic habitats (coral reefs, seagrass beds, mangrove forests and tidal marshes) and ecological buffers to coastal flooding,
4. Distribution and condition of calcareous organisms (cold and warm water corals, coccolithophores and pteropods)
5. Distribution and abundance of exploitable fish stocks.

Monitoring needs to include external pressures and ecosystem states. Of the latter, **the biological states are**:

1. phytoplankton biomass
2. toxic phytoplankton
3. waterborne pathogens
4. calcareous plankton
5. copepod indicator species
6. fish eggs and larvae
7. extent of living benthic habitats
8. coral skeletal density
9. species diversity
10. abundance and diet of exploitable fish stocks
11. bycatch
12. abundance and size of apex predators

this from page ix of executive summary

Convergence of Biological EOV's selected by PICO and GEOWOW

The FOO task team recommended that the development of EOVs for biogeochemical and ecosystem variables build upon the work of IOCCP and PICO to mediate among observing networks and determine an agreed-to set of EOVs.

For groups of organisms that may form observation units for EOV's, I have adopted the Canadian terminology "Focal Ecosystem Component" (DFO 2012).

Focal Ecosystem Component	PICO	GEOWOW
Bacteria		Bacterial communities
	Waterborne pathogens	Abundance of waterborne pathogens
Phytoplankton	Phytoplankton biomass	Phytoplankton (pigments and size)
		Primary productivity / phytoplankton biomass (chl-a)
	Toxic phytoplankton	Toxic phytoplankton abundance
		Diatoms/non-diatom ratio
	Calcareous plankton	Calcareous phytoplankton abundance
Zooplankton	Copepod indicator species	Abundance of copepod indicator species
	Fish eggs and larvae	Abundance of eggs, larvae and size classes of exploited fish stocks
		Zooplankton (abundance, size structure, composition and timing)
Benthos	Extent of living benthic habitats	Extent of living benthic habitats
	Species diversity	Species diversity of communities associated with living benthic habitats
	Coral skeletal density	Coral skeletal density
Fish & Fisheries	Abundance and diet of exploitable fish stocks	Diet of exploitable fish species
		Fish stocks
	Bycatch	Bycatch
	Abundance and size of apex predators	Abundance and size of apex predators

Ecosystem		Food webs and trophic changes
		Geographic distribution of taxa (biodiversity)

Summary of FOO Analysis of Focal Ecosystem Components (from Page 25)

This is intended as a framework for discussion only.

Focal Ecosystem Component	Requirements			Observations	Data & Products
	Biodiversity	Ecosystem Structure	Ecosystem Function		
Microbes & Phyto-plankton	Genetic structure, pathogens, calcareous phytoplankton	Microbial function, Phytoplanton biomass, size structure and composition	Primary Production. Biogeochemical processes for models	Satellite imagery, Molecular and flow cytometric observations required	Ocean colour NPZ and biogeo-chemical models
Zooplankton	Species composition, Indicator species	Size structure, Community structure, including jellies.	Microbial vs "Classical" food chains	CPR program, development of new tools required to span all the pelagic	GACS COPEPOD
Shallow Benthos	Benthic cover, species composition	Removal of species by human activities	Resilience	Composition and condition of benthos	Local databases, but no global co-ordination
Deep Benthos	Recognized as very high diversity, but poorly known	Poorly known	Driven by Chemo-synthesis and detrital fall. Poorly understood, but characterised by episodic events linked to surface layers.	ROV's and some cabled observatories.	Not yet standardized or integrated.
Fish & Fisheries	Fisheries supported by biodiversity, and negatively affected when biodiversity is lost.	Stock structure important for management.	Debate over removal of specific trophic levels.	Still need to determine the most appropriate indices to monitor fishing effects.	Many global databases.
Ecosystem	Biodiversity not completely documented – apex predators may be indicators.	Changes in community size spectrum	Implications of warming, acidification and deoxygenation on ecosystem energetics	Need indices of vigor, organisation and resilience.	Regional databases and global LME's.

Observing Biodiversity

GEOBON (Group on Earth Observations (GEO) Biodiversity Observation Network (BON)), define the term "Essential Biodiversity Variables" (http://www.earthobservations.org/geobon_ebv.shtml, and reported in Pereira et al. 2013 (*Science* 339:277-278). **Essential Biodiversity Variables** (EBVs) are measurements required for study, reporting, and management of biodiversity change. These EBV's *are general enough for use across taxa and terrestrial, freshwater and marine realms* i.e. **are not restricted to marine**.

EBVs facilitate the harmonization of existing monitoring schemes and guide the implementation of new monitoring schemes, especially in gap areas where information on biodiversity change is still very sparse. Examples of essential variables are the allelic diversity of selected wild and domestic species, the population abundances for groups of species representative of some taxa (e.g. birds), the three-dimensional structure of habitats, and the nutrient retention rate in sensitive ecosystems. These variables can be measured or modelled globally, by combining satellite remote sensing observations with local observations obtained by citizens, scientists, and local, national and regional organizations. EBVs are crucial for robust estimation of the indicators to assess progress towards the 2020 targets of the **Convention on Biological Diversity**. They can also provide the foundation for developing scenarios of the future of biodiversity under different policy and management options. http://www.earthobservations.org/geobon.shtml

- EBVs are sensitive to change over time
- EBVs are focused on 'state' variables
- EBVs are defined at a level of specificity intermediate between that of low-level (primary) observations and high-level indicators of biodiversity change
- EBVs should be of relevance to the broader biodiversity community (incl. scientists/researchers, governments, decision/policy makers, assessment bodies, conservation professionals and conventions)
- EBVs should be feasible in terms of monitoring (e.g. if the technology for monitoring it is unlikely to be available in the near future, the EBV isn't feasible)"

These overarching principles for the selection of GEOBON's "essential biodiversity variables" may equally well apply to our search for EOV's

Pereira et al. (2013) refine that definition to: *We define an EBV as a measurement required for study, reporting and management of biodiversity change. The EBV framework emphasises repeated measurements for the same taxa at the same locations or regions at short time intervals, rather than a species inventory*

With this approach, GEOBON steers away from community indicators and toward selecting key species for continuous monitoring. Can we identify keystone species in the marine environment?

approach.

Observing Biogeochemical Cycles

The IOCCP (International Ocean Carbon Coordination Project) aims to establish a sustained global observation network for marine biogeochemistry. Activities include:

1. **Underway CO_2 observations -** for the past several decades, surface water partial pressure of carbon dioxide (pCO_2) has been measured from research and volunteer observing ships (VOS) to quantify the spatial and temporal (seasonal, inter-annual, decadal) patterns of carbon uptake and release.
2. **GO-SHIP** (Global Ocean Ship-based Hydrographic Investigations Program) which aims to develop a globally coordinated network of sustained hydrographic sections as part of the global ocean/climate observing system.
3. Time Series Efforts, which aim to develop a web-based global network of biogeochemical time-series.
4. Synthesis Activities, both for the surface ocean and the ocean interior, focussing on carbon-relevant data.
5. **Ocean Acidification, toward the development of a Global Ocean Acidification Observing Network** (GOA-ON), in strong collaboration with the NOAA Ocean Acidification Program, the Global Ocean Observing System, the Ocean Acidification International Coordination Center and other institutional and programmatic partners worldwide.
6. Nutrients, toward establishing comparable and accurate nutrient data globally.
7. Oxygen (in development)
8. Data management of ocean carbon observations
9. Facilitating sensor development.

Claustre et al. (2010) list the core "bio-variables" needed for ecosystems and biogeochemical cycles, primarily selected because they are amenable to non-intrusive and automatic measurement:

1. **Nitrate**
2. **Oxygen**
3. **Variables of the CO2 system**
4. **Chlorophyll a**
5. **Optically resolved Particulate Organic Carbon**
6. **Plankton or particulate functional types**

The platforms for these measurements potentially include Bio-profiling floats, Bio-gliders, animal based sampling platforms, ship-based, fixed-point (Eulerian) time-series, and remotely sensed variables such as ocean colour.

Biogeochemical data can be assimilated into operational models such as Dynamic Green Ocean Models (le Quere and Harrison 2005). This modelling approach is being progressed by the Marine Ecosystem Model Intercomparison Project (MAREMIP: http://pft.ees.hokudai.ac.jp/maremip/index.shtml). These models use "Plankton Functional Types (PFT's)" requiring a wide range of observations. Ten PFTs have been identified that need to be simulated explicitly in order to capture important biogeochemical processes in the ocean:

1. Pico-heterotrophs (bacteria that remineralise dissolved and particulate organic matter)
2. Pico-autotrophs (bacteria that contribute to primary production but not to export of carbon)
3. N2-fixers (bacteria that control the total amount of reactive N)
4. Calcifying phytoplankton (produce more than half the marine carbonate flux, sensitive to pH)
5. DMS-producing phytoplankton (influence atmospheric sulphur cycle)
6. Mixed phytoplankton (the background biomass of phytoplankton)
7. Silicifiers (phytoplankton that contribute to export of carbon to deep ocean)
8. Protozooplankton (graze on small phytoplankton, control blooms)
9. Mesozooplankton (graze on all sizes of plankton, produce fast-sinking faecal pellets which export carbon)
10. Macrozooplankton (graze on all sizes of phyto-plankton and produce fast-sinking faecal pellets)

Marine Monitoring Programs and Observatories

This section reviews some of the recent reports that synthesise information on monitoring programs established in various countries of the world, with emphasis on the variables that have been selected as meaningful for detecting change in marine ecosystem status or biodiversity. Though not specifically oriented toward EOV's, the monitoring variables established may be candidates.

Coral Reefs

Goal **The International Coral Reef Initiative** of 1995 called on nations to commit to increasing research and monitoring of coral reefs in order to provide the data needed to inform policies of nations to sustain coral reefs and to strengthen management. The **Global Coral Reef Monitoring Network** (GCRMN) was established to support ICRI's Call to Action and Framework for Action.

Approach The GCRMN works through a global network of stakeholders to support management and conservation of coral reefs, and is focused on strengthening understanding of status and trends of coral reefs, and strengthening communication and capacity. The GCRMN publishes periodic reports on the coral reefs of the world, the last of which was published in 2008. In addition, **ReefBase** http://www.reefbase.org/main.aspx acts as a data repository for information on location, status, threats, monitoring and management of coral reefs in over 120 countries.

Live coral cover is the primary metric reported for coral reefs, and is certainly a potential EOV. Data on reef fish, reef fisheries and biodiversity (numbers of species, species lists) are also available.

Europe

Goal To establish and implement coordinated monitoring programmes in order to assess the environmental status of marine waters.

Approach The **Marine Strategy Framework Directive** (MSFD: 2008/56/EC) requires that Member States take measures to achieve or maintain Good Environmental Status (GES) by 2020. However, EU legislation has already established a number of monitoring frameworks. The MSFD aims to ensure consistency, coherence and comparability within marine regions and subregions by coordination of monitoring methods in the framework of Regional Seas Conventions, staking also into account transboundary features and impacts. **OSPAR** (Oslo and Paris Conventions for the protection of the marine environment of the North-East Atlantic), **HELCOM** (Helsinki Commission: Baltic Marine Environment Protection Commission), **Barcelona Convention – Mediterranean Action Plan**, **Bucharest Convention – Black Sea Commission** are all Regional Seas Conventions covering European Seas.

EUR 25187 EN (http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/23169/1/lbna25187enn.pdf) compares monitoring requirements of the following EU legislation:

Acronym	Policy Directive

MSFD	Marine Strategy Framework Directive
WFD	Water Framework Directive
EQS	Environmental Quality Standards Directive
HD	Habitats Directive
BD	Birds Directive
CFP	Common Fisheries Policy

Biological Monitoring Parameters of the MSFD and WFD compared.

MSFD Annex III	WFD
Angiosperms biomass and its annual/seasonal variability	Angiosperms abundance
Angiosperms species composition and its annual/seasonal variability	Angiosperms composition Angiosperms cover Angiosperms depth distribution Angiosperms presence of sensitive taxa
Fish abundance	
Fish age / size structure	
Fish distribution	
Genetically distinct forms of native species abundance	
Genetically distinct forms of native species occurrence	
Genetically distinct forms of native species spatial	
Habitats'(predominant, special, protected and endangered) characteristics	
Introduction of microbial pathogens	
Introduction of non□indigenous	
Invertebrate bottom fauna biomass and its annual/seasonal variability	Benthic Invertebrate fauna – presence of sensitive taxa Benthic invertebrate fauna abundance
Invertebrate bottom fauna species composition and its annual/seasonal variability	Benthic invertebrate fauna composition Benthic invertebrate fauna diversity

Macro□algae biomass	Macro-algae abundance Macro-algae cover Macro-algae depth distribution
Macro□algae species composition	Macro□algae species composition Macro-algae presence of sensitive taxa
Marine mammals actual range	
Marine mammals natural range	
Marine mammals population dynamics	
Marine mammals status	
Non□indigenous or exotic species abundance	
Non□indigenous or exotic species occurrence	
Non□indigenous or exotic species spatial distribution	
Other protected species actual range	
Other protected species natural range	
Other protected species population dynamics	
Other protected species status	
Phytoplankton species compositions and its geographical and seasonal variability	Phytoplankton abundance Phytoplankton biomass Phytoplankton bloom frequency/intensity
Reptiles actual range	
Reptiles natural range	
Reptiles population dynamics	
Reptiles status	
Seabirds actual range	
Seabirds natural range	
Seabirds population dynamics	
Seabirds species’ status	
Selective extraction of species	
Translocations of non□indigenous species	
Zooplankton species compositions and its geographical and seasonal variability	

Biological effects of contaminants

The **EQS** addresses only synthetic and non-synthetic pollutants. The **HD** addresses habitat types and plant and animal species of “community interest”, and appears therefore to be more oriented toward terrestrial habitats. Similarly, the BD is only of limited application to marine environments, though most points relating to threatened species are included in MSFD. The **CFP** includes 26 fisheries parameters; there is little overlap, and only 4 of the MSFP parameters apply.

The OSPAR approach

The OSPAR Convention is the current legal instrument guiding international cooperation on the protection of the marine environment of the North-East Atlantic. Work under the Convention is managed by the OSPAR Commission, made up of representatives of the Governments of 15 Contracting Parties and the European Commission, representing the European Union.

Abbreviations and categories of the 33 proposed biodiversity OSPAR “common indicators” that were described in the ICG-COBAM (Intersessional Correspondence Group - Coordination of Biodiversity Assessment and Monitoring) **Part C: Technical Specifications document available to WGBIODIV (ICES Working Group on Biodiversity Science).**
Mammals
M-1 Distributional range and pattern of grey and harbour seal haul-outs and breeding colonies
M-2 Distributional range and pattern of cetaceans species regularly present
M-3 Abundance of grey and harbour seal at haul-out sites
M-4 Abundance at the relevant temporal scale of cetacean species regularly present
M-5 Harbour seal and Grey seal pup production
M-6 Numbers of individuals within species being taken as bycatch in relation to population
Marine birds
Species-specific trends in relative abundance of non-breeding and breeding
B-1 marine bird species
B-2 Annual breeding success of kittiwake
B-3 Breeding success/failure of marine birds
B-4 Non-native/invasive mammal presence on island seabird colonies
B-5 Mortality of marine birds from fishing (bycatch) and aquaculture
B-6 Distributional pattern of breeding and non-breeding marine birds

Fish and cephalopods
FC-1 Population abundance/ biomass of a suite of selected species
FC-2 OSPAR EcoQO for proportion of large fish (LFI)
FC-3 Mean maximum length of demersal fish and elasmobranchs
FC-4 Bycatch rates of Chondrichthyes
Benthic habitat
BH-1 Typical species composition
BH-2 Multimetric indices
BH-3 Physical damage of predominant and special habitats
BH-4 Area of habitat loss
BH-5 Size-frequency distribution of bivalve or other sensitive/indicator species
Pelagic habitat
PH-1 Changes of plankton functional types (life form) index Ratio
PH-2 Plankton biomass and/or abundance
PH-3 Changes in biodiversity index (s)
Foodwebs
FW-1 Reproductive success of marine birds in relation to food availability
FW-2 Production of phytoplankton
FW-3 Size composition in fish communities (LFI)
FW-4 Changes in average trophic level of marine predators (cf MTI)
FW-5 Change of plankton functional types (life form) index Ratio
FW-6 Biomass, species composition and spatial distribution of zooplankton
FW-7 Fish biomass and abundance of dietary functional groups
FW-8 Changes in average faunal biomass per trophic level
FW-9 Ecological Network Analysis indicator (e.g. trophic efficiency, flow diversity)

**Helcom_coreset_biovariables.pdf (provided by Nic Hoepffner) compares Helcom biovariables to OSPAR. The Helcom list is shorter, and where variables align there have been minor edits to accommodate regionally specific fauna.*

Spain has recently implemented a sophisticated real-time observation system (Bahamon et al. 2011), primarily biogeochemical in nature.

Canada

Goal To detect and understand long-term change in Arctic marine ecosystems and key biodiversity elements to address the marine plan of the **Circumpolar Biodiversity Marine Program**. The intent is to develop and recommend a suite of indicators that can be used to monitor changes in Canadian Arctic biodiversity based on current or existing information and monitoring programs where possible.

Approach Indicators for a biodiversity monitoring program were chosen on the basis that they should be: 1) relevant, 2) simple and easily understood, 3) scientifically sound, 4) quantitative, and 5) cost effective (DFO 2012).

Focal Ecosystem Components (FECs) are biological categories of major importance to Arctic residents and/or considered central to the functioning of an ecosystem and likely to be good proxies of any changes in the environment. FEC categories will be monitored according to key biological parameters and indicators in the appropriate Arctic Marine Areas. Marine FEC categories are microbes, phytoplankton, ice flora, ice fauna, macroalgae, zooplankton, benthic meio- macro- and mega fauna, benthic/demersal fish, pelagic fish, seabirds and marine mammals.

Key biodiversity parameters and indicators were chosen for a number of FEC's.

Table 1: Key parameters and indicators for microbes, metazoan zooplankton and sympagics and the rationale for their use in Canadian marine biodiversity monitoring.

Key Parameter	Indicator	Rationale
Species Richness	• Number of species observed in a sample using taxonomic and/or molecular genetics • Diversity indices	• A measure of biodiversity • As new species are 'discovered' using new identification techniques, the list will continue to grow and therefore there may be a false impression of an increase in biodiversity
Abundance	• Abundances of key species and total abundance of key taxonomic or functional groups	• Abundance indicates standing stocks and is useful for comparing among years provided standard caveats are followed. These include time of year or stage of annual production cycle, depth or integrated depths of the samples
Biomass	• Biomass of key species • Total biomass of trophic levels, which provides a food web health indicator	• Same comments and caveats as for abundance, this can provide an overall indication of standing stock of different trophic levels
Community Composition	• Size composition (plankton and sea-ice biota) • Small versus large • Assemblage structure • Ratio diatoms/dinoflagellates • Ratio pennates/centrics • Ratio Arctic/sub-arctic species	• Proportion of species and population sizes relative to total within and among functional trophic levels in a given area
Biogeography	Loss of species or changes in relative dominance of species within geographical regions	• Biogeographical representation of key species or species complexes • Indicate changes in habitat type or structural properties
Boundary Shifts	• Presence of colonizers, vagrants, and invaders • Change in species range	• As the Arctic climate continues to change there will likely be shifts in species ranges

For benthos, corals and sponges and fishes similar core indicators (species richness, abundance, and biomasss) were adopted. Subsequent indicators for those groups differed, to include physiological stress, reproductive stress and anthropogenic disturbance in the case of corals and sponges, and health, condition and diet, habitat use, genetics, unusual events (e.g. die-offs), biogeography, and harvest statistics in the case of fishes. For seabirds, colony size, survivorship, reproductive success, chick diet, harvest statistics and phenology were selected as indicators.

Australia

IMOS Australia's Integrated Marine Observing System (IMOS) is designed to be a fully-integrated national array of observing equipment to monitor the open oceans and coastal marine environment around Australia, covering physical, chemical and biological variables. IMOS observations are guided by societal needs for improved ocean information, and focused through science planning undertaken collaboratively across the Australian marine and climate science community.

Goals

1. To provide sustained ocean observations that meet the broad needs of the Australian marine and climate research communities
2. To provide the marine and climate research community with free and timely access to quality assured observational data
3. To involve the marine and climate research community in defining future needs and to strengthen the technical and operational capability of the marine and climate community and hence sustain the ocean observing paradigm into the longer term.

Approach There are are five major research themes that unify IMOS science plans and related observations:

- Multi-decadal ocean change
- Climate variability and weather extremes
- Major boundary currents and interbasin flows
- Continental shelf processes
- Ecosystem responses.

Biological data for IMOS are collected via Ships of Opportunity (the **Australian Continuous Plankton Recorder Survey**), **Animal Tracking and Monitoring** and the **National Reference Stations** (of which there are currently 7 around the country). Chlorophyll is measured routinely in conjunction with technologies primarily designed for physical oceanography such as the use of gliders and floats.

In addition to a suite of physico-chemical variables, the National Reference Stations collect water samples for phytoplankton composition via pigment analysis, and zooplankton species composition. I believe that one or more has also trialled the collection of samples for microbial community analysis.

SOOS The Southern Ocean Observing System (SOOS) is an international initiative to enhance, coordinate and expand the strategic observations of the Southern Oceans that are required to address key scientific and societal challenges.

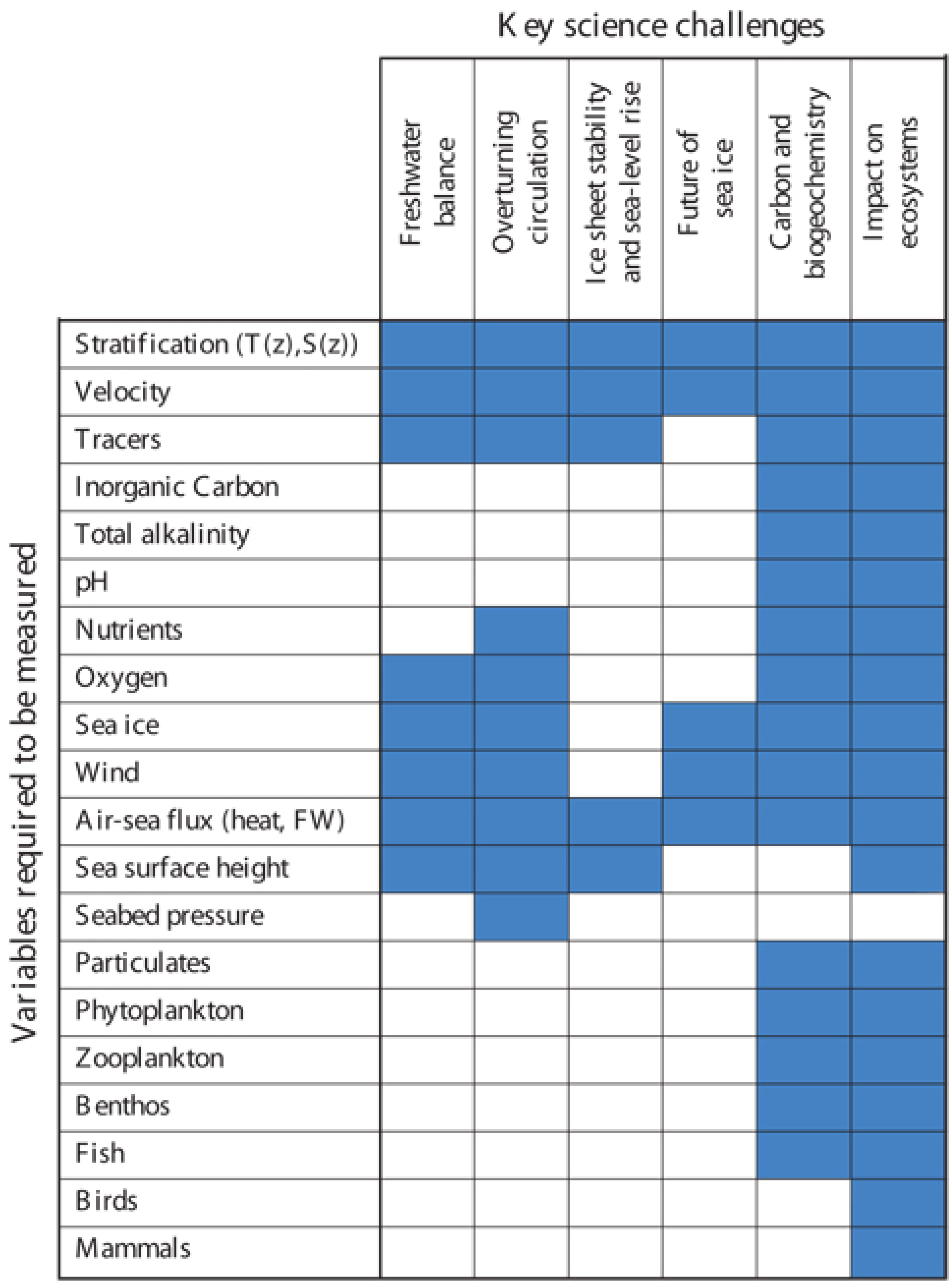
Goal To implement a *sustained*, *multidisciplinary*, and *internationally coordinated* observing system for the Southern Ocean.

Approach SOOS will address 6 overarching challenges:

1. The role of the Southern Ocean in the planet's heat and freshwater balance
2. The stability of the Southern Ocean overturning circulation
3. The role of the ocean in the stability of the Antarctic Ice Sheet and its future contribution to sea-level rise
4. The future and consequences of Southern Ocean carbon uptake
5. The future of Antarctic sea ice

6. Impacts of global change on Southern Ocean ecosystems

SOOS recognises the need to identify EOV's to address these challenges. The table below summarises the likely variables required.



Southern Ocean Sentinel is an international program to assess climate change impacts on marine ecosystems of the Southern Ocean.

Goal To detect and assess early warning signals of climate change impacts on marine ecosystems of the Southern Ocean.

Approach In 2009 an international workshop on 'Monitoring climate change impacts: establishing a Southern Ocean Sentinel' was held in Hobart Australia to develop a long-term monitoring and assessment capability for Southern Ocean ecosystems as a whole. The workshop considered what "indicators" (effectively EOV's) would best meet their goals, and agreed that components of the ecosystem will be used to assess climate change impacts. Indicators will be chosen either to signal the state of particular components of the ecosystem (structural indicators) or to determine if ecosystem dynamics (process indicators) are suitably represented in models for correctly predicting ecosystem dynamics under future, as yet untested, climate change. Some indicators may have coarse biological resolution in what they are measuring but are monitored easily and cheaply with the intent of signalling when more detailed sampling might be undertaken. Good indicators will be easily:

1. measured and understood
2. cost effective
3. sensitive to the drivers of interest
4. based on an understandable relationship to the ecosystem
5. easily communicable

UK

The **Western Channel Observatory** (WCO) is an oceanographic time-series and marine biodiversity reference site in the Western English Channel.

Goal Integrating observational disciplines with ecosystem modelling and satellite remote sensing will mean "we can begin to disentangle the complexity of the marine ecosystem".

Approach In situ measurements are undertaken weekly at coastal station L4 and fortnightly at open shelf station E1. Station L4 has some of the longest time-series in the world for zooplankton and phytoplankton, and fish trawls have been made by the MBA for a century. Station E1 has a hydrographic series dating from 1903 using the research vessels of the Plymouth Marine Laboratory and the Marine Biological Association.

A microbial observatory operated at L4 for a short period (Gilbert et al. 2010).

Biological/Biogeochemical measurements made at L4

Measurement	Method
Chlorophyll *a*	Fluorometric Analysis
Pigments	High Performance Liquid Chromatography (HPLC)
Phytoplankton	Microscopy and Flow Cytometry (
Mesozooplankton abundance	Net tows, microscopy
Calanus egg production	Incubations

USA

U.S. IOOS (Integrated Ocean Observing System http://www.ioos.noaa.gov) is a tool for tracking, predicting, managing, and adapting to changes in the U.S. ocean, coastal and Great Lakes environments. Ecosystems, fisheries, and water quality have been identified as priority issues. U.S. IOOS supports ecosystem, fisheries and water quality observing.

Goal: To deliver the data and information needed so that decision-makers can take action to improve safety, enhance the economy, and protect the environment.

Approach: Regional Associations are involved with observing the following ecosystem, fisheries and water quality variables:

1. Ocean acidification
2. Hypoxia
3. Tagging studies of marine animals
4. Water quality monitoring
5. HAB phytoplankton
6. Acoustic studies e.g. the Hawaii Tuna Tracking Project

The Joint Global Ocean Flux Study (JGOFS) aims to understand the controls on the concentrations and fluxes of carbon and associated nutrients in the ocean.

Goal: The objectives of the time-series studies within JGOFS are:

1. to observe and interpret the annual and interannual variability in the biology and chemistry of the mixed layer and euphotic zone as forced by physical processes
2. to observe and interpret the annual and interannual variability in the rates of particle flux and the apparent rates of particle remineralization over the entire water column
3. to understand the interrelationships between the biological, chemical and physical processes involved in (1) and (2) above
4. to provide data on global trends of selected oceanic properties over seasonal and interannual time scales.

Approach: JGOFS supports 2 ocean time series stations, each of which has been making repeated measurements since 1988.

The Bermuda Atlantic Time-series Station (BATS)

BATS was established in early 1988. The station is located at the **Ocean Flux Program** (OFP) site (3150N, 6410W) 80 km southeast of Bermuda with a water depth of 4,800m.

The Hawaii Ocean Time-series (HOT)

The Hawaii Ocean Time Series (HOT) is a long time-series of physical and biochemical observations in the North Pacific subtropical gyre. The physical oceanographic component of HOT provides CTD/rosette sampling support for the biogeochemistry & ecology (**BEACH**) time-series sampling program, and supports development of new instrumentation for hydrographic observations.

The objectives of HOT specific to the BEACH program are to:

- Document and understand seasonal and interannual variability in the rates of primary production, new production and particle export from the surface ocean.

- Determine the mechanisms and rates of nutrient input and recycling, especially for nitrogen (N) and phosphorus (P) in the upper 200m of the water column.
- Measure the time-varying concentrations of dissolved inorganic carbon (DIC) in the upper water column and estimate the annual air-to-sea CO_2 flux.

Biological/Biogeochemical measurements made at HOT and BATS

Measurement	Depth range	Method
Biomass		
Chlorophyll *a* & Pheopigments	0-175	Fluorometric Analysis using 10-AU
Chlorophyll *a*, *b* & *c*	0-175	Fluorometric Analysis using TD-700 (discontinued)
Pigments	0-175	High Performance Liquid Chromatography (HPLC)
Phycoerythrin	0-175	Fluorometric Analysis using TD-700 (discontinued)
Adenosine 5'-Triphosphate *	0-350	Firefly Bioluminescence
Bacteria and Cyanobacteria	0-175	Flow Cytometry (HOT), Direct Count (BATS)
Nanoplankton and Microplankton	0-175	Epi-fluorescence Microscopy
Mesozooplankton abundance and biomass	0-175	Net tows, elemental analysis
Carbon Assimilation and Particle Flux		
Primary Production	5-125	^{14}C Incubations
Carbon, Nitrogen, Phosphorus & Silica Flux	150	Free-Floating Particle Interceptor Traps

*ATP concentration reflects the total abundance of microbiota

CALCOFI/CCE

The California Oceanic Cooperative Fisheries Investigation (CalCOFI) is a partnership of the California Department of Fish and Game, the NOAA Fisheries Service and the Scripps Institution of Oceanography founded in 1949. The California Current Ecosystem Long Term Ecological Research program (CCE-LTER) (http://cce.lternet.edu/) is part of the NSF funded LTER network and was started in 2004.

Goal: CALCOFI: To study of the marine environment off the coast of California to facilitate management of its living resources

CCE: To study the mechanisms leading to temporal transitions between different states of the California Current ecosystem. It is an extension of the CalCOFI program and consists of four parts:

1. augmentations to the CalCOFI program to further characterize the biogeochemistry and ecology of the ecosystem
2. a series of process studies to characterize and quantify system processes
3. A modelling program to integrate observations and test hypotheses

Approach: CalCOFI conducts quarterly cruises off southern & central California, collecting a suite of hydrographic and biological data on station and underway. Data collected at depths down to 500 m include: temperature, salinity, oxygen, phosphate, silicate, nitrate and nitrite, chlorophyll, transmissometer, PAR, C14 primary productivity, phytoplankton biodiversity, zooplankton biomass, and zooplankton biodiversity.

Variable	Method
Primary production (particulate C)	^{14}C uptake
Primary production (DOC)	^{14}C uptake
Bacterial production	
Mesozooplankton C, N, mass	Displacement volume/Size fractionated C, N, DW
Chlorophyll *a*	Fluorometer (CTD profiles, discrete)
Taxon--□specific phyto--□pigments	HPLC
Heterotrophic bacteria	Flow cytometry
Picophytoplankton	Flow cytometry
Nano- and microplankton	Epifluorescence microscopy
Mesozooplankton, sentinel species	Microscopy
Mesozooplankton, size composition	ZooScan
Mesozooplankton, size distributions	Laser OPC
Fish egg distributions	Nets and underway pumping
Ichthyoplankton (~400 species)	Microscopy
Krill & small pelagic fish	Acoustical survey
Seabird abundance, distribution	Visual survey
Marine mammal census	Visual & acoustic survey

How did CALCOFI determine sentinel species?

The USC Microbial Observatory focuses on exploratory investigation of prokaryotic and unicellular eukaryotic diversity in the San Pedro Channel, California, with a focus on time-dependent changes in community composition in relation to environmental parameters. The project has been running since 2000 with the site visited monthly for sampling to 890 m depth. Routine sampling includes oceanographic as well as microbial data and sample collection. In addition to basic oceanographic parameters measured by the Wrigley Institute for Environmental Studies as part of the **San Pedro Ocean Time Series** (temperature, salinity, chlorophyll, inorganic nutrients and dissolved oxygen), the abundance of the microbial assemblages were monitored by flow cytometry (*Synechococcus*, *Prochlorococcus*, total prokaryotes, phototrophic picoeukaryotes), microscopical analysis (phototrophic and heterotrophic nanoplankton, microplankton, prokaryotes), prokaryotic activity by incorporation of labeled leucine and thymidine, and the diversity by an array of molecular-based techniques. These techniques provide abundance and biomass estimates of the entire microbial community, including bacteria, archaea and eukaryotes. Molecular biological analyses of these samples provide culture-independent estimates of microbial diversity.

Summary: Aggregated Focal Ecosystem Components occurring in International monitoring programs, but NOT in GEOWOW or PICO

Monitoring Program	FEC
European Union	Seagrasses (as Angiosperms)
	Macroalgae
	Reptiles
	Protected species
Western Channel Observatory	Copepod egg production (=zooplankton growth rate)
CALCOFI	Seabirds
	Marine Mammals

In some legislation, the issue of population genetic structure arises. This is probably only of regional interest (i.e. relevant to specific problems) at this stage. There is also the question of how to identify indicator species, or keystone species, that might provide some synoptic insight into ecosystem state. In the FOO analysis below there is brief discussion on the use of higher trophic level “charismatic” organisms to achieve these goals.

FOO Analysis by Focal Ecosystem Component

1. Bacteria and Phytoplankton

There is a clear overlap between bacteria and phytoplankton, since photosynthetic bacteria account for over 80% of the primary production of the oceans. The abundance and role of both autotrophic and heterotrophic microbes is critical for understanding biodiversity and ecosystem function in the ocean.

1.1.1.1 Requirements

PICO and GEOWOW suggest EOV's in the bacterial and phytoplankton domains, as do most other monitoring programs reviewed here. Harmful algal blooms and pathogenic bacteria are concerns in coastal environments.

Biodiversity issues include bacterial community structure, abundance of pathogens, calcareous phytoplankton abundance.

Ecosystem structure issues include phytoplankton biomass, phytoplankton pigments and size, diatom/non-diatom ratio. The size structure of phytoplankton communities (e.g. ratio of picoplankton to microplankton) is a key determinant of food chain structure.

Ecosystem function issues include primary productivity. Proponents of Dynamic Green Ocean Models claim to be able to model biogeochemical processes on the basis of plankton functional types, most of which lie in the bacterial and phytoplankton domains.

1.1.1.2 Observations

An overall consideration of microbial community structure would address all of the articulated EOV's. Emerging technologies based upon flow-cytometric and molecular approaches (most of which are reviewed in (Gunn et al. 2010) make the quantification of both the abundance and role of microbes a possibility, though at present these are at a low state of Readiness – somewhere between "concept" and "pilot".

1.1.1.3 Data and Products

There is a clear overlap between remotely sensed data (ocean colour – chl a etc), and the direct measurement of autotrophic biomass identified as EOV's, and for which data management structures exist. These technologies are at a "mature" state of readiness. However, this is not the case for data that would result from flow-cytometric and molecular approaches, and would be challenging to implement. Once achieved, however, inclusion of these data into biogeochemical models would go a long way to achieving the GOOS objectives of describing, understanding and forecasting ocean processes.

2. Zooplankton

The **Continuous Plankton Recorder** (CPR) survey, originally conceived in the 1920's, is the longest continuous time series in the world's ocean, and is proof-positive of the value of zooplankton as sentinels of climate change. A large volume of literature based on the CPR survey in the North Sea and Atlantic has very convincingly demonstrated distributional and community changes in near-surface zooplankton. As a result, CPR surveys have begun in other regions of the globe, including the Antarctic, the North Pacific and Australia.

1.1.1.4 Requirements

Zooplankton EOV's are included in all monitoring programs reviewed in this document, as the CPR surveys have established their value. However, the emergence of new and sophisticated zooplankton sampling equipment such as the video-plankton recorder, Biomapper and the use of laser holography begs the question of how the 1920's technology of the CPR will endure into the future, especially in an age where expertise in conventional taxonomy is diminishing.

Biodiversity issues CPR surveys are confined to surface waters, and sample organisms whose size and biology allow them to be captured by the narrow aperture and coarse mesh of the CPR. The comparatively simple taxonomic approach taken in the more established surveys is not necessarily appropriate to more diverse communities of smaller organisms, such as occur in the tropics. Epipelagic waters comprise <6% of the volume of the ocean, and there is a need to develop enduring technologies that allow observation of zooplankton in all ocean realms.

SAHFOS and the CPR survey have also developed a discreet water sampler that is housed in the rear of the CPR. This new technology is known as the Water and Microbial Sampler (WaMS) and was specifically developed to address the issue of sampling pico and nano plankton. Usually the water samples are analysed using a flow cytometer and molecular analysis (Edwards 2014 pers.comm).

Ecosystem structure issues include changes in the size-structure of zooplankton communities and flow-on trophic effects, potential changes in the contribution of gelatinous zooplankton to community structure,

Ecosystem function issues include changes in the link between primary production and fish recruitment via microbial vs classical food chains.

1.1.1.5 Observations

For zooplankton, there is a strong argument to be made to continue the CPR approach and to build on the time series available. These technologies are fully mature. However, observations are required in environments not easily sampled by CPR's but emerging technologies currently at a low state of Readiness – somewhere between "concept" and "pilot" will be required to develop a whole of ocean approach.

1.1.1.6 Data and Products

The **Global Alliance of Continuous Plankton Recorder Surveys** http://www.globalcpr.org/ has been established *to understand changes in plankton biodiversity at ocean basin scales through a global network of CPR surveys*, to serve as a data repository and to standardise methodology. The **Coastal & Oceanic Plankton Ecology, Production & Observation Database** (COPEPOD) http://www.st.nmfs.noaa.gov/plankton/ is a global repository of plankton data that includes atlases and time series.

3. Shallow-water Benthos

Shallow water benthos bears the brunt of anthropogenic disturbance, since by definition it is mostly coastal and accessible

EOV's differ depending on the specific environment in which they occur. For instance, coral cover is an excellent indicator of coral reef health, but is inappropriate to soft bottom communities

to human use. Seagrass beds, macroalgal forests and coral reefs are all iconic shallow water ecosystems.

1.1.1.7 Requirements

Knowledge of distribution patterns of live cover (coral reefs, oyster reefs, kelp beds, seagrass beds, salt marshes, and mangrove forests) is essential information for fisheries management, conservation of species diversity, and assessing vulnerability to coastal flooding. These habitats are also being lost and modified (e.g., fragmented) at an alarming rate due to coastal development (e.g., urbanization, agriculture, hardening shorelines), land-based inputs of sediments and nutrients, aquaculture, over fishing, destructive fishing (dynamiting, dredging), channelization (e.g., flood "control" and channels for marine commerce), sea level rise, ocean warming and ocean acidification

Biodiversity issues Overfishing, pollution, eutrophication and coastal development (to name a few) threaten biodiversity of shallow water benthos.

Ecosystem structure issues include disruptions to trophic structure by selective removal of taxa.

Ecosystem function issues include loss of resilience as a consequence of biodiversity loss.

1.1.1.8 Observations

Spatial extent of the composition and condition of benthic biota are required. Requirements change depending on the specific habitat, and concerns of the local community. Remote sensing methods can be combined with direct estimation using diving techniques, video and line transects, drop cameras, etc. Most observation technologies are fully mature, but not necessarily effectively co-ordinated.

1.1.1.9 Data and Products

Only two mature networks are global in scope: the **Global Coral Reef Monitoring Network** (GCRMN) and the **SeaGrass Monitoring Network** (SeagrassNet). AIMS' Long Term Monitoring Project (LTMP) of the Great Barrier Reef is a good example of a regional monitoring system that incorporates directly-observed field data into a modern database structure, including web-based data delivery http://www.aims.gov.au/docs/data-centre/reef-monitoring-surveys.html.

3. Deep- water Benthos

Most benthos occurs below the euphotic zone (~200m), on the shelf, seamounts and abyssal plains. Even in the deep sea anthropogenic effects are taking their toll (Ramirez-Llodra et al. 2011) and in the last decade 30% of ocean warming has occurred in depths >700m (Balmaseda et al. 2013).

1.1.1.10 Requirements

Biodiversity issues The biodiversity of the deep sea is now recognized as among the highest on the planet (Ramirez-Llodra et al. 2010), yet is greatly undersampled.

Ecosystem structure issues are poorly understood because of lack of data.

Ecosystem function issues are poorly understood, but increased human use of the deep sea requires that this knowledge gap be filled to ensure sustainable use and effective management.

1.1.1.11 Observations

While ship-based sampling has enabled snapshots of the ecology of deep-sea communities, longer term and continuous sampling is required to capture the highly episodic events that are so important in driving these communities (Larkin et al. 2010). A number of observatories have been established around the world, including sites that are driven by detrital fall from the euphotic zone and by chemosynthetic processes on the sea-floor itself (see map below, from Larkin et al. 2010). Note that there are currently no observatories in the Southern Hemisphere.

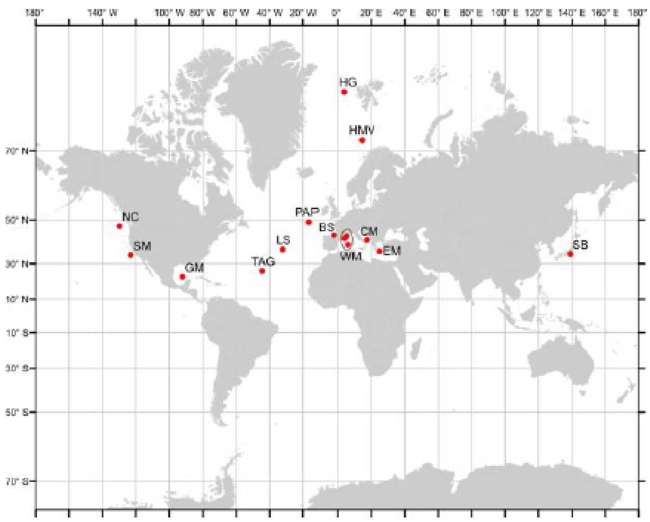


Figure 1. Location map of selected key Long-term reference stations for seafloor biological observations.

Observations include biogeochemical variables, abundance of infauna and photographic studies of macrofauna. The technology required to establish deep-water observatories is somewhere between “pilot” and “mature”.

1.1.1.12 Data and Products

The existing research is uncoordinated and the data collected are not integrated or standardized, but many observatories plan infrastructure to facilitate autonomous long-term observations that could be facilitated within GOOS (Larkin et al. 2010). Data products for deep-sea observation are between “concept” and “pilot”.

4. Fish and Fisheries

1.1.1.13 Requirements

Overfishing is the primary cause of biodiversity loss in the ocean (Pitcher and Cheung 2013), and so the selection of appropriate EOV’s to observe and monitor fishing effects is a critical requirement of an effective observing system, but it is also the most complex. At present, ocean observing is not presently widely applied to fisheries management, but this is likely to change as a result of the additive effects of climate change and increased resource usage (Checkley 2010). The need for ecosystem-based management of fisheries is generally accepted, in which case observations of biogeochemical and lower trophic level biology are implicit. The issue of which higher level variables should be incorporated in observing systems is more problematic.

Ecosystem based management of fisheries requires **Integrated Ecosystem Assessment**. (Koslow et al.) outline the 5 step process adopted by NOAA for IEA:

1. Initial scoping of management objectives, ecosystem attributes of concern, and relevant stressors
2. Development and testing of indicators that reflect these, and which are linked to decision criteria
3. Risk analysis to determine susceptibility and resilience of indicators
4. Integration of risk analyses into an ecosystem assessment
5. Evaluation of management options to influence ecosystem status.

Biodiversity issues Loss of biodiversity, primarily through fishing effects, is compromising the provision of ecosystem services(Worm et al. 2006).

Ecosystem structure issues The most widely adopted marine indicator of fishing effects on marine biodiversity is mean trophic level (MTL) from catches, intended to measure removal of larger high-trophic-level fishes ''fishing down marine food webs''. However, (Branch et al. 2010) dispute the utility of this approach since catches from all trophic levels appear to be increasing, and conclude that catch MTL does not reliably measure the magnitude of fishing impacts or the rate at which marine ecosystems are being altered by fishing. Instead, they recommend tracking trends in abundance of species vulnerable to fishing and the development of more sophisticated trend detection methods. Checkley (2010) suggests that it is useful to resolve age structure of fish stocks – eggs, larvae, juveniles, adults; and predator prey relationships (from gut contents).

Ecosystem function issues result from biodiversity loss - (Worm et al. 2006) claim that restoration of lost biodiversity resulted in a four-fold increase in productivity.

1.1.1.14 Observations

(Fulton et al. 2005) performed a modelling study to determine which environmental indicators best detected fishing effects, and concluded indicators at the community level of organization are the most reliable, and that it is necessary to use a variety of indicators simultaneously to detect the full range of impacts from fishing. Several key functional groups provide a good characterization of ecosystem state, or indicate the cause of broader ecosystem changes in most instances.

(Pitcher et al. 2009) consider that information and monitoring systems necessary for EBM should include an efficient and effective fishery information system that provides data and information on stock and ecosystem performance (additional to information needed for stock management), and that identifies specific effects of fishery strategies on ecosystem values. This could include:

- Periodic mapping of important habitat distributions
- Population census of important protected species

- Species diversity in fished habitats
- Distribution of fishing effort by gear types and fine spatial scale
- Size/age classes in harvested species
- Species diversity in closed areas

Information needs and priorities should embrace comprehensive research programmes targeted at resolving key ecosystem and stock issues in the fishery. These could include:

- habitat mapping; impact of fishing on specific habitat types
- effects of coastal development on recruitment of harvested species
- design of monitoring programmes to resolve important changes in habitats
- biological data of key species (both utilised and nonutilised)
- determining the dietary preferences of harvested species and their major predators
- species composition of bycatch with different gear types used in the fishery

(Nicol et al. 2012) highlight the potential of fisheries observer programs for documenting not only the details of the target species, but also to collect spatially explicit and long-term time-series of distribution, abundance, size, composition and biological information on target and non- target species and mid trophic level organisms. Specifically, the collection of gonads, otoliths and stomachs could provide information relating to life history, growth and diet.

1.1.1.15 Data and Products

There are many databases relating to fish and fisheries; the largest probably the FAO data http://www.fao.org/fishery/en. Other resources include the Sea Around Us database http://www.seaaroundus.org/ and FishBase http://www.fishbase.org/.

5. Ecosystem

1.1.1.16 Requirements

(Rapport et al. 1998) highlight the need for measurements of ecosystem vigor, organisation and resilience (see Text Box) as indicators of "ecosystem health".

Indicators of ecosystem health

Ecosystem health can be assessed using measures of resilience, vigor and organization:

- **Vigor** is measured in terms of 'activity, metabolism or primary productivity'.
- **Organization** can be assessed as the diversity and number of interactions between system components.
- **Resilience** (counteractive capacity), is measured in terms of a system's capacity to maintain structure and function in the presence of stress. When resilience is exceeded, the system can 'flip' to an alternate state.

(Rapport et al. 1998)

Biodiversity issues One way of simplifying the ecological complexity implicit in these requirements might be by observations of apex predators, since these are linked to biodiversity by means of resource facilitation, trophic cascades, dependence on ecosystem productivity, sensitivity to dysfunctions, selection of heterogeneous sites and links to multiple ecosystem components(Sergio et al. 2008).

Examples of potential EOV's based on top predators come from:

- Seabird breeding success reflects the availability of prey such as forage fish and mid-trophic level organisms (Cury et al. 2011)
- Breeding participation by terns reflecting the long-line catch per unit effort (Devney et al. 2009)

Ecosystem structure issues include changes in size structure arising from the removal of certain size classes by human activity, or climate-driven change in size class e.g. temperature effects on plankton, micronekton and forage fishes.

Ecosystem function issues include changes in trophic transfer and energetics that may occur in a warming ocean (e.g. increases in respiration) and changes in community calcification rates.Warming effects are compounded by those of increasing oxygen minimum zones (Stramma et al. 2008) and acidification (Fabry et al. 2008).

1.1.1.17 Observations

Vigor might be accommodated by the biogeochemical EOV's, e.g. primary production.

The identification of EOV's that address the concepts of organisation and resilience is non-trival.

Organisation requires observation of community structure and of the trophic links between ecosystem components.

Resilience would be best measured by repeated observations of EOV's relating to community structure before and after disturbance, but is compromised by "shifting baselines" e.g.(Duarte et al. 2009).

Observations appropriate to gauge ecosystem health are still in the "concept" stage of readiness.

1.1.1.18 Data and Products

Large Marine Ecosystems (LME's) data is compiled at http://www.lme.noaa.gov/

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APPENDIX 4: PRELIMINARY LIST OF EOVS (AS DEFINED BY GEOWOW, 2012)

These candidate EOVs were identified as those being essential to observe in order to address a series of societal and scientific issues that have resonance with numerous GEO Societal Benefit Areas (SBAs). While all of these issues have connection to ocean ecosystems, the required candidate EOVs cover physical, chemical, biological, and socioeconomic variables, showing the inter-linkages between ocean domains and with human systems. These issues are:

1. **Coastal eutrophication and hypoxia**, which can lead to changes in coastal ecosystem food webs, potentially fish and invertebrate kills and the loss of biologically structured benthic habitats and biodiversity;
2. **Human exposure to waterborne infections microbes**, triggered by land-based wastes and marine water warming, and which through contact by recreational use and shellfish contamination has human health impacts;
3. **Toxic Harmful Algal Blooms (HABs)**, besides those that occur as natural events, they can also be driven by anthropogenic forcing like land-based nutrient input, ocean warming, ballast water discharge, commercial fishing, alteration of coastal habitats and water circulation patterns. They can endanger human health in fish and shellfish consumers as well as direct recreational contact with the ocean, and cause environmental damage (e.g. hypoxia, coral bleaching);
4. **Loss and modification of biologically structured benthic habitats**, which support high species diversity and economically important living marine resources;
5. **Distribution and condition of calcareous organisms affected by ocean acidification**, driven by global anthropogenic carbon emissions, and having potentially profound effects on the capacity of marine ecosystems to support living marine resources;
6. **Abundance of exploitable fish stocks related to food resources and availability**. These food resources are under pressure from fishing, loss of habitats and species diversity, ocean warming and acidification. Loss of fish stocks has obvious economic and livelihood impacts;
7. More generally, **Understanding the impact of anthropogenic global change on ocean ecosystems and ecosystem services**, which will help inform policy decisions on global matters, as well as help identify regions where local pressures will need additional managing to adapt to global change; and
8. Developing **Management and policy responses** to the issues above. This requires information about the natural system, and human impacts /vulnerabilities to changes in ocean ecosystem services.

Broadly, the candidate EOVs are split into four categories (Physical, Chemical, Biological and Socio-Economic/Human Impact) and compiled in the table below.

Table : Preliminary List of Essential Ocean Variables

(Note: Symbol 'x' denotes a link between Societal Issues & EOVs; and symbols 'o' and '#' denote where EOVs are relevant to Open Ocean & Coastal Margins, respectively)

GEO SBA			*Ecosystems, Agriculture, Biodiversity*	*Health*	*Health*	*Ecosystems, Biodiversity*	*Disaster*	*Ecosystems, Biodiversity*	*Agriculture*	*Ecosystems, Biodiversity, Agriculture, Climate*
SOCIETAL ISSUE			Eutrophication & Hypoxia	Human Exposure to Waterborne Pathogens	Harmful Algal Blooms	Habitat Loss & Modification	Vulnerability to Coastal Flooding	Ocean Acidification	Food Security	Understanding impact of anthropogenic global change on ecosystem services
CANDIDATE EOVs	**Open Ocean**	**Coastal**								
EOVs Physical										
Water temperature/Ocean Heat Content	o	#	x	x	x	x (especially impacts to corals).	x (in addition to coastal flooding, it may also be linked to rainfall changes and drought on land)		X	x

GEO SBA			Ecosystems, Agriculture, Biodiversity	Health	Health	Ecosystems, Biodiversity	Disaster	Ecosystems, Biodiversity	Agriculture	Ecosystems, Biodiversity, Agriculture, Climate
SOCIETAL ISSUE			Eutrophication & Hypoxia	Human Exposure to Waterborne Pathogens	Harmful Algal Blooms	Habitat Loss & Modification	Vulnerability to Coastal Flooding	Ocean Acidification	Food Security	Understanding impact of anthropogenic global change on ecosystem services
Water temperature stratification	o	#	x	x	x	x (especially impacts to primary productivity.			X	x
Sea Ice	o	#				x (especially loss of sea ice can leading to increased shipping activity and marine pollution)	x		X	x
Salinity	o	#				x			X	x
Currents	o	#	x	x	x				X	x

GEO SBA			*Ecosystems, Agriculture, Biodiversity*	*Health*	*Health*	*Ecosystems, Biodiversity*	*Disaster*	*Ecosystems, Biodiversity*	*Agriculture*	*Ecosystems, Biodiversity, Agriculture, Climate*
SOCIETAL ISSUE			Eutrophication & Hypoxia	Human Exposure to Waterborne Pathogens	Harmful Algal Blooms	Habitat Loss & Modification	Vulnerability to Coastal Flooding	Ocean Acidification	Food Security	Understanding impact of anthropogenic global change on ecosystem services
Surface wave height & direction	o	#			x (dispersion or confinement)		x			
Absolute sea level	o	#				x	x			x
Shoreline Position		#			x (benthic HABs, ciguatera, clupeism, *Ostreopsis blooms in the Mediterranean beaches)*	x	x			x
Bathymetry	o	#			x (as above)		x			
Total suspended matter	o	#	x		x	x			X	
Seamounts	o					x				x

EOVs Chemical										
Dissolved inorganic nutrients (N, P, Si) concentrations	o	#	x	x	x	x			X	x
Dissolved organic nutrients (C, N and P forms)		#	x		x					x
GEO SBA			*Ecosystems, Agriculture, Biodiversity*	*Health*	*Health*	*Ecosystems, Biodiversity*	*Disaster*	*Ecosystems, Biodiversity*	*Agriculture*	*Ecosystems, Biodiversity, Agriculture, Climate*
SOCIETAL ISSUE			Eutrophication & Hypoxia	Human Exposure to Waterborne Pathogens	Harmful Algal Blooms	Habitat Loss & Modification	Vulnerability to Coastal Flooding	Ocean Acidification	Food Security	Understanding impact of anthropogenic global change on ecosystem services
Dissolved oxygen concentration	o	#	x		X	x			X	x
pH, fCO2 & total alkalinity (calcarous plankton/Aragonite saturation state)	o	#			x (to be explored)	x		x	X	x
Colored dissolved	o	#				x			X	x

organic matter										

GEO SBA			*Ecosystems, Agriculture, Biodiversity*	*Health*	*Health*	*Ecosystems, Biodiversity*	*Disaster*	*Ecosystems, Biodiversity*	*Agriculture*	*Ecosystems, Biodiversity, Agriculture, Climate*
SOCIETAL ISSUE			Eutrophication & Hypoxia	Human Exposure to Waterborne Pathogens	Harmful Algal Blooms	Habitat Loss & Modification	Vulnerability to Coastal Flooding	Ocean Acidification	Food Security	Understanding impact of anthropogenic global change on ecosystem services
EOVs Biological										
Phytoplankton (pigments and size)	o	#	x		x	x			X	x
Primary Productivity / Phytoplankton biomass (chlorophyll-a)	o	#	x		x	x			X	x
Toxic phytoplankton abundance	o	#	x	x	x	x			X	x
Calcareous plankton abundance	o	#				x		x	X	x
Diatoms/non-diatom ratio	o	#		x	x					x

Abundance of copepod indicator species	o	#						x	X	x
Abundance of waterborne pathogens		#		x	x				X	
Bacterial communities	o	#								x
Zooplankton (including abundance, size structure, composition and timing)	o	#	x			x			X	x
Extent of living benthic habitats	o	#	x		x (coral bleaching due to benthic dinoflagellates outbreaks)	x				
Species diversity of communities associated with living benthic habitats	o	#			x (as above)	x			X	
Coral skeletal density		#			x (as above)	x		x	X	x
Abundance of eggs, larvae & size classes of exploited fish stocks	o	#							X	x
Fish stocks	o	#	x			x			X	x
Bycatch	o	#							X	x
Diet of exploitable fish species	o	#								

Abundance & size of apex predators	o	#				x			X	x
GEO SBA			*Ecosystems, Agriculture, Biodiversity*	*Health*	*Health*	*Ecosystems, Biodiversity*	*Disaster*	*Ecosystems, Biodiversity*	*Agriculture*	*Ecosystems, Biodiversity, Agriculture, Climate*
SOCIETAL ISSUE			Eutrophication & Hypoxia	Human Exposure to Waterborne Pathogens	Harmful Algal Blooms	Habitat Loss & Modification	Vulnerability to Coastal Flooding	Ocean Acidification	Food Security	Understanding impact of anthropogenic global change on ecosystem services
Food Webs and trophic changes	o	#	x		x (at microbial level)	x		x	X	x
Geographic distribution of taxa (Biodiversity)	o	#			x (spread distribution of harmful taxa, e.g. Gambierdiscus, ciguatera)	x		x	X	x
Complementary Variables (Non Ocean) for Socioeconomic/Human Impact										
Pollution (including Hg, oil spills, plastics)	o	#			x	x			X	x
Fish catch value	o	#							X	

Destructive fishing practices	o	#								
Seabed mining activity	o	#				x	x			
Population distribution		#	x	x	x	x	x	x	X	x
Dependence on ocean ecosystem services	o	#			x (aquaculture, beach use)				X	

APPENDIX 5: VARIOUS CONVENTIONS AND POLICY THAT DRIVE A NEED FOR UNDERSTANDING MARINE ECOSYSTEMS

- Convention on Biological Diversity (CBD) Aichi Targets
- GEOBON Essential Biodiversity Variables (EBVs)
- Rio+20 '*The Future We Want'* (2012)
- *Oceans Compact* (2012)
- United Nations Convention on the Law of the Sea (UNCLOS) & the 2009 UN Session on Oceans
- Agreement on the Conservation & Management of Straddling & Highly Migratory Fish Stocks
- Global Program of Action for the Protection of the Marine Environment from Land Based Sources
- UNCED Agenda 21, Program of Action for Sustainable Development
- Implementation Plan of the World Summit on Sustainable Development
- International Convention for the Prevention of Pollution From Ships
- Ramsar Convention
- Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)
- World Heritage Convention (WHC)
- Convention on the Conservation of Migratory Species of Wild Animals
- Other Regional Conventions

APPENDIX 6: EXCERPT FROM THE *OCEANS COMPACT (2012)*

First three paragraphs of the ***Oceans Compact 'Healthy Oceans for Healthy Prosperity – an initiative by the UN Secretary General (2012)*** states that:

'The world's oceans are key to sustaining life on the planet. The ocean constitutes a conduit for ninety per cent of the world trade, and for connecting people, markets and livelihoods. In light of the ocean's interconnectedness, all nations of the world should strive to make the oceans places of safety and sustainability of maritime activities for all humankind.

They provide a range of benefits for human well-being and prosperity – food production, employment creation, temperature moderation, carbon sequestration, nutrient cycling, habitats and biodiversity, tourism, an energy source, and others. Humans, however, have put the oceans under risk of irreversible damage by over-fishing, climate change and ocean acidification (from absorbed carbon emissions), increasing pollution, unsustainable coastal area development, and unwanted impacts from resource extraction, resulting in loss of biodiversity, decreased abundance of species, damage to habitats and loss of ecological functions.

We need to reverse these trends by using the vast potential wealth of the oceans to build a society that uses ocean resources wisely and is less vulnerable to ocean-related hazards. We need to adopt a more proactive vision for the oceans and establish a new understanding of their capacity. We need to create new partnerships while strengthening key existing ones, and develop ways of sharing the wealth of the oceans to benefit all.'

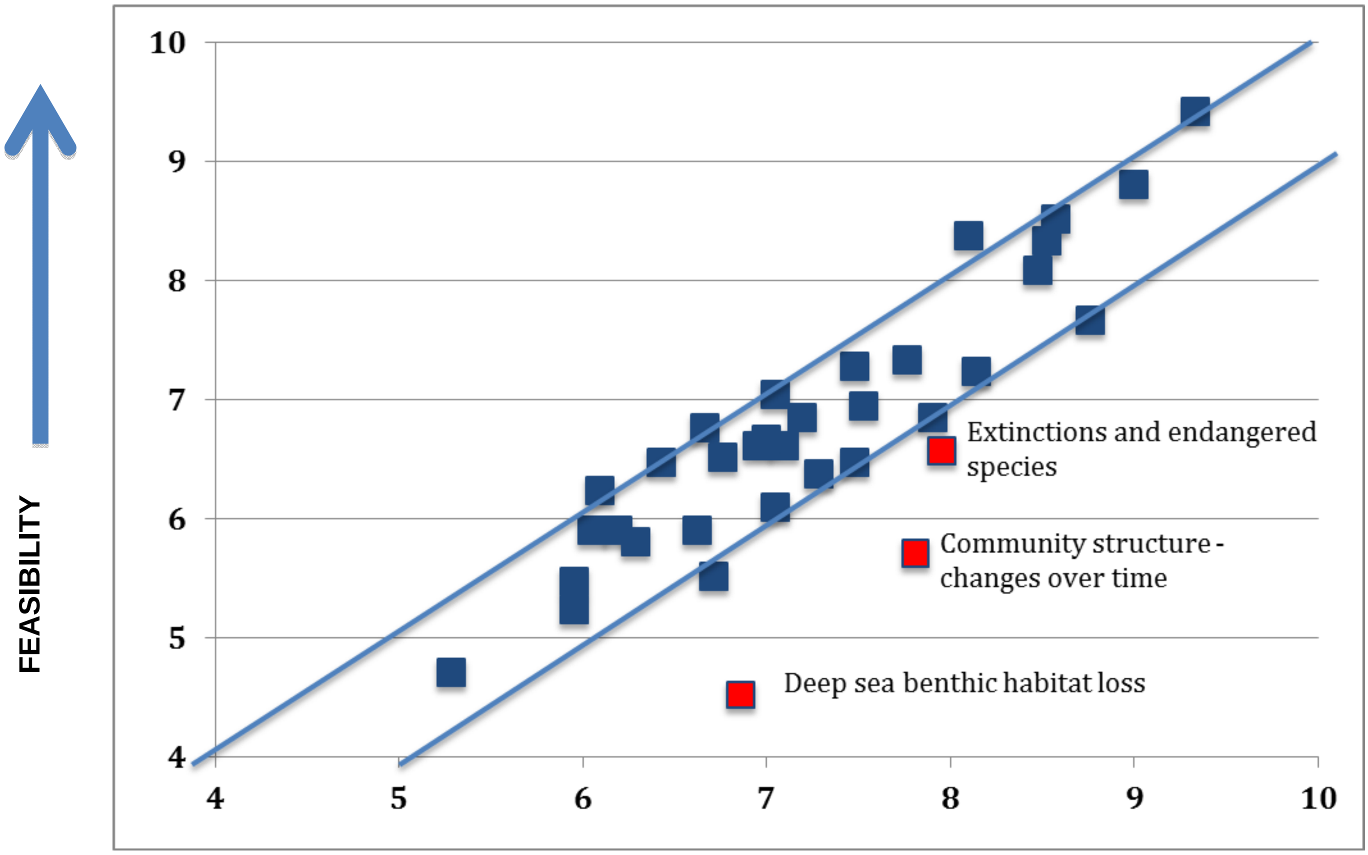
APPENDIX 7: RESULTS OF RANKING 49 eEOVS

TABLE OF THE TOP 20 eEOVS ESTIMATED BY MEAN IMPACT /FEASIBLITY (>7)

- HUMAN ACTIVITIES REMOVED
- SORTED BY (INTEGRATED TERM)

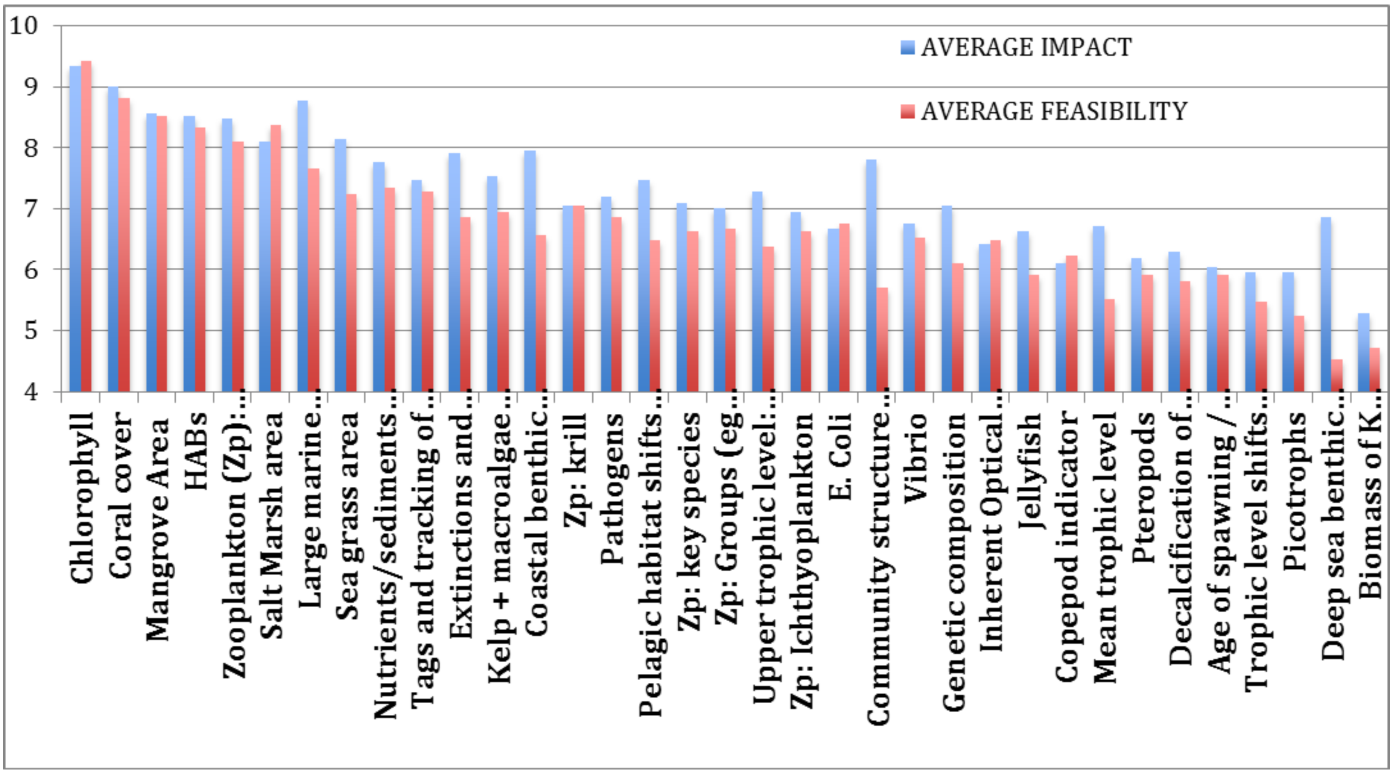
	MEAN (IMPACT+FEASIBILITY) >7	**MEAN (IMPACT) > 7**	**MEAN (FEASIBILITY) > 7**
1	Chlorophyll	Chlorophyll	Chlorophyll
2	Coral cover	Coral cover	Coral cover
3	Mangrove Area	Mangrove Area	Mangrove Area
4	HABs	HABs	HABs
5	Zooplankton (Zp): biomass/abundance	Zooplankton (Zp): biomass/abundance	Zooplankton (Zp): biomass/abundance
6	Salt Marsh area	Salt Marsh area	Salt Marsh area
7	Large marine vertebrates: abundance/distribution	Large marine vertebrates: abundance/distribution	Large marine vertebrates: abundance/distribution
8	Sea grass area	Sea grass area	Sea grass area
9	Tags and tracking of species of value / large marine vertebrates	Tags and tracking of species of value / large marine vertebrates	Tags and tracking of species of value / large marine vertebrates
10	Zp: krill	Extinctions and endangered species (from CITES/IUCN and other existing sources)	Zp: krill
11		Kelp + macroalgae area	
12		Coastal benthic habitat loss	
13		Zp: krill	
14		Pathogens	
15		Pelagic habitat shifts (defined by oceanographic boundaries)	
17		Zp: key species	
18		Upper trophic level: abundance, distribution, size	
19		Community structure - changes over time	
20		Genetic composition	

ECOSYSTEM EOV RANKINGS: SCATTER PLOT ESTIMATED IMPACT/FEASIBILITY



IMPACT

ECOSYSTEM EOVS– ESTIMATED IMPACTS AND FEASIBILITY



APPENDIX 8: POTENTIAL GOOS BIOLOGY AND ECOSYSTEMS CANDIDATE PILOT PROJECTS

A **preliminary set of candidate pilot projects** drafted at the Workshop are below. Participants considered the availability of known monitoring systems and datasets, feasibility of continued or new monitoring infrastructure, and potential availability of funds (prioritized projects are in bold italics):

Candidate Pilot Project	eEOV Theme/s	eEOV	FOO Readiness
Global mapping of mangroves by satellite	A. Productivity (Primary) B. Biodiversity. D. Human / Climate impacts	Mangroves Habitat Extent and Loss	Mature
Abundance & Distribution of Large Marine Vertebrates as a signal of the health of the marine ecosystem (via tagging and tracking techniques)	A. Productivity (Food Web) D. Human / Climate impacts	Tags and Tracking Species of Value (eg whales) and Top Predators	Mature
Abundance, distribution and size of upper trophic levels	B. Biodiversity. D. Human / Climate impacts		Mature
Coral Cover (in collaboration with GCRMN)	B. Biodiversity. C. Ecosystem Services		Mature ?
Zooplankton sampling using standardized emerging genetic technologies		*Potential EOS	Feasible within 2-3 years?
Ocean Acidification and impact on shellfish and molluscs (food) – increasing de-calcification of bivalves (in collaboration with Global Ocean Acidification Observing Network [GOA-ON].	C. Ecosystem Services D. Human / Climate impacts		
Co-ordination of the Chlorophyll community to standardize Cal/Val for productivity	A. Productivity (Primary) D. Human / Climate impacts		
Product: Synthesis of Continuous Plankton Recorder (CPR) records to produce EOV time series for ocean biomes (zooplankton) = zooplankton sampling using standardized emerging genetic technologies	A. Productivity (Food Web) D. Human / Climate impacts		Feasible within 2-3 years?
Develop purpose built environment DNA system for EOVs in collaboration with the biodiversity observation network (e.g. USA: MarineBON)	B. Biodiversity.	*Potential EOS	
CALCOFI/genomics: test/validate efficacy (ichthyoplankton)	A. Productivity (Food Web) D. Human / Climate		

	impacts		
Global High Resolution Ocean Colour Project (w/ existing initiatives). Validation/calibration for productivity	A. Productivity (Primary) D. Human / Climate impacts * also relevant to BGC Panel		
Temperate coral reef surveys: standardization/inter-comparison (with existing initiatives, e.g. GCRMN, Reef Life Survey)	B. Biodiversity. C. Ecosystem Services D. Human / Climate impacts		
Mangrove surveys: standardization/inter- comparison (with existing initiatives)	A. Productivity (Primary) B. Biodiversity. D. Human / Climate impacts		
Human activity data for oceanographers: develop an operating basis for this information	D. Human / Climate impacts		
Universality of tagging/tracking/historic archive (already underway in Southern Ocean)			
Promote the use of animal data in ocean physcial analysis+forecasting (e.g. GODAE OceanView, CLIVAR)			
Develop bio-acoustics for mid-trophic mesopelagic EOVs (with existing communities).			

Additional Pilot Projects were also selected based on a 'concept' to inform the design of the GOOS Biology and Ecosystems System:

Concept Pilot Project	**eEOV Theme**
Can we invert the CALCOFI ? e.g. if we had to re-construct it, what variables would we target? Perhaps some indicator species rather than all fish indicators? (given the known 60 years of data)	A. Productivity (Food Web) D. Human / Climate impacts
Review of the literature around design of an ocean observation system, which is then peer reviewed. Or utilise the programs in existence to do the review.	all
Develop a global system with traditional techniques that can be transitioned to emerging techniques (on the basis that this will provide significant advances to the specified EOVs).	all

APPENDIX 9: EXAMPLE TABLE FOR INDICATING KNOWN OBSERVATION PLATFORMS AND HOW THEY RELATE TO THE GOOS PHYSICS, BIOGEOCHEMISTRY AND BIOLOGY/ECOSYSTEM EOVS.

	Physics, BGC	**Biology & Ecosystems**
Satellite Oceanography • Altimetry • SST • Salinity • **Ocean Colour** • Sea Ice • Winds		
Volunteer Observing Ships		
Surface Drifters		
Tide Gauges		
XBT		
Argo		
Repeat Hydrography		
Tropical Moored Buoys – TAO, PIRATA, RAMA		
Time Series (OceanSITES)		
Transport Monitoring		
Tsunami Warning Buoys		
Gliders (EGO/GROOM)		
CPR (GACS)		
Animal Tagging, acoustic and satellite (OTN)		
Aircraft Oceanography		

APPENDIX 10: ACRONYMS AND ABBREVIATIONS

Abbreviation	Name
AIMS	Australian Institute of Marine Science
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CBD	Convention on Biological Diversity
CO_2	Carbon dioxide
EBVs	Essential Biodiversity Variables
ECVs	Essential Climate Variables
eEOVs	ecosystem Essential Ocean Variables
EOS	Essential Ocean Samples
EOVs	Essential Ocean Variables
EuroGOOS	The European GOOS
EVs	Essential Variables
FAO	Food and Agriculture Organisation of the United Nations
FOO	A Framework for Ocean Observing
FP7 EC	Seventh Framework Programme of the European Commission
GCOS	Global Climate Observing System
GEF	Global Environment Facility
GEO	Group on Earth Observations
GEOBON	Group on Earth Observations Biodiversity Observation Network
GEOSS	Global Earth Observation System of Systems
GEOSS DataCORE	GEOSS Data Collection of Open Resources for Everyone
GEOWOW	GEOSS interoperability for Weather, Ocean and Water
GOOS	Global Ocean Observing System
GRA	GOOS Regional Alliances
HABs	Harmful Algal Blooms
ICES	International Council for the Exploration of the Sea
ICSU	International Council for Science
IPBES	Inter-governmental Science-Policy Platform on Biodiversity and Ecosystem Services
IMOS	Australian Integrated Marine Observing System
IOC	Intergovernmental Oceanographic Commission
IOCCG	International Ocean Colour Co-ordinating Group
IOCCP	International Ocean Carbon Co-ordination Project
IODE	International Oceanographic Data and Information Exchange
IPCC	Intergovernmental Panel on Climate Change
O_2	Oxygen
OBIS	Ocean Biogeographic Information System
PICES	North Pacific Marine Science Organization
PICO	GOOS Panel for Integrated Coastal Observation
SBAs	Societal Benefit Areas
SCOR	Scientific Committee on Oceanic Research
SOKI	Southern Ocean Knowledge and Information wiki
SOOS	Southern Ocean Observing System
UNESCO	United Nations Education, Science and Cultural Organization
UNCLOS	United Nations Convention on the Law of the Sea
US IOOS	United States Integrated Ocean Observing System
US NMFS-NOAA	United States National Marine Fisheries Service of the National Oceanic and Atmospheric Administration
WMO	World Meteorological Organisation
WP6	Work Package 6

APPENDIX 11: BIBLIOGRAPHY

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