Essential Ocean Variables (EOV) for Biology and Ecosystems:

Fish abundance and distribution

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Background and Justification

Fish and fisheries are key parts of ecosystems, economies and societies. Fish consume lower trophic level organisms, including plankton and other fish, and are consumed by marine mammals, seabirds, fish, invertebrates, and microorganisms. Many fish serve as grazers in different ecosystems (coral reefs, rocky bottoms), ensuring their ecological balance. Fisheries provide food for a large fraction of the world's population, meal and oil for aquaculture, and livelihoods for fishers. Fish and fisheries occupy important roles in societies, including traditional cultures. Fish and fisheries are affected by climate variability and are vulnerable to climate change. Food security affects fisheries and, in turn, both are affected by human population growth and climate. For these and other reasons, the abundance and spatial distribution of fish of different species need to be measured routinely, widely and in a standardized manner. Such information is useful to inform a variety of types of decisions, including those that involve fisheries management, conservation and sustainable use policies, and that affect economic investment and societal resilience in the face of climate change.

Fish abundance describes the biomass or numbers of fish in the ocean. It can be reported in terms of species or taxonomic or functional groups (e.g., small pelagic fish, mesopelagic fish, and tuna-like species) in an assemblage, population, stock or area, or globally. Fish spatial distribution describes the presence-absence of fish in the ocean or the spatial distribution of fish abundance. Both fish abundance and distribution can be reported at local, national, regional or global scales.

There are two main sources of information on fish: fisheries data and scientific monitoring (fisheries-independent) data. Time series of fisheries data are more accessible and have broader geographic coverage when reported. Yet they only concern target species and stages of larger fisheries. However they may also include bycatch species collected through observer programs. Overall fisheries data can be biased as they highly depend on fishing effort and strategy. Many nations conduct stock assessments for valuable species within their EEZs; while inter-governmental organizations conduction stock assessments for transboundary species. The Food and Agriculture Organization (FAO) of the United Nations routinely receives fisheries data and stock information from most nations, although these are generally restricted to fish catch and not

abundance. The Sea Around Us Project (SAUP) compiles data from a large variety of sources to estimate fishery statistics for stocks and regions globally, and attempts to correct it with some bycatch estimates and other data. Other sources include many national, multinational and regional fishery management organizations (RFMOs). Small-scale, artisanal fisheries and recreational fisheries are less well documented.

Access to fisheries-independent data is more complicated. Such data are often the property of non-governmental or government institutions. Fisheries independent data are costly to acquire, and thus time series do not exist for many areas, especially in developing countries. Fisheries independent data are however essential to monitor and evaluate the status of fish species and marine ecosystems more accurately than using only fisheries-dependent catch estimates. Because most fisheries-independent surveys target exploited species and their ecosystems, observations of unexploited species are often also lacking.

Fish are observed in a variety of ways. Basic reporting of presence or absence or species richness of fish can be derived from diverse observational programs and are compiled in global databases, such as the Ocean Biogeographic Information System (OBIS). Collections from museums can also be used for some assessments. Time series of the catch of many fish are publically available from the FAO. Complex issues of data collection, standardization and access exist with data time series of fish abundance. There is no standardized protocol or specific design required for reporting at the international level. Routine scientific sampling of fish eggs and larvae (ichthyoplankton), juveniles, and adults has occurred since the start of commercial fisheries in support of their management. The abundance of many exploited stocks of fish as well as non-target species is routinely assessed by scientific sampling (e.g., trawl nets, hook and line, traps) and active acoustics combined with trawling. Fish are also observed using mark-recapture and electronic tracking (biologging), which can provide finer scale data on distribution (geographic and depth), phenology, habitat selection, and ecological interactions. However, the methods of collection and analysis of data on fish can vary widely, and the spatio-temporal coverage is heterogeneous. Thus, while significant amounts of data exist, standardized data on the abundance and distribution of all types of fish, both fished and unfished, are needed. Many RFMOs have access to large amounts of data from scientific surveys, while global databases of fish abundance and their time series are still missing. Some programs aim to fill the gaps (e.g. Indicators of the Seas – IndiSeas), with an attempt to gather collections of fisheries independent data, and analyse them to evaluate the status of marine ecosystems.

Table 1 EOV Information (definitions of terms in glossary)	
Name of EOV	Fish abundance and distribution
Sub-Variables	Number, biomass or abundance index of fish of different taxa per unit volume or area of water in a specific region, stock or population, and measured by a standard or known protocol Numbers or biomass of fish by size/age/stage
Derived products	Fish abundance indices Fish diversity indices Size-based indicators of fish assemblages, including mean fish size, size spectra, and large fish indicators Food web indicators, including proportion of predatory fish Fish production Fish habitat
Supporting Variables	Fisheries management area, Large Marine Ecosystem, FAO area Fishing effort (where available with catch, to compute Catch per unit Effort, CPUE)
Complementary EOVs	Phytoplankton biomass and productivity Zooplankton biomass and diversity Marine turtles, birds and mammal diversity, abundance and distribution Physics EOVs (Temperature, Salinity, Currents) Biogeochemical EOVs (Oxygen, pCO_2)
Additional Contact/Expert(s)	Francis Marsac, Kevin Weng

Table 2: Requirements Setting						
Responsible GOOS Panel	Biology and Ecosystems Panel					
Societal Drivers	Knowledge, sustainable use, conservation, capacity building, management (integrated ecosystem approach), threat prevention and impact mitigation, food security, environmental quality					
Societal Pressures	Loss of resources (habitat, biodiversity, fishing), climate variability and change, pollution/eutrophication, invasive species, ocean acidification					
Readiness Level	Requirements Processes: Level 7 (Mature).					
Scientific questions	What is the current status of life in the ocean? How is life in the ocean changing? What are the natural and anthropogenic drivers of changing life in the oceans? How does the changing life in the ocean affect ecosystem function, (health and services)?					
Phenomena addressed (general)	Change in abundance of species, diversity Changes in fish distribution Functional role of a (group of) species in the ecosystem Species invasions Fish recruitment Phenology (spawning, migration)					
Phenomena to capture	1 Change in sizes of individuals, species populations, taxonomic	2 Changes in fish distribution	3 Functional role of a (group of) species in the ecosystem	4 Species invasions	5 Fish recruitment	6 Phenology
Temporal Scales of the Phenomena	Annual to decadal	Seasonal to decadal	Decadal or longer	Decadal or longer	Annual	Seasonal to decadal or longer

Spatial Scales of the Phenomena	100-1000+km	100-1000+km	1000+km	100-1000km	1000+km	1000+km
Magnitudes/range of the signal, thresholds to capture for the processes	Trend (increasing, stable, decreasing)	Migration, latitudinal shifts, contraction to refugia	Trend in functional complexity	New sites of presence / absence	Strong / weak year-classes	Shifts earlier or later
Desired detection limit relative to signal	20%?	100km?		Presence or absence	Order of magnitude?	Weeks?

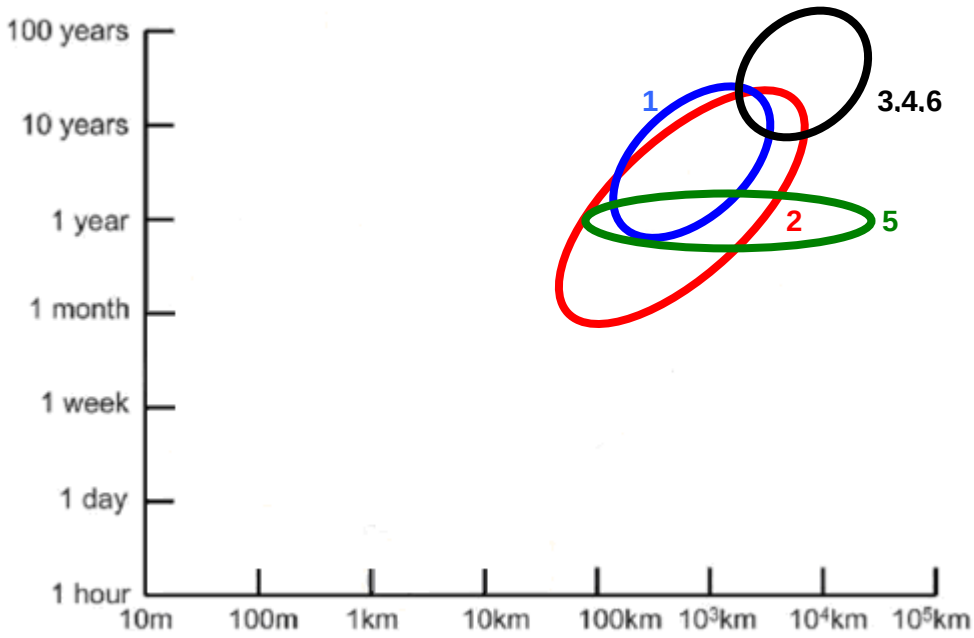

Figure 1: Draw Scales of processes to be addressed, and fill in the magnitude of the signal to capture.

Table 3: Current Observing Networks (or current Communities of Practice)						
Observing Networks/Elements	**Target Fish Surveys (FS)**	**Acoustic-Trawl Surveys (ATS)**	**Ichthyoplankton Surveys (IS)**	**Ecosystem Surveys (ES)**	**Commercial fisheries (CF)**	**Fish Tracking and Tracers (FTT)**
Phenomena addressed	Single or multiple target species abundance and distribution	Single or multiple target species abundance and distribution	Single or multiple species or fish assemblage abundance and distribution	Single or multiple species or fish assemblage abundance and distribution; ecosystem role	Single or multiple species commercial landings	Changes in fish distribution, phenology
Readiness Level of the Network as described in the FOO	Level 7 (Mature) in some regions	Level 7 (Mature) in some regions	Level 8 (Mature) in some regions	Level 4 (Pilot) in some regions	Level 8 (Mature) at global scale	Level 4 (Pilot) in some regions
Spatial scales captured by the network	10-1000km	1-1000+km	10-1000km	10-1000km	10-1000km	10-1000+km
Typical observing frequency	Annual or greater	Annual or greater	Seasonal to annual	Occasional	Seasonal to annual	Daily to annual or greater
Supporting variables measured						Temperature, depth
Sensor(s)/Technique	Nets, hook and line, traps	Scientific echosounders, sonars and trawls	Plankton net and microscopic analysis (or genomics)	Nets, acoustics, imaging, genomics	Purse seine, gillnets, trawls, poles, hooks and lines, traps	Archival tags, otolith structure and chemistry
Accuracy / Uncertainty estimate (units) Biases.	Significant uncertainty and	Significant uncertainty about taxa of	Patchiness in time and space	Highly challenging	Unreported catches, discards,	Good

	sampling biases	acoustic targets			illegal fishing	
Reporting mechanism	National or international data archives	National data archives	National or international data archives	National archives and international literature	National and international data archives	Individual program data distribution

Table 4: Future observing Elements						
Observing Elements/Networks	**Fishery Surveys (FS)**	**Acoustic Surveys (AS)**	**Ichthyoplankton Surveys (IS)**	**Ecosystem Surveys (ES)**	**Commercial fisheries (CF)**	**Fish Tracking and Tracers (FTT)**
Phenomena addressed	Single or multiple species abundance and distribution	Acoustic backscatter and inferred biomass of target species	Single or multiple species or fish assemblage abundance and distribution	Single or multiple species or fish assemblage abundance and distribution; ecosystem role	Single or multiple species commercial landings	Changes in fish distribution, phenology
Readiness Level of the Network as described in the FOO	Concept	Concept	Concept	Concept	Level 7 (Mature)	Level 3 (Concept)
Spatial scales captured by the network	10-1000km	1-1000+km	10-1000km	10-1000km	10-1000km	10-1000+km
Typical observing frequency	Seasonal to annual	Seasonal to annual	Seasonal to annual	Annual to occasional	Seasonal to annual	Daily to annual and greater

Time scale until part of the observing system	10y	10y	10y	20y	n/a	5y
Supporting variables measured		Trawl data			Purse seine, gillnets, trawls, poles, hooks and lines, traps	Temperature, Depth
Sensor(s)/Technique	Combined acoustic – fishing surveys using autonomous platforms (AUVs, gliders, moorings) & current technology		Genomic analysis of samples combined with current technology	Challenging; diverse methods	All fishing methods	Archival tags (recovered and pop-up satellite tags)
Accuracy/uncertainty estimate (units)	n/a	n/a	n/a	n/a	n/a	good

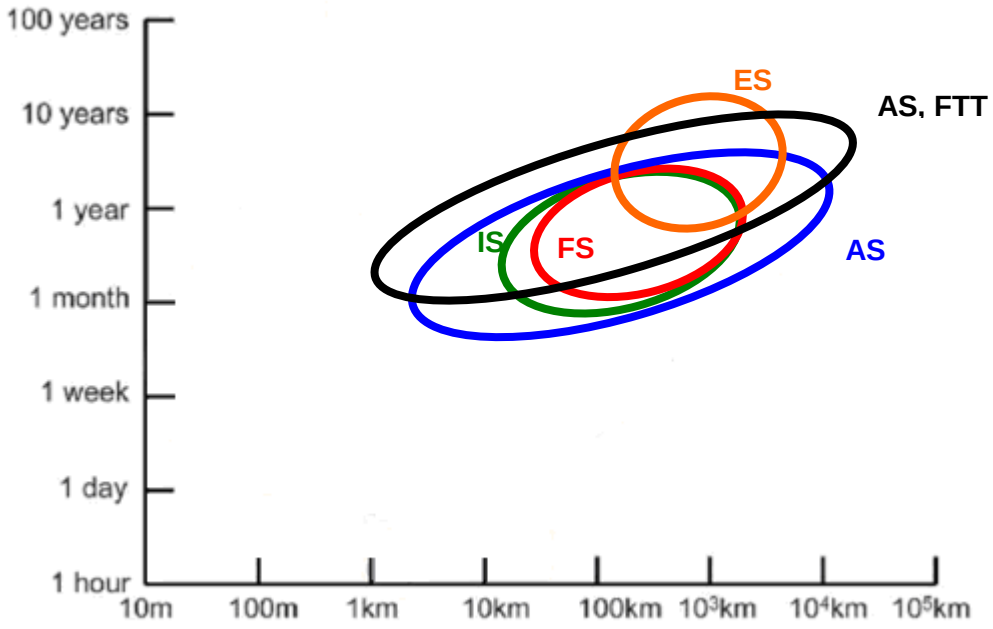

Figure 2. Draw in the well resolved observation scales of the component networks. If these scales are highly dependent on location or time, separate ovals could be drawn to capture this variability (e.g., one for the North Atlantic Ocean, and another for the Southern Ocean). If the capability changes greatly in recent times or will change in the near future (i.e., within five years), provide examples from two times. This refers to the scales that can be resolved, rather than the scales by the network, rather than for individual observations.

Table 5: Data & Information Creation				
	Fishery Surveys (FS)	**Acoustic Surveys (AS)**	**Ichthyoplankton Surveys (IS)**	**Ecosystem Surveys (ES)**
Readiness Level[5]	Level 7 (Mature) in some regions	Level 7 (Mature) in some regions	Level 8 (Mature) in some regions	Level 4 (Pilot) in some regions
Oversight & Coordination	National & multinational organizations	National scientific organizations	National scientific organizations	National and multinational scientific organizations
Readiness status of Metadata	Parts are mature; much is proprietary	Parts are mature; much is proprietary	Parts are mature; much is proprietary	Pilot; much is proprietary
Data Centre/repository	National and multinational organizations	National and multinational organizations	National and multinational organizations	National and multinational organizations
Data Stream delivery and QC…	Incremental delivery of data; quality controlled	Data not generally available; on demand; some QC	Incremental delivery of data; quality controlled	Occasional; quality controlled

Derived Products	Annual estimate of fish stock abundance and status (sustainability)	Periodic active acoustic data, either scattering or estimated biomass of inferred target types	Periodic estimates of abundance of fish eggs and larvae of selected or all fish species in a region	Diverse properties of ecosystems (e.g., structure, dynamics, health)

Table 6: Links & References	
Links (especially regarding Background & Justification)	http://www.fao.org/fishery/en (Food and Agriculture Organization) http://www.seaaroundus.org/ (Sea Around Us Project) http://www.geftwap.org/water-systems/large-marine-ecosystems (UNESCO IOC Large Marine Ecosystems site) http://www.indiseas.org (Indicators for the Seas) http://www.iobis.org/ (Ocean Biogeographic Information System) http://www.imber.info/Science/Regional-Programmes/CLIOTOP Kleisner KM, Coll M, Lynam CP, Bundy A, Shannon L, et al. 2015. Evaluating changes in marine communities that provide ecosystem services through comparative assessments of community indicators. Ecosystem Services 16: 413-29
Links for Contributing Networks	
Data References	http://www.fao.org/fishery/en http://www.seaaroundus.org/ http://www.geftwap.org/water-systems/large-marine-ecosystems http://www.indiseas.org http://www.iobis.org/ http://www.imber.info/Science/Regional-Programmes/CLIOTOP

Acronyms

AUV – Autonomous Underwater Vehicle
EOV – Essential Ocean Variable
FAO – Food and Agriculture Organization
FOO – Framework for Ocean Observing
GOOS – Global Ocean Observing System
IndiSeas – Indicators for the Seas
IOC – Intergovernmental Oceanographic Commission
NDES – Non-Declining Exploited Species
OBIS – Ocean Biogeographic Information System
QA/QC – Quality assurance / Quality control
RFMO – Regional Fishery Management Organization
SAUP – Sea Around Us Project

Glossary of terms and definitions

Community of practice: a group who are using the same or similar instruments or methods, sharing or working towards best practices, analysis techniques, data analyses, etc., and aiming towards increased comparability.

Complementary variables: are other EOVs and/or EBVs that are necessary to fully describe the phenomena or understand impacts on the EOV of natural and anthropogenic pressures.

Contact experts: include experts or teams for platforms and for products related to the EOV.

Derived products: outputs calculated from the EOV and other relevant information, in response to user needs.

Essential Ocean Variable: is a sustained measurement or group of measurements necessary to assess ocean state and change of a global nature, universally applicable to inform societal benefits from the ocean at local, regional, and global scales.

Framework for Ocean Observing: an IOC report to identify the requirements and their priorities, testing new technologies, endorsing implementation plans, and setting data sharing standards for the highest-priority global ocean observations required for both scientific and societal needs (doi: 10.5270/OceanObs09-FOO)

Framework processes: refers to the requirements, observation elements, and data and information products for each EOV (see matrix of “Framework Processes by Readiness Levels”).

Observing Network: refers to reasonably well coordinated observing groups that have developed calibrated observations using the same instruments/method to share best practice, analysis techniques, data standards, etc., so that regional and global comparisons can be made.

Phenomena: is an observable process, event or property measured or derived from one or a combination of EOVs having characteristic spatial and time scale(s) that addresses the GOOS scientific questions.

Processes: refer to processes of interest (not space and time scales which can be seen in the plot). For example, western boundary currents or ENSO. The time scales refer to the processes themselves rather than the scales needed to observe these processes. It is OK to include processes to which the EOV substantially contributes, but is not the sole variable.

Readiness: refers to the feasibility and usefulness of a measurement approach as described in the FOO. There are nine levels within three major categories: concept, pilot and mature, for each of the ***framework processes*** (see matrix of "Framework Processes by Readiness Levels").

Societal drivers: refers to the societal requirements (needs) related to ocean living resources and ecosystems that may determine policy directions and processes of change. A review of international bodies and conventions has identified these as: (1) the need for scientific knowledge and data access, (2) sustainable economic growth and development, (3) conservation of biodiversity and ecosystems, (4) sustainable use of biodiversity and resources in general, (5) environmental quality and health, (6) capacity building and technology transfer, (7) food security, (8) threat prevention and impact mitigation, and (9) to improve management through an integrated ecosystem approach

Societal pressures: refers to the direct stresses caused by humans on marine biodiversity and ecosystems. A review of international bodies and conventions has identified these as: (1) climate change, (2) ocean acidification, (3) extreme weather events, (4) loss of resources (habitats and biodiversity) including overfishing, (5) pollution and eutrophication, (6) mining, (7) solid wastes (trash), (8) invasive species, (9) noise, and (10) coastal development.

Sub-variables: are components of the EOV that may be measured, derived or inferred from other elements of the observing system and used to estimate the desired EOV.

Supporting variables: are other EOVs or other measurements from the observing system that may be needed to deliver the sub-variables of the EOV.

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 speci¿cations • Quality speci¿cations	System in Place: • Globally • Sustained inde¿nitely • Periodic review	Information Products Routinely Available: • Product generation standardized • User groups routinely consulted
Level 8 "Mission quali¿ed"	Requirements "Mission Quali¿ed:" • Longevity/stability • Fully scalable	System "Mission Quali¿ed:" • Regional implementation • Fully scalable • Available speci¿cations 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 speci¿cations • Peer review certi¿ed	Validation of Data Policy • Management • Distribution
Pilot			
Level 6 "Operational"	Requirement Re¿ned: • Operational environment • Platform and sensor constraints	Implementation Plans Developed: • Maintenance schedule • Servicing logistics	Demonstrate: • System-wide availability • System-wide use • Interoperability
Level 5 "Veri¿cation"	Sampling Strategy Veri¿ed: • Spatial • Temporal	Establish: • International commitments and governance • De¿ne standardized components	Verify and Validate Management Practices: • Draft data policy • Archival plan
Level 4 "Trial"	Measurement Strategy Veri¿ed 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)	Veri¿cation 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 Identi¿ed: • Physical • Chemical • Biological	System Formulation: • Sensors • Platforms • Candidate technologies • Innovative approaches	Specify Data Model • Entities, Standards • Delivery latency • Processing flow