BIOLOGICAL AND ECOSYSTEM OBSERVATIONS WITHIN UNITED STATES WATERS II:

A WORKSHOP REPORT TO INFORM PRIORITIES FOR THE UNITED STATES INTEGRATED OCEAN OBSERVING SYSTEM

PRODUCT OF THE

National Ocean Council

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EXECUTIVE OFFICE OF THE PRESIDENT

NATIONAL OCEAN COUNCIL

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December 19, 2016

Dear Colleagues:

We are pleased to transmit to you *Biological and Ecosystem Observations within United States Waters II: A Workshop Report to Inform Priorities for the United States Integrated Ocean Observing System®* This document is a summary of a workshop held by the Biological Integration and Observation Task Team of the Interagency Ocean Observation Committee, which is organized under the National Science and Technology Council; Committee on Environment, Natural Resources, and Sustainability; Subcommittee on Ocean Science and Technology (SOST). The SOST also functions as the Ocean Science and Technology Interagency Policy Committee under the National Ocean Council. This document is a companion to *Biological and Ecosystem Observations within United States Waters I: A Survey of Federal Agencies.*

This report responds to actions within the National Ocean Policy Implementation Plan to expand current biological observations and extend current biological data standards to allow increased interoperability with other biological, physical, and social data systems. This document also responds to recommendations developed by the ocean observing community during the 2012 United States Integrated Ocean Observing System Summit. The Summit participants identified the need to effectively integrate biological and ecosystem observations into ocean and coastal information systems.

Sincerely,

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About the National Ocean Council

The National Ocean Council (NOC) is charged with implementing the National Ocean Policy, established in July 2010 under Executive Order 13547, Stewardship of the Ocean, Our Coasts, and the Great Lakes. The NOC released the National Ocean Policy Implementation Plan in April 2013 to translate the National Ocean Policy into specific actions Federal agencies will take to address key ocean challenges, streamline Federal operations, save taxpayer dollars, and promote economic growth. Federal agencies, states, tribes, and regional fishery management councils may choose to form regional planning bodies to provide communities greater collaborative input in these efforts. More information is available at www.WhiteHouse.gov/administration/eop/oceans.

About the National Science and Technology Council

The National Science and Technology Council (NSTC) is the principal means by which the Executive Branch coordinates science and technology policy across the diverse entities that make up the Federal research and development (R&D) enterprise. One of the NSTC's primary objectives is establishing clear national goals for Federal science and technology investments. NSTC prepares R&D packages aimed at accomplishing multiple national goals. The NSTC's work is organized under five committees: Environment, Natural Resources, and Sustainability; Homeland and National Security; Science, Technology, Engineering, and Mathematics Education; Science; and Technology. Each of these committees oversees subcommittees and working groups that are focused on different aspects of science and technology. More information is available at www.WhiteHouse.gov/ostp/nstc.

About the Office of Science and Technology Policy

The Office of Science and Technology Policy (OSTP) was established by the National Science and Technology Policy, Organization, and Priorities Act of 1976. OSTP's responsibilities include advising the President in policy formulation and budget development on questions in which science and technology are important elements; articulating the President's science and technology policy and programs; and fostering strong partnerships among Federal, state, and local governments, and the scientific communities in industry and academia. The Director of OSTP also serves as Assistant to the President for Science and Technology and manages the NSTC. The Director of OSTP co-chairs the National Ocean Council, along with the Managing Director of the Council on Environmental Quality (CEQ). More information is available at www.WhiteHouse.gov/ostp.

About the Council on Environmental Quality

The Council on Environmental Quality (CEQ) coordinates Federal environmental efforts and works closely with agencies and other White House offices in the development of environmental policies and initiatives. CEQ was established within the Executive Office of the President (EOP) by Congress as part of the National Environmental Policy Act of 1969 (NEPA), and additional responsibilities were provided by the Environmental Quality Improvement Act of 1970. Through interagency working groups and coordination with other EOP components, CEQ works to advance the President's agenda. It also balances competing positions, and encourages government-wide coordination, bringing Federal agencies, state and local governments, and other stakeholders together on matters relating to the environment, natural resources, and energy. The Managing Director of CEQ co-chairs the National Ocean Council, along with the Director of OSTP. More information is available at www.WhiteHouse.gov/ceq.

About the Subcommittee on Ocean Science and Technology

The purpose of the Subcommittee on Ocean Science and Technology (SOST) is to advise and assist the NSTC on national issues of ocean science and technology. The SOST contributes to the goals for Federal ocean science and technology, including developing coordinated interagency strategies, and fosters national ocean science and technology priorities, including implementation of the National Ocean Policy. The SOST also serves as the Ocean Science and Technology Interagency Policy Committee under the NOC, and ensures the interagency implementation of the National Ocean Policy and other priorities for ocean science and technology objectives. More information is available at www.WhiteHouse.gov/administration/eop/ostp/nstc/oceans.

About the Interagency Ocean Observation Committee

The purpose of the Interagency Ocean Observation Committee (IOOC) is to advise and assist the SOST on matters related to ocean observations, including coordination of Federal activities on ocean observations and other activities as described in the Integrated Coastal and Ocean Observation System Act of 2009 (P.L. No. 111-11, Subtitle C).

About the IOOC Biological Integration and Observation Task Team

The IOOC established the Biological Integration and Observation Task Team (BIO-TT) to: (1) improve the availability of observations on the five currently identified United States Integrated Ocean Observing System (U.S. IOOS®) core biological variables; and (2) identify and prioritize additional cross-cutting Federal agency biological and ecosystem observation needs. To meet these goals, the IOOC BIO-TT collaborated with the U.S. Integrated Ocean Observing System (U.S. IOOS) Program Office, the U.S. IOOS Regional Associations, and other Federal interagency working groups as necessary.

About this Document

This document was developed by IOOC BIO-TT and published by the NOC.

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Executive Summary

To further the mission of the United States Integrated Ocean Observing System (U.S. IOOS) and in response to a call from the ocean observation community for wider inclusion of biological variables into U.S. IOOS at the 2012 U.S. IOOS Summit (IOOC 2012), the Interagency Ocean Observation Committee (IOOC), which is organized under the National Science and Technology Council; Committee on Environment, Natural Resources, and Sustainability; Subcommittee on Ocean Science and Technology, established the Biological Integration and Observation Task Team (BIO-TT) in 2013. The BIO-TT conducted a survey of Federal agencies to identify agency needs for biological observations and then prioritized those and additional cross-cutting biological and ecosystem observational needs through an expert workshop. The primary goals of the BIO-TT were to: (1) improve the availability of observations on the existing U.S. IOOS biological core variables[1] and (2) identify and prioritize additional cross-cutting biological and ecosystem observational needs. The approach to address these objectives was to:

- Conduct a two-part survey of Federal agencies' to identify (1) existing biological core variables[2] and (2) prioritized needs for biological and ecosystem observations (see companion report *Biological and Ecosystem Observations within United States Waters I: A Survey of Federal Agencies*);
- Based on identified needs, prioritize cross-cutting biological and ecosystem variables that should be considered for addition to the list of U.S. IOOS core biological variables; and
- Conduct an expert workshop to analyze the survey findings, explore best available science of biological and ecosystem observing, and determine implementation strategies for biological and ecosystem observation needs identified from the survey (this report).

The BIO-TT considerations built on the actions and recommendations made previously by several other groups working toward the development of a global, coordinated ocean observation system. The BIO-TT leveraged this knowledge in the expert workshop specifically by using impact and feasibility analyses (IFAs) based on the Framework for Ocean Observing (FOO). Evaluation criteria used for those IFAs were developed by the Global Ocean Observing System (GOOS) Biology and Ecosystem Panel.

The workshop was held in November 2014 in Washington D.C. The workshop participants reviewed and refined the list of potential biological variables identified in the survey of Federal agencies, created overarching frameworks of functional groupings within which to consider prioritization of biological variables, conducted an IFA for 35 variables, and ultimately identified 11 new core biological variables for inclusion in U.S. IOOS, as shown in the table below. The IFA addressed both the significance and the practicality of adopting each new variable. Thus, with the existing full suite of U.S. IOOS core variables, these recommended new biological variables provide the core information, or the ability to derive products, that will be directly used by researchers, managers, and the public to inform decisions and actions to manage marine biological resources in an ecosystem context.

Workshop participants agreed that in order to ensure responsible stewardship of the Nation's oceans and Great Lakes we must consider interactions, both spatial and temporal, among climate, physics, chemistry, and

[1] Defined by the BIO-TT as phytoplankton species, zooplankton species and abundance, and fish species and abundance. For completeness in Part I of the survey, the BIO-TT also included phytoplankton abundance as a core variable. Phytoplankton abundance, however, is not officially recognized by U.S. IOOS as a core variable.

[2] The terms biological core variables and core biological variables are both used in the report. Biological core variables refers to the subset of IOOS core variables, which are biological (versus physical or chemical) while core biological variables refers to the set of variables among all biological variables that are considered to form the core of a sustained observing system.

biology. Consistent with this, the workshop participants provide the following recommendations to the IOOC and the broader IOOS enterprise to advance the biological observing component:

- The workshop participants agreed that, in addition to the existing IOOS biological core variables, the highest priority should be to include species and abundance of other core functional groups (pelagic and benthic) that are not in the current list. (Phytoplankton abundance, species and abundance of corals, invertebrates, marine mammals, microbes (including microbial activity), sea birds, sea turtles, and submerged aquatic vegetation).
- Following species and abundance, biological vital rates (BVR) are recommended as the next priority of biological information to be included as IOOS core variables. BVRs include, but are not limited to, production, recruitment, mortality, fecundity, growth, and feeding rates.
- Participants also recommend that information on nekton diet be included as a U.S. IOOS core variable. This could be initiated very rapidly through incorporation of existing diet datasets for fish, sea birds, sea turtles, and marine mammals.
- Finally, participants recommended that sound be included as an IOOS core variable. Sound is a fundamental ocean property, which originates from biological (e.g., marine mammals, soniferous fish, snapping shrimp), physical (e.g., wind, surface waves, sea ice; geological (e.g., earthquakes), and anthropogenic (e.g., ships, air guns) sources, and affects many aquatic species. Analogous to ocean color, measurement of sound enables derivation of numerous variables, such as marine mammal and fish presence, wind speed estimates, and ambient noise. Sound provides a natural bridge between some of the physical and biological elements of an ocean ecosystem.

Existing U.S. IOOS core and biological core variables (lower case) in alphabetical order and the proposed new core biological variables (UPPER CASE BOLD). The new biological core variables are proposed to better observe the biological components of ocean ecosystems. No importance is implied by the order of listing (alphabetical within a category). Higher priority among new variables is given to variables in black and then those in blue.

Core variables
Acidity
Bathymetry
Bottom Character
Colored Dissolved Organic Matter
Contaminants
Dissolved Nutrients
Dissolved Oxygen
Heat Flux
Ice Distribution
Ocean Color
Optical Properties
Partial Pressure of CO_2
Pathogens
Salinity
Sea Level
Stream Flow
Surface Currents
Surface Waves
Temperature
Total Suspended Matter
Wind Speed and Direction

Biological core variables (Including pelagic and benthic organisms)
Fish species/abundance
Phytoplankton species/**ABUNDANCE**[1]
Zooplankton species/abundance
CORAL SPECIES/ABUNDANCE
INVERTEBRATE SPECIES/ABUNDANCE[4]
MARINE MAMMAL SPECIES/ABUNDANCE
MICROBIAL[2] **SPECIES/ABUNDANCE/ACTIVITY**[3]
SEA BIRDS SPECIES/ABUNDANCE
SEA TURTLES SPECIES/ABUNDANCE
SUBMERGED AQUATIC VEGETATION SPECIES/ABUNDANCE
BIOLOGICAL VITAL RATES[5]
NEKTON DIET[6]
SOUND

[1] Phytoplankton species (but not abundance) is already an identified core variable.

[2] Here, "microbial" refers to heterotrophic bacteria and archaea. Although, in general terms, microbes encompass microbial eukaryotes, which include the phytoplankton and smaller zooplankton species, the distinction between microbes versus phyto- and zooplankton was retained for simplicity and historical continuity.

[3] Microbial activity is included here rather than within biological vital rates, since it is more relevant for characterizing rates and quantities associated with the biogeochemical cycling of elements, which in turn influence primary and secondary production.

[4] Includes pelagic invertebrate nekton (as distinct from zooplankton) as well as benthic invertebrates.

[5] Includes production, recruitment, mortality, fecundity, growth, and feeding rates.

[6] Includes the diets of fish, sea birds, sea turtles, and marine mammals.

Socialization of this report with additional input from a broader cross section of the ocean observation community, including the private sector and the international ocean science community, would serve two purposes: (1) improve integration of biological observations across other components of U.S. IOOS, including connections with physical and chemical/biogeochemical observations; and (2) advance the ocean observing enterprise towards a predictive capacity for ecosystem structure and function.

Background

As articulated in *United States Integrated Ocean Observing System (U.S. IOOS) Report to Congress* (U.S. IOOS 2015), the core U.S. IOOS mission is to lead the integration of ocean, coastal, and Great Lakes observing capabilities, in collaboration with Federal and non-Federal partners, to maximize access to data and generation of information products, inform decision making, and promote economic, environmental, and social benefits to our Nation and the world. To further this mission, and in response to a call from the ocean observation community for wider inclusion of biological variables into U.S. IOOS, at the 2012 U.S. IOOS Summit (IOOC 2012), the Interagency Ocean Observation Committee (IOOC), which is organized under the National Science and Technology Council; Committee on Environment, Natural Resources, and Sustainability; Subcommittee on Ocean Science and Technology (SOST), established the Biological Integration and Observation Task Team (BIO-TT) in 2013.

The BIO-TT

The primary goals of the BIO-TT were to: (1) improve the availability of observations on the five currently identified U.S. IOOS core biological variables defined by the BIO-TT as phytoplankton species, zooplankton species, zooplankton abundance, fish species, and fish abundance; and (2) identify and prioritize additional cross-cutting Federal agency biological and ecosystem observational needs. The approach to address these objectives was to:

- Conduct a two-part survey of Federal agencies to identify: (1) datasets on the existing biological core variables; and (2) prioritized needs for biological and ecosystem observations (see companion report *Biological and Ecosystem Observations within United States Waters I: A Survey of Federal Agencies*);
- Based on identified needs, prioritize cross-cutting biological and ecosystem variables that should be considered for addition to the list of U.S. IOOS core variables; and
- Conduct an expert workshop to analyze the survey findings, explore best available science of biological and ecosystem observing, and determine implementation strategies for biological and ecosystem observation needs identified from the survey results (workshop participants listed in Appendix 1).

This report summarizes some of the key results from the survey that were used to inform workshop discussions, but focuses on the analyses and outcomes from the expert workshop, and provides recommendations for new and enhanced biological variables as part of U.S. IOOS. Additional information on the Federal survey can be found in the companion report *Biological and Ecosystem Observations within United States Waters I: A Survey of Federal Agencies*.

The BIO-TT held the workshop in November 2014 in Washington D.C. The workshop activities build on the actions and recommendations made previously by several other groups working toward the development of a global, coordinated ocean observation system (IGOS UNESCO 2006). The BIO-TT leveraged that knowledge and followed the guidelines developed by the Framework for Ocean Observing (FOO) (UNESCO 2012) and the "Report of the First Workshop of Technical Experts for the Global Ocean Observing System (GOOS) Biology and Ecosystem Panel: Identifying Ecosystem Essential Ocean Variables (EOVs)" (IOC 2014).

The Bigger Picture

In March 2002, a group of over 100 experts representing Federal and state government agencies, private enterprise, academia, and non-governmental organizations from different regions of the coastal United States participated in the first workshop that defined the United States Integrated Ocean Observing System (Ocean, U.S. 2002). Individual attendees at that workshop identified numerous key properties and processes, known as core variables, that should be measured as part of a national backbone for U.S. IOOS, and thus form the observational component of U.S. IOOS. Individual workshop attendees identified key criteria including:

- Core variables should encompass the minimum number of variables necessary to detect and/or predict the maximum number of phenomena of interest to user groups;
- A small number of variables would be required by all regions participating in U.S. IOOS; and
- Variables must be suitable for measurement in a national system of sustained, routine, and robustly calibrated observations.

Using those criteria, many workshop attendees defined an initial set of 20 core variables, to be included in U.S. IOOS, based on an Impact and Feasibility Analysis (IFA) as follows:

- Physical – salinity, temperature, bathymetry, sea level, surface waves, surface (vector) currents, ice concentration, surface heat flux, and bottom characteristics;
- Chemical – water column contaminants, dissolved inorganic nutrients, and dissolved oxygen; and
- Biological – fish species and abundance, zooplankton species and abundance, optical properties, ocean color, and phytoplankton species.

In addition, several workshop attendees identified the following core variables as required to quantify the external drivers of environmental change on a national scale:

- Meteorological – vector winds, temperature, pressure, precipitation, and humidity;
- Terrestrial – river discharge; and
- Human Health and Use – seafood contamination and water column concentration of human pathogens.

Following the workshop, six additional variables were added as U.S. IOOS core variables (U.S. IOOS 2010, and references therein). These include:

- Acidity (pH);
- Colored Dissolved Organic Matter;
- Partial pressure of carbon dioxide (pCO_2);
- Stream flow;
- Total suspended matter; and
- Wind speed and direction.

The inclusion of these six additional variables highlights an important concept that the U.S. IOOS core variables are subject to change through time. The recommendations in this report for an expanded list of biological core variables is subject to modification and addition as new questions, methods, and approaches are developed in the future.

Approach

Although this BIO-TT workshop was focused on soliciting individual views and recommendations specific to U.S. IOOS and their core biological variables, the relevance of this effort to identifying biological and ecosystem Essential Ocean Variables (EOVs), and how those fit or overlap with other sectors of a global observing system, (Figure 1) was considered throughout the planning and execution of the workshop.

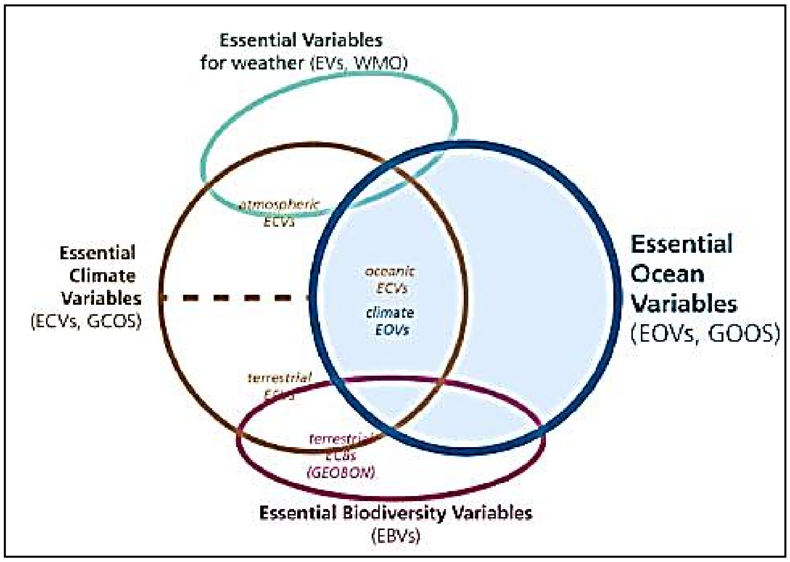


Figure 1. Conceptual Overlap of Essential Ocean Variables with other essential variables.

To build on the actions and recommendations made previously by several other groups, the workshop activities followed the guidelines developed by the FOO (UNESCO 2012). The Framework was developed following OceanObs09, a conference held in Venice, which jump-started a systems approach to ocean observation. The FOO provides an integrated approach to a sustained observing system that moves beyond physical climate observations toward a more holistic approach to ocean observations. The Framework provides a standardized way of assessing the value of variables to develop a more coherent national backbone and strategy to meet ocean observation needs.

Impact Feasibility Analysis (IFA)

Recognizing that it is not possible to measure everything, the aim is to determine the top priorities for observations and those measurements that can act as indicators for larger scale systems. Top priorities are identified by conducting an IFA (Figure 2).

To evaluate the impact of each variable: For the IFA conducted at the workshop, each of the candidate variables was scored against scientific and societal themes taken from the "Report of the First Workshop of Technical Experts for the Global Ocean Observing System Biology and Ecosystem Panel: Identifying Ecosystem Essential Ocean Variables (EOVs)" (IOC 2014). The five themes used were: productivity, biodiversity, ecosystem services, human activities and pressures, and scientific benefit.

To evaluate the feasibility of each variable: Feasibility criteria for the workshop IFA, including readiness level, were taken directly from the FOO (Figure 3).

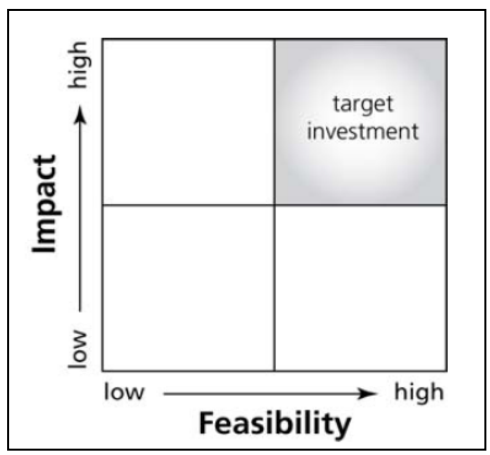


Figure 2. Impact and Feasibility Matrix.

Qualitatively scaled scores were assigned for impact (low, medium, high, essential) and feasibility (concept, pilot, mature) to provide a graphical representation of a first order ranking scheme for the complete list of biological variables under consideration. A variable that cannot be measured practically has less weight (lower priority) than a variable that is practical to measure, and a variable that has little societal value has less weight (lower priority) than one with more immediate information value to society as a whole.

Highest Readiness Level

	Requirements	Observations	Data & Information
Mature	Measurement validated through peer review, implemented at regional or global scales, and capable of being sustained.	Following validation of observation via peer review of specifications and documentation, system is in place globally and indefinitely.	Validation of data policy via routinely available and relevant information products.
Pilot	Measurement and sampling strategy verified at sea. Autonomous deployment in an operational environment.	Establishment of international governance mechanism, international commitments, and sustaining components. Maintenance and servicing logistics negotiated.	Data management practices determined and tested for quality and accuracy throughout the system. Creation of draft data policy.
Concept	Need for information identified and characteristics determined. Feasibility study of measurement strategy and technology.	The system is articulated, capability is documented and tested. Proof of concept validated by a basin scale feasibility test.	Data mode is articulated, expert review of interoperability strategy. Verification of model with actual observation unit.

Lowest Readiness Level

Figure 3. Framework Processes and Readiness Levels. Requirements, Observations, and Data & Information products move through readiness levels within the Framework.

Federal Survey Results

Before the workshop, participants were asked to review the results from a survey of Federal agencies about their needs for biological and ecosystem observations. An analysis of survey results is presented in the companion to this report, *Biological and Ecosystem Observations within United States Waters I: A Survey of Federal Agencies.* A brief summary of the survey results is provided here.

Eighty-six survey respondents from 14 Federal departments or agencies (Appendix II) were asked four questions related to identifying Federal biological and ecological observational needs. The BIO-TT analyzed the survey responses, generated a list of biological variables from the needs identified, and categorized the results into four categories:

- "Primary variables" – ones that represent key biological variables or those that would form the "core" of a biological observing system (Table 3 in Appendix II);
- "Secondary variables" – those that are important but which require further discussion in order to identify key monitoring components necessary to deliver those variables as part of an observing system (Table 4 in Appendix II);
- "Taxonomic information only" describes survey responses that contained only a taxonomic grouping (Table 5 in Appendix II); and

- "Other topics of consideration" consists of responses that were considered to be techniques as opposed to variables, not biological, or other qualifiers in relation to a variable, such as timing, geographic location, or resources necessary (Table 6 in Appendix II).

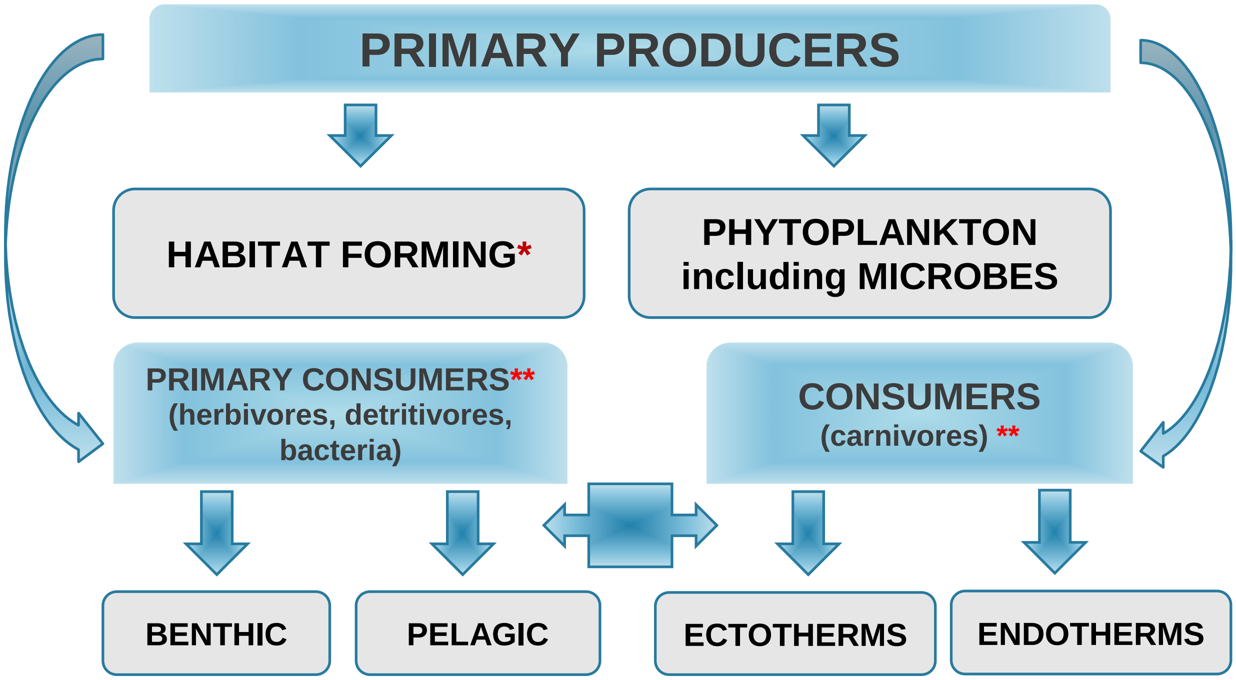
The frequency counts of survey responses are provided in the tables in Appendix II and indicate the relative importance of the variables based on the survey results. For example, data and observations on benthic species and benthic abundance were the most frequently occurring need identified across all questions (Table 3 Appendix II). Other frequently identified needs that are not currently U.S. IOOS core variables included data and observations on marine mammal abundance and species, sound, sea bird abundance, phytoplankton abundance, primary production, and invertebrate species and abundance.

Workshop Analyses and Discussions

Identifying Variables to be Evaluated in the IFA

Following review of background materials (Appendix II) and a more detailed presentation on the Federal survey results, the workshop participants discussed and determined a suite of "primary variables" that would be analyzed in an IFA. The starting point for these discussions was the primary variables table identified from survey responses (Table 3 in Appendix II).

Workshop participants considered the variables identified in survey responses and discussed the inconsistencies in some of the results. For example, data on sea turtle abundance were listed, but data on sea turtle species were not. Workshop participants also noted that in selecting variables it is important to consider the observations that are needed to generate specific products. These types of observations prompted discussions regarding which variables should be included from a broader ecosystem or biosphere perspective, i.e. what functional groups could/should be considered. Workshop participants constructed two conceptual diagrams that were then used to frame subsequent discussion in terms of functional groupings of the biosphere that are important to consider in observing systems. These diagrams were not meant to be all encompassing or exhaustive, but supported the participants in framing their thoughts and discussion. The first diagram (Figure 4) considers functional groupings with respect to energy flow through the environment. The second diagram (Figure 5) considers functional groupings by groups of organisms with similar roles in the biosphere.



* Macroalgae, seagrasses, corals, crusto-coralline algae
** Considerable range of functional groups contained within these consumer groups

Figure 4. Diagram of functional "energy flow" groupings. Primary producers are divided into habitat forming and phytoplankton (including both eukaryotes and prokaryotes). At the level of consumers, primary consumers are distinguished from other consumers, benthic organisms are distinguished from pelagic organisms, and ectothermic organisms are distinguished from endothermic organisms. Reasons for making these distinctions, for example endotherms are warm-bodied organisms, whether air-breathing vertebrates, tunas or sharks, they are a key functional group that are found in all U.S. IOOS regions, and they are important to consider because the combination of physiological, life history, and natural history constraints make these species sensitive indicators and integrators of ecosystem change. Specifically, endotherms require a much higher rate of energy (or food) intake relative to similarly-sized ectotherms. They are less numerous than ectotherms at a comparable trophic level, but due to their higher rate of energy intake they have a disproportionate effect on energy flow. They are often highly mobile, range broadly across regions, and are long-lived. The double-arrowed box represents "Strong Interactors." Sometimes referred to as "keystone species," strong interactors are those organisms in the regional ecosystem that have a major influence on ecosystem structure through ecological interaction (e.g., competition, predation, and disease) such that a change in the distribution and/or abundance of these organisms will result in significant changes in biodiversity and production of the system.

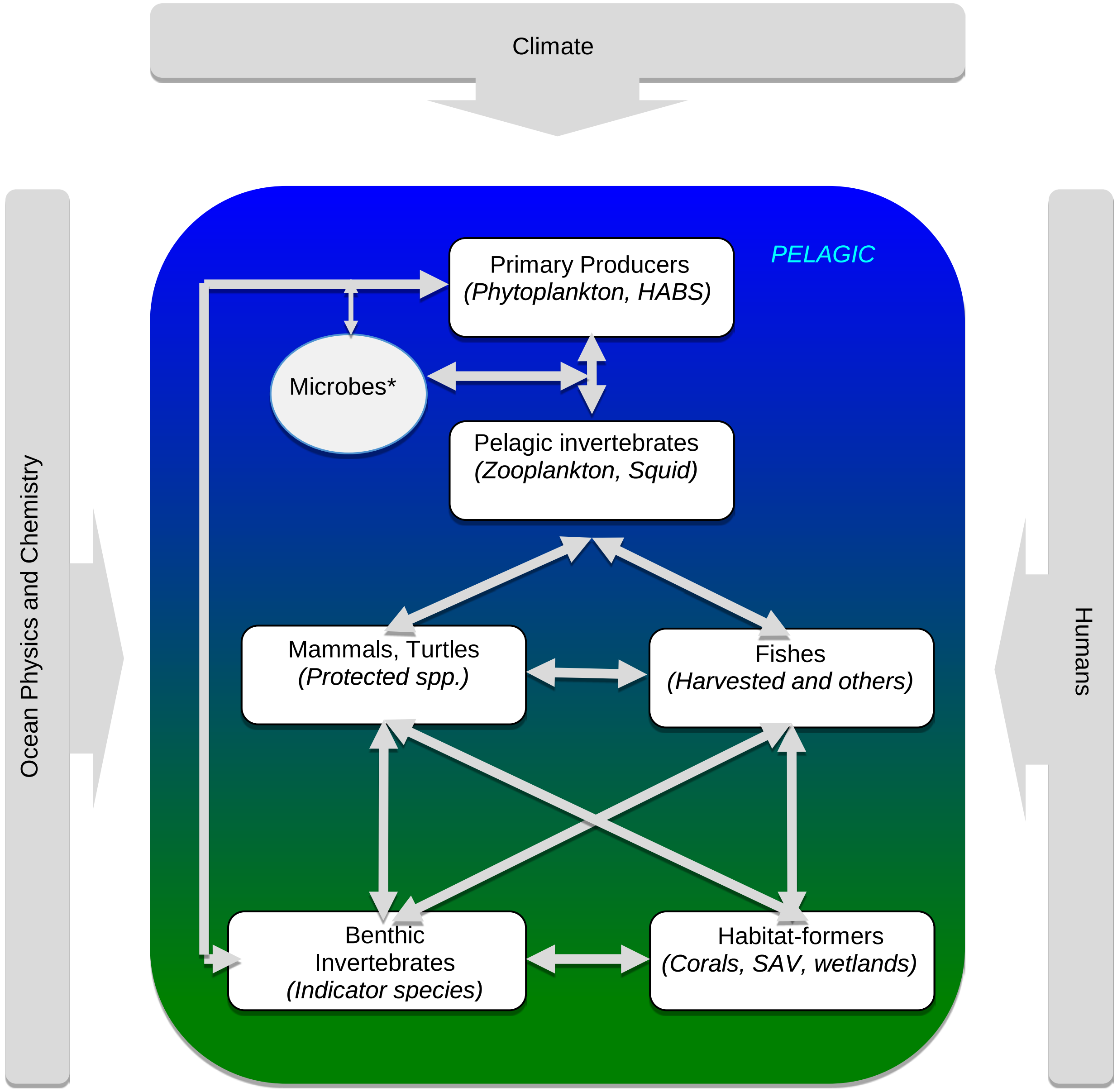


*Figure 5. Diagram of functional "organismal" groupings. This diagram represents outside pressures on and interactions with the biosphere (large grey arrows acting on the central box). Within the ocean biosphere, both pelagic and benthic zones are important. However, as reflected by the color gradation from blue to green in the figure there are no sharp boundaries between these zones in the ocean nor the organisms that occur there. The boxes within the biosphere characterize a minimum number of marine biological components that Federal agencies (and U.S. IOOS) should monitor or strive to understand, as determined by the workshop participants. The arrows provide examples of interactions that may occur. *Microbes refers in this diagram to non-photosynthetic organisms. SAV = Submerged Aquatic Vegetation.*

Based on the discussions of functional groupings and with reference to the survey results, the workshop participants evaluated the 'impact' and 'feasibility' of the 35 biological variables shown in Table 1 and presented in the groupings as derived from the survey results in Table 3 of Appendix II.

Table 1. Variables evaluated during the workshop using an Impact and Feasibility Analysis.

Species	**Abundance**	**Productivity/ Production**	**Diet**	**Sound**
benthic invertebrate	benthic invertebrate	benthic invertebrate fecundity		ambient sound or passive acoustics
fish	fish	fish fecundity	fish diet	
phytoplankton	phytoplankton	primary productivity		
marine mammal	marine mammal	marine mammal fecundity	seal diet	
zooplankton	zooplankton	zooplankton fecundity		
seabird	sea bird	sea bird fecundity	sea bird diet	
sea turtle	sea turtle	sea turtle fecundity	sea turtle diet	
coral	coral	coral recruitment		
microbial	microbial	microzooplankton grazing		
submerged aquatic vegetation	submerged aquatic vegetation			
pelagic invertebrate nekton				

IFA Results and Discussions

Each workshop participant completed an initial IFA for variables on which they had expertise prior to a group discussion of the process and overall rankings. Participants were then given additional time to revisit and finalize their rankings. The final scores were adjusted to account for the number of experts that completed the evaluation for each variable and normalized to give impact and feasibility scores between 0 and 1 for each variable (Figure 6).

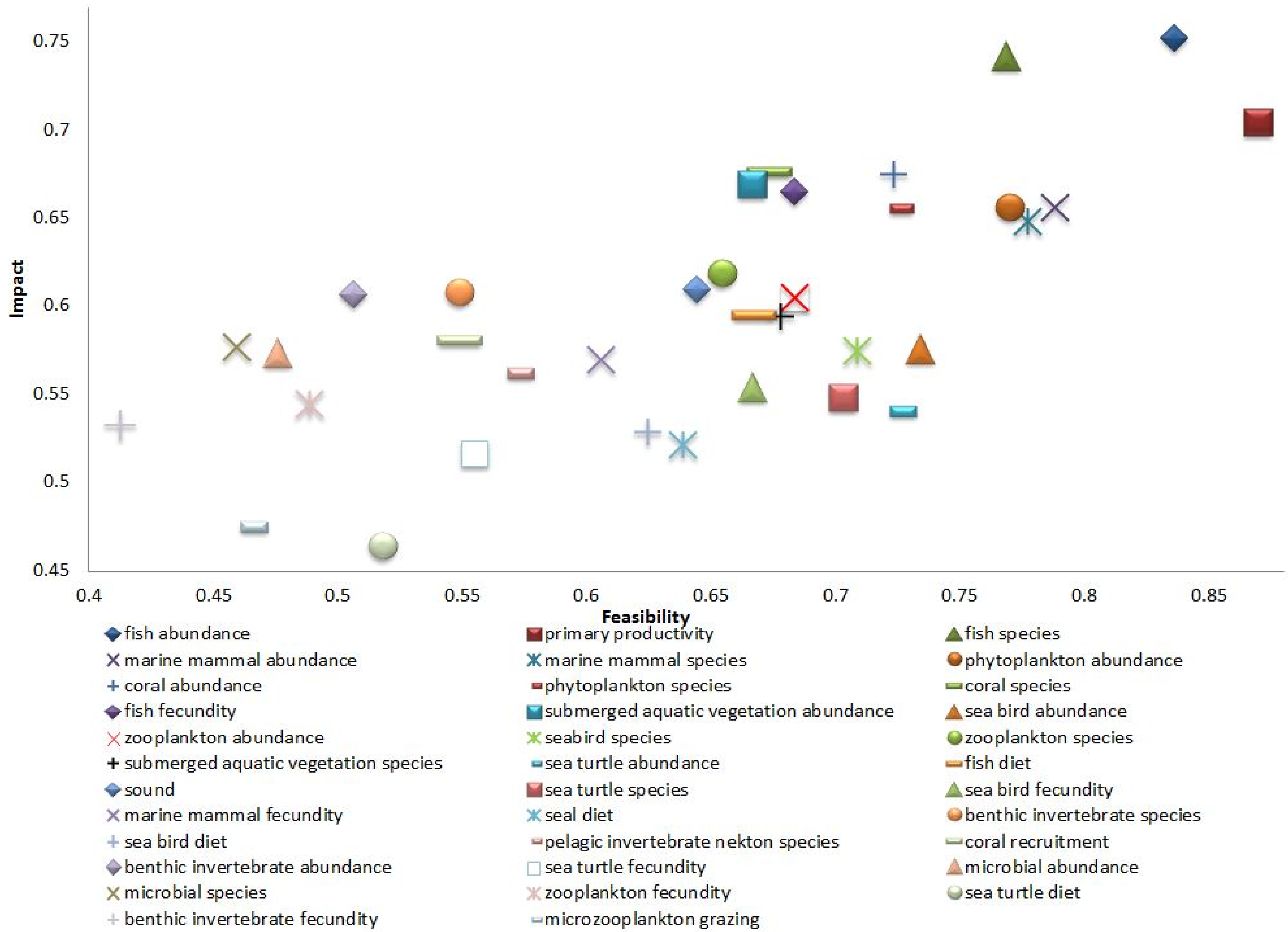


Figure 6. Impact Feasibility Analysis results for 35 biological variables scaled relative to total impact and feasibility scores and to account for the number of experts contributing to the evaluation of each variable. The variables (reading left to right, top to bottom in the legend) appear in the figure in rank order of the sum of the two scaled scores (i.e., top right to bottom left).

During the discussions of the IFA, common topics emerged relevant to interpretation of the IFA results and should be considered if the analysis be repeated in the future. Many workshop participants struggled with a distinction between prioritizing what should be considered as a "variable" and therefore monitored as part of an ocean observing system and what "observations" or biological needs might be intrinsically important. Therefore, future IFAs should consider additional and more explicit societal benefits to refine the evaluations of impact. For example, in the impact evaluation under the broad category of "societal benefit" it may be hard to determine broad benefits to society from a sea turtle, which is associated with specific environments, as compared with the benefits to society from phytoplankton, which are ubiquitous and form the base of the food chain. If assigned a specific societal benefit factor such as tourism, however, the evaluation of societal benefits from turtles might rank higher than phytoplankton.

The feasibility of making the observations proved to be a difficult criterion to evaluate in the IFA. Feasibility can mean different things to different people and be quite different in different oceanographic settings. In addition, the feasibility of obtaining measurements one time can differ from the feasibility of performing the same measurements routinely over the long-term (monitoring). Despite the inclusion of the categories described in the FOO, more effort could be made to educate the evaluators prior to conducting an IFA to ensure greater comparability in how they are approaching the evaluations. This education could include considerations of whether feasibility is referring to single observations versus sustained/routine observations, and how to incorporate the differences in feasibility at national/global scales versus what might be feasible locally/regionally.

Most significantly, participants acknowledged that the ranking of individual variables was heavily biased by the expertise of the workshop participants. Thus, in the final recommendations from the workshop the specific rankings of individual variables from the IFA were not used to prioritize variables. Rather, the participants agreed to groupings of variables that should be given "primary" and "secondary" consideration (Table 2). In this way participants acknowledge the importance of a suite of variables while indicating the initial focus for incorporation into U.S. IOOS.

Recommendations

Workshop participants expressed that, in order to ensure responsible stewardship of the Nation's oceans and Great Lakes, the ocean observations community should consider interactions, both spatial and temporal, among climate, physics, chemistry, and biology. Consistent with this understanding, individual workshop participants suggested recommendations including the following to the IOOC and the broader IOOS enterprise to advance the biological observing component:

- In addition to the existing IOOS biological core variables, the highest priority could be to include **species and abundance** of other core functional groups (pelagic and benthic) that are not in the current list (phytoplankton abundance, species and abundance of corals, invertebrates, marine mammals, microbes (including microbial activity), sea birds, sea turtles, and submerged aquatic vegetation).

- Following species and abundance, **biological vital rates (BVRs)** could be the next priority of biological information to be included as IOOS core variables. BVRs include, but are not limited to, production, recruitment, mortality, fecundity, growth, and feeding rates.

- Information on **nekton diet** should be included as an IOOS core variable. This could be initiated very rapidly through incorporation of existing diet datasets for fish, sea birds, sea turtles, and marine mammals.

- Finally, **sound** should be included as an IOOS core variable. Sound is a fundamental ocean property, which originates from biological (e.g., marine mammals, soniferous fish, snapping shrimp); physical (e.g., wind, surface waves, sea ice); geological (e.g., earthquakes); and anthropogenic (e.g., ships, air guns) sources, and affects many aquatic species. Analogous to ocean color, measurement of sound enables derivation of numerous variables, such as marine mammal and fish presence, wind speed estimates, and ambient noise. Sound provides a natural bridge between some of the physical and biological elements of an ocean ecosystem.

Future Considerations

In addition to the individual views shared regarding additional U.S. IOOS core biological variables, many workshop participants noted the importance of developing data management and accessibility policies as the new variables are integrated into U.S. IOOS. Specifically, many participants encouraged that the Data Management and Communications policy for U.S. IOOS focus on the following core standards:

- For metadata, the use of Federal Geographic Data Committee & International Organization for Standardization metadata standards[3];
- For Data Terminology, be based on Darwin Core International Standard[4]; and
- For data publishing tools, be based on United States and International Data publishing tools.

Some workshop participants acknowledged that the major challenge of any prioritization exercise is the bias introduced by the expertise among the participants. They suggested that prioritization exercises be conducted regionally, in relation to specific scientific questions or societal benefit areas important in that region to determine more specific priorities for ocean observing. In this report, the workshop participants have identified some broader functional groupings that could serve as a constructive starting point for such regional prioritization processes. Conducting regional exercises, possibly on a rolling basis, would be in line with the philosophy that U.S. IOOS core variables should not be static, but should be open to modifications as expertise, needs, and management approaches change over time.

Socialization of this report and additional input from a broader ocean observation community, including the private sector and the international ocean science community would accomplish two goals: (1) improve integration of biological observations across other components of U.S. IOOS, including connections with physical and chemical/biogeochemical observations; and (2) advance the ocean observing enterprise towards a predictive capacity for ecosystem structure and function, moving beyond a biodiversity observing network that might result from observations of species and abundance alone.

[3] Federal Geographic Data Committee (FGDC). Geospatial Metadata Standards, available at www.fgdc.gov/metadata/geospatial-metadata-standards.
[4] DCTG. Darwin Core XML Guide. Darwin Core Task Group. 2015, available at http://rs.tdwg.org/dwc/terms/guides/xml.

Table 2. Existing U.S. IOOS core and biological core variables (lower case) in alphabetical order and the proposed new core biological variables (UPPER CASE BOLD). The new biological core variables are proposed to better observe the biological components of ocean ecosystems. No importance is implied by the order of listing (alphabetical within a category). Higher priority among new variables is given to variables in black and then those in blue.

Core variables
Acidity
Bathymetry
Bottom Character
Colored Dissolved Organic Matter
Contaminants
Dissolved Nutrients
Dissolved Oxygen
Heat Flux
Ice Distribution
Ocean Color
Optical Properties
Partial Pressure of CO2
Pathogens
Salinity
Sea Level
Stream Flow
Surface Currents
Surface Waves
Temperature
Total Suspended Matter
Wind Speed and Direction

Biological core variables (Including pelagic and benthic organisms)
Fish species/abundance
Phytoplankton species/**ABUNDANCE**[1]
Zooplankton species/abundance
CORAL SPECIES/ABUNDANCE
INVERTEBRATE SPECIES/ABUNDANCE[4]
MARINE MAMMAL SPECIES/ABUNDANCE
MICROBIAL[2] **SPECIES/ABUNDANCE/ACTIVITY**[3]
SEA BIRDS SPECIES/ABUNDANCE
SEA TURTLES SPECIES/ABUNDANCE
SUBMERGED AQUATIC VEGETATION SPECIES/ABUNDANCE
BIOLOGICAL VITAL RATES[5]
NEKTON DIET[6]
SOUND

[1] Phytoplankton species (but not abundance) is already an identified core variable.

[2] Here, "microbial" refers to heterotrophic bacteria and archaea. Although, in general terms, microbes encompass microbial eukaryotes, which include the phytoplankton and smaller zooplankton species, the distinction between microbes versus phyto- and zooplankton was retained for simplicity and historical continuity.

[3] Microbial activity is included here rather than within biological vital rates, since it is more relevant for characterizing rates and quantities associated with the biogeochemical cycling of elements, which in turn influence primary and secondary production.

[4] Includes pelagic invertebrate nekton (as distinct from zooplankton) as well as benthic invertebrates.

[5] Includes production, recruitment, mortality, fecundity, growth, and feeding rates.

[6] Includes the diets of fish, sea birds, sea turtles, and marine mammals.

Appendix I

List of BIO-TT Workshop Participants and Affiliations

Participant	Affiliation
Bob Houtman	IOOC Co-Chair, National Science Foundation
Carl Gouldman	U.S. Integrated Ocean Observing System
Daniel Costa	University of California, Santa Cruz
Danie Kinkade	Woods Hole Oceanographic Institution
Derrick Snowden	National Oceanic and Atmospheric Administration (NOAA), U.S. Integrated Ocean Observing System
Eileen Hofmann	Center for Coastal and Physical Oceanography, Old Dominion University
Emmett Duffy	Smithsonian Tennenbaum Marine Observatories Network
Eric Lindstrom	National Aeronautics and Space Administration
Francisco Chavez	Monterey Bay Aquarium Research Institute
Frank Schwing	NOAA National Marine Fisheries Service, Office of Science & Technology
Fred Whoriskey	Ocean Tracking Network
Gabrielle Canonico	NOAA, U.S. Integrated Ocean Observing System
Hassan Moustahfid	NOAA, U.S. Integrated Ocean Observing System
Heidi Sosik	Woods Hole Oceanographic Institution
Jamison Gove	NOAA National Marine Fisheries Service, Pacific Islands Center
Jay Pearlman	Institute of Electrical and Electronics Engineers
Jim Price	Bureau of Ocean Energy Management
Julia Parrish	School of Aquatic and Fisheries Science, University of Washington
Kandy Binkley	National Science Foundation
Laura Lorenzoni	Institute for Marine Remote Sensing, University of South Florida
Mark Baumgartner	Biology Department, Woods Hole Oceanographic Institution
Mark Fornwall	United States Geological Survey, Ocean Biogeographic Information System
Melissa Carter	Scripps Institute of Oceanography
Michael Weise	Office of Naval Research
Mitch Roffer	Roffer's Ocean Fishing Forecasting Service Inc.
Najih Lazar	University of Rhode Island
Oscar Schofield	Coastal Ocean Observation Lab, Rutgers University
Pamela Plotkin	Texas Sea Grant, Texas A&M University
Raphael Kudela	University of California, Santa Cruz
Rebecca Shuford	NOAA National Marine Fisheries Service, Office of Science & Technology
Rosa Meehan	ArcticTurn
Rost Parsons	National Centers for Environmental Information, Marine Ecosystems
Samantha Simmons	Marine Mammal Commission
Sarah Miller	Environmental Laboratory, U.S. Army Corps of Engineers
Tawnya Peterson	Oregon Health and Science University

Appendix II

Background Materials Provided to Workshop Participants

BACKGROUND AND CONTEXT FOR THE WORKSHOP

Following the IOOS Summit in 2012 (Summit Report available at: www.iooc.us/summit) and an ongoing recognition from the community of a need for better integration of biological variables into observing systems, the IOOC established a Biological Integration and Observation Task Team (BIO- TT). The team has two goals: (1) to improve the availability of observations on the currently identified IOOS core biological variables[1] and (2) to identify and prioritize additional cross-cutting biological and ecosystem observational needs.

To address these goals the task team has undertaken two activities. The first of these activities was a two-part, online survey that was distributed to all Federal agencies collecting marine biological data earlier this year. Appendix A provides a copy of all the survey questions. The first part of the survey was designed to provide information that the team will use to address their first goal of increasing the availability of observations on the existing IOOS core biological variables. The second part of the survey was designed to ascertain the biological and ecosystem observational needs of the Federal agencies to address, in-part, the team's second goal. The current workshop will build on the responses from the second part of the survey, collect input from community sectors beyond the Federal government about biological and ecosystem observational needs and associated variables, and help inform priorities for IOOS.

WORKSHOP GOALS: Identify and prioritize additional cross-cutting biological and ecosystem variables (beyond the existing six IOOS biological core variables[1]).

As this process is intended to inform IOOS it is important to keep in mind the IOOS mission:

> "Lead the integration of ocean, coastal, and Great Lakes observing capabilities, in collaboration with Federal and non-Federal partners, to **maximize access to data and generation of information products**, inform decision making, and promote economic, environmental, and social benefits to our Nation and the world." (Emphasis added by the BIO Task Team)

This helps guide our efforts towards identifying variables that will be easily accessible and lead to generation of products.

While this process is focused on U.S. needs, the task team acknowledges similar efforts to identify Essential Ocean Variables, including biological and ecosystem variables, are ongoing at larger scales through, for example, the Global Ocean Observing System (GOOS). The team has designed the prioritization exercise proposed for this workshop in line with that described in the Framework for Ocean Observing (http://www.oceanobs09.net/foo/) and similar to what has been used to identify other Essential Ocean Variables to date (Appendix B provides a list of the currently identified IOOS Core Variables as well as EOVs).

WORKSHOP OUTPUTS: (1) A refined list of variables for stewardship (observing, understanding, and managing) of our oceans; building on the existing IOOS biological core variables, including the results from the survey of Federal agencies, and completed by workshop participant inputs. (2) A prioritized list of variables. A two-step prioritization process will be used, considering "impact" of the variables (Federal agency needs and societal benefits will be considered when categorizing the variables) and "feasibility" of measuring them (based on the FOO "Framework Processes and Readiness Levels" descriptions). (3) A workshop report summarizing the process, discussions and rationale involved in reaching the two lists of variables.

BIOLOGICAL NEEDS ASSESSMENT:

SURVEY RESULTS FROM FEDERAL AGENCIES

The survey was initially distributed to 219 individual scientists/agency representatives and a total of 86 responses (a response rate of approximately 40 percent) were received from individuals at 14 different departments or agencies within the Federal government (Table 1).

Table 1: Number of individuals that responded to the survey by agency:

Agency	Responses
Bureau of Ocean Energy Management	11
Department of Energy	1
Environmental Protection Agency	5
Marine Mammal Commission	2
National Aeronautics and Space Administration	8
National Oceanic and Atmospheric Administration	25
National Park Service	6
National Science Foundation	1
U.S. Department of the Navy	5
Office of Naval Research	1
Smithsonian Institution	1
United States Army Corps of Engineers	10
United States Fish and Wildlife Service	4
United States Geological Survey	6

Analysis of the survey responses for 'needs'

More than 60 percent of the respondents provided information in the second part of the survey focused on their needs for biological and ecosystem observations. For this part of the survey respondents were given the opportunity to answer primarily open-ended questions with responses gathered in the form of text and narrative. As a result, responses varied from generic terms such as "fish", or "Salmonids" to very specific responses such as a species name, or "Predictive changes in fish abundance accounting for potential

[1] Currently recognized IOOS core biological variables are phytoplankton species, phytoplankton abundance, zooplankton species, zooplankton abundance, fish species, and fish abundance. For completeness in Part I of the survey, the BIO-TT also included phytoplankton abundance as a core variable. Phytoplankton abundance, however, is not officially recognized by U.S. IOOS as a core variable.

climate change effects." Thus, to be able to compare responses, the BIO-TT aggregated them into categories and subcategories. An initial effort to categorize the responses was undertaken to reflect the highest level of "organism" with subcategories to capture more specific information when provided (Table 2).

Table 2. Major categories and corresponding subcategories used to represent responses to survey questions 24 to 33.

Category	Subcategory	
Organism	Benthos	Invertebrates Birds
		Phytoplankton
	Corals	Protected Species
	Endangered Species Act-Listed	Sea Turtles
	Fish	Zooplankton
	Marine Mammals	
Non-Organism	Geography	Physical
	Chemistry	Oceanography
Ecosystem	Habitat	
	Population Characteristics	
Anthropogenic	Anthropogenic	Human Impacts
	Human Uses	
Other	Data	Sound
	Optical	

However, respondents also provided additional information "qualifiers" such as "abundance" or "health/condition" or "density." To try and capture this information and derive a more practical list of potential variables from the survey responses, the team conducted a second round of analyses using the following main categories: Species, Abundance, Life History, Productivity/Production, Diet, Sound, Derived Variables, Health/Condition, Habitat, Behavior, Anthropogenic, Taxonomic grouping (without a qualifier), Techniques, Beyond our Scope, and Other Qualifiers. This categorization provides a more informative starting point for workshop discussions and the team has taken the added step of suggesting primary versus secondary variables for consideration at the workshop (Tables 3-6). The primary variables are ones that represent key biological variables or 'the heart' of what might meet the spirit of the IOOS mission to identify variables that will be easily accessible and lead to generation of products. Secondary variables, as proposed, are those acknowledged to be important, but which require further discussion to identify the key components necessary to monitor to deliver those variables as part of an ocean observing system.

Table 3. Proposed Primary Variables with Qualifiers from the Survey (with Response Count)

Primary Variables											
Species		**Abundance**		**Life history**		**Productivity/Production**		**Diet**		**Sound**	
Benthic species	25	Benthic abundance	21	Fish ages	3	Phytoplankton	10	Fish diet	3	Ambient/passive acoustic measurements	12
Fish species	20	Marine mammal abundance	16	Fish length	3	Primary	9	Diet and food chain/trophic linkages	3	Bioacoustics	9
Phytoplankton species	8	Fish abundance	14	Fish weight	3	Catch Per Unit Effort	7	Diet	2	Soundscape	3
Marine mammal species	7	Zooplankton abundance	13	Fish maturity	2	Zooplankton	5			Marine mammal acoustics	2
Zooplankton species	6	Sea bird abundance	7	Marine mammal	1	Grazing rates	3			Impacts of	2
Invertebrate species	4	Phytoplankton abundance	5	Marine mammal movements	1	Recruitment	1			Anthropogenic	2
Seabird species	4	Invertebrate abundance	4	Fish sex	1	Sea bird	1			Vocalizations	1
Invasive species	2	Protected/listed species abundance	4	Fish migration	1	Productivity rates	1			Fish acoustics	1
Protected/listed species	2	Coral abundance	2	Species migration	1	Surface	1				
Coral species	2	Sea turtle abundance	1			Ecosystem	1				
Microbial species	1	Microbe abundance	1			Coral spawning	1				
Macroalgae species	1	Predator abundance	1			Coral recruitment	1				
		Prey abundance	1								
		Mid-water species abundance	1								
		Submerged aquatic vegetation abundance	1								
		Macroalgae abundance	1								

Table 4. Proposed Secondary Variables with Qualifiers from the Survey (with Response Count)

Secondary Variables									
Derived variables		**Health/Condition**		**Habitat**		**Behavior**		**Anthropogenic**	
Fish distribution	4	Ecosystem	6	Habitat	9	Marine mammal behavior	3	Human use	21
Protected/listed species distributions	4	Marine mammal mortality events	5	Benthic habitat	8	Invertebrate life stage behavior	1	Human impacts	8
Marine mammal distribution	4	Pathogens	3	Wetland spatial extent	3	Fish life stage behavior	1		
Marine mammal density	4	Benthos	3	Seafloor mapping	1				
Sea bird distribution	3	Marine mammal	3	Seabird habitat use	1				
Phytoplankton distribution	3	Contaminants	2	Fish habitat	1				
Protected/listed species density	3	Health/condition monitoring	2	Seagrasses	1				
Coral distribution	2	Habitat	1	Habitat use	1				
Invertebrate distribution	2	Population	1	Fragmentation	1				
Submerged aquatic vegetation distribution	2	Watershed	1	Migration corridors	1				
Plankton diversity index	1	Wetland	1						
Turtle density	1	Recovery	1						
Zooplankton distribution	1	Health (human)	1						
Fish demographics	1								
Benthic trends	1								
Invertebrate trends	1								
Prey distribution	1								

Background Materials Provided to Workshop Participants

Table 5. Survey Responses with Taxonomic Information Only

Taxon (no qualifier)	Response Count	Taxon (no qualifier)	Response Count
Phytoplankton	18	Benthic bivalves	2
Marine mammal	13	Benthic	2
Fish	13	Benthic epifauna	1
Sea birds	5	Benthic meiofauna	1
Coral	4	Non-plankton invertebrates	1
Protected/listed species	3	Zooplankton	1
Gelatinous zooplankton	3	Epibenthic invertebrates	1
Microbes	3	Benthic vertebrates	1
Benthic infauna	2	Ichthyoplankon	1
Sea turtles	2	Meroplankon	1
Seagrasses	2	Microzooplankton	1
Invertebrates	2	Macrozooplankton	1

Background Materials Provided to Workshop Participants

Table 6. Other Topics of Consideration from Survey Results (with Response Count)

Other considerations					
Techniques		**Beyond our scope**		**Other qualifiers**	
Optics	13	Hydrodynamic modelling/currents/hydrography	17	Timing	27
Genomics	3	Nutrient concentrations	10	Geography	24
Marine mammal passive acoustic detection	2	pH	6	Resources	8
Marine mammal passive acoustic classification	2	Temperature	5		
Acoustic Doppler Current Profiler	2	Carbon stocks (Dissolved Organic Carbon, Particulate Organic Carbon , pCO2)	4		
Video Plankton Recorder	2	Carbon fluxes	4		
Fish finders/sonar	2	Dissolved Oxygen	4		
Autonomous Underwater Vehicles	1	Colored Dissolved Organic Matter	3		
Process studies	1	Salinity	3		
High Pressure Liquid Chromatography	1	Turbidity	3		
Marine mammal tracking	1	Ocean acidification	3		
		Marine sediment chemistry	2		
		Water quality	2		
		Total particles	1		
		Coastal erosion	**1**		
		Water chemistry	**1**		
		Carbon species	1		
		Sea ice	1		
		Air quality	1		
		Sand quality	1		
		Wave height	1		
		Subsurface data	1		
		Economic and societal impacts to human communities	1		

WORKSHOP DISCUSSIONS AND PRIORITIZATION PROCESS

We invite the workshop participants to review Tables 3 to 6 and come to the workshop prepared to discuss the variables listed in their area of expertise, to propose additional variables they feel are of societal or scientific value that are not represented in Table 3, and participate in a prioritization exercise for these variables, in order to inform recommendations to IOOS about priorities for biological and ecosystem variables moving forward.

PRIORITIZATION: A two-step prioritization process will be used to evaluate the **Impact** and **Feasibility** of measuring the variables. The impact will be evaluated independent of the ability to measure a variable. Variables will be placed into four categories considering their impact across five societal benefit areas: Primary productivity, Food web, Biodiversity, Ecosystem services, Human activities (as used by the GOOS biology and ecosystems panel). The categories are: "Critical," "High Impact," "Medium Impact," and "Low Impact." The feasibility will be evaluated using the Framework Processes and Readiness Levels descriptions from the Framework for Ocean Observing:

Highest Readiness Level	Requirements	Observations	Data & Information
Mature	Measurement validated through peer review, implemented at regional or global scales, and capable of being sustained.	Following validation of observation via peer review of specifications and documentation, system is in place globally and indefinitely.	Validation of data policy via routinely available and relevant information products.
Pilot	Measurement and sampling strategy verified at sea. Autonomous deployment in an operational environment.	Establishment of international governance mechanism, international commitments, and sustaining components. Maintenance and servicing logistics negotiated.	Data management practices determined and tested for quality and accuracy throughout the system. Creation of draft data policy.
Concept	Need for information identified and characteristics determined. Feasibility study of measurement strategy and technology.	The system is articulated, capability is documented and tested. Proof of concept validated by a basin scale feasibility test.	Data mode is articulated, expert review of interoperability strategy. Verification of model with actual observation unit.
Lowest Readiness			

Some examples of the full prioritization process applied to a few of the variables in Table 3 will be provided at the workshop.

Background Materials Provided to Workshop Participants

APPENDIX A – BIO Task Team Survey Information

Text of Survey Questions:

1. Contact Information
2. Please check off all Departments/Agencies/Bureaus with which you are affiliated.
3. Please specify the office or offices within your Agencies that you are affiliated with.
    - Please try to be explicit and type the full name of the offices.
    - For Example, if you selected NOAA above, you might list "National Marine Fisheries Service" in line 1 and "Office of Protected Resources" in line 2.
4. For each core biological variable, does YOUR GROUP WITHIN YOUR AGENCY collect, provide or use data?
5. If you answered "Other" for any of the core biological variables in the question above, please provide additional information.
6. For each core biological variable, please indicate how YOU interact with the data.
7. If you answered "Other" for any of the core biological variables in the question above, please provide additional information.
8. For each of the core biological variables that your agency collects, provides or uses, indicate how the metadata are documented.
9. If you are using another format for your metadata not listed above, please describe that format, including information about where to access details and/or a description of the format.
10. After reviewing information provided on IOOS biological data standards respondents were asked the following questions:
    - Were you aware, prior to this survey, of these IOOS biological data standards?
    - Are your data consistent with these IOOS biological data standards?
    - If you answered "No" to the second question, please describe the data standards you use (if any), or please use this space to provide any additional comments:
11. For each of the core biological variables that your agency collects or provides are the data stored on an internal system/database?
12. How do you access the data?
13. What format are the data available in?
14. If "Other" provide the data format(s).
15. If your database is accessible only internally what measures are used to restrict/allow access? (Please insert N/A below if this is not applicable).
16. Is there a mechanism for updating the data/replacing flagged data?
17. Do you track data versions?
18. For each of the core biological variables that your agency collects or provides are the data stored in a public repository/accessible to the public?
19. If you answered "Yes" above please provide a url or link to the data or a description of how the data can be accessed.
20. For each of the core biological variables that your agency collects or provides please indicate if the data are archived at a National Data Center
21. If "Other" please provide the name and a link to the National Data Center where the data are archived.
22. Are revisions to the data made internally also updated in the archived record?
23. Would you be interested in participating with IOOS and other partners in:
    - Making your data compatible with IOOS Standards?
    - Helping define, refine, and enhance standards for biological data (to enable interoperability and integration with other like biological data and complementary physical / chemical ocean observational data)?
    - Helping develop plans for integration of biological data into IOOS and IOOS standards?
    - Comments:

Background Materials Provided to Workshop Participants

In questions 24 through 28, please indicate the top 5 biological or ecosystem observational needs, excluding the current IOOS core biological variables, which are CURRENTLY NOT BEING MET in YOUR GROUP WITHIN YOUR AGENCY.

24. Need 1
25. Need 2
26. Need 3
27. Need 4
28. Need 5
29. For each of the needs you just identified as not being met please indicate where the problem(s) lies. Check all that applies and please give a brief elaboration of the problem(s).
    - geographic areas of interest contain too few observations
    - too few observations in general
    - data quality
    - data precision
    - timely data availability is inadequate
    - repeated observations over time needed but unavailable
    - funding limitations
    - infrastructure limitations (e.g. not enough boats, aircraft, etc.)
    - lack of data documentation
    - data available in limited format

    Please elaborate on problems or describe additional problem(s) here:
30. For YOUR GROUP WITHIN YOUR AGENCY, excluding the current IOOS core biological variables, what are the top 5 biological or ecosystem observational needs to meet your mission that ARE MET by data collected WITHIN YOUR AGENCY? (i.e. needs that you meet internally).
31. For YOUR GROUP WITHIN YOUR AGENCY, excluding the current IOOS core biological variables, what are the top 5 biological or ecosystem observational needs that MAY NOT BE MET in the FUTURE?
32. If time and money was no obstacle what changes would you make in the data acquisition operations of your bureau?

    For example:
    - Would you conduct repeated surveys in a particular geographic area with particular spatial and temporal sampling over an indefinite period of time?
    - If you would conduct repeat surveys, how would these observations be conducted?
33. In your opinion, other than the current IOOS core biological variables, which biological variables should IOOS consider next for inclusion as a core variable? Please list up to five biological variables and include your reasoning for why they should be considered.
34. Would you recommend others in your agency who might be interested in completing this survey or who might be interested in improving integration of biological data into US IOOS?

APPENDIX B – CORE/ESSENTIAL OCEAN VARIABLE CHARTS

U.S. IOOS Core Variables

#	Variable
1	Acidity
2	Bathymetry
3	Bottom Character
4	Colored Dissolved Organic Matter
5	Contaminants
6	Dissolved Nutrients
7	Dissolved Oxygen
8	Fish Abundance
9	Fish Species
10	Heat Flux
11	Ice Distribution
12	Ocean Color
13	Optical Properties
14	Partial Pressure of CO2
15	Pathogens
16	Phytoplankton Species
17	Salinity
18	Sea Level
19	Stream Flow
20	Surface Currents
21	Surface Waves
22	Temperature
23	Total Suspended Matter
24	Wind Speed and Direction
25	Zooplankton Abundance
26	Zooplankton Species

Background Materials Provided to Workshop Participants

GOOS Biology and Ecosystem Panel Proposed EOVs. Full workshop report: Identifying Ecosystem EOVs: Report of the first workshop of technical experts for the GOOS Bio and Ecosystem Panel

EOV Category	EOVs
PRIMARY PRODUCTIVITY	Chlorophyll (signaling global change in primary productivity in the ocean surface)
	Mangrove Area
	Salt Marshes
	Seagrass (Kelp and Macroalgae)
FOOD WEB	Zooplankton
	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
BIODIVERSITY	Coral Cover
	Genetic Composition
	Extinctions/endangered species
	Community Structure and Changes Over Time (as an indication of species composition)
	Charismatic Species (e.g. 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)
	Habitat Loss (Structural e.g., Rocky Shore, Coral Reef)
	Deep Sea Benthic Habitat Loss
	Changes in Pelagic Habitat defined by Oceanographic Boundaries
ECOSYSTEM SERVICES	Impacts of Nutrients / Sediment on Coastal Water Quality
	Coastal
	Open Ocean
	De-calcification for Bivalves and Mollusks– an indicator of ocean acidification
HUMAN ACTIVITIES	Plastics Density/Biomass (in both space and time)
	Soundscape (ideally measuring the sound spectrum every 15 minutes)
	Footprint of Fishing
	Dredge Area (in cubic meters)
	Impacts of Oil and Gas Wells & Pipelines
	Seabed Mining Footprint
	Hardened Coastlines (measured in kilometers)
	Mercury Levels in Apex Predators (Change over Time)
	Commercial Shipping Route Destiny
	Coastal Aquaculture Footprint
	Desalinization Plant Number and Capacity
	Freshwater Input/Budget
	Sustainable Energy Structures 'Footprint' (Wind/Tide/Wave/Current)

Background Materials Provided to Workshop Participants

GOOS Biogeochemistry Panel Proposed EOVs

Full workshop report: First Technical Experts Workshop of the GOOS biogeochemistry Panel: Defining EOVs for Biogeochemistry

Category	EOVs	Notes on EOV
Proposed Essential Ocean Variables	Oxygen	Understanding trends in concentrations of dissolved oxygen in the ocean over the last few decades have important implications for our understanding of anthropogenic climate change.
	Macro Nutrients	NO_3, PO_4, Si, NH_4, NO_2
	Carbonate System	The observations required to constrain the carbon system at a point in space and time are any two of Dissolved Inorganic Carbon, Total Alkalinity, pCO_2 and pH, and associated physical variables (temperature and salinity). The carbon system is in a delicate balance such that high quality observations will continue to be required.
	Transient Tracers	Transient tracers are a group of (chemical) compounds that can be used in the ocean to quantify ventilation, transit time distribution, and transport time-scales. Commonly measured transient tracers are the chlorofluorocarbons 11 and 12, also the related compound SF_6. The radioactive isotopes ^{14}C and tritium (that decays to the stable ^3He) are commonly used, and new technologies are emerging that might allow for a global survey of ^{39}Ar in the near future.
	Suspended Particulates	Includes Particulate Organic Carbon (POC) and Particulate Organic Nitrogen (PON). Princeton Ocean Model concentration in the surface ocean provides quantitative information on spatial gradients and temporal variations in biomass. Also included is Particulate Inorganic Carbon observations of which could be used to address the question of what impacts ocean acidification has on calcareous organisms and thus community structure.
	Particulate Matter Export	This EOV constitutes fluxes of particulate organic as well as inorganic matter (particulate organic carbon, calcium carbonate $CaCO_3$, particulate organic nitrogen, particulate organic phosphorus, biogenic silica, and fairly inert clay minerals of continental origin) sinking out of the ocean surface layer.
	Nitrous Oxide	Nitrous oxide is an important climate-relevant trace gas in the Earth's atmosphere. The oceans - including its coastal areas such as continental shelves, estuaries and upwelling areas - are a major source of N_2O and contribute about 30 percent to the atmospheric N_2O budget.
	Carbon-13	Seasonal $\delta^{13}C$ changes in the surface ocean indicate the magnitude of organic matter export rate, the foundation of the ocean's biological pump. Decadal changes in ocean $\delta^{13}C$ depend on the accumulation rate of anthropogenic CO_2 in the ocean. Thus, measured $\delta^{13}C$ inventory changes over time can be used to estimate anthropogenic CO_2 uptake in the ocean.
	Dissolved Organic Matter	Dissolved organic matter represents one of the largest exchangeable 16 reservoirs of organic material on earth. The size of the reservoir (comparable to that of atmospheric CO_2), as well as its role as a sink for autotrophically fixed carbon (Hansell and Carlson, 1998), as a substrate to heterotrophic microbes (Carlson and Hansell 2014), and as a sink/source of carbon involved in climate variations over long time scales (Sexton et al. 2011), highlights its importance in the ocean carbon and nitrogen cycles.

Background Materials Provided to Workshop Participants

Southern Ocean Observing System Ecosystem EOVs

March 2014 workshop report: Southern Ocean Observing System Ecosystem EOVs for the Southern Ocean, 2014.

Category	Sub-Categories
Ecosystem Questions to be Addressed by a Southern Ocean Observing System	Foodwebs
	Habitats
	Diversity
	Regional Human Pressures
Ecosystem Properties	Primary production
	Production
	Abundance
	Energy Transfer
	Habitat Characteristics
	Spatial Distribution of Organisms
	Diversity
	Regional human pressures

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Abbreviations

BIO-TT	Interagency Ocean Observation Committee Biological Integration and Observation Task Team
BVR	Biological Vital Rates
CEQ	Center for Environmental Quality
EOP	Executive Office of the President
EOV	Essential Ocean Variable
FGDC	Federal Geographic Data Committee
FOO	Framework for Ocean Observing
GEO BON	Group on Earth Observations Biodiversity Observation Network
GOOS	Global Ocean Observing System
IFA	Impact and Feasibility Analysis
IGOS	Integrated Global Observing Strategy
IOC	Intergovernmental Oceanographic Commission
IOOC	Interagency Ocean Observation Committee
NEPA	National Environmental Policy Act
NOC	National Ocean Council
NOAA	National Oceanic and Atmospheric Administration
NSTC	National Science and Technology Council
OSTP	Office of Science and Technology Policy
pCO2	Partial pressure of carbon dioxide
R&D	research and development
SAV	Submerged Aquatic Vegetation
SOST	Subcommittee on Ocean Science and Technology
UNESCO	United Nations Educational, Scientific and Cultural Organization
U.S. IOOS	United States Integrated Ocean Observing System