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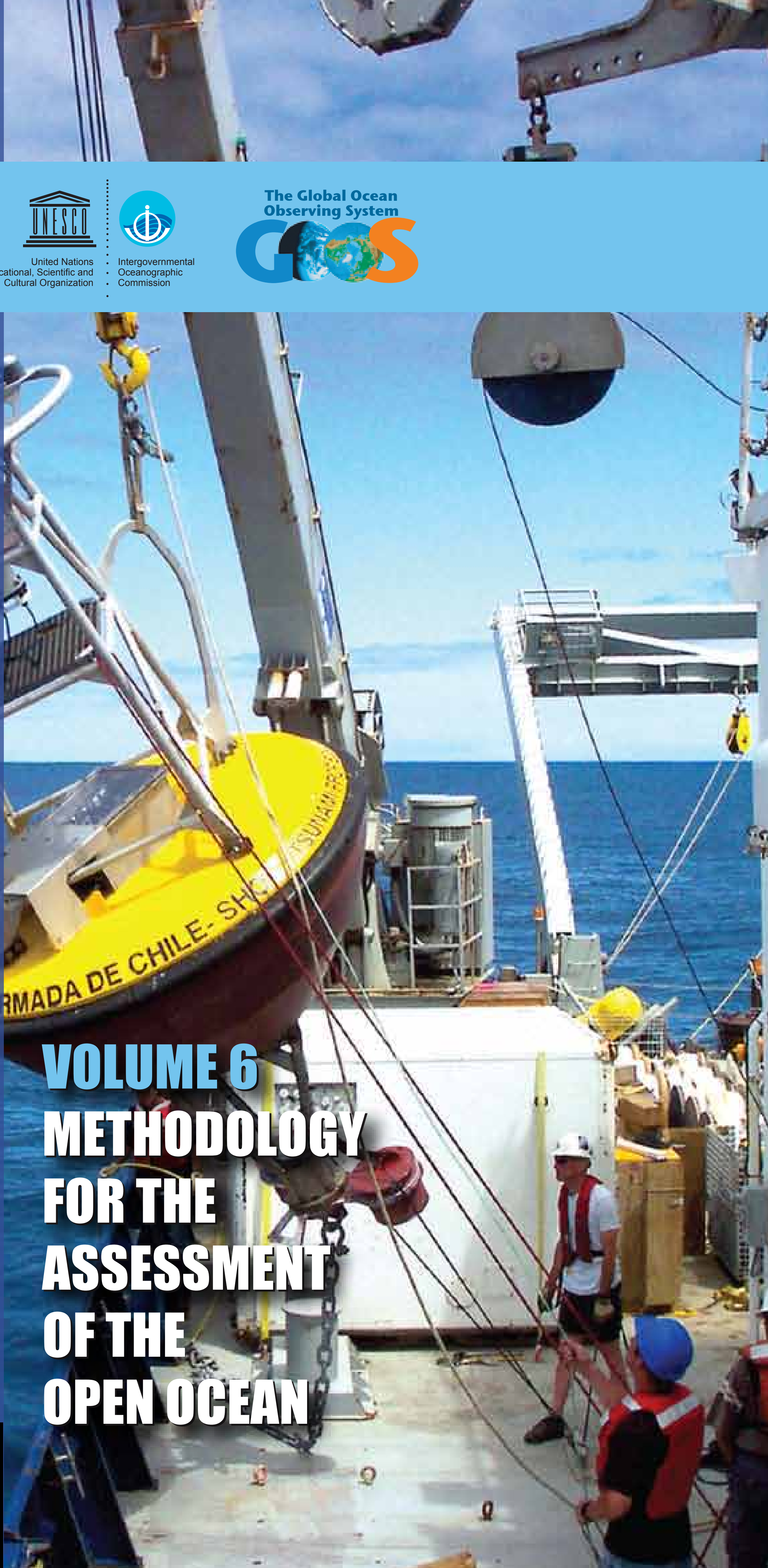

VOLUME 6

METHODOLOGY FOR THE ASSESSMENT OF THE OPEN OCEAN

METHODOLOGY FOR THE GEF TRANSBOUNDARY WATERS ASSESSMENT PROGRAMME

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PREFACE

The GEF Medium Size Project (MSP) *Development of the Methodology and Arrangements for the GEF Transboundary Waters Assessment Programme,* approved in January 2009, was envisioned as a partnership among existing programmes, which was considered to be more cost effective than the conduct of an independent data and information gathering exercise. The Project Objective was to develop the methodologies for conducting a global assessment of transboundary waters for GEF purposes and to catalyse a partnership and arrangements for conducting such a global assessment.

This Project has been implemented by UNEP as Implementing Agency, UNEP Division of Early Warning and Assessment (DEWA) as Executing Agency, and the following lead agencies for each of the water systems: the International Hydrological Programme (IHP) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) for transboundary aquifers including aquifers in small island developing states (SIDS); the International Lake Environment Committee (ILEC) for lake basins; UNEP-DHI Centre for Water and Environment (UNEP-DHI) for river basins; and Intergovernmental Oceanographic Commission (IOC) of UNESCO for LMEs and the open ocean.

This Project resulted in developed methodologies for the following five transboundary water systems: (i) groundwater aquifers; (ii) lake/reservoir basins; (iii) river basins; (iv) large marine ecosystems; and (v) open oceans.

The results of this Project are presented in the TWAP MSP Publication, *Methodology for the GEF Transboundary Waters Assessment Programme*, which consists of the following six volumes:

- *Volume 1 – Methodology for the Assessment of Transboundary Aquifers, Lake Basins, River Basins, Large Marine Ecosystems, and the Open Ocean;*
- *Volume 2 – Methodology for the Assessment of Transboundary Aquifers;*
- *Volume 3 – Methodology for the Assessment of Transboundary Lake Basins;*
- *Volume 4 – Methodology for the Assessment of Transboundary River Basins;*
- *Volume 5 – Methodology for the Assessment of Large Marine Ecosystems; and*
- *Volume 6 – Methodology for the Assessment of the Open Ocean.*

Volume 1 is a summary of the detailed methodologies described in volumes 2 – 6. At the back cover of volume 1 is attached a DVD that contains electronic version of all six volumes.

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SUMMARY FOR DECISION MAKERS

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Figure 1. Earth is the ocean planet, with 70 per cent of its surface covered by oceans, and 50 per cent covered by ocean areas beyond national jurisdiction.

The open ocean is remote from human society, and usually remote from our thinking. Our ability to monitor it is limited, and humans directly in contact with the high seas are limited to a small community of fishers, commercial shipping vessels, navies, and the occasional recreational vessel.

But the global open ocean deserves a higher profile when examining and trying to improve our management of the relationship between human society and the environment. Global impacts on the ocean such as pollution and fishing come from human drivers on land and at sea, and global impacts on human society can be driven by the global open ocean through its role in the climate system, through ocean-related natural hazards, and by loss of ocean ecosystem services upon which society depends.

The open ocean is by international convention the largest transboundary space, with ocean areas beyond national jurisdiction covering about half of the surface of planet Earth (ocean areas under national jurisdiction cover a further 20 per cent), under the ultimate governance of the UN General Assembly. Governance of the open ocean is mediated largely through global international treaties based on particular themes (climate change, fisheries, pollution, biodiversity), as well as some regional conventions.

CHALLENGES OF ASSESSING GLOBAL OPEN OCEAN ISSUES

The challenges to assessing how human well-being and stakeholder behaviour are affected by and linked to changes in the open ocean are numerous.

The first challenge is related to the limited natural science data on the state of the ocean: its physical state, chemical state, the state of ocean ecosystems and living marine resources. While the scientific community has made great progress on monitoring the state of the physics of the upper ocean, and good progress on monitoring the ocean carbon system related to climate, these monitoring systems are not fully implemented and have gaps in their adequacy. Monitoring of the state of ocean ecosystems in particular is lacking. The open ocean assessment will therefore have to focus on where data are available, making extrapolations, assumptions and projections based on best scientific knowledge to generalize where data are lacking. The assessment will also have to address key gaps for research and observations to point to a future path towards reducing uncertainties about our knowledge. Quantifying uncertainty will always be a key part of the natural science assessment of the oceans to support their management.

For an assessment to have impact, it needs to carry clear, high-level messages about the issues raised, and point towards interventions in governance that can help mediate the relationship between humans and the oceans, improving human well-being. The number of key indicators and key messages has to be limited. Balancing this political need with scientific reality requires simplifications and assumptions, and a conceptual framework is needed to organize these and make these clear.

A lack of sufficient monitoring and scientific understanding should not rule out an assessment of the high uncertainty, long timescale, and yet potentially very high impact environmental problems associated with the global oceans. These types of 'foresight' projections are best done by an expert assessment of the latest scientific literature, in an analogue to the WMO-UNEP Intergovernmental Panel on Climate Change (IPCC) assessment of the human relationship to climate. Therefore the assessment cannot rely solely on indicators, even if they are key to communicating problems and tracking progress. This function of the assessment acts as a scoping analysis for looming future problems.

Despite the remoteness of the open ocean from most of human society, they have strong remote effects on each other, the open ocean on society, and society on the open ocean—communicating this remains a challenge. The oceans have a role in mediating patterns of rainfall and drought (an important input for the other TWAP water systems), global climate change is leading to sea-level rise and ocean acidification with growing impacts on ocean ecosystems and on tourism and fisheries, and human activities on land and sea are impacting the open ocean through fishing and pollution. The assessment will need to clearly link human vulnerabilities on land to the open ocean, as well as ecosystem vulnerabilities in the ocean to human threats.

The cost of management action to limit human impact on the open ocean, and of the open ocean on human lives, is often difficult to establish when the threats and benefits are not clearly monetized. Of the many ecosystem services (regulatory services, provision of food, energy, recreational and cultural services) provided by the open ocean, the only one that is traded on markets is fish. An assessment of changes in the valuation of natural capital with changes in the ocean could help inform debate.

The global governance arrangements for the open ocean fall under the authority of the UN General Assembly and the framework of the UN Convention on the Law of the Sea, but include a larger number of thematic arrangements, for climate, biodiversity, fisheries, and pollution. Some regional arrangements also exist, but are overlapping and often also thematic. The full governance of the relationship of human and natural systems involving the open ocean is much larger than these global conventions, involving regional and national structures, markets, and civil society. In deciding where future interventions can help to mediate this relationship between human and natural systems and increase human well-being, the Global Environment Facility (GEF) and other stakeholders will first need to target these global conventions, but then work to ensure that the links to lower-level policy cycles are fully appreciated.

THE PROPOSED ASSESSMENT

The proposed TWAP open ocean assessment will address these challenges through a globally-scoped assessment that directly addresses four broad themes: climate, ocean ecosystems, fisheries, and pollution. Rather than carving the open ocean into assessment units based on natural system criteria (which can vary depending on the scientific discipline consulted, and whether the surface, mid, or deep ocean is being considered), the assessment will take the cue from the human system side and the global governance arrangements already in place and focus on a global thematic assessment.

A conceptual framework links human and natural systems, puts human well-being at the centre of concerns, but allows a focus on where data are available, in particular on indicators of human-related stress on ocean systems. The framework allows clarity on where simplifications and assumptions are being made in the causal chain, and emphasizes the vulnerability of human and natural systems. It puts a broad definition of governance at the centre of the human system side to help guide future interventions.

To communicate messages at a high level, a global mapping approach with a limited number of metrics is taken, linking as far as possible stresses on the natural or human system with vulnerabilities. Projections of these stresses and vulnerabilities will be used wherever possible. To support an eventual regional focus, the mapping approach can be scaled to smaller spatial domains, where regional governance arrangements exist or interventions on a regional scale are decided. This also acts as a complement in coastal regions to parts of the LME assessment methodology which focuses on fixed assessment units.

This global mapping approach will be accompanied by expert assessment of the latest scientific literature in each thematic area, particularly with an eye to addressing high uncertainty but potentially high-impact problems. Expert assessment will also be sought to identify the key research and monitoring needs in each thematic area, as a bridge between the scientific need for exactness and the political need for clear direction. Finally, an expert assessment of estimates of changes in natural capital associated with the identified threats and vulnerabilities will be made.

Embedded in the assessment methodology will be a simple expert assessment of the global governance arrangements in place in each thematic area, with a view to identifying gaps in the policy cycle and links with regional and national levels. Socio-economic metrics will be connected to consideration of human system vulnerability.

A communications strategy will be identified as an early part of implementing the open ocean assessment, in order to engage the widest possible number of stakeholders in the outputs of the assessment.

GENERAL INTRODUCTION

THE TWAP PROJECT

The purpose of Transboundary Waters Assessment Project (TWAP) is to help the Global Environment Facility (GEF) identify priority areas for intervention in the management of shared water systems, and to help governments in managing their shared water bodies. The project should develop a scientifically credible methodology for conducting a global assessment of transboundary water systems (groundwater, lakes/reservoirs, river basins, Large Marine Ecosystems, and open ocean areas) and catalyse a partnership and establish arrangements for conducting such a global assessment. The assessment methodology should allow the monitoring of evolving trends in these water systems, and the identification of the impacts of GEF International Waters programmes and those of other agencies and actors.

The assessment methodology must therefore be able to decipher the complex interaction of the natural system with human systems, speaking to a high level and pointing to environmental problems related to the open ocean. At the same time it needs to maintain a high level of scientific credibility, making the best use of sometimes very sparse data about the open ocean, and identifying clearly the uncertainties driven from gaps in knowledge and in data.

THE OPEN OCEAN AS GLOBAL COMMONS

The open ocean is the largest areas of global commons, vital to life on the planet, and under the legal jurisdiction of no one nation but the common stewardship of all. About half of the entire surface of our planet is open ocean areas beyond national jurisdiction.

While most of the human population of the planet may feel remote from the open ocean - fishers and sailors being a small fraction of us - the open ocean influences our lives in profound ways. The oceans hold 97 per cent of all the water on Earth, most of it in the open rather than coastal oceans. Open ocean dynamics play a key role in regulating and modulating the Earth system and hydrological cycle. The oceans have absorbed about one quarter of human emissions of greenhouse gases and prevented stronger warming of the planet, but as a consequence they are acidifying, with future potential impacts on marine ecosystems. The oceans provide some key ecosystem services to the human population - they produce the majority of oxygen through ocean primary productivity, hold the major part of the planet's biodiversity, and while the significant fraction of fish catch is in LMEs / coastal waters, the open ocean provides a source of food and economic gain from fish and a habitat to highly mobile species, as well as the transport of nutrients into coastal waters. More than 90 per cent of goods in international trade are transported by sea, and the Intergovernmental Oceanographic Commission (IOC)'s Global Ocean Observing System (GOOS) estimates the value of marine activities globally (including open ocean and coastal areas) to be about 5 per cent of global GDP.[1]

[1] http://ioc-goos.org/spm

The legal framework governing the uses of the oceans and their resources is defined by the UN Convention on the Law of the Sea (UNCLOS), which entered into force in 1994. It defines internal waters; territorial seas; rights of Coastal States in Exclusive Economic Zones (EEZs) over natural resources, certain economic activities, marine scientific research and environmental protection; and rights of Coastal States on their Continental Shelf (limited to the seabed) for exploration and exploitation. Areas beyond the internal waters and EEZs are the high seas, where all states enjoy freedoms of navigation, over-flight, scientific research and fishing.

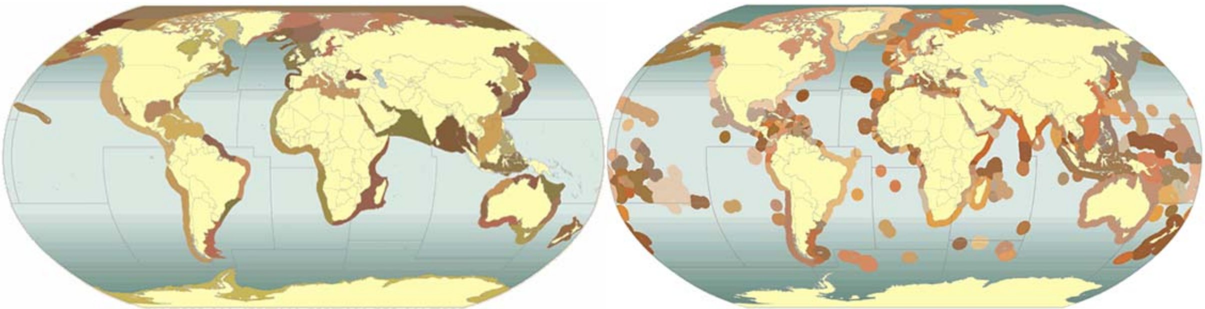

Figure 2. Large Marine Ecosystem areas (left) and Exclusive Economic Zones (EEZs, right). About 50 per cent of the surface of the earth is areas legally beyond national jurisdiction, the open ocean is the largest transboundary space on the planet. (Source: Sea Around Us project)

For the purposes of TWAP, the open ocean is defined as the ocean areas beyond the defined LME areas[2]. However the open ocean assessment will in fact take a global approach, complementary to the LME fixed assessment unit approach. While this definition of open ocean is similar to the high seas of UNCLOS, there is a notable addition of many island EEZs in the large ocean basins, particularly in the tropical Pacific. Conditions in the open oceans have impacts on the natural system and particularly on human systems beyond this strict geographic zone, and in assessing the vulnerability and impact of environmental problems associated with the open ocean, this methodology's scope is global.

Principles guiding the global partnership for the environment and development are encapsulated in the Rio Declaration of the 1992 Earth Summit (the United Nations Conference on Environment and Development), and they are worth noting in the context of the open oceans. These principles include:

- putting human beings at the centre of concerns for sustainable development;
- the responsibility of states not to cause damage to the environment of areas beyond their national jurisdiction;
- the equitable meeting of the needs of present and future generations should be a goal of development;
- that states shall cooperate in a spirit of global partnership to conserve, protect and restore the health and integrity of the Earth's ecosystems;
- environmental issues are best handled with the participation of all concerned citizens, at the relevant level; and
- the precautionary approach shall be widely applied.[3]

Under UNCLOS, all states are obliged to adopt, or cooperate with other states in adopting measures to manage and conserve living marine resources. Highly migratory species of fish and marine mammals are accorded special protection. States are bound to prevent and control marine pollution and are liable for damage caused by violation of their international obligations to combat such pollution.

[2] http://www.lme.noaa.gov/LMEWeb/Images/Images_LME/lme64_bw.jpg
[3] Full text of the Rio declaration: http://www.un.org/documents/ga/conf151/aconf15126-1annex1.htm

There are a variety of governance arrangements for the open oceans in addition to UNCLOS, detailed in Section 3.5.2, which are generally thematic: for managing fisheries, climate change, or ocean-based pollution. They are based on State consensus and cooperation, and generally have weak or no enforcement mechanisms. The TWAP open ocean assessment will need to evaluate governance arrangements related to open ocean environmental problems and point towards potential interventions to manage these. In some cases these interventions will point to areas of management and governance that are not directly related to the open ocean, because of geographic links between human systems, other natural systems, and open ocean systems. In the context of GEF these may not fall under the International Waters focal area, but might cut across other GEF focal areas.

PREVIOUS AND ONGOING ASSESSMENT EFFORTS AND LESSONS LEARNED

TWAP is not the only assessment focused on the open oceans or international waters, and it is important to learn from previous efforts, and align with ongoing ones, to maximize the synergies between assessment efforts and improve their chances of being sustained by local and international involvement.

Global approaches

The Global International Waters Assessment (GIWA) published in 2006 was a previous effort by GEF and implemented by UNEP to assess international freshwater and coastal ocean systems in a holistic and globally comparable manner, but it did not address the open oceans. Four major concerns were addressed: freshwater shortage, pollution, overfishing, and habitat modification, along with the overarching concern of global change. In 66 sub-regions, building on strong local involvement, GIWA assessed the concerns above, and proposed policy options. Finally, while GIWA built local ownership from a strong bottom-up approach, it was hampered by a lack in many cases of social scientists and policy expert involvement, and limited stakeholder involvement. The GIWA approach to assessment will not be repeated by GEF. GIWA provides an interesting background to the TWAP open ocean assessment methodology, in emphasizing the importance of social science and policy in assessing management options for environmental problems, and in pointing out the geographic areas of current and future water stress - since rainfall and drought are controlled mainly by open ocean processes.

The UN General Assembly is contemplating the development of a 'regular process for global reporting and assessment of the state of the marine environment, including socio-economic aspects' (Regular Process). In its start-up phase, a group of experts led by IOC-UNESCO and UNEP has conducted an Assessment of Assessments which identified best practices for an influential assessment, published in 2009. TWAP has a different main client than the Regular Process, GEF rather than the Member States of the UN, and is clearly defined in scope and objectives, while the Regular Process continues to be developed. Nevertheless, it is hoped that the TWAP open ocean and LME assessments will contribute to the Regular Process once it has been defined.

The open ocean methodology will also take note of some other global assessment initiatives that have some relevance:

- IOC's Global Ocean Observing System (GOOS, a joint project with the World Meteorological Organization (WMO), UNEP, and ICSU) has been developing and working with partners to publicize indicators of open ocean variability and change, and is developing further information on the impacts related to these indicators. Its multilateral network of ocean observations are key for monitoring change in the oceans. While originally developed as a climate observing system, the open ocean extent of GOOS is now expanding into biogeochemical variables, and would like to work with additional partners to expand to sustained observations of biological and ocean ecosystem variables. The IOC's International Oceanographic Data and Information Exchange (IODE) programme coordinates the management of open ocean data, and has recently adopted the Ocean Biogeographical Information System (OBIS), a key output of the decade-long Census of Marine Life which ended in 2010;

- One of the most extensive scientific assessment efforts that includes the open ocean is thematic: the one performed by the Intergovernmental Panel on Climate Change (IPCC). It is based on the assessment of peer-reviewed published scientific articles, and includes the open ocean in assessing the role of the oceans in changing climate, and the vulnerabilities to and impacts of the changing climate on natural marine systems; and
- The UNEP Global Environmental Outlook (GEO) is a consultative, participatory, capacity-building process for global assessment and reporting on the state of the environment, trends and future outlooks. It aims to facilitate the interaction between science and policy. The conceptual framework of GEO is consistent with the one proposed for the TWAP marine assessment (open ocean and LMEs).

Regional approaches

The European Union's Marine Strategy Framework Directive (MSFD) adopted in 2008 aims to achieve good environmental status of the EU's marine waters by 2020. It requires each EU Member State to conduct a detailed assessment of the state of the marine environment based on definitions of 'good environmental status' and to establish targets and monitoring programmes. The descriptors of 'good environmental status' are now being developed through scientific advice, and are focused on biodiversity, non-indigenous species, healthy fish stocks, marine food webs, human-induced eutrophication, sea-floor integrity relating to ecosystems, hydrographic conditions, pollution, contaminants in seafood, marine litter, and underwater noise. The assessment will include open-ocean portions of the northeast Atlantic Ocean, and the descriptors and methodology are relevant to both the open ocean and the LME components of TWAP.

Some regional and national efforts of note:

- Cooperation Across the Atlantic for Marine Governance Integration is a project to rationalize indicators in the coastal zones and open ocean across the Atlantic, and has links to other ocean health index projects;
- The US agency NOAA is developing Integrated Ecosystem Assessments[4] for marine ecosystems with indicators to track ecosystem health; and
- The OSPAR Quality Status Report 2010[5] provides a thematic assessment of the level of human threats and ecosystem health in the Northeast Atlantic.

Development of the TWAP open ocean assessment

The IOC coordinated the development of the TWAP open ocean assessment. A working group of natural and social science experts was convened and met twice, in February and June 2010. An extended group of experts, including governance experts, also corresponded with the coordinator, and contributed to the development of the methodology. From written input and the input at the meetings, the coordinator produced drafts of the methodology, which were then reviewed by the working group.

A partnership to conduct the full-sized open ocean assessment was proposed based on the comparative advantage that partners brought in terms of expertise, existing programmes, and infrastructure, as well as their level of co-investment in the project.

The GEF Secretariat was consulted on numerous occasions through formal and informal contacts. Finally, a number of validation exercises were conducted through presentations of the methodology to potential stakeholders. These are listed in Section 2.3.

[4] http://www.st.nmfs.noaa.gov/st7/iea/
[5] http://qsr2010.ospar.org/

PART 1. CONCEPTUAL FRAMEWORK

1.1 OVERALL CONCEPTUAL FRAMEWORK

The conceptual framework of the TWAP open ocean assessment (similar to the TWAP LME assessment) is meant to clarify the relationship between human and natural systems, to help identify why particular indicators are proposed and their relevance, where assumptions have been made, and where there are gaps in knowledge and data. The framework draws on assessment efforts that focus on the idea of 'causal chains'. In short, human activities have associated stressors that in turn impact natural systems and this in turn affects the delivery (and value) of services to people (Figure 3, starting in box 1 below and going clockwise). Ultimately we want to know how people are affected (box 5 in bold), but these ultimate responses may not have easy indicators to develop and may take time, so there is value in having rapid 'early indicator' metrics that are earlier in the causal chain. Understanding and modelling this causal chain allows one to assess the relationship between indicators earlier in the causal chain while keeping in mind the ultimate goal.

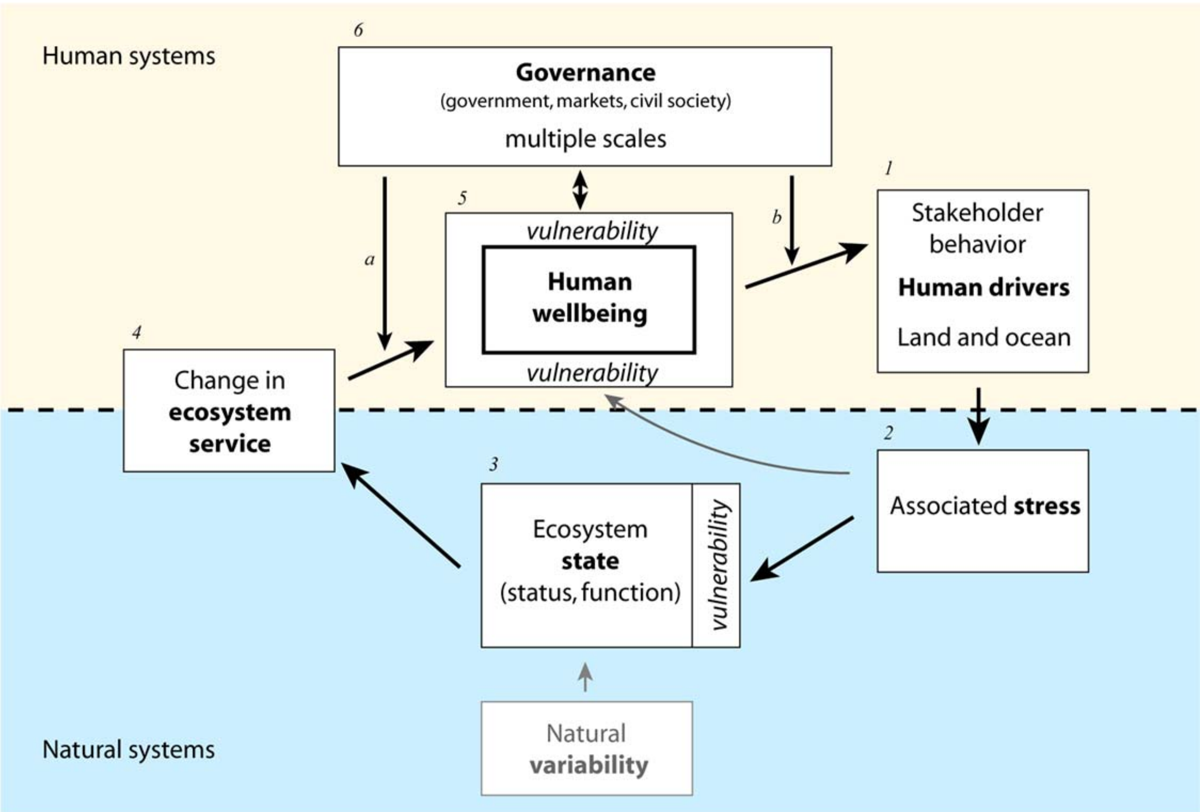

Figure 3. Conceptual framework for the Open Ocean assessments (adapted from the LME conceptual framework), describing the relationship between human and natural systems from the point of view of ecosystem services and its consequences for people expressed as human well-being. Within TWAP this allows an identification of data sources and gaps, of assumptions made, of some factors peripheral to the central framework that may come into play, and of natural points of intervention for management.

The framework tries to merge several existing conceptual frameworks: the Driving force-Pressure-State-Impact-Response (DPSIR) framework, indicator science, an emerging focus on ecosystem services, and cumulative impact modelling, all with a strong focus on governance and socio-economics - on how to manage the human-natural system interaction.

The top half of the diagram is the human system, the bottom half the natural system.

On the human system side, all the interactions between boxes are strongly mediated by socio-economic factors. Governance is defined broadly as including government, markets, and civil society, operating at global, regional, national, and local scales. Governance factors influence each other across scales, including through personal behaviour, and determine, for example, which people benefit from the delivery of ecosystem services (i.e. equity) and what kinds of activities people engage in (regulations, social norms, etc.). One could reasonably and conceivably have indicators for any of these boxes, but the ideal indicators would connect directly to 'human well-being' (box 5).

Effective governance is fundamental to achieving healthy ecosystems (inclusive of people), and in this context, should focus on sustaining ecosystem services (box 4) in addition to other politically-negotiated goals. Governance affects what activities people pursue and with what intensity (arrow b), and if or how value derived from natural systems reaches human communities and is or is not distributed equitably among community members (arrow a).

On the natural system side, the framework concentrates on stresses associated with human activities (box 2, which on the ocean side can come from both ocean-based activities like fishing and land-based activities like carbon emissions or plastics pollution), how they affect the state of the ecosystem under consideration (box 3, modulated by the ecosystem vulnerability), which may lead to changes in the ecosystem services (box 4, for example fish catch). Finally, crossing the natural-human system boundary, the changes can lead to consequences for people, buffered or exacerbated by their vulnerability (surrounding box 5). Natural variability, whether a regular seasonal change or more complex nonlinear interaction within the natural system, will need to be evaluated separately from the interaction with the human system, so that the impact of a change in the human system - through a change in governance or a particular GEF intervention, can be separately identified. It is also important to characterize natural variability in order to understand which ecosystem state changes require or can be subjected to management.

There are a few additional pathways depicted that are peripheral to this central framework, but should also be mentioned. Depending on the problem being examined, an associated stress may have a direct consequence for people without being mediated through an ecosystem service (arrow connecting box 2 to box 5 directly), such as in the case of human-induced sea-level rise and its direct physical impact displacing populations.

While this conceptual framework identifies the protection of ecosystem services as the main pathway to mitigate consequences for people, under some other internationally-recognized value systems for management (protection of biodiversity, endangered species, natural heritage sites), the goal of management is not focused on sustaining ecosystem services but on directly conserving ecosystem state. In systems where thresholds might exist but uncertainty is high, and where future benefits are unknown, such a conservative approach has been politically negotiated.

The framework itself has no details, so many of the specifics and details need to be fleshed out (e.g. exactly which items we care about in each box, the models/functions that connect the boxes and the associated assumptions behind these models).

1.2 INDICATORS IN THE FRAMEWORK

The way that indicator science fits into this framework is via the need to select indicators that actually indicate what you care about. We ultimately care about human well-being, so long-term indicators should focus on this box. But all the preceding boxes can give us insights into likely outcomes for people, and often respond on much shorter time frames. On the human system side, we should therefore clearly articulate our management goals and the reasons for wanting to track particular information, and then design indicators that meet these goals. For example, we might want to track the amount of area set aside in Marine Protected Areas (MPAs, the human activity of protection) because it gives us an easy-to-measure indicator of changes in stressors (fishing pressure) that we assume improves the status of ecosystems (which is much harder to measure, particularly in the vastness of the open ocean), and this has been shown to provide benefits to humans. The indicator is indirectly connected to the thing we care about (benefit to people) through a number of assumptions. Making clear all these assumptions and how directly or indirectly an indicator connects to our ultimate goal is critical so that we can give a sense of the amount of uncertainty in how well our indicator tracks what we ultimately care about, and clearly articulate exactly what the indicator is tracking within the broader framework.

The framework allows and is useful for assessing the potential consequences of different management scenarios within a context of changing human activities and associated stressors (through the addition of new stressors and the changing intensity of existing stressors). A given management decision (or change in the intensity of a stressor due to other reasons) will lead to a changing suite of human activities and stressor intensities, which in turn will alter the attributes of the following boxes in the framework. These changes can be predicted, and then monitored to test the validity of the predictions.

There is an implicit temporal component to this framework, in that it takes time to move from box to box, and the time it takes will vary depending on which human activity and which ecosystem service is of interest. For political and practical reasons, GEF may need to focus primarily on attributes within this framework that respond more quickly, but it is important to keep the longer timeframe and relevant consequences in mind, particularly for the large and common spaces of the open ocean.

Within the context of the TWAP assessment, indicators for all elements of the human and natural systems cannot be developed - as the systems and their interrelationships on different time and spatial scales are complex. But the framework allows some clarity in TWAP on where data is available to assess or capture in an indicator/descriptor, and what assumptions have to be made to link that indicator with its ultimate consequences. In many cases for the open oceans, data on the state of the natural ecosystem is localized or non-existent, and we may know more about the stressor (for example fishing) than the state itself.

In the context of a future GEF intervention, the full framework could be useful in determining the main points of intervention in the human system to help manage a positive outcome via the environment (the natural system). These assumptions and scenarios will have to be scientifically tested and validated.

1.3 SCOPE OF THE ASSESSMENT

Level 1

Most of the assessment methodology described in the rest of this report is considered a Level 1 analysis. It builds on existing data and knowledge, interpreted for the assessment through mapped metrics and indicators, and, for thematic areas with high uncertainty, through expert assessment of published peer-reviewed natural and social science literature. The Level 1 assessment will provide a baseline assessment with projections where possible of future state, stress, or vulnerability. The Level 1 assessment of the global open ocean will extend to its role in climate change and variability, with, as a key input for the other transboundary water assessments, changes and trends in precipitation and glacier melting provided by climate projections prepared for the next IPCC assessment (see also Section 4.1), which will be measures of state or stress for those water systems. For governance, the Level 1 analysis will look at the structural arrangements in place for governance of the high seas: the global ocean areas beyond national jurisdiction, which are the majority of the open ocean.

The goal of the Level 1 assessment will be to communicate the baseline role of the global open ocean to all of society, to identify key threats to the maintenance of ecosystem services, and, through mapping of indices and expert assessment, allow for a scaling of the global open ocean assessment to some degree of regional concern.

Level 2

As the conceptual framework puts human well-being at its centre, it is important to connect open ocean conditions, which are physically far removed from concentrations of human populations, to local specific impacts. A Level 2 analysis will attempt this particular linking.

The Level 2 analysis will have to be scoped to the resources available. It could be as simple as a desk study which pulls together, for one particular region, the scientific knowledge of the impact of conditions in the global ocean on local human well-being. Or, with additional resources, it could include studies of the economic valuation of open ocean ecosystem services mediated for a particular human population, as well as studies of the social impact of such changes.

This impact comes for example through the global ocean's role in climate variability and change that bring changes in trends and extremes in rainfall, as well as melting of land ice that can be the source of other key transboundary water systems. Local sea-level rise, with its impact on coastal human and natural habitats and ecosystems, is dependent on large-scale changes in coupled global ocean - atmosphere temperature and wind patterns, and the melting of land ice. The global ocean's large-scale absorption of human emissions of greenhouse gases is leading to ocean acidification with impacts on local coral ecosystems that provide food and livelihoods for coastal populations. Many exploited fish species move in and out of territorial waters and into open ocean areas beyond national jurisdiction.

The Level 2 analysis will be important in concretely demonstrating the potential local impact of changes that are happening far away. These 'teleconnections', as they are known in climate science, are the physical, chemical, biological, economic, and societal links between local conditions and ecosystem services and large-scale open ocean conditions. If society is to be convinced to put limited resources towards the monitoring and conservation of open ocean ecosystem resources, people must be convinced of their local impact.

The region chosen for the Level 2 analysis may be linked with the Level 2 analyses in the other transboundary water systems of TWAP—this remains to be decided in the preparation of the full-sized project. Small Island Developing States have strong links to the oceans in general and so have strong impacts from the global open ocean, but these teleconnections extend far inland and to continental populations, where a Level 2 analysis might then have more political impact.

PART 2. INVENTORY AND CHARACTERIZATION OF THE OPEN OCEAN

2.1 THEMATIC APPROACH

The TWAP open ocean assessment will be thematic, primarily because governance and management arrangements for the open ocean are largely thematic (see Section 3.5.2).

This differs from the traditional approach to assessment methodology, which is to divide the surface of the area of the zone to be assessed into polygons, assess the same quantities in each, and do a comparative analysis. This is the approach taken by all the other components of TWAP (rivers, lakes, groundwater, and LMEs). In the context of a web of regional, national and local management arrangements that are place-based, this type of geographic assessment unit makes sense.

But for the open oceans, this approach makes less sense, for a number of reasons. As mentioned above, the management of the open oceans is multilateral and largely global and thematic. The oceans are also relatively deep, harbouring very different surface pelagic and benthic ecosystems for example. While they have some links, they are very different and cover distinct regions, as a recent biogeographical mapping exercise for the world oceans (GOODS) shows[6]. Many different assessment units are used for the open oceans, but these are often political and non-homogeneous: the FAO fishing regions, the Regional Fishing Bodies, the IMO high seas regions, the UNEP and non-UNEP Regional Seas Conventions and Action Plans, the Assessment of Assessment regions; others are more geographical and based on ocean variables, such as the ocean basins, surface wind-driven gyres, and Longhurst polygons[7] that identify key pelagic ocean ecosystems. Each of these assessment units has been developed for a different purpose, and none specifically for the purposes of TWAP.

2.2 IDENTIFYING KEY AREAS OF CONCERN

The assessment will as far as possible develop mapping approaches for visualization of key indicators and natural and human system vulnerabilities, which will help direct geographic interest towards areas with current or future problems. Where relevant, scientifically-based projections will be used to identify future consequences under relevant scenarios.

In order to speak to a high level with a simple, clear, but scientifically grounded voice, the assessment will be based on a small number of indexes or indicators. On the natural system side these words are often interchanged, but to avoid confusion we make a few definitions: *indicators on the natural system side* are defined as key natural system or stress variables, averaged over spatial scales of relevance, which help track the state of the natural system or the stress placed on it. If there are *reference levels* put on these indicators, they will reflect natural features intrinsic to the ecosystem and its response to stress. *Indicators on the human systems side* are generally associated with societal goals, are also key social system variables or a combination of variables averaged over the scales of relevance. If there are *targets* for these indicators, they often reflect a political process that has decided a societal goal. An *index* for the open ocean TWAP is then a combination of these indicators that exposes the central question being asked, linking as far as possible the human and natural systems.

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6 Vierros, M., Cresswell, I., Briones, E. E., Rice, J., and Ardron, J. (eds.), 2009. Global Open Oceans and Deep Seabed (GOODS) biogeographic classification. International Oceanographic Commission, *IOC Technical Series* No. 84. UNESCO, Paris, 87 pp.

7 Longhurst, A. R., 2006. Ecological Geography of the Sea, 2nd edition. Academic Press, NY, 560 pp.

Due to a lack of data about the natural systems in the open ocean, the assessment will also have to point to gaps in observations, in scientific knowledge linking human stressors to changes in ecosystem state and services, and in the governance of human interaction with the open ocean. These allow for a bridging between scientific exactitude and a management desire for simplicity, highlighting gaps in knowledge and uncertainty, and helping to define whether effective environmental management is possible based on the current state of knowledge.

The assessment will also be based, for a number of themes and sub-themes, on expert assessment of the scientific literature. Some issues identified by the open ocean working group experts have high uncertainty but potentially high impact, with potential ecosystem thresholds, or in the case of governance issues, subjective judgments, and the only way to assess these is through expert judgment.

GEF has also highlighted their desire to identify the results of their interventions over time using repeat assessments - this approach will to some extent help in doing this, but will be complicated by the fact that there are likely to be many actors in the management of the open oceans; future assessments will have to respond directly to the question of the impact of particular GEF interventions by trying to identify specifically the indicators best suited to this purpose among those proposed here. Future elaboration of the conceptual framework will help with this.

2.3 PRIORITY ISSUES

The priority issues and thus the grand themes of the open ocean assessment were drafted by the first February 2010 meeting of the working group (Paris, France), and further refined at its June 2010 meeting (Arendal, Norway). They were also refined through a series of consultations:

- at a panel on Marine Indicators at the 5th Global Ocean Conference on Oceans, Coasts, and Islands, Paris, France, 3 May 2010;
- at the UN-Oceans meeting, Paris, France, 5 May 2010;
- at the TWAP Steering Committee meeting, Geneva, Switzerland, 12 July 2010; and
- at the UNEP Meeting of the Regional Seas Conventions and Action Plans, Bergen, Norway, 20-21 September 2010.

A final consultation took place with a presentation at the American Geophysical Union meeting, San Francisco CA, USA, 13 December 2010.

The themes of the assessment in fact mesh well with the concerns of the scientific members of the working group, and with the thematic international governance arrangements in place for the open oceans.

The assessment will focus on four major themes, and two cross-cutting aspects on governance and the adequacy of observations and research:

- Climate change and variability in the global ocean, and global and local impacts, related to:
    - sea level and human vulnerability;
    - changes in temperature, stratification, and sea ice and their impacts on extreme weather; corals, and primary productivity;
    - rainfall and drought changes on land linked to the oceans;
    - ocean deoxygenation;
    - the fate of continued ocean CO_2 uptake;
    - ocean acidification;
- Ocean ecosystems, habitats, and biodiversity;
    - primary productivity changes due to climate change and their downstream impact;

  - zooplankton changes;
  - higher-level trophic changes in the food web;
  - candidate Ecologically and Biologically Significant Areas (EBSAs), including seamounts at risk;
  - assessments of the social science of economic valuation of ecosystem services;
- Open-ocean fisheries;
  - as a stress, including bottom fishing;
  - its sustainability, looking at the marine trophic index and projected catch potential;
  - and its equity by looking at the distribution of fish catch value in the high seas;
- Pollution as a stressor of the marine environment, with indicators for;
  - ship traffic as a proxy for ocean-based pollutants and stress;
  - plastics, focused on the convergent subtropical gyres;
  - seabed mining claims;
  - atmospheric inputs of pollutants: nutrients and mercury;
  - and a clear need for a scientific literature-based assessment to address high uncertainty potentially high-impact issues;
- A cross-cutting governance assessment that starts by looking at the policy cycle at the global level, and its links with regional and national arrangements; and
- Underlying all: how adequate are the observational, understanding, and management/ governance capabilities? This aspect of the assessment is of key value to the Intergovernmental Oceanographic Commission.

Since the assessment will in part be based on expert assessment of the latest scientific literature, new issues that are brought to light in the natural science or social sciences of managing the oceans will emerge.

In a thematic approach, the priority ordering of issues for the open ocean is not immediately evident. This will be addressed in the assessment by tools for assessment of cumulative impact, which can geographically pinpoint estimates of the stresses on open ocean ecosystems (see Section 5.2).

2.4 LINKING KNOWLEDGE OF HUMAN AND NATURAL SYSTEMS FOR MANAGEMENT

Ultimately, identifying where interventions should take place will depend on good monitoring and knowledge of the natural system side as well as the human system side. GEF is part of the human system and its interventions will be focused there - on improving governance to mitigate human activities that cause stress to key natural systems, and improving the resilience of human systems to reduce vulnerability. Both of these however will require a good understanding of the interactions and assumptions embodied by the conceptual model, which in turn will require scientific information and knowledge of both the natural systems and social systems.

The TWAP open ocean assessment seeks above all to interpret natural and social science with clear and understandable messages that will spark action for management of the environment.

The understanding of the human and natural systems will necessarily be imperfect, but a pragmatic approach to improving this understanding through scientific monitoring and study should be taken. The open oceans are under-observed and under-explored, and their full impacts on present and future human society imperfectly known. However, this should not prevent GEF and others from acting despite this lack of information, as imperfect scientific information can still point to key concerns and management needs, and management goals can be refined iteratively as scientific understanding from research and monitoring improves. The governance of the open ocean is generally poor, and action is needed to prevent adverse consequences to people, and to the environment that provides key ecosystem services.

For the open oceans, a robust scientific support enterprise will continue to be needed to help GEF and others to have confidence that they are directing resources and energy correctly.

PART 3. METRICS, INDICATORS, AND INDICES

The indicators approach to assessment for the open ocean is primarily designed to draw attention to key natural system environmental problems in the open ocean and their impact on living marine resources, ecosystem services, and ultimately human well-being. They will also serve in a baseline assessment of the open oceans.

For each of the four major themes below (climate, ecosystems, fisheries, and pollution), the metrics, indicators, and indices in the TWAP open ocean assessment methodology will primarily allow for simplifications of scientific and social data to clearly and simply express the priority issues defined by the working group. Generally these will be globally mapped in order to pinpoint areas of priority concern for the theme. This also allows scaling for different assessment purposes, or to support the development of a management intervention. Wherever possible, a top-level global index will be constructed to relate changes in stress to ocean ecosystem vulnerabilities, or changes in ecosystem state to human vulnerabilities, but always on the basis of mapped indicators or metrics.

As GEF management interventions in the open oceans are just beginning, the focus is on highlighting the need for management, and only some of the indicators will be useful for evaluating the impact of a management regime. When GEF or others develop interventions related to the open oceans, the conceptual framework could be used to identify monitoring indicators to track the success and impact of any particular intervention.

The metrics, indicators, and top global-level indices are described by theme and sub-theme, and summarized in Table 1.

This approach will be complemented by expert assessment of the latest scientific literature to address emerging issues and issues with high uncertainty but potentially high impact. Due to a lack of data these are difficult to address in an indicator framework (see Section 6.2).

Two cross-cutting assessments will work across all themes: one of governance, and one of research and monitoring priorities. These are described in Sections 3.5 and 3.6 below even though they are not based on metrics, indicators, and indices, as they form an integral part of the TWAP open ocean assessment methodology.

3.1 CLIMATE CHANGE, VARIABILITY AND IMPACT ASSESSMENT

3.1.1 Overview / In the conceptual framework

The assessment issues covered in this section are linked to human emissions of greenhouse gases (1, numbers refer to boxes in Figure 3), which create a natural system stress (2) by changing the physical and chemical environment of the open oceans.

The physical changes have a number of direct consequences for people (link to 5). The first is <u>sea-level rise</u>[8], which is currently caused in about equal proportions by the expansion of water by increasing <u>ocean heat content</u> and melting of land ice. Evidence also suggests that groundwater extraction

[8] Underlined text refers to the sub-themes and particular indicators that are then detailed later in the section.

contributes to sea-level rise[9]. Links can be drawn between projections of sea-level rise and the human population in low-lying areas to identify vulnerabilities. Increases in ocean heat content also affect the frequency of tropical cyclones (commonly called hurricanes or typhoons). The second direct consequence of the physical changes in the open ocean from climate change is the changes in the global patterns of rainfall and drought driven by changes in sea surface temperature. Links can be drawn between projections of ocean-driven drought and rainfall patterns and areas of water scarcity on land. Each of these subthemes demonstrate the 'teleconnection' of open ocean conditions with consequences on land, and in the case of rainfall/drought create a link to the other TWAP water systems.

Physical changes in the ocean also create specific stresses (2) changing marine ecosystem state (3), reducing ecosystem services (4) and affecting human well-being (5). Ocean heat content again has impacts on corals by creating bleaching events, and impacts on primary productivity through changes in plankton habitat: surface temperature extremes, and vertical stratification strength (temperature profiles and mixing that keep plankton near or drive it far from the surface) and its seasonal timing. Marine habitats will be changed by increasing temperatures and in polar regions by changes in sea ice distribution, which may also allow increased shipping and potential pollution in polar areas (all associated stresses on ecosystem state, in box 2). Physical changes in ventilation and circulation patterns driven by the changing winds and temperatures also influence the open ocean distribution and transport of oxygen, with widespread deoxygenation observed. These change a fundamental characteristic of marine habitats (3), and in some cases affect coastal hypoxia (link with LMEs). Oxygen minimum layers also have an impact on fisheries (4).

The chemical changes in the ocean from the absorption of CO_2 drive ocean acidification (2) which has potential consequences for calcifying organisms and habitats (3), with presumed impacts on future ecosystem services (4) and consequences for humans (5).

The open ocean has a net uptake of anthropogenic CO_2 from the atmosphere (about 26 per cent of the emissions since the industrial revolution), an important service provided by the ocean (4) that has mitigated climate change, and is driven by changing ocean biogeochemical and ecosystem state (3), mainly because of warming. It is a feedback within the natural system that potentially exacerbates the rate of climate change as a stress (2) to other pathways in the framework. The implication for policy (6) is in where to set targets for mitigation to avoid dangerous interference with the climate system, an objective of the UN Framework Convention on Climate Change (UNFCCC).

All of these stresses (2) are unevenly distributed around the globe, and the vulnerabilities of human systems (modulating the consequences for human well-being 5) and natural systems (modulating the ecosystem state response 3) are also unevenly distributed.

The governance arrangements (6) for climate change fall globally under the UNFCCC, which brokers climate mitigation and adaptation strategies, but is also expressed in multiple forms (governments, markets, civil society) at levels from global to local.

Key indicators/metrics are identified below by subtheme underlined above. The detailed methodology for calculating each metric, indicator or index can be found in Annex 2. These metrics, indicators, and indices are noted in *italics* below.

The metrics and indicators in this theme, when they are related to human vulnerability, could also in some cases be interpreted as metrics and indicators of the links between the water systems. They are most precisely metrics and indicators of the teleconnections between global ocean conditions and

[9] Wada, Y., van Beek, L. P. H., van Kempen, C. M., Reckman, J. W. T. M., Vasak, S., Marc, and Bierkens, F. P., 2010. Global depletion of groundwater resources. *Geophysical Res. Lett.*, Vol. 37, L20402, 5 pp., doi: 10.1029/2010GL044571

local impacts on human well-being, and so can also be related to the Level 2 assessment (see Sections 1.3.2 and 6.3).

3.1.2 Vulnerability to sea-level rise

The relevant metrics and indicators related to sea-level rise are physical and related to human vulnerability. *Sea-level rise* is non-homogeneous across the globe (see Figure 4), and projections of future rise are being produced under the World Climate Research Programme (WCRP) and assessed by the IPCC. The vulnerability to this open ocean phenomenon is at the coasts and particularly in low-lying Small Island Developing States (SIDS). This vulnerability is captured in two metrics: *human population in low-lying areas* and *GDP per capita* as an estimator of adaptive capacity (to develop coastal protection or to retreat from inundation-prone areas).

A *global index* will combine actual and projected change in local sea-level rise (positive only) with human vulnerability.

Another key index of relevance to this theme is upper ocean heat content, which currently contributes half of the global sea-level rise budget. It also has relevance in tracking the ocean's role in absorbing excess heat in the climate system.

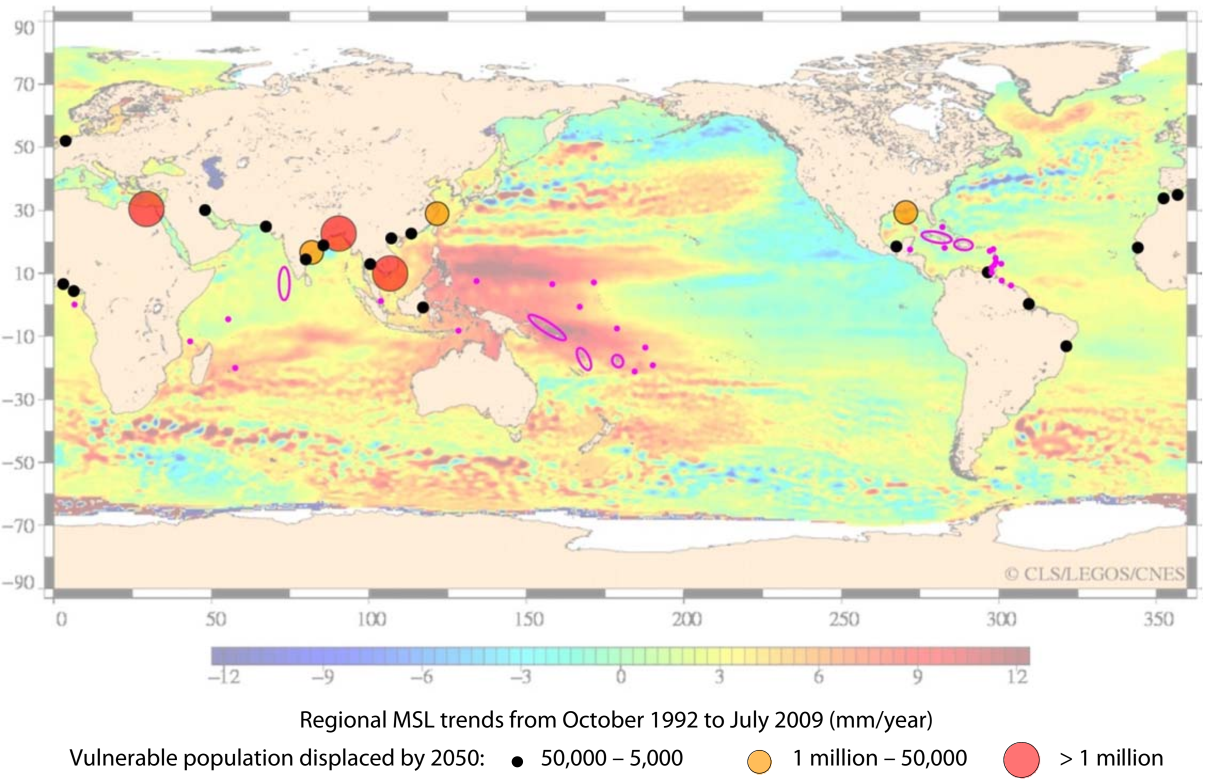

Figure 4. A map of regional mean sea-level rise trends from 1992 through 2009, showing areas where sea level is rising much faster or slower than the mean global rate, with the vulnerabilities of key coastal populations in large river delta areas shown as circles. Vulnerability of these populations is also based on local capacity to adapt, a socio-economic assessment. Additional vulnerabilities are faced by Small Island Developing States (SIDS, represented here by the Alliance of Small Island States AOSIS members in magenta), based on their capacity for adaptation and the importance of coastal zones to those countries. (Source: Reference 27 and Ericson, J.P., C.J. Vorosmarty, S.L. Dingman, L.G. Ward and M. Meybeck, 2006: Effective sea-level rise and deltas: causes of change and human dimension implications. *Global Planet. Change*, **50**, 63-82, doi:10.1016/j.gloplacha.2005.07.004)

3.1.3 Patterns of ocean heat content change and impacts

Ocean heat content change is a mapped and global indicator of the open ocean response to climate change in and of itself, and is relevant because of its impacts on extreme weather, corals, and as a constraint on open ocean primary productivity.

The impact on corals is illustrated in Figure 5, and a relevant indicator of the stress posed by the global oceans on corals is an indicator of *coral degree heating weeks*. This indicator can be mapped or expressed as a yearly average, and projected into the future.

Severe weather phenomena depend on ocean heat and evaporation at the sea surface to provide their energy, and in particular tropical cyclone intensities (also called hurricanes or typhoons) are very sensitive to the upper ocean heat content available in their path. A good illustrative example of this is the strengthening of Hurricane Katrina as it passed over a warm loop current eddy in the Gulf of Mexico before striking New Orleans[10]. The *Tropical Cyclone Heat Potential* (TCHP) can be derived from ocean heat content to describe areas where cyclones can form and gain strength. Figure 6 shows an instantaneous map of TCHP for 1 August 2009 during a particularly strong Pacific typhoon season. As with coral degree heating weeks, this indicator can be mapped or expressed as a yearly average, and projected into the future.

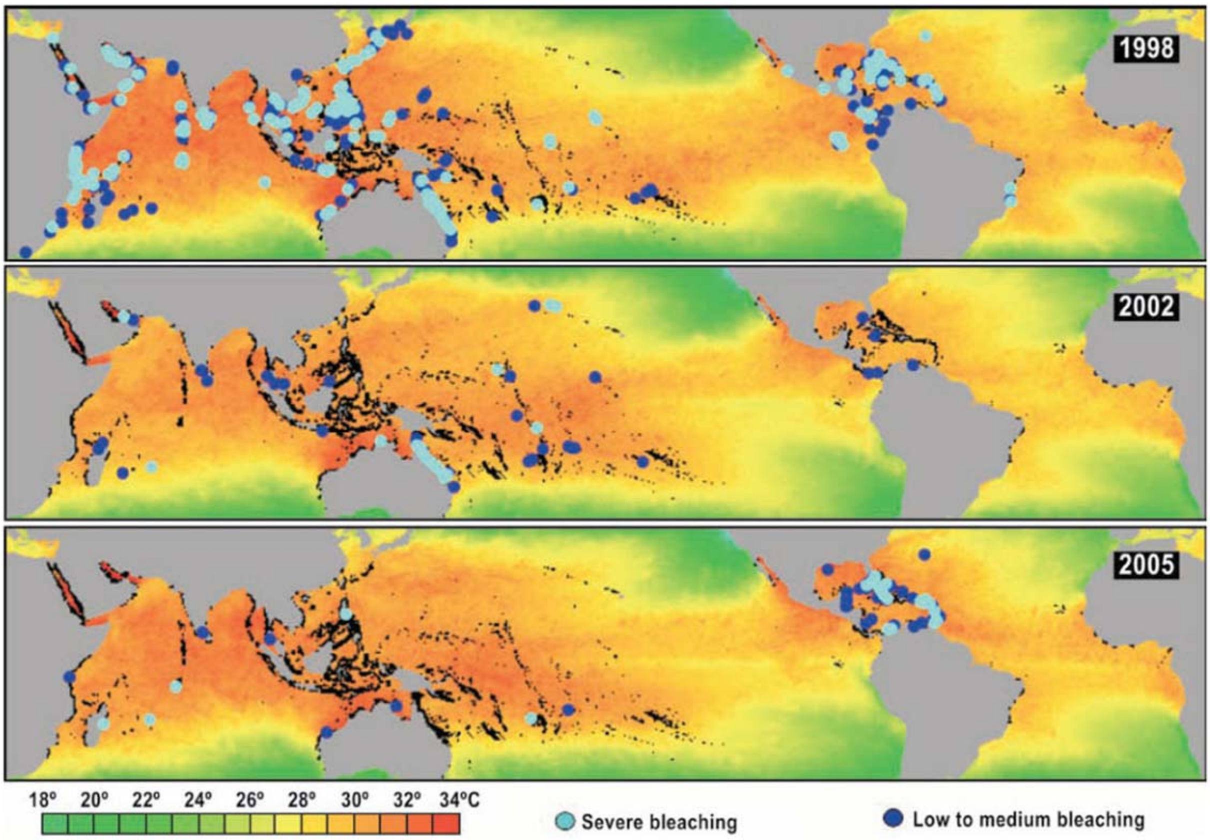

Figure 5. Coral bleaching events are linked to global patterns of sea surface temperature rise. The maps show tropical maximum monthly mean sea surface temperature for three different years, and locations of coral bleaching. From the IPCC Fourth Assessment Report[11].

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10 see http://www.aoml.noaa.gov/phod/altimetry/katrina1.pdf

11 adapted from Fig. 6.3, Nicholls, R.J., Wong, P. P., Burkett, V. R., Codignotto, J. O., Hay, J. E., McLean, J. F., Ragoonaden, S., and Woodroffe, C. D., 2007. Coastal systems and low-lying areas. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry, M. L.,Canziani, O. F., Palutikof, J. P., van der Linden, P. J., and Hanson, C. E. (eds.), Cambridge University Press, Cambridge, UK, pp. 315-356.

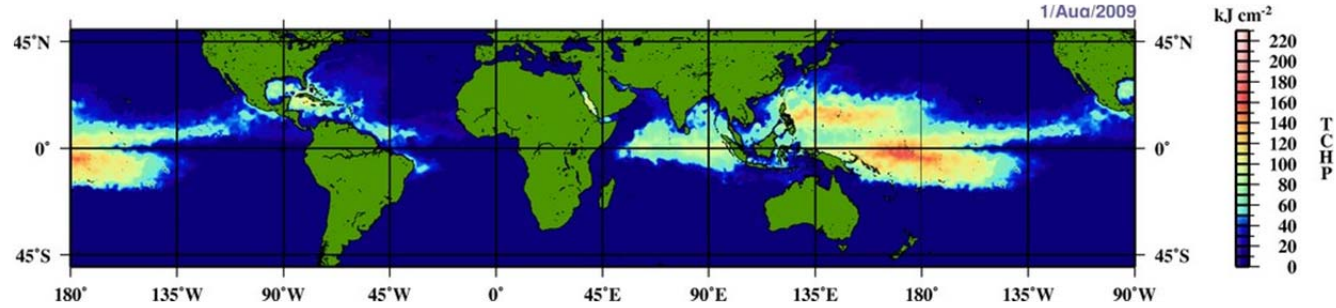


Figure 6. Global tropical cyclone heat potential (see Annex 2) for August 2009, during an active Pacific typhoon season. Over 2 000 lives were lost and about US$12 billion in damage was caused by Pacific typhoons in 2009. Their intensity is linked to THCP over the open ocean which is increasing with climate change. (Source: NOAA/OAML, www.aoml.noaa.gov/phod/cyclone/data/)

3.1.4 Consequences of ocean-driven changes in global patterns in rainfall and drought

This subtheme is dealt with in Section 4.1 (Interlinkages), as it is the major output link from the open oceans to the other TWAP water systems. The strongest environmental and socio-economic impacts of water scarcity are felt mainly in the tropics, where the short and long-term changes in rainfall and drought patterns are most intimately linked with global ocean sea surface temperature changes. The major mapped indicator for this subtheme will be coupled climate model projections of future *rainfall and drought* patterns, matched to areas of human vulnerability and *water stress*.

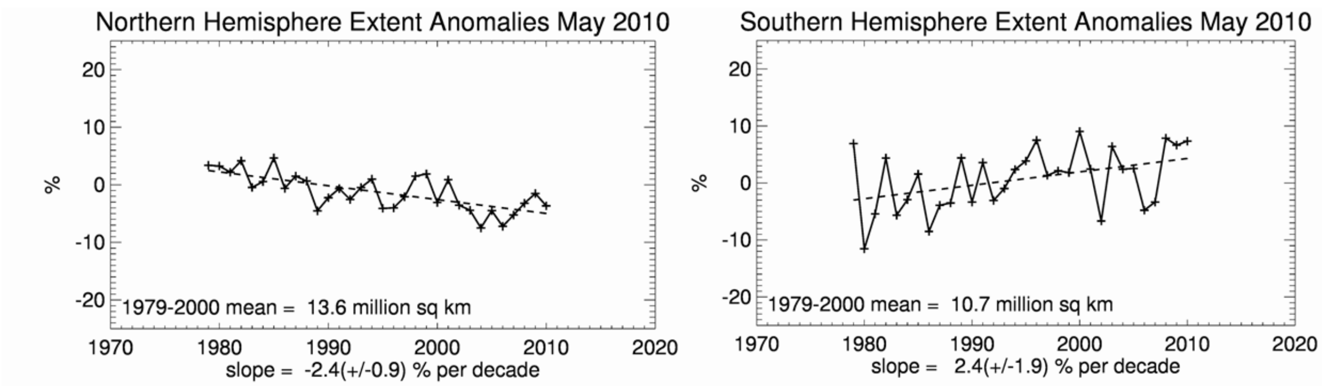


Figure 7. Arctic (left) and Antarctic (right) sea ice extent anomalies from the US National Snow and Ice Data Center (NSIDC), proposed as one element of a key index for sea ice. Antarctic sea ice has been on a recent upwards trend, even as Arctic sea ice has reached record minima in recent years. (Source: NSIDC, www.nsidc.org)

3.1.5 Sea ice

The seasonal *sea ice* in each polar region is a unique marine habitat. Although technically within an LME, the Antarctic region is a global commons as are the open oceans, while the Arctic has a minority of high seas compared to EEZs. Consequences of changes in sea ice distribution include a change to this marine habitat, associated living marine resources, and prospects for shipping and associated contaminants. Polar regions are also particularly affected by ocean acidification (see Section 3.1.8 for the related *aragonite saturation state* indicator).

Polar open ocean regions are now nearly pristine, but will face a triple set of pressures with changes in *sea ice*, the effects of *ocean acidification*, and likely increased *shipping intensity* (see Section 3.4.2). A key global index could be derived from the two time series of sea ice extent (for each pole) with *shipping intensity* and *aragonite saturation state*.

3.1.6 Open ocean deoxygenation

Open ocean oxygen minimum zones are a strong habitat constraint for most species, and an area of highly reduced biodiversity. Open ocean oxygen is being measured from Argo floats (about 200 today giving limited geographical coverage) and ship-based hydrography, and projections from climate models have also been generated. The key indicator for *ocean deoxygenation* will be a mapping of the extent of oxygen minimum zones with suboxia ($O_2 < 10\ \mu mol\ kg^{-1}$) [12], an approximate identification of a natural threshold. A global index is the volume of these zones globally. This is the first of our subthemes that will require expert assessment as a complement (see Table 1).

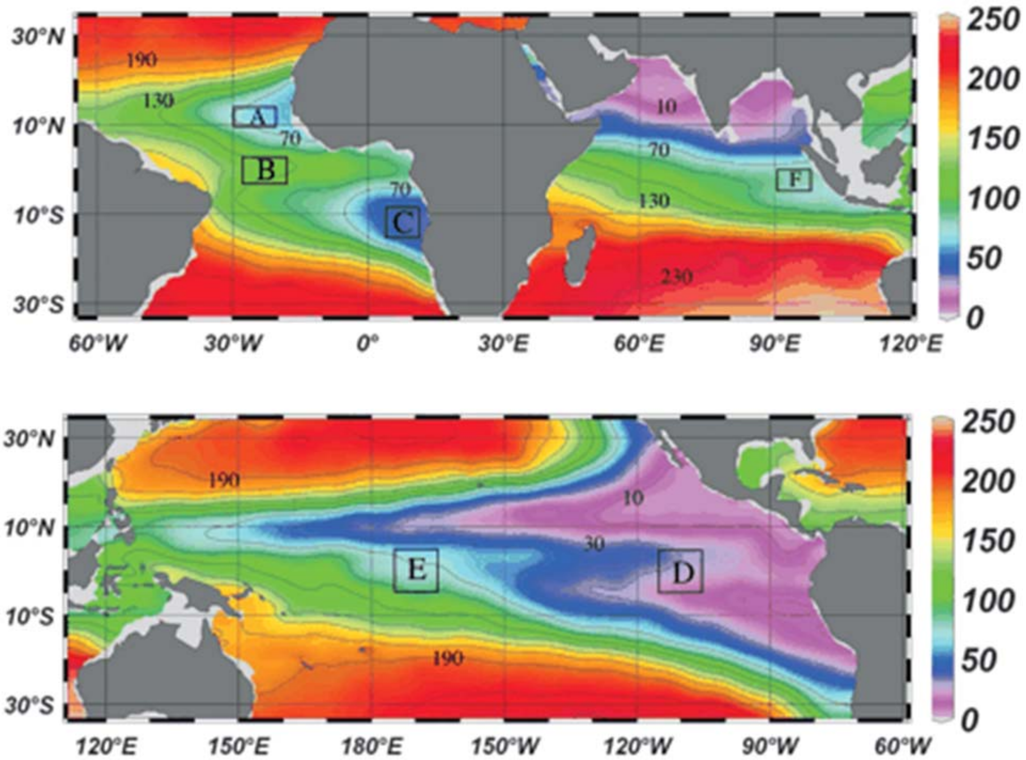


Figure 8. Climatological mean distribution of dissolved oxygen concentration at 400 m depth, identifying key open ocean zones of suboxia in the eastern Pacific. (Source: Reference 13)

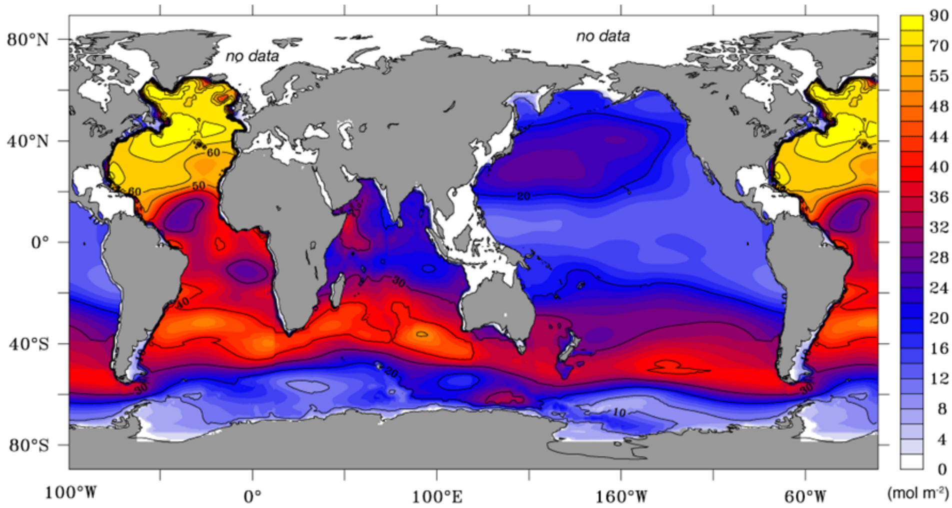
[12] Gruber, N., Doney, S., Emerson, S., Gilbert, D., Kobayashi, T., Körtzinger, A., Johnson, G., Johnson, K., Riser, S. and Ulloa, O., 2010. Adding Oxygen to Argo: Developing a Global in-situ Observatory for Ocean Deoxygenation and Biogeochemistry in *Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society (Vol. 2),* Venice, Italy, 21-25 September 2009, Hall, J., Harrison, D.E. and Stammer, D., Eds., ESA Publication WPP-306, doi:10.5270/OceanObs09.cwp.39

[13] Stramma, L., Johnson, G.C., Sprintall, J., and Mohrholz, V., 2008. Expanding oxygen-minimum zones in the tropical oceans. *Science*, Vol. 320, pp. 655-658, doi:10.1126/science.1153847

3.1.7 Future open ocean uptake of anthropogenic CO_2

The oceans have absorbed about 26 per cent of historic anthropogenic CO_2 emissions, preventing an even greater accumulation of greenhouse gases in the atmosphere, and providing a crucial ecosystem service. This absorption is concentrated in areas of deep circulation and formation of bottom water (see Figure 9 top panel). Projections from coupled ocean-atmosphere-biogeochemistry climate models suggest that the rate of uptake by the open oceans is slowing (see Figure 9 bottom panel).

The key indicator here is the rate of *ocean uptake of anthropogenic CO_2*, which will be estimated by models, but requires careful evaluation by the expert assessment component of the TWAP open ocean assessment.



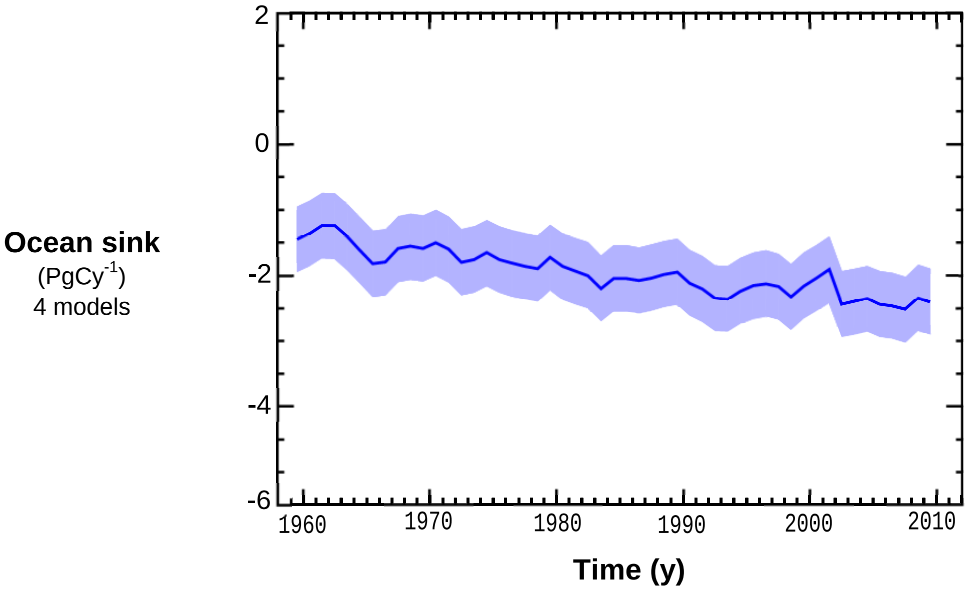


Figure 9. Top: map of the vertically integrated amount of anthropogenic CO_2 stored in the ocean since pre-industrial times (in mol m^{-2}). Bottom: model estimates of the global ocean carbon uptake of CO_2 show a decrease in this key open ocean ecosystem service with time, although these results are being debated in the scientific literature. (Source: Reference 14 and the Global Carbon Project, reference 15)

[14] Sabine C. L., Feely, R. A., Gruber, N., Key, R. M., Lee, K., Bullister, J. L., Wanninkhof, R., Wong, C. S., Wallace, D. W. R., Tilbrook, B., Millero, F. J., Peng, T. H., Kozyr, A., Ono, T., and Rios, A. F., 2004. The Oceanic sink for anthropogenic CO_2. *Science* Vol. 305, pp. 367-371, doi: 10.1126/science.1097403

3.1.8 Ocean acidification and impacts

The ocean's absorption of carbon dioxide referred to above leads to its acidification. A key natural system indicator here is the *aragonite saturation state*, above which many threshold calciferous ocean organisms may no longer be able to construct their shells or habitat. Models have been used to project this state forward in time based on climate scenarios (see Figure 10). Maps of these projections can be matched to coral reef locations. A global indicator combining vulnerability and threat, the *coral reefs at risk from ocean acidification indicator*, is the percentage of tropical coral reefs in different aragonite saturation states. This allows identification of timing, as well as areas that will be first affected by ocean acidification. Other areas that are vulnerable to ocean acidification are upwelling regions and the polar and sub-polar oceans - and these are more vulnerable than the tropics (see Figure 10).

Expert assessment will extend this by trying to identify other key ocean regions, habitats and species threatened by ocean acidification, or a combination of acidification and warming that allows competition by invasive species.

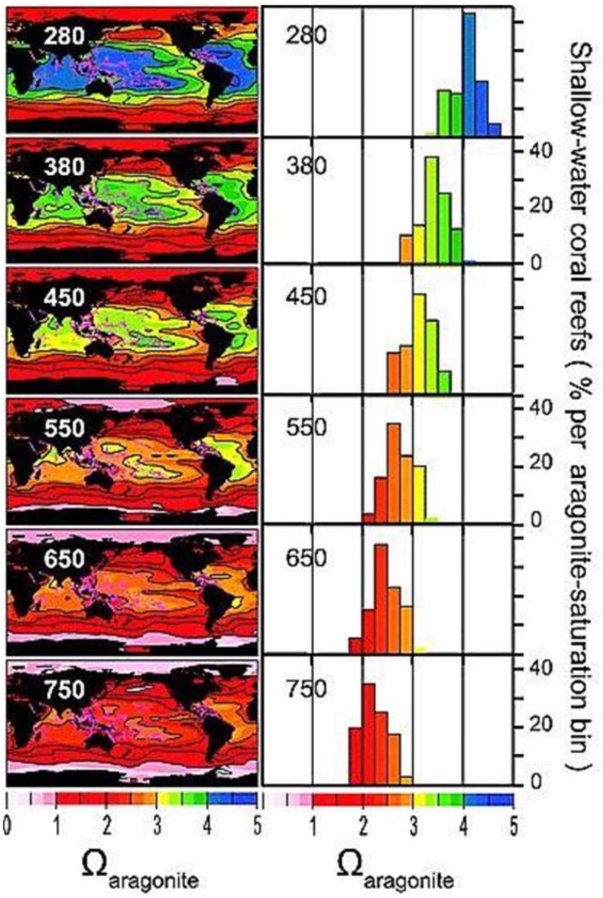


Figure 10. Aragonite saturation state and coral reef distribution (left). Maps of model-predicted aragonite saturation states at different atmospheric CO_2 stabilization concentrations (ppm) plotted over existing shallow-water coral reef locations (shown as magenta dots) (right). Percentage distribution of modern-day coral reefs at each aragonite saturation under different atmospheric CO_2 stabilization concentrations. Aragonite saturation value at each reef location is interpolated from nearby open ocean values simulated by the model (Source: Cao, L., and K. Caldeira (2008), Atmospheric CO_2 stabilization and ocean acidification, Geophys. Res. Lett., 35, L19609, doi:10.1029/2008GL035072).

[15] Global Carbon Project, 2010. Carbon budget and trends 2009. Available at www.globalcarbonproject.org/carbonbudget, released on 21 November 2010; and from Le Quéré, C., Raupach, M. R., Canadell, J. G., Marland, G, et al., 2009. Trends in the sources and sinks of carbon dioxide. *Nature Geoscience*, Vol. 2, 831-836, doi: 10.1038/ngeo689

3.2 OPEN OCEAN ECOSYSTEMS, HABITATS AND BIODIVERSITY

3.2.1 Overview / In the conceptual framework

Open ocean ecosystems, habitats and biodiversity are all properties of the ecosystem state (3, numbers refer to boxes in Figure 3) which is central to the assessment under this theme. Human well-being (5) is in part linked to sustained ecosystem services (4), which are in turn driven by the ecosystem state (3). Ideally a monitoring system feeding policy and governance would monitor the ecosystem state.

Ecosystem state changes include changes in primary productivity, the base of marine food webs, due to changes in ocean temperature, stratification and its interaction with the seasonal cycle (2, addressed in the previous theme), nutrients, and pollution from land-based nutrient input (1, addressed under the pollution theme). These result in changes one step up in the trophic chain in zooplankton, and have repercussions further up in the ocean food web. These changes will have impacts on the rest of the pelagic ecosystem including commercially valuable species that are fished (4) with consequences for people (5).

The remoteness and vastness of the oceans pose a serious barrier to a comprehensive open ocean ecosystem state monitoring system; it is simply impractical at this time. Given scientific knowledge, we can make educated guesses about how ecosystem state (3), including biodiversity, is linked to stresses from human activities (2). In many cases these stresses are easier to measure comprehensively, at least for the few stressors that are thought to have global impact (see Sections 3.1, 3.3, and 3.4 for indicators of stressors).

Ocean ecosystem features that are particularly vulnerable are worthy of assessment, as a complement to a mapping of where the stresses are strongest. This provides a way to direct energy for better monitoring at certain key locations in the open ocean where vulnerability and stress are highest, to ensure that these features are protected and can continue to provide ecosystem services. The Convention on Biological Diversity (CBD) has adopted a vulnerability-based approach to defining criteria for candidate Ecologically and Biologically Sensitive Areas (EBSAs), and a number of assessments of these for the open ocean are under way. Seamounts are hotspots for pelagic biodiversity in the open ocean[16] that deserve particular attention.

The economic consequences of a change in governance (6) designed to change stakeholder behaviour (1) driving an associated stress (2) on the open oceans can be significant. It can therefore be useful to attempt to link ecosystem state (3) through the services it provides (4) to human well-being (5) with an economic valuation of the ecosystem service (4) being examined.

Key indicators/metrics are identified below by sub-theme underlined above.

One key metric cross-cuts this entire theme, and that is the governance measure of the *open ocean area covered by Marine Protected Areas (MPAs)*. More on this metric, see Annex 2.

[16] Morato, T., Hoyle, S. D., Allain, V., and Nicol, S. J., 2010. Seamounts are hotspots of pelagic biodiversity in the open ocean. *PNAS* 107, 9707-9711, doi:10.1073/pnas.0910290107.

3.2.2 Primary production

Primary production is a measure of the transformation of solar energy and nutrients into organic matter by marine photosynthetic plankton, forming the base of the food web and most biology in the oceans, and eventually linked to the complete biosphere. It is a key quantity in the ocean carbon cycle and in understanding the long-term fate of anthropogenic carbon absorbed by the oceans. Primary production is estimated from ocean satellite colour data using models. Affected by physical controls such as the strength and timing of ocean stratification (related to *ocean heat content* and affected by climate variability and change) as well as by *ocean acidification*, global primary production has strong inter-annual variability, and has increased somewhat in the past two decades (see Figure 11). Linked to the surface pelagic zone, this indicator is one of only two in the assessment where a gyre-based average will be useful[17].

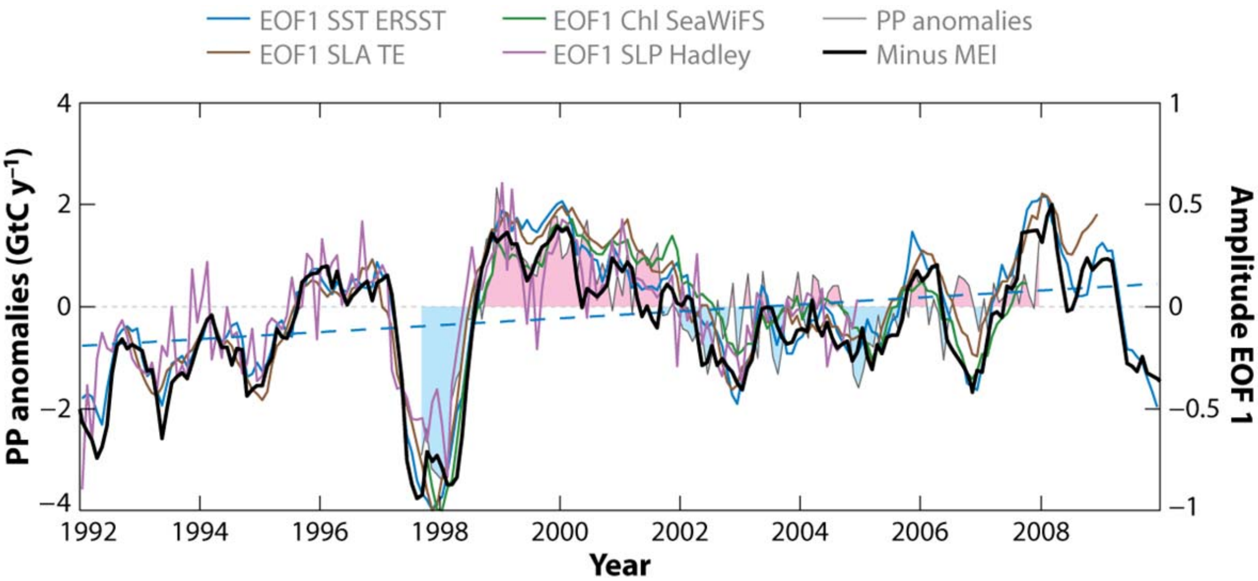


Figure 11. Variability in global average primary production values for the last 20 years, estimated from a model using ocean satellite observations of chlorophyll and SST. While there is a small linear trend in the past 20 years, the record is dominated by inter-annual variability associated with El Niño in the tropical Pacific. (Source: Reference 18)

3.2.3 Zooplankton

Zooplankton underpin each marine ecosystem by supplying nutrition derived from primary production to higher tropic levels either directly or indirectly through intermediate trophic levels. In addition, because they are not normally harvested, have limited control over their movements, and have short generation times, they respond to physical and biogeochemical changes in their environment in a rapid and unambiguous way, often integrating multiple signals. They are relatively easy to measure over large spatial scales and can act as indicators of ecosystem change in their own right; for example, they have been shown to identify ecosystem regime shifts before they were evident in physical data time series[19]. *Zooplankton abundance, composition, and timing* have together proved useful in management regimes. Data are not available globally, and so this indicator will need to be supplemented by expert assessment of the latest scientific literature.

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[17] see extended online information from Belkin and Sherman at http://ioc-unesco.org/twap-oo-supplementary-material

[18] Chavez, F. P., Messié, M., and Pennington, J. T., 2011. Marine Primary Production in Relation to Climate Variability and Change, *Annu. Rev. Mar. Sci*. 3, 227-60, doi: 10.1146/annurev.marine.010908.163917

[19] Ebbesmeyer, C. C., Cayan, D. R., McLain, D. R., Nichols, F. H., Peterson, D. H., and Redmond, K. T., 1991. 1976 step in the Pacific climate: forty environmental changes between 1968-1975 and 1977-1984. In: Betancourt, J. L. and Tharp, V. L. (eds.). Proceedings of the 7th Annual Pacific Climate Workshop, April 1990. Calif. Dept. Water Resources, Interagency Ecological Studies Program Technical Report 26, 115-126.

Hare, S. R. and Mantua, N. J., 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. *Progress in Oceanography*, Vol. 47, pp. 103-145.

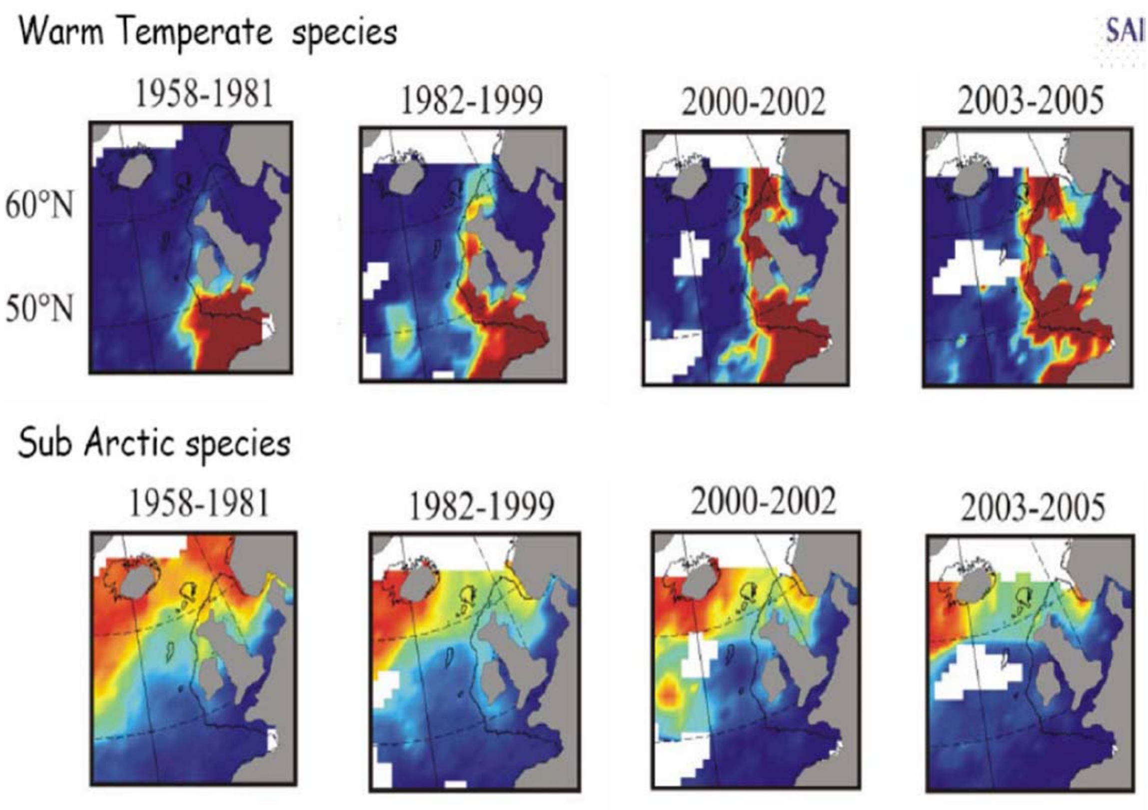

Figure 12. Decadal scale changes in the distribution of warm temperate and sub-Arctic communities of plankton on decadal timescales. (Source: Reference 20)

3.2.4 Food webs and trophic changes

Overall changes in food webs, in the links between trophic levels, and the ultimate consequences of these large-scale changes in ocean ecosystems were a primary concern of the working group that developed the TWAP open ocean methodology. But global data to underpin this knowledge are particularly weak. This subtheme remains in the methodology as a reminder for the expert assessment component.

3.2.5 Biodiversity

A systematic database of biological taxa has been created for the Census of Marine Life, the Ocean Biogeographical Information System (OBIS). While biodiversity in the oceans remains severely under-sampled - a fact clearly pointed to by the preponderance of single individual specimens representing new species in the samples taken during the Census of Marine Life - scientists are beginning to be able to generalize relationships between global ocean biodiversity and areas of human impact. This remains an area of active research and will be evaluated by the natural science expert assessment team.

[20] Burkill, P. and Reid, P., 2010. Plankton Biodiversity of the North Atlantic: Changing Patterns Revealed by the Continuous Plankton Recorder Survey in Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society (Vol. 1), Venice, Italy, 21-25 September 2009, Hall, J., Harrison, D.E., and Stammer, D., eds., ESA Publication WPP-306, doi:10.5270/OceanObs09.pp.09

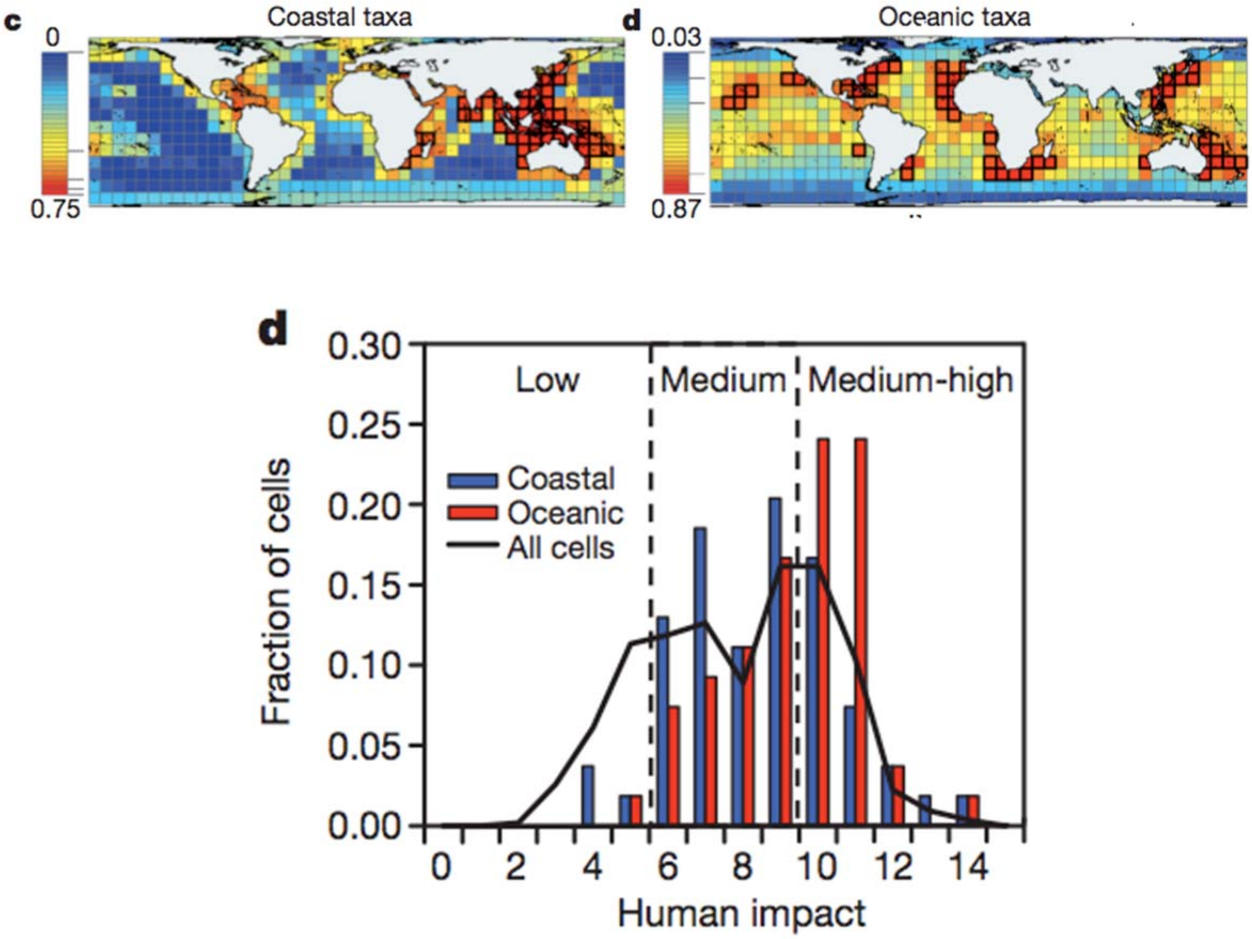

Figure 13. Global Patterns of marine biodiversity[21] and the correlation of these cells with areas of high human impacts on marine ecosystems as noted in reference 42.

3.2.6 Candidate EBSA: Ecologically and Biologically Significant Areas

The Convention on Biological Diversity (CBD) is developing a framework for the identification of Ecologically and Biologically Significant Areas (EBSAs) based on scientific criteria, subject to political approval. The identification of these areas will help the Parties to the convention to meet their goals for reducing the rate of biodiversity loss, applying ecosystem-based approaches, and establishing a network of Marine Protected Areas (MPAs).

IUCN-GOBI (Global Ocean Biodiversity Initiative) is leading a cooperative effort to define candidate EBSAs in the open oceans, and an indicator for the open ocean assessment will be the *area of candidate Ecologically and Biologically Sensitive Areas identified*.

[21] Tittensor, D. P., Mora, C., Jetz, W., Lotze, H. K., Ricard, D., Vanden Berghe, E., and Worm, B., 2010. Global Patterns and predictors of marine biodiversity across taxa. *Nature*, Vol. 466, pp. 1098-1101, doi:10.1038/nature09329

3.2.7 Seamounts at risk

Seamounts exhibit a range of environmental conditions suitable for a number of other habitats to form, including cold-water corals, sponge beds, and hydrothermal vent communities. Some species of cold-water coral can form lush thickets or forests on seamounts or the seabed, generally in areas of strong current flow[22]. Seamounts also interact with the water column to induce localized areas of high productivity which results in aggregation sites for a wide range of fish, including commercial species, and large marine fauna[23].

Many fishing operations have serious physical and biological impacts but bottom trawling is deemed the most damaging to seabed and seamount habitats[24]. Studies have suggested that the impact of bottom trawling equals or exceeds the impact of all other types of fishing combined[25] and this type of fishing is likely to increase in coming years as deep sea fish stocks within national jurisdiction are depleted and/or increasing restrictions are placed on them.

Deep seabed habitats harbour life that can be particularly vulnerable to damage as they are often fragile and long-lived[26], thus exhibiting less resilience to human disturbance and slower recovery rates than life in habitats in shallower waters.

Seamounts, long known by fishers as aggregation sites for commercial fish species, have been particularly targeted by bottom trawlers, a behaviour enabled by advances in fishing technology. Catch and effort levels, and associated impacts, can be much greater and more concentrated in time and in space on seamounts than on the continental slope where effort is spread over larger areas[27].

The *Seamounts at risk* indicator is hampered by a lack of data of ocean ecosystem state on seamounts, and will be defined through mapping and a number of seamount observations. Complementary to this will be identification of demersal fishing intensity (see Section 3.3.2). The expert assessment component will be important for this subtheme.

[22] UNEP, 2006. Ecosystems and Biodiversity in Deep waters and High Seas, *UNEP Regional Seas Reports and Studies* No. 178. UNEP/IUCN, Switzerland 2006.

[23] Corrigan, C. and Kershaw, F., 2008. Working toward high seas marine protected areas: An assessment of progress made and recommendations for collaboration, UNEP World Conservation Monitoring Centre, Cambridge, UK, 102 pp.

[24] Clark, M. R. and Koslow, J. A., 2007. Impacts of fisheries on seamounts, see Pitcher, Morato, Hart, Clark, Haggen, Santos 2007, pp. 413-441.

[25] Eastwood, P. D., Mills, C. M., Aldridge, J. N., Houghton, C. A., and Rogers, S. I., 2007. Human activities on UK offshore waters: an assessment of direct, physical pressure on the seabed, *ICES Journal of Marine Science*, Vol. 64(3): pp. 453-463.

[26] Probert, P. K., McKnight, D. G., and Grove, S. L., 1997. Benthic invertebrate bycatch from a deep-water fishery, Chatham Rise, New Zealand, Aquatic Conservation: Marine and Freshwater Ecosystems, 7: 27-40.

[27] Clark, M. R., Rowden, A. A., Schlacher, T., Williams, A., Consalvey, M., Stocks, K. I., Rogers, A. D., O'Hara, T., White, M., Shank, T. M. and Hall-Spencer, J. M., 2010. The Ecology of Seamounts: Structure, Function, and Human Impacts, *Annual Review of Marine Science*, Vol. 2: pp. 253-278.

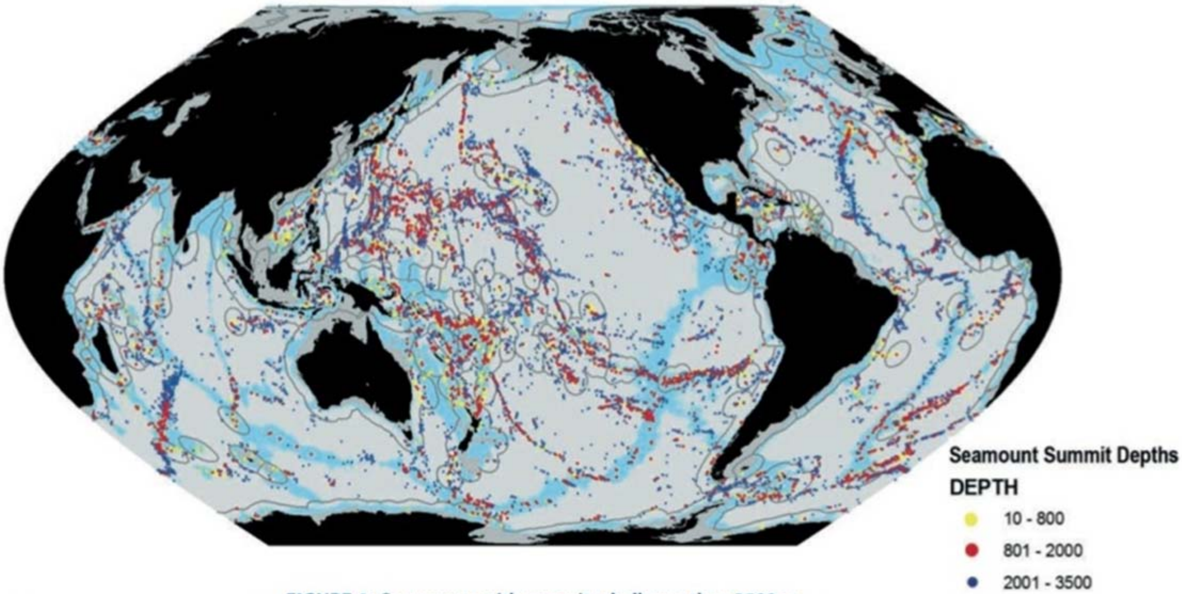

FIGURE 4: Seamounts with summits shallower than 3500 m.
Bottom depths 2000 - 3500 m are indicated in light blue. Most of the seamounts with summits shallower than 800 m are within areas of national jurisdiction; however, there are many seamounts with summits at fishable depths (<2000 m) in high seas areas. Predicted seamount locations from Kitchingman & Lai 2004. Bathymetry data from ETOPO2.

Figure 14. A mapping of ocean seamounts, from the Global Open Oceans and Deep Seabed (GOODS) biogeographic classification[28]

3.2.8 Other open ocean habitats

A number of other sensitive open ocean benthic habitats include hydrothermal vents and nodule fields, for which there is interest in mining manifest as claims filed with the International Seabed Authority, are worthy of note and some areas have been identified as candidate EBSAs (see Section 3.2.6 above). Little systematic data has been collected from these regions, and they will have to be further covered under the expert assessment of scientific literature under this theme (see Section 6.2.1). Pelagic systems, which are harder to define geographically, may also be at risk from changing ocean conditions and human impact. Again the expert assessment will be needed to fully integrate this concern into the assessment.

3.2.9 Valuation of associated natural capital changes

In the development of management strategies that have associated costs, there has been a longstanding desire to place a monetary value on the ecosystem services provided by nature, in order to facilitate comparisons of costs and benefits.

An early attempt to do this that included the marine environment estimated the value of open ocean ecosystem services at $8 trillion per year (1997 US$), compared to a global gross national product of $18 trillion per year[29].

Evolution in ecosystem service valuation theory means that such global estimates are now frowned on, as they make too many assumptions and cannot account for natural system or human

[28] Global Open Oceans and Deep Seabed (GOODS) - Biogeographic Classification, *IOC Technical Series*, 84, IOC/UNESCO, Paris, France, 2009.

[29] Costanza, R., D'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., and Van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. *Nature,* Vol. 387: pp. 253-260, doi:10.1038/387253a0

system thresholds. Valuations depend on particular socio-economic settings and cultural values, and so must be interpreted and assessed from multiple points of view.

The Economics of Ecosystems and Biodiversity project (TEEB) study and other projects have developed methods to recognize, demonstrate, and capture the value of ecosystem services in the development of environmental policy and management actions.

The expert assessment component of the TWAP open ocean assessment will examine the latest literature and knowledge on ecosystem service valuation.

3.3 OPEN OCEAN FISHERIES: IMPACT AND SUSTAINABILITY

3.3.1 Overview / In the conceptual framework

In the conceptual framework, open ocean fisheries are both an ecosystem service (4, numbers refer to boxes in Figure 3 above) we would like to sustain in the face of changing catch potentials, and an associated stress on ocean ecosystems (2) through direct effects (removal of biomass and resulting changes in trophic levels) and indirect effects (destruction of ocean habitats from demersal fishing). The governance of fisheries through international agreements and private sector initiatives (6) has many existing frameworks. Since open ocean fisheries are largely commercial and dependent on a significant infrastructure, the economic benefit of open ocean fisheries is quite targeted.

Key indicators/metrics are identified below by sub-theme underlined above.

3.3.2 As a stressor of open ocean ecosystems: demersal fishing

There are multiple ways that fisheries effort acts as a stress on the natural system: through the removal of biomass in particular trophic levels which perturbs the natural food web, through bycatch, and through direct habitat destruction. Here a key indicator will focus on *destructive demersal fishing effort*, which is based mainly on bottom trawling and dredging (see Section 3.2.7 on why this is a particular stress on seamounts).

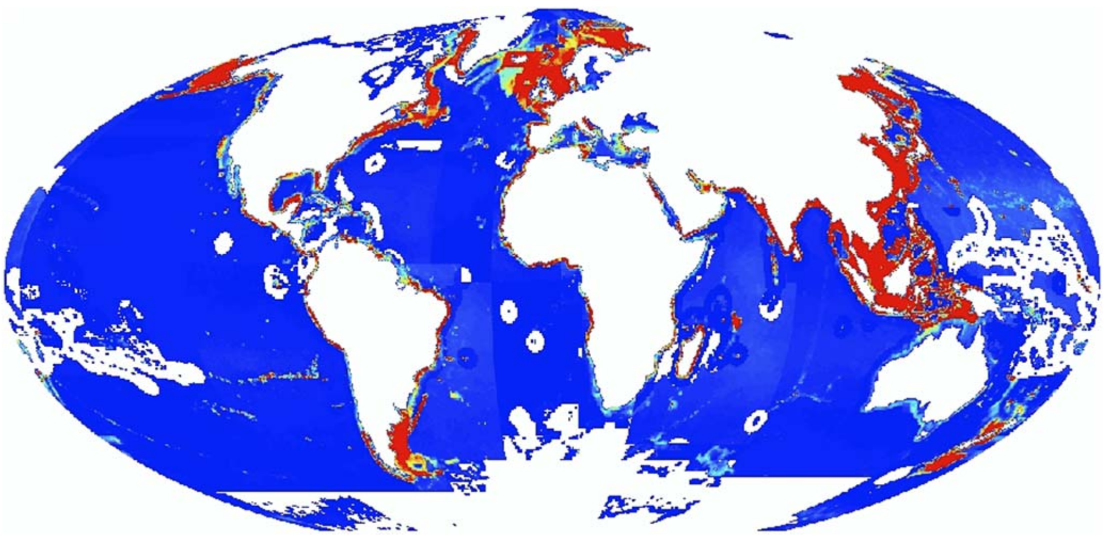

Figure 15. Demersal destructive fishing (primarily bottom trawling and dredging) from reference 42 and the Sea Around Us project. While much of this effort is concentrated on coastal waters covered by the LME assessment, there are significant levels in the global open ocean. However, in open ocean areas much of the fishing effort distribution within an FAO reporting area is assumed, and almost certainly misses concentrated fishing effort in areas around seamounts for example.

3.3.3 How sustainable is open ocean fishing?

The sustainability of open ocean fishing is the subject of extensive scientific literature as well as studies by the FAO. This is connected to climate change and its effect on temperature as well as on primary productivity. The TWAP open ocean assessment will rely on three primary indicators to complement the expert assessment component.

The *Marine Trophic Index (MTI)* is an indicator of ecosystem integrity. Declining trophic levels reflect depletion of the largest fish, and fisheries turning to less desirable smaller species (see Figure 16). The MTI is evaluated along with the Fishing in Balance Index (FiB). The FiB index will decline when both the MTI and landings decline, but will increase when increases in landings more than compensate for a declining MTI.

The MTI index derived from catch data has been questioned by work that shows a mismatch between catch-derived MTI from true trophic levels and biodiversity as measured by surveys and assessments[30]. A component of expert assessment of the evolution of the scientific literature on trophic level indices will be required to reach conclusions in the TWAP assessment.

The effects of climate change on fisheries can be expressed in an integrated way through models[31] via changes in *catch potential* (see Figure 17). The catch potential is the maximum exploitable catch over species combined, assuming that the geographic range and selectivity of fisheries remain unchanged. The model is based on an analysis of the 1 066 major commercially exploited fish species. Future distributions of these species are projected using a dynamic bioclimate envelope model, while primary production is projected by empirical models. The model is run on a 0.5° resolution global grid. This indicator will need to be augmented by expert assessment of the latest scientific literature, as the method is based on a large number of assumptions, and does not take into account the changes in the food web caused by different species bioclimate envelopes.

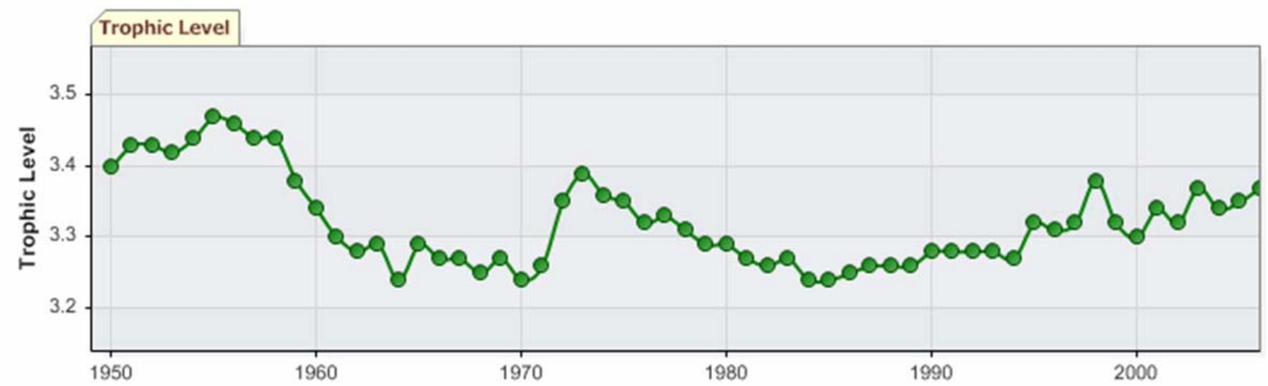

Figure 16. A time series of the global Mean Trophic Level Index from the Sea Around Us project[32].

[30] Branch, T. A., Watson, R., Fulton, E. A., Jennings, S., McGilliard, C. R., Pablico, G. T., Ricard, D., and Tracey, S. R., 2010. The trophic fingerprint of marine fisheries. *Nature*, Vol. 468: pp. 431-435, doi:10.1038/nature09528.

[31] Cheung, W. W. L., Lam, V. W. Y., Sarmiento, J. L., Kearney, K., Watson, R., Zeller, D., and Pauly, D., 2010. Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biology*, Vol. 16: pp. 24-35.

[32] http://www.seaaroundus.org/

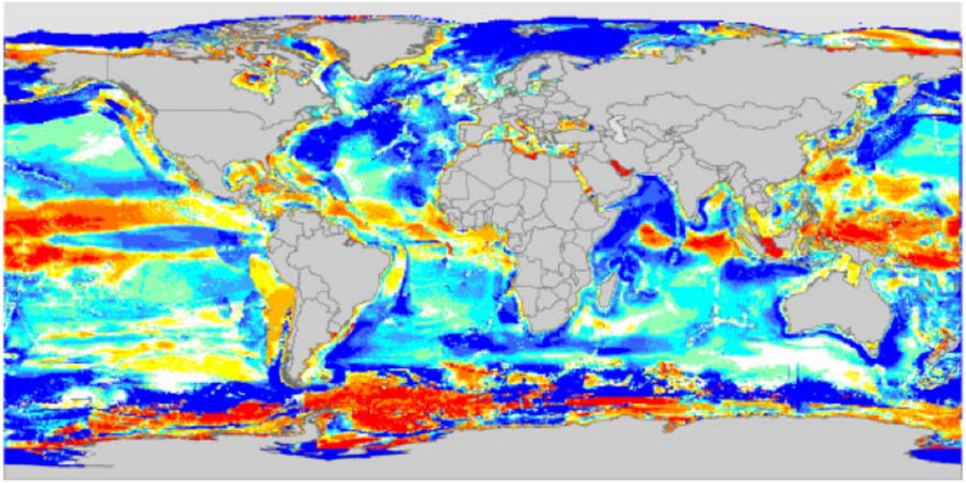

Figure 17. Change in catch potential in 2055 relative to 2005, based on a model. Many areas in the tropics and the Southern Ocean will have reduced catch potential according to this model, but other subpolar areas will be winners. (Source: Reference 31)

3.3.4 Particular socio-economic and governance considerations

The global ocean areas beyond national jurisdictions are part of the common heritage of all humankind. Exploiting fish stocks from these high seas areas, or those that straddle high seas areas, requires vessels and methods that are generally costly, and beyond the reach of fishers in developing countries. A proposed socio-economic evaluation for the global open ocean assessment is a simple listing of catches by country and value in high seas areas, as compared to a listing of country population. The mismatch in ranking of these lists will lead to further questions on the equitable nature of access to the global commons.

The authority and practical difficulty of enforcement of governance arrangements on the high seas will be another area examined by the expert group.

3.4 CONTAMINANTS AND POLLUTION AS A STRESSOR OF MARINE ECOSYSTEMS

3.4.1 Overview / In the conceptual framework

In the conceptual framework, contaminants and pollutants stemming from stakeholder behaviour (1, numbers refer to boxes in Figure 3) are all stressors (2) of ocean ecosystems. Major impacts identified by the working group include shipping, plastics from both sea and land-based sources, potential impact from future seabed mining activity, and atmospheric deposition of contaminants such as nutrients and mercury. For the open ocean, scientific understanding of the effects of many contaminants is uncertain, but the potential impacts are high, making this theme one in particular need of expert assessment of the latest scientific literature.

3.4.2 Shipping intensity

Shipping intensity is a proxy for ocean-based pollution, which can take the form of direct release of contaminants in the open ocean environment or through the transport of invasive species in ballast water. Shipping is also the dominant source of anthropogenic sound in the ocean. Since commercial ships are an important platform in the Global Ocean Observing System, acting as Volunteer Observing Ships, an extensive database of a representative sample of ships is available. The working group identified climate change as a bigger vector of invasive species in the open ocean than ship-based ballast water, however both topics will be addressed in the expert assessment of contaminants and pollution.

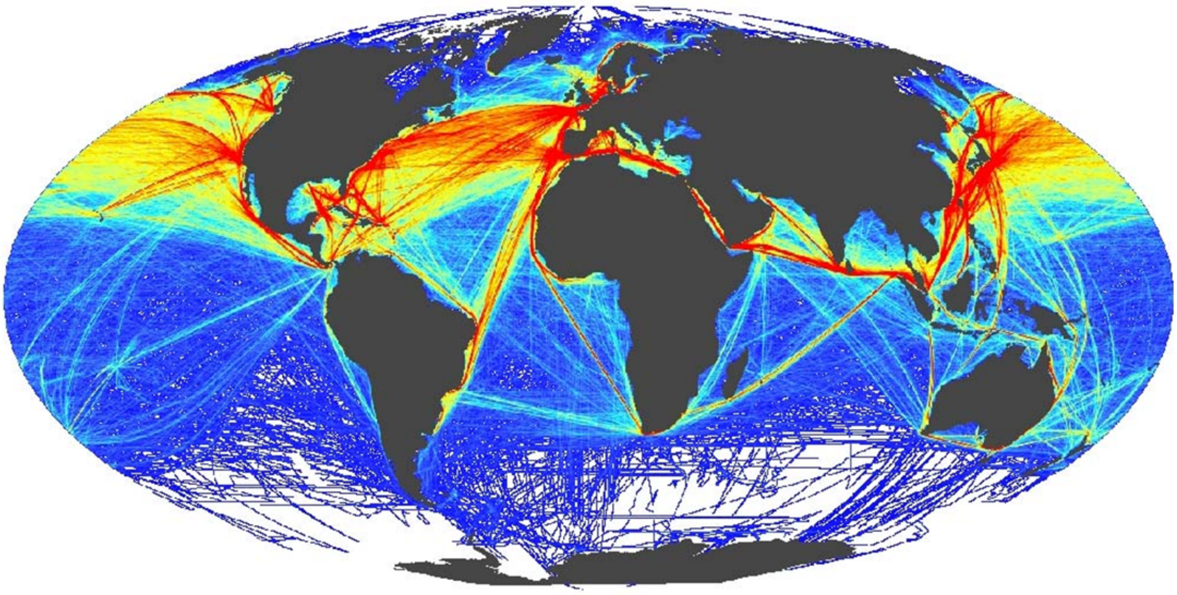

Figure 18. Shipping intensity. (Source: Reference 42)

3.4.3 Plastics

Plastic resin pellets are ubiquitous in coastal waters, and assumed also to be ubiquitous in the open ocean, although systematic observations are confined to limited areas. The pellets have been shown to absorb hydrophobic compounds such as persistent organic pollutants (POPs) present in the surrounding seawater, with a concentration factor of up to 1 000 000. The *plastic concentration* in the open ocean subtropical convergence gyres is not well-known, except in the North Atlantic Ocean where extensive plankton net tows yield broad-scale open ocean data (see Figure 19).

The full environmental impact of plastics in the open ocean is not well known. But the combination of potential high impact, the long lifetime of plastics, and growing public attention to the problem, means that this will be an indicator in the assessment that will also feed the expert assessment.

The International Pellet Watch programme has established a global network of volunteers who collect pellets from beaches and send them to a single laboratory for analysis. The results are sent to the collectors and made available on the programme website[33]. These pellets in isolated open ocean island locations may be an additional data source to substitute for a lack of complete open ocean observations of plastics.

[33] http://www.pelletwatch.org

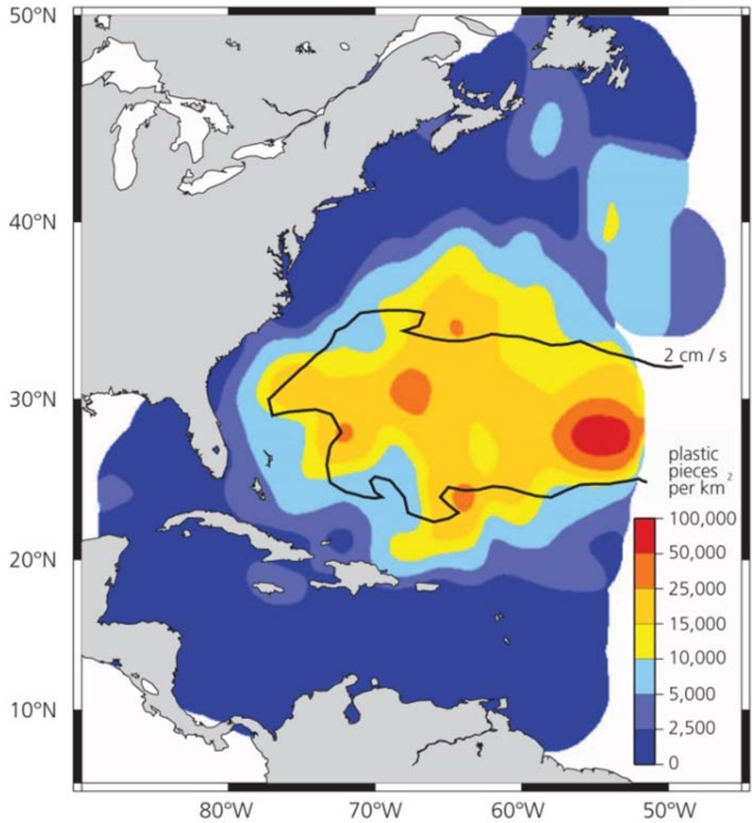

Figure 19. Average plastic concentration from Sea Education Association plankton tows in the northwest Atlantic Ocean. Data on the prevalence and the impact of these plastics is sparse. (Source: Reference 34)

3.4.4 Seabed mining

Potential seabed mining in the high seas is regulated by the UN Convention on the Law of the Sea. The International Seabed Authority was established to authorize seabed exploration and mining and collect and distribute royalties. No mining activity has yet proved to be economically viable, but *seabed mining claims* remain a TWAP open ocean assessment indicator as their potential impact is very high.

3.4.5 Other contaminant inputs

The pollution theme of the open ocean assessment is one where expert assessment of the latest scientific literature is important. The threshold for determining when a contaminant in the open ocean becomes pollution, with negative effects on the environment and human well-being, is difficult to determine. Very little systematic data exists, and an expert assessment of the latest scientific literature will be carried out, as the best way to identify looming problems with global ocean impacts from contaminants and pollution.

The Joint Group of Exerts on the Scientific Aspects of Marine Environmental Protection (GESAMP), an expert group commissioned by a number of UN specialized agencies, will be the primary partner in this expert assessment exercise under this theme.

[34] Law, K. L., Morét-Ferguson, S., Maximenko, N. A., Pruskurowski, G., Peacock, E. E., Hafner, J., and Reddy, C. M., 2010. Plastic Accumulation in the North Atlantic Subtropical Gyre. *Science,* Vol. 329, p. 1185, doi:10.1126/science.1192321

3.4.6 Reactive Nitrogen Inputs

Reactive nitrogen availability is the main determinant of primary productivity in large parts of the ocean. *Atmospheric nitrogen deposition* is the dominant input pathway for anthropogenic reactive nitrogen in the open ocean. Increased anthropogenic inputs are unlikely to be such as to result in dramatic responses such as intense algal blooms, but chronic, long-term shifts in productivity and ecosystem structure could result.

Direct measurements of reactive nitrogen concentrations in surface water are not considered likely to have value as an indicator of open-ocean pollution, because of measurement difficulties and the rapid dynamics of reactive nitrogen. Estimates of atmospheric anthropogenic nitrogen input, and changes in such inputs over time, are likely to be more a more useful indicator than direct measurement of seawater concentrations.

3.4.7 Mercury

Mercury is of major concern for human health, especially in the sub-polar regions and where people depend on long-lived, high-trophic level food, e.g., marine mammals. Like nitrogen, *atmospheric mercury deposition* is the primary input pathway for the open ocean.

Models can be used to estimate this deposition in the open ocean.

3.5 CROSS-CUTTING ASSESSMENT OF GOVERNANCE

3.5.1 Overview / In the conceptual framework

In the conceptual framework, governance and its interaction with personal behaviour and collective human activities lie at the top (boxes 5, 6, and 1 in Figure 3). This reflects their importance as points of entry for understanding how to manage the human relationship with the natural systems.

Governance is defined broadly for the TWAP open ocean assessment, starting with governments and in particular their interaction in the UN system, but also including markets/economics and civil society.

Effective governance that accomplishes societal goals while sustaining the state of the natural system and the services it provides requires complete policy cycles[35]. This would include:

- data and information (from both natural and social science);
- analysis and advice (where natural science, social science, and politics meet);
- decision-making;
- implementation; and
- review and evaluation.

For the open oceans globally, the decision-making arrangements are fairly small in number. But the highest level of governance arrangements that have effective enforcement mechanisms are national, and many interactions between personal behaviour and governance occur at smaller scales. Policy cycles are therefore needed at multiple levels, and ultimately many different scales of governance arrangements will need to be assessed. These will also include informal civil society forms of governance, including the press, conservation NGOs, and the private sector.

[35] For more details, see the Mahon, Fanning and McConney discussion paper developed for the TWAP governance assessment

3.5.2 Identification of arrangements in place

Assessing governance arrangements starts with a simple identification of the arrangements in place.

This is simplest for the global arrangements in place for the open oceans, which include:

- An overall framework provided by the UN Convention on the Law of the Sea (LOS);
- For climate change mitigation and adaptation: the UN Framework Convention on Climate Change (UNFCCC);
- For the protection of open ocean ecosystems;
  - the UN Commission on Sustainable Development (CSD) reviews Oceans and Seas on a regular basis;
  - the UN Convention on Biological Diversity (CBD) covers the protection of biodiversity, but under national jurisdiction;
  - the UN General Assembly has set up the 'Ad-hoc open-ended informal working group to study issues relating to the conservation and sustainable use of marine biological diversity beyond areas of national jurisdiction' (BBNJ WG) to explore intergovernmental mechanisms;
- Protected species conventions;
  - Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES), UNEP;
  - Convention on the conservation of migratory species of wild animals (CMS), UNEP;
  - CBD;
  - International Whaling Commission (IWC);
- For the sustainability of open ocean fisheries;
  - LOS and its agreement on conservation and management of straddling fish stocks and highly migratory fish stocks;
  - Agreement to promote compliance with international conservation and management measures by fishing vessels on the high seas (FAO);
  - Regional Fisheries management organizations (with varying levels of contact with the FAO);
- Pollution;
  - for ship-based pollution: MARPOL (IMO);
  - for ocean dumping: London Convention (IMO); and
  - Regional Seas Conventions and Action Plans covering open ocean areas.

As some of the indicators in previous sections reveal, however, teleconnections exist between open ocean state and its impacts, as well as between remote (land-based or coastal/LME-based) human activity and the impact on open ocean natural system state, and so, ultimately, the relevant regional, national and local governance mechanisms will need to be assessed in the context of developing an intervention.

3.5.3 Assessing flow of information about natural systems to governance arrangements

A baseline assessment would then ask whether each governance arrangement had a full policy cycle in place. Two objective and simple (yes/no) indicators will be:

- Does a monitoring programme exist to give sustained data on the natural system the governance arrangement seeks to manage?; and

- Does the governance arrangement include a regular assessment of the status or quality of the natural system (what the EU MSFD calls 'Good Environmental Status')?

A further indicator will seek to qualify these arrangements. The natural science expert team will judge these indicators.

This covers the 'data and information' and 'analysis and advice' parts of the policy cycle described above.

3.5.4 Assessing social aspects of the governance arrangements

Further indicators could seek to identify whether the rest of the policy cycle is being implemented and judge it more subjectively, including for effectiveness and social justice questions.

The governance arrangements should be assessed for the following criteria:

- administrative: efficiency, effectiveness, responsiveness;
- appropriateness, accountability and transparency; and
- social justice: inclusivity, representativeness, legitimacy, equitability.

These are value-based judgments that will be interpreted through the prism of politics and culture. They will have to be made by judgment by a panel of governance experts, realizing that at the global level this will have to reflect the political and cultural differences of the many different constituencies at national and local levels, and their differing societal goals. Simple global indicators for these types of criteria do not exist, and there is a need for further work in this area.

This type of extended assessment is difficult, but is needed to improve governance related to the combination of human and natural systems. This assessment might help increase the effectiveness of GEF interventions by identifying features of management leading to good governance.

3.6 CROSS-CUTTING ASSESSMENT OF KEY RESEARCH AND MONITORING NEEDS

A key challenge in developing an assessment based on natural and social science is constructing simple and clear messages in order to have impact on policymakers. This is compounded when there is a lack of data, as in much of the open ocean. Experts involved in the assessment will have to negotiate scientific uncertainty in crafting clear but scientifically-sound messages.

One way to meet this challenge is to make the identification of key research and monitoring needs an integral part of the assessment. This communicates uncertainty to the policymaker, and points to a way forward to improving understanding. A mesh of policymaker interest in thematic and scientific assessment of research and monitoring needs can lead to leaps forward for developing information for management.

The assessment of key research and monitoring needs is part of the mandate of the IOC, for its ocean science and Global Ocean Observing System (GOOS) programmes.

For each of the themes the expert assessment portion of the TWAP open ocean assessment will negotiate with other stakeholders and identify which research and ocean observation investments are likely to be both feasible and have high impact in terms of the information needed for good management of the open oceans (see Figure 20). This assessment of where to target investment in research and monitoring will consider the natural and human system sides, investigating both natural and social sciences.

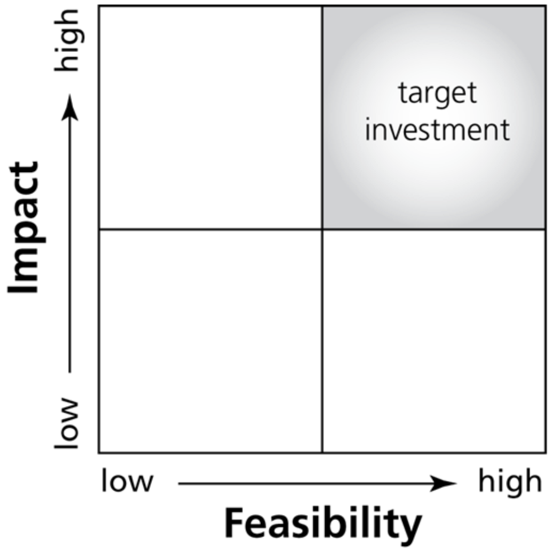

Figure 20. Matrix of impact of information for management of the open ocean environment vs. feasibility of research or monitoring to lead to that information. An assessment of where research and observing investment will fit into the upper right quadrant will guide investment for stakeholders in that area.

Identifying capacity-building needs will be an integral part of this analysis. Currently research and observations of the open oceans are dominated by a small number of countries with the scientific capacity to be active in these areas. With increasing clarity of the role of the open oceans in the well-being of many people around the world, a target should be to improve the ability of all nations to participate in the assessment and management of the open oceans. With increasing stakeholder involvement in research and monitoring, the questions posed by science will be of greatest relevance to all stakeholders.

Table 1. Overview of the metrics, indicators, and indices in the TWAP open ocean methodology. Those in bold are the core natural system indicators and human system metrics that at the global level can be combined for the assessment. Wherever possible a mapping approach is taken to allow for geographic scoping and scaling. Expert assessment of literature is needed to complement the metrics, indicators, and indices for high uncertainty, potentially high impact, and/or subjective issues, and the importance of this need for each subtheme is noted by * below.

THEME/SUBTHEME	*GLOBAL INDEX*	STRESS INDICATOR	ECOSYSTEM VULNERABILITY INDICATOR	ECOSYSTEM STATE INDICATOR	HUMAN VULNERABILITY METRIC	GOVERNANCE ASSESSMENT/METRIC	EXPERT ASSESSMENT NEEDED	NOTES	DATA SOURCE OR PARTNER
Climate change, variability, and impacts						overall assessment of UNFCCC / adaptation / services measures related to the oceans	*		
sea level	*projection of human population at risk*			**sea-level rise projections map**	**human pop in low-lying areas map**			potential link with groundwater extraction	WCRP, IPCC
ocean heat storage/structure	*average ocean heat content*			**ocean heat content map**					NOAA/ NODC
' and impact on corals	*global yearly coral heating days*	**coral heating days index map**	coral locations map		linked to LME indicators of socio-economic dependence on fisheries/tourism				NOAA/ NODC, NOAA Coral Reef Watch
' and impact on extremes	*global yearly cyclone heat potential mean*	**cyclone heat potential map**			linked to 3 above				NOAA/AOML
' and impact on primary productivity	*global estimate of stratification strength/timing*	**gyre/mapped estimate of stratification strength/timing**		(gyre/mapped primary productivity below)					NOAA/NODC
rainfall-drought changes linked to ocean		**projections of rainfall changes, mapped on land**			**estimates of water scarcity, mapped on land**			link to ocean heat content; Major link with other water systems	WCRP, TWAP modules
sea ice	*global yearly sea ice minimum extent / shipping / acidification*	**sea ice extent map +projection**	(connected to shipping and acidification)						NSIDC
ocean deoxygenation	*global estimated volume oxygen minimum zones*	**estimated volume oxygen minimum zones map +projection**	(linked to catch potential changes below)				*		scientific literature assessment

THEME/SUBTHEME	*GLOBAL INDEX*	STRESS INDICATOR	ECOSYSTEM VULNERABILITY INDICATOR	ECOSYSTEM STATE INDICATOR	HUMAN VULNERABILITY METRIC	GOVERNANCE ASSESSMENT/METRIC	EXPERT ASSESSMENT NEEDED	NOTES	DATA SOURCE OR PARTNER
ocean CO_2 uptake	*global uptake estimate*	**surface map uptake +projection**		(linked to primary productivity below)			**		scientific literature assessment, IOCCP, Global Carbon Project
ocean acidification	*global estimate of reefs at risk +projection*	surface map aragonite saturation +projection	**coral locations map**	(linked to primary productivity below)			*		scientific literature assessment, IOC acidification program
Ocean ecosystems, habitats, and biodiversity						Marine Protected Areas: % of high seas covered			
primary productivity	*global estimate of open ocean productivity +projection*	(related to stratification above)		**gyre/mapped primary productivity history +projection**			*	linked to fisheries below	University of Plymouth / NOAA
zooplankton		(linked to climate above)		**mapped changes in mesozooplankton abundance, species distribution, timing**			**	‘	SAHFOS
food web / trophic level changes		(linked to climate above / fishing below)		(some indication from fisheries data: trophic level)			***		scientific literature assessment
candidate ecologically and biologically significant areas candidate (EBSA, CBD)		(linked to all climate and all below)	**mapping of candidate EBSAs as proposed to CBD by associated projects**				**		IUCN/GOBI, UNEP-WCMC
seamounts at risk		(linked to all climate and all below)	**mapping of seamounts at risk**				*	shared with LME	UNEP-WCMC
ecosystem service valuation	*(indicative global values, but better in evaluating different management scenarios)*				(how ecosystem services are shared through governance filter)		***	goal would be to provide guidance for decision-support	Natural Capital Project, UNEP/DEPI, literature

THEME/SUBTHEME	*GLOBAL INDEX*	STRESS INDICATOR	ECOSYSTEM VULNERABILITY INDICATOR	ECOSYSTEM STATE INDICATOR	HUMAN VULNERABILITY METRIC	GOVERNANCE ASSESSMENT/METRIC	EXPERT ASSESSMENT NEEDED	NOTES	DATA SOURCE OR PARTNER
Open ocean fisheries: impacts and sustainability						Overall assessment of fisheries management organizations	**		FAO, Sea Around Us Project, literature
demersal fishing effort	*yearly effort*	**mapping of FAO/Sea Around Us reported demersal fishing**	(linked to above through habitat destruction)						Sea Around us Project
open ocean fisheries sustainability		(linked to climate above)		**MTI ; map of projected changes in fish catch**			**		Sea Around Us Project, literature
fish catch value	*global ranking of countries benefiting from high seas fisheries*				(linked to questions of equity)				FAO, Sea Around us Project
Pollution as stressor of marine ecosystems						overall assessment of global and regional governance for open ocean pollution issues	*		GESAMP
shipping	*highlighted changes in pristine areas*	**mapping of shipping patterns**	(stress on candidate EBSAs, increase in atm nitrogen input)						IMO
plastics		**mapping of convergent gyre plastic load**	(low knowledge of vulnerability)				**		scientific literature
seabed mining	*global claimed area, global area active*	**mapping of claims, activity**		(linked to habitat destruction)					International Seabed Authority (ISA)
nutrient input (atmospheric)		**atmospheric nitrogen deposition**		(linked to primary productivity)			*		GESAMP
mercury input (atmospheric)		**atmospheric mercury deposition**			(linked to fisheries)		*		GESAMP
pollution watch			(to capture ecosystem vulnerability)		(to capture human vulnerability)		**	an expert assessment is needed	GESAMP
Global impact estimates									
cumulative impact of human stresses on ocean ecosystems	*ranking of stresses*	**global mapping of cumulative impact (combines stress, vulnerability, state)**						shared with LME	Center for Marine Assessment and Planning (CMAP)

PART 4. INTERLINKAGES WITH OTHER WATER SYSTEMS

The interlinkages between water systems are controlled on the natural system side by the physical flow of water through the hydrological cycle and the flow of pollutants, and on the human system side by the shared usages and governance arrangements for water bodies.

Discussions within the working group revealed surprisingly few links between the priority issues for the open oceans and the other water systems. The links that do exist are important, and include the influence of open ocean changes on the patterns of rainfall and drought that are the immediate source of fresh water replenishment for surface water systems and a source for groundwater systems, as well as the teleconnections between global open ocean conditions and local conditions. These teleconnections will be revealed in the climate-related metrics and indicators as well as expert assessment. The Level 2 assessment (see Section 1.3.2) will expose these links for a specific region or regions.

The links with the Large Marine Ecosystem water system are also strong, through physical and biogeochemical circulation links, migratory species, and continuous habitats across these human-drawn marine boundaries. However some issues that are acute in coastal waters, such as eutrophication from land-based nutrient input and freshwater flow, have quite a different character in the open oceans, where the main nutrient input is from the atmosphere and not from rivers.

4.1 OPEN OCEANS AS A DRIVER OF CLIMATE: AFFECTING RAINFALL AND DROUGHT ON LAND

An analysis of the inputs and outputs of the five TWAP water systems covering physical and chemical properties and the impact they have on ecosystem services was made by the working group. It revealed one major output of the ocean being a key input for two of the five other water systems, and an important input for a third. This output is evaporation of freshwater from the ocean surface (controlled by air sea fluxes highly dependent on sea surface temperature and winds) which is an input to freshwater recharge for rivers and lakes through their catchment basins. Variations in freshwater recharge for groundwater systems are of varying importance, as these are replenished on widely varying time scales from immediate contact with surface water to geological time scales.

Because of the enormous volume of the open oceans compared to the largely coastal waters enclosed in LMEs, outputs from LME systems are not of global environmental concern in the open oceans, where inputs from atmospheric deposition dominate. One exception is the relationship between groundwater extraction and sea-level rise, with recent work suggesting that groundwater extraction could contribute up to 25 per cent of current rates of sea-level rise[36]. This will be considered in the open ocean sea-level rise assessment subtheme (see Section 3.1.2).

In the climate system composed of atmosphere, ocean, and the terrestrial biosphere, the oceans are the major heat reservoirs and transporters, and their dynamic interaction with the atmosphere can lead to both short-term and permanent ocean-driven changes in global patterns of rainfall and drought.

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[36] Wada, Y., van Beek, L. P. H., van Kempen, C. M., Reckman, J. W. T. M., Vasak, S., Marc, and Bierkens, F. P., 2010. Global depletion of groundwater resources. *Geophysical Res. Lett.*, Vol. 37, L20402, 5 pp., doi: 10.1029/2010GL044571

On shorter timescales, from seasons to a number of years, climate variability such as El Niño and La Niña events can have profound impacts on human well-being through increased rainfall or drought (see Figure 21) and changes in storminess that have downstream environmental and human consequences. Projections of changes in rainfall and drought patterns are made by coupled atmosphere-ocean climate models, and the IOC co-sponsored World Climate Research Programme (WCRP) coordinates the production and sharing of these projections for the Intergovernmental Panel for Climate Change. The IPCC Fourth Assessment Report (2007) examined projected changes in rainfall and drought (see Figure 22) and their uncertainty. These projections are currently being updated to include improved decadal time scale and regional climate projections, and will be published in time to be assessed for the 2013 IPCC Fifth Assessment Report. These climate model outputs will be provided by the WCRP during the proposed TWAP full-sized assessment, and will be available for the other water systems to use in their assessments. In the context of the assessment, they will be most useful in conjunction with assessments of vulnerability to water stress, such as reliance on rain-fed agriculture or areas prone to flooding (see, for example, Figure 23).

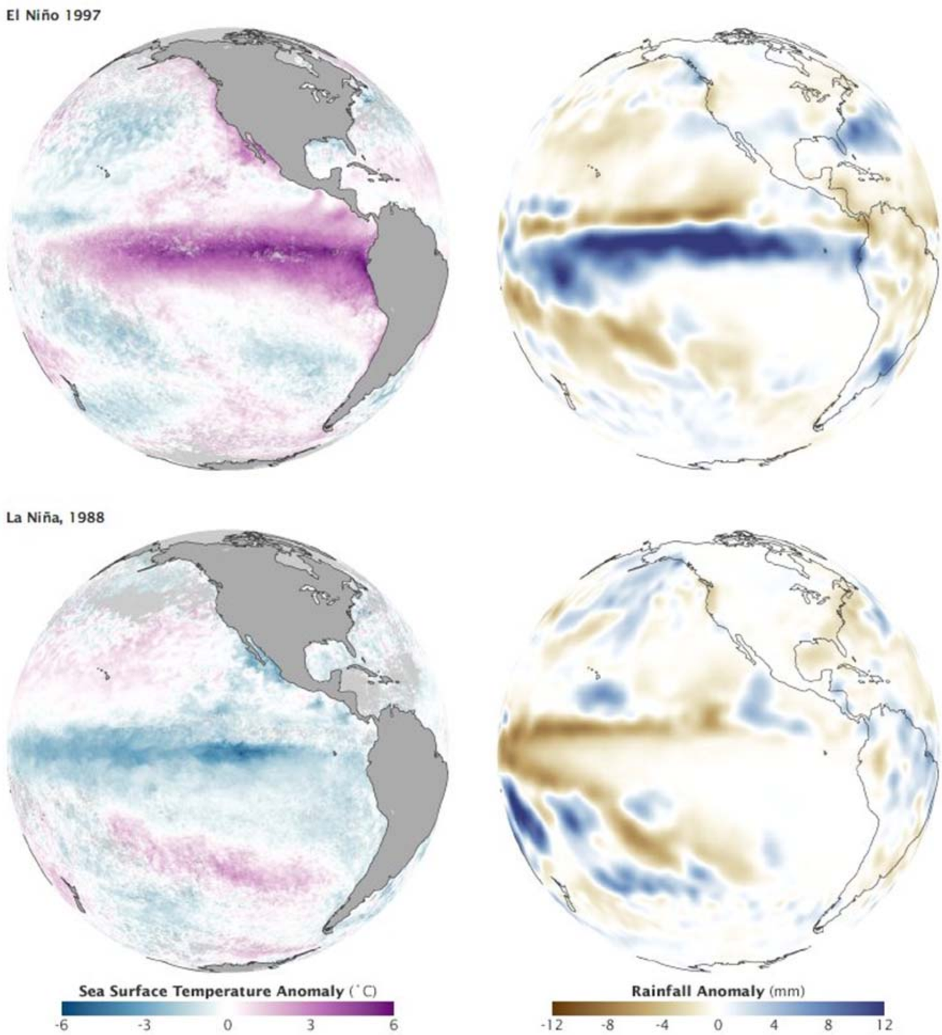


Figure 21. Through teleconnections, sea surface temperatures that are the result of open ocean dynamics in the climate system can profoundly influence rainfall and drought patterns globally. The left panels show sea surface temperature anomaly, the right panels rainfall anomaly. The top two panels show conditions at the peak of the 1997 El Niño event, and the bottom two at the peak of the 1998 La Niña event. Permanent changes in the open ocean due to climate change could drive permanent changes in rainfall and drought patterns, the key input to freshwater for the other TWAP water systems. Image courtesy NASA.

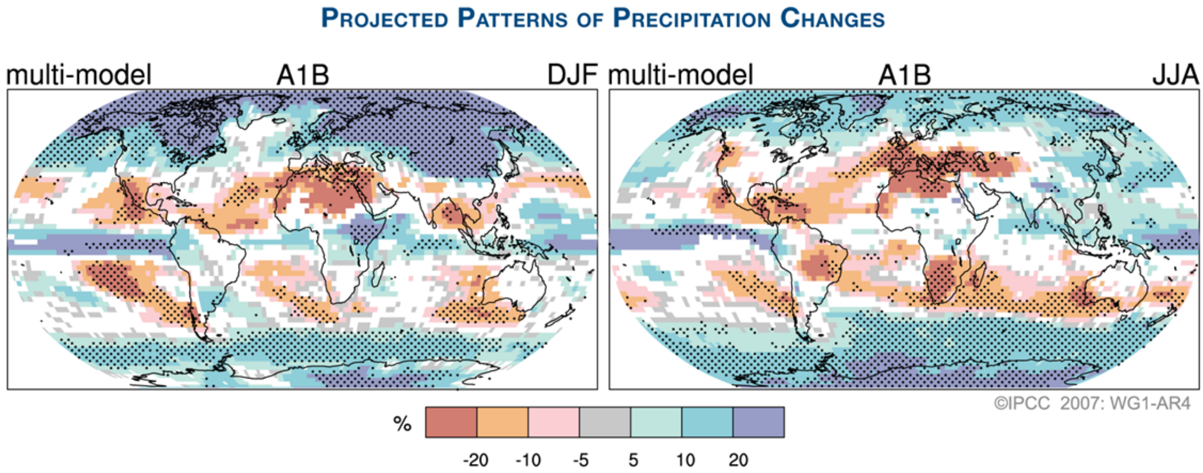
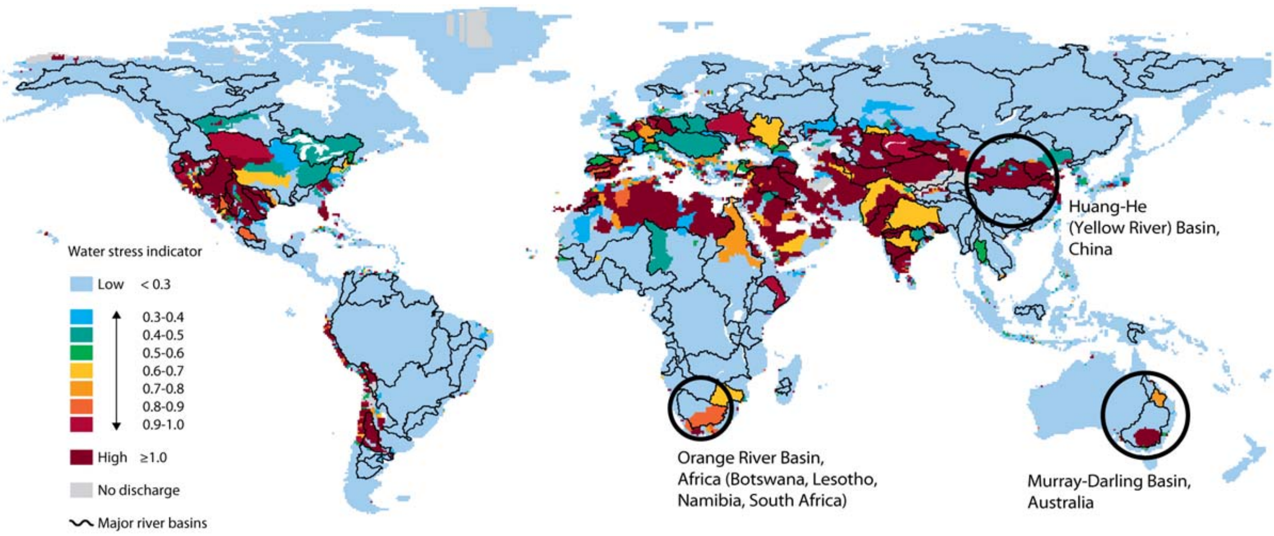


Figure 22. IPCC Fourth Assessment Report[37] (2007) projections of relative changes in precipitation (in percentage) for 2090-2099 relative to 1980-1999. Values are multi-model averages based on a 'business as usual' scenario for December-February (left) and June-August (right). White areas are where less than 66 per cent of the models agree on the sign of the change, and stippled areas are where more than 90 per cent of the models agree on the sign of the change. The WCRP is leading an effort to coordinate publication of new climate model results, including an emphasis on decadal and regional climate projections, for the IPCC assessment to be published in 2013, during the proposed TWAP full-sized assessment.



Source: Based on Smakhtin, Revenga, and Döll 2004.

Figure 23. Water stress levels of major river basins as reported in the World Water Assessment Programme 2009 report[38]. Open ocean-driven changes in global patterns of rainfall and drought will ameliorate or exacerbate this situation, and form an important input to rivers, lakes, and to some extent groundwater systems.

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[37] IPCC, 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., Qin, D., Manning, M. Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., and Miller, H. L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

[38] WWAP, 2009. The United Nations World Water Development Report 3: Water in a Changing World. Paris: UNESCO, and London: Earthscan.

4.2 LINKS WITH OTHER WATER SYSTEMS: FOCUS ON LMES

Precise human-drawn boundaries between Large Marine Ecosystems and the open oceans do not exist in nature. Transport of physical, chemical, and biological properties between the open ocean and the LMEs is strong.

Many of the indicators in the TWAP Open Ocean methodology are shared with the LME methodology, but the overall approach is rather different. In the LME assessment the approach focuses on calculation of the indicators for the pre-defined LME assessment units, and on a ranking of LMEs by concern. The Open Ocean assessment focuses on a global mapping of environmental and human system stresses and vulnerabilities, with a strong component of expert assessment of the scientific literature.

The working group identified a number of key interlinkages between the Open Oceans and LMEs, which can be divided into two categories: balanced influence (inputs and outputs have consequences for both LMEs and Open Oceans in approximately equal amounts) and open-ocean dominated influence (where outputs from the open ocean have potential high impact on LMEs).

The major balanced influence links were:

- vulnerable open ocean species with part of their life cycle in LMEs, sensitive to habitat changes in coastal regions; and
- highly migratory and straddling fish stocks across the open-ocean / LME boundaries, and both of these will be dealt with in the governance assessments under the ocean ecosystem and fisheries themes of the open ocean assessment, in cooperation with the LME assessment. The FAO has extensive ongoing assessment of straddling and highly-migratory fish stocks related to its governance arrangements, and these will be fully exploited in the TWAP open ocean and LME assessments.

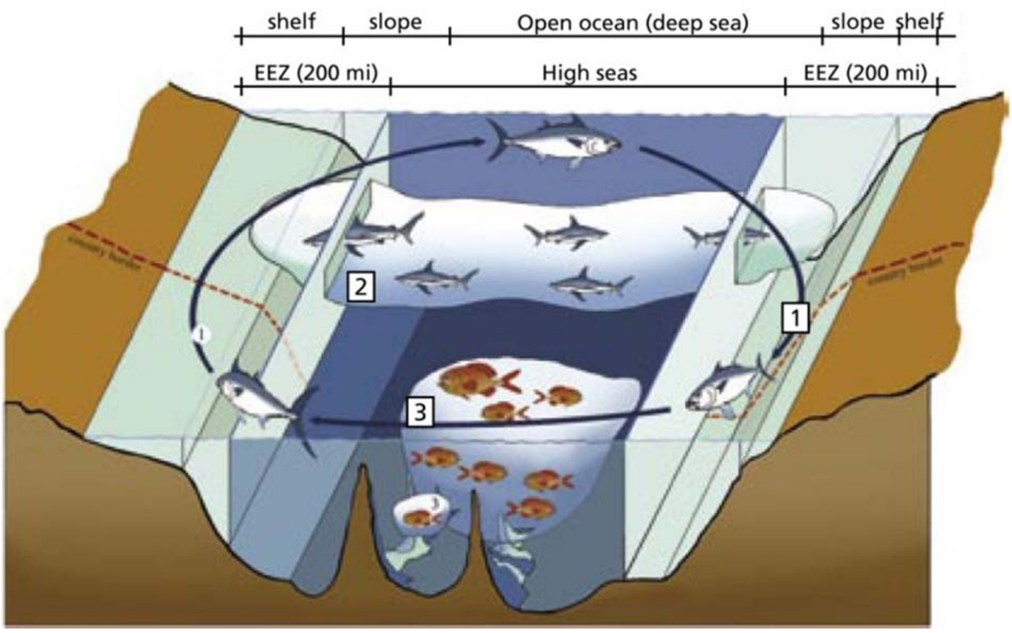

Figure 24. Types of fish stocks as defined by UNCLOS and FAO occurring partially or entirely in the high seas (open ocean areas beyond national jurisdiction). 1. highly migratory, 2. straddling, 3. high seas only. A fourth category not shown are straddling fish stocks that cross a single EEZ-high sea boundary. The figure also shows the mismatch between geographic definitions of open oceans and legal definitions of the high seas (open ocean areas beyond national jurisdiction). Adapted from reference 39.

[39] Maguire, J. -J., Sissenwine, M., Csirke, J., Grainger, R., Garcia, S., 2006. The state of world highly migratory, straddling and other high seas fishery resources and associated species. *FAO Fisheries Technical Paper*. No. 495. Rome: FAO. 84 pp.

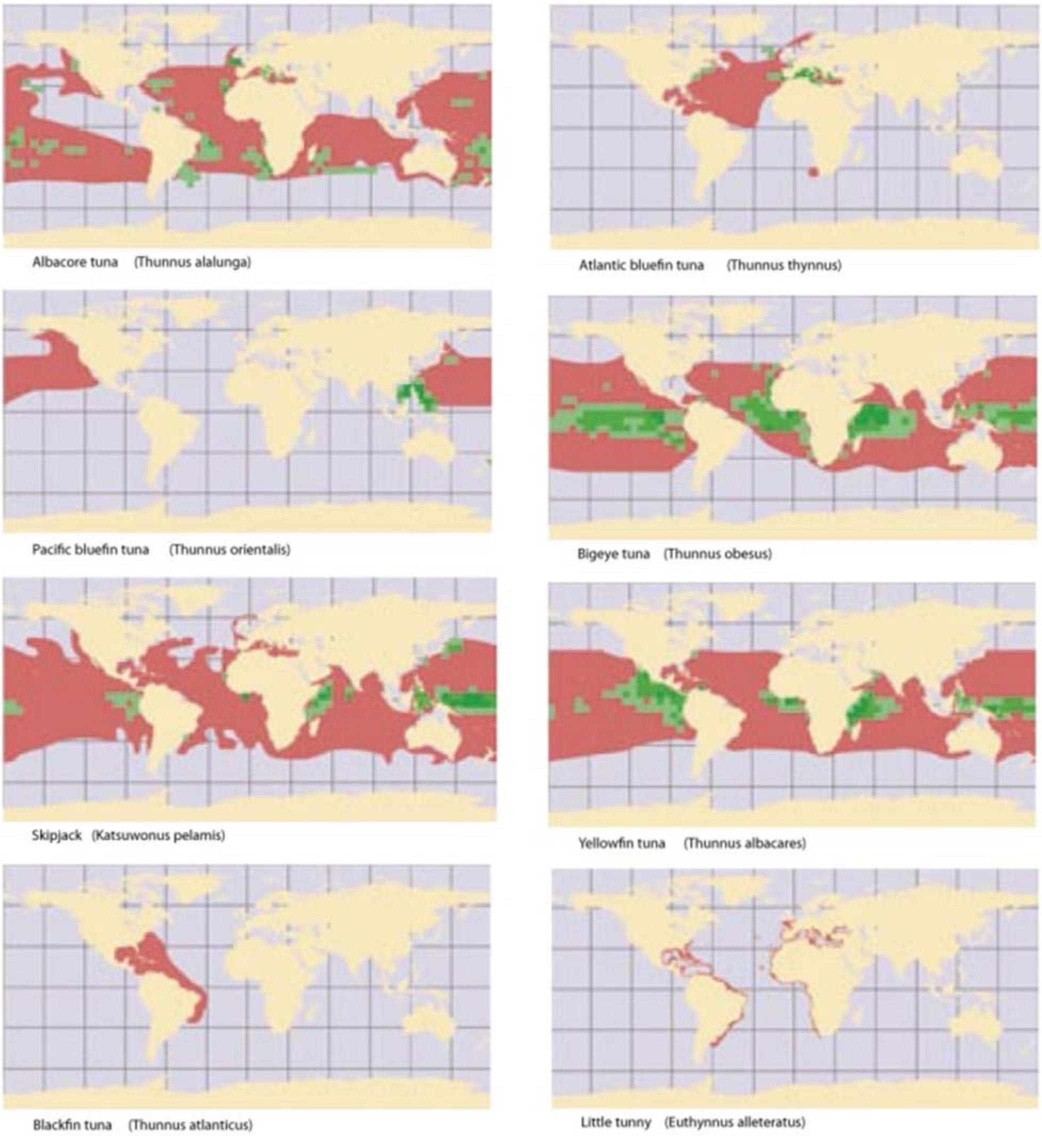

Figure 25. General geographic distribution and main fishing grounds of highly-migratory tuna species, showing the links between open ocean and LME areas. (Source: Reference 39)

Two major open-ocean dominated influences were identified by the working group. The first is changes in open ocean oxygen concentration and circulation that can lead to coastal hypoxia in some LMEs. The ocean deoxygenation mapped indicator will be of use to the LMEs in this context (see Section 3.1.6 and Figure 26). The second is potentially enhanced nutrient supply to some coastal current ecosystems due to global warming and increased stratification[40]. While now identified for a few specific current systems, this input from the global ocean to LMEs is probably general.

The nutrients and mercury indicators in the open ocean assessment under the pollution theme have minor links with the other water systems, but the impacts on the open ocean come mainly from the atmosphere and not from other water systems. They are therefore not a direct link between the water systems, and will not be a central concern of the open ocean assessment.

[40] Rykaczewski, R. R. and Dunne, J. P., 2010. Enhanced nutrient supply to the California Current Ecosystem with global warming and increased stratification in an earth system model. *Geophys. Res. Lett.*, Vol. 37, L21606, doi: 10.1029/2010GL045019

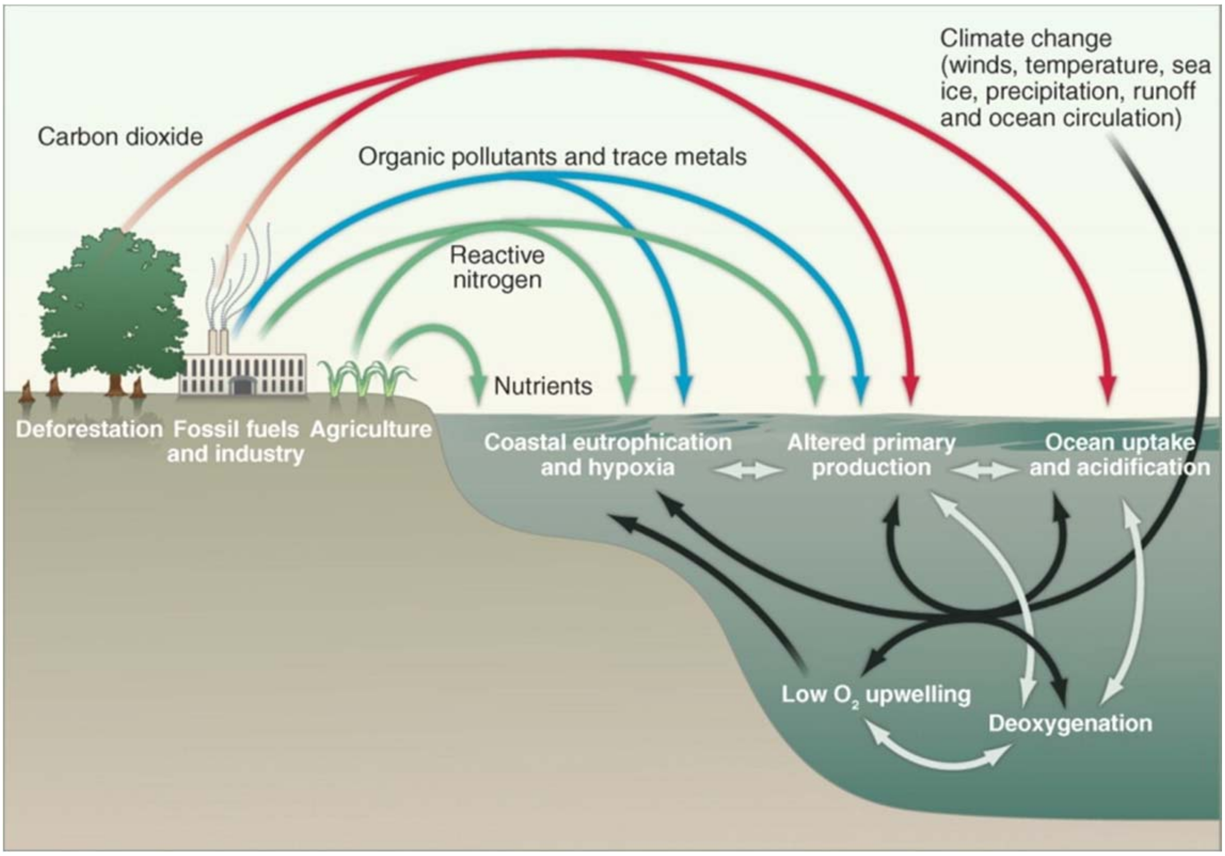

Figure 26. A schematic of the human impacts on ocean biogeochemistry that shows a link between open ocean oxygen conditions and coastal eutrophication and hypoxia. This only occurs in upwelling regions. (Source: Reference 41)

[41] Doney, S. C., 2010. The Growing Human Footprint on Coastal and Open-Ocean *Biogeochemistry*. *Science*, Vol. 328, pp. 1512-1516. doi:10.1126/science.1185198

PART 5. DATA AND INFORMATION MANAGEMENT

5.1 DATA SOURCES AND INFORMATION MANAGEMENT

A key concept in the TWAP open ocean assessment methodology is a global mapping approach to metrics, indicators, and indices. This allows for visual explanation of key concepts, a scaling to the needed domain depending on context or policymaker interest, and the ability to project stress on vulnerability to pinpoint areas of concern.

The data sources for each of the indicators is listed in Table 1 as well as in each indicator template in Annex 2. The sources are varied, distributed, involve both natural system and human system data, and the number of sources is large. The TWAP open ocean assessment will rely on a distributed data source and information management model that puts primary responsibility on a data provider for maintaining the data set used as a source for the indicator.

The mapping approach will require the lead partner (IOC-UNESCO) in the assessment to serve as a centralized system for assembly, dissemination, archiving, and mapping of the source data for each indicator. Assembly involves the transformation of each relevant data set into an interoperable format for the assessment. Dissemination and archiving will allow transparent access to all TWAP partners, but also to a larger stakeholder community. The mapping, transforming data into useful information, is a key step.

The IOC has been selected to receive a grant as a part of a larger consortium to the European Union Seventh Framework Programme (FP7) for research. The grant for the GEOWOW project responds to a call for 'Inter-operable integration of shared Earth Observations in the Global Context'. This project will contribute to the Global Earth Observation System of Systems (GEOSS) Common Infrastructure of data, and make global ocean ecosystems data and information (including model outputs) available on a common data system. The main objective of this work package in the project is to support the research and development of marine assessments such as TWAP, and it will provide the IOC with the resources necessary to make a strong co-investment in the execution of the TWAP open ocean assessment.

5.2 TOOL FOR COMBINING KNOWLEDGE TO SUPPORT IDENTIFICATION OF PRIORITY CONCERNS AND PLANNING INTERVENTIONS

The indicators and expert assessments in the TWAP open ocean assessment are divided by theme. While they will allow a clear communication of the environmental problems associated with each theme, they do not allow easy and direct comparison across themes of how to set priorities in management.

This section describes the proposed application of a tool to map cumulative human impact on ocean ecosystems in the context of the TWAP open ocean assessment. This is a complementary analysis to the thematic approach, and cannot replace in situ measurements of the open ocean state as validation. Cumulative human impact mapping focuses, in the conceptual framework, on the natural system stresses caused by human stakeholder behaviour. It allows, with caveats, the comparison of relative impacts and the development of scenarios to test governance strategies. Scenarios will also allow the testing of different management strategies.

5.2.1 Background on Cumulative Impact Tool

Any effective management of marine systems requires information on where and how much human activities are affecting the health of the systems, and these assessments need to be comprehensive not just within a single sector (for example, only fishing). A cumulative impact assessment tool[42] represents the only existing tool for comprehensively assessing the cumulative impact of all human activities on the state of all marine ecosystems at a global scale, in turn providing an assessment of ocean health.

Cumulative impact is calculated as the sum of the weighted impacts of each stressor, at a given intensity, on each ecosystem, summed into a single, directly comparable measure of ecosystem condition. To date the focus has been on the current level of cumulative impact, allowing us to answer a host of policy- and management-relevant questions, including where the most and least impacted areas are, which are the top threats, which are the most vulnerable ecosystems, and the relative impacts of different suites of stressors (e.g. climate change vs. pollution). What is missing from these analyses, and what forms the core of the methodology proposed below, is a need to be able to evaluate the potential costs and benefits of different management scenarios on ocean health at different points in time in the future.

5.2.2 Management applications and implications

In the context of the open oceans, and in particular for areas beyond national jurisdictions, the cumulative impact tool can serve to highlight human impacts on a common resource, and the need to develop common global management instruments. It can help identify the most vulnerable regions now, and, with extension of the methodology, in the future. It will help identify the relative impacts of stressors, which can potentially orient effort towards the development of particular management agreements.

5.2.3 Methodology

The details described below explain how the cumulative impact tool works and what it can provide. It is important to note that it does not replace the need for in situ measurements of ecosystem condition and the related indicators of ocean health that are derived from those measurements. The tool provides predictions about the state of the ocean that indicator assessments help validate. As the two processes (model predictions and indicator assessments) proceed and are refined, model predictions will become increasingly accurate and have finer resolutions.

A. General description and outputs

The cumulative impact tool requires three types of data: maps of each habitat, maps of the intensity of stressors (drivers) of interest, and vulnerability weights for each stressor-habitat combination. These have been developed for analyses at global scales.

The initial focus was on producing a global map of the cumulative impact of human activities. The tool also allows one to produce results tailored to any geography of interest, including LMEs and open ocean regions. By comparing the relative impact of individual or sets of stressors within a given geography, one can, for example, determine the top threats to the region or the relative contribution of stressor(s) to overall ocean degradation. This in turn helps to highlight hotspots of impact from different stressors, as well as where and how much different management actions might be able to mitigate cumulative impacts. Which LME needs the most immediate conservation attention? Where within a given ocean region is climate change or fishing having the biggest impact? Which locations

[42] Halpern, B. S., Wallbridge, S., Selkoe, K. A., Kappel, C. V., Micheli, F., D'Agrosa, C., Bruno, J. F., Casey, K. S., Ebert, C., Fox, H. E., Fujita, R., Heinemann, D., Lenihan, H. S., Madin, E. M. P., Perry, M. T., Selig, E. R., Spalding, M., Steneck, R., and Watson, R., 2008. A Global Map of Human Impact on Marine Ecosystems. *Science*, Vol. 319: pp. 948-952. doi: 10.1126/science.1149345

are most vulnerable and might therefore merit precautionary protection? These and many other management questions can all be easily addressed with the cumulative impacts assessment tool.

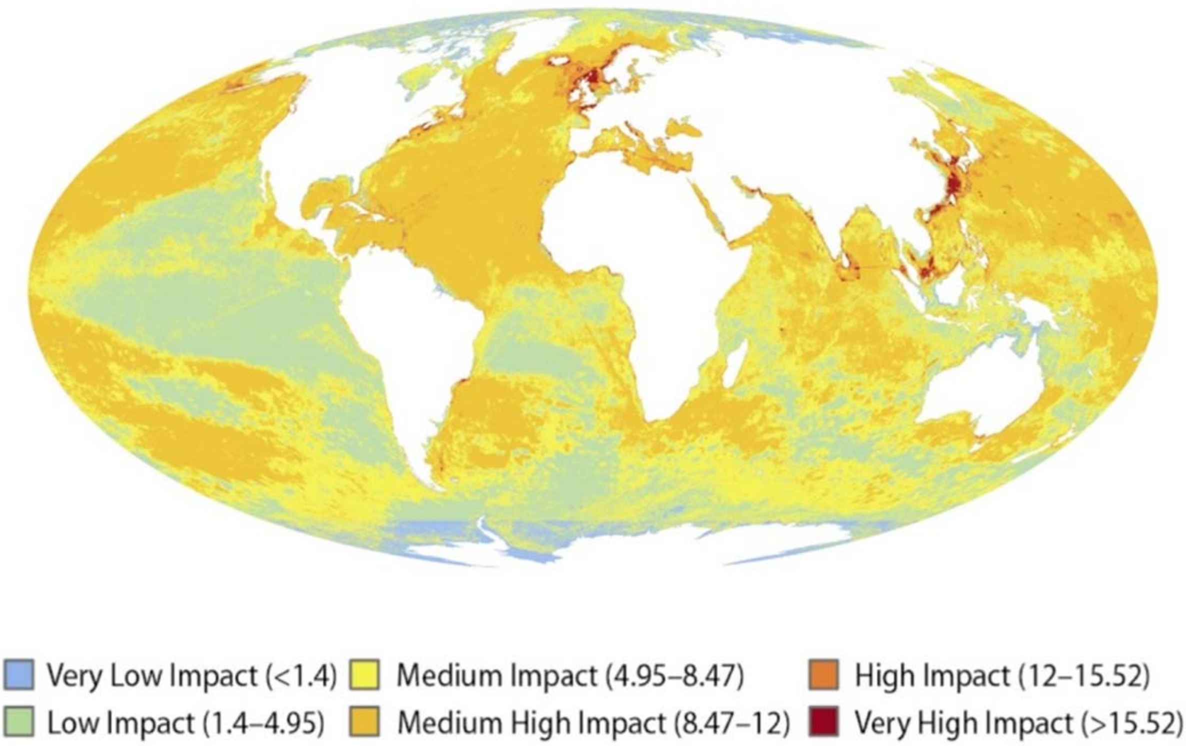

Figure 27. The global map of cumulative impact of 17 human activities on 20 different marine ecosystems. Adapted from reference 42.

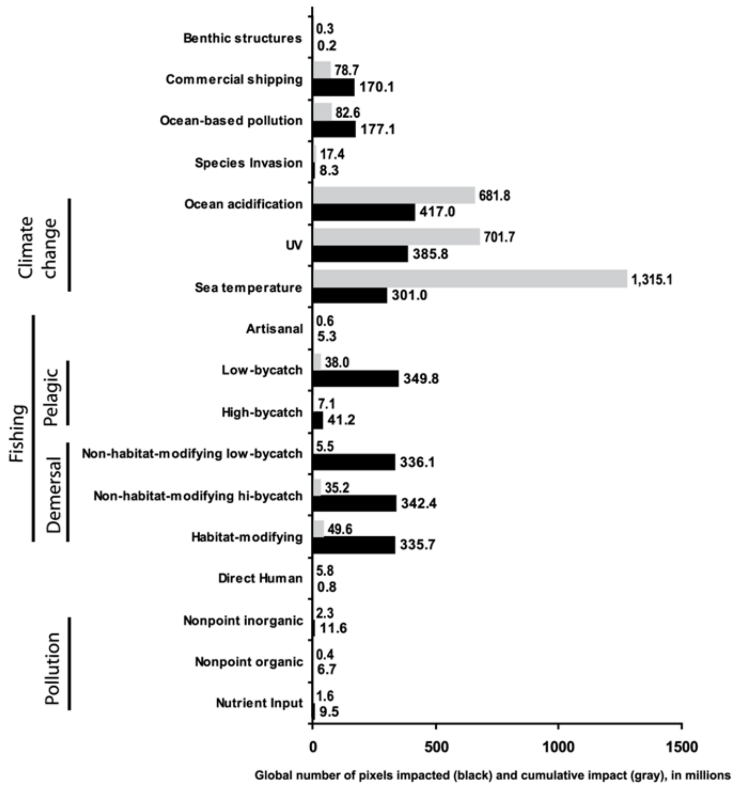

Figure 28. Total affected area and summed threat scores for the global oceans in the cumulative human impact analysis.

B. *Assumptions*

There are a few key assumptions to the model, many of which have been tested and none of which yet have enough scientific information to resolve. In all cases the sensitivity of the results to these assumptions is tested. Linear relationships are assumed between increases in the intensity of stressors and the impact on ecosystems. In other words, there is no accounting for thresholds and nonlinearities of impacts. Such thresholds are known to exist, but exactly where they occur and why is not known for most stressors, and in the few cases where they are understood they remain unpredictable at a global scale.

Second, individual impacts of stressors are assumed to be additive. Stressors are known to act synergistically in some cases (the whole is greater than the sum of the parts) and be mitigative in other cases (e.g. a small amount of nutrient input can increase productivity, helping to buffer a system from other stressors). A global meta-analysis of all empirical work evaluating what might lead to synergies or mitigative responses found that results are completely unpredictable by any known variable[43]. Thus, an additive model serves as a moderate approach.

Finally, two additional aspects of reality are missing from the current maps due to insufficient data availability. In all cases annual averages were used for stressor intensities, but many stressors vary temporally, and the timing of the stressor relative to other variables (such as ecosystem productivity) can mitigate or exacerbate the impact of the stressor. Accounting for these temporal dynamics will be challenging, but more information on the nature of these dynamics for each stressor will at least allow better quantification of the uncertainty in the model output. Second, ecosystem vulnerability is treated as constant around the world, so that, for example, a coral reef in the Caribbean is as vulnerable to each stressor as a coral reef in the Great Barrier Reef. This may not be true, and so vulnerability estimates tailored to each region of the planet would improve the accuracy of the maps. Given these assumptions, there remains a need to continue or improve efforts to monitor the state of natural systems and human stressors to the natural system, and to continue research on the relationship between the two, in order to validate and improve future versions of this tool.

5.2.4 Proposed work to develop the tool for TWAP: future scenarios and forecasting

The critical missing piece from the cumulative human impact methodology which, when developed, will allow managers, stakeholders, and policy makers to evaluate the potential outcome of different management scenarios, is spatially-explicit forecasting of cumulative impacts. The cumulative impact model structure described above can easily be adapted to include forecasted stressor layers, allowing for a full suite of powerful scenario analyses. With each individual stressor layer forecast into the future, one simply has to determine the number of years into the future of interest and slide maps of the layers at those time points into the cumulative impact model. Iteration of this analysis at successive time points allows temporal trajectories to be analysed and represented graphically.

In order to complete these forecasting and scenario analyses, each input data layer will need to be forecast into the future. This is true for both the stressor maps and the habitat maps – as species migrate or habitats are lost due to changing human stressors, the maps of where habitats exist will clearly change. In some cases (such as stressors associated with climate change) these forecast models exist, although they will need to be tailored to our purposes. In other cases we will need to develop novel forecast models. For the open oceans, the analysis of current impacts shows climate change (temperature and acidification) as well as fishing to be the key stressors of ocean ecosystems. If we assume that these two stressors will continue to dominate, the addition of future projections is limited to a smaller number. More on the proposed extension to this tool can be found in the supplementary online material[44].

[43] Crain, C. M., Kroeker, K., and Halpern, B. S., 2008. Interactive and cumulative effects of multiple human stressors in marine systems. *Ecology Letters*, Vol. 11: pp. 1304-1315.

[44] http://ioc-unesco.org/twap-oo-supplementary-material

PART 6. IMPLEMENTING THE ASSESSMENT

The final TWAP open ocean assessment product will be a set of accessible mapped and global metrics, indicators, and indices accompanied by two summary reports. The first report will be a high level report with the main findings of the assessment. This will be accompanied by a technical summary which includes detail on the importance and meaning of the indicators and the expert assessment of the scientific literature.

Implementing the assessment will involve two major activities:

- implementation of the mapping of indicators; and
- implementation of the expert assessments

followed by an assembly of the reports and wide dissemination of their results.

The assessment will be carried out as a partnership between institutions, with IOC-UNESCO playing the coordinating role and ultimately responsible for the final product. Partners have been selected for their comparative advantage and their co-investment in the assessment processes.

In developing the assessment implementation plan, the coordinators have been and will continue to be guided by work preparing for a UN Regular Process for the global reporting and assessment of the marine environment including socio-economic aspects. The Assessment of Assessment[45] findings on best practices identify an assessment as a process, rather than merely an analytical method. It found that the basic design features for an influential assessment include:

- clear goals and definitions of objective and scope;
- regular dialogue to improve the science/policy relationship;
- stakeholder participation;
- transparent criteria and procedures for the nomination and selection of experts;
- agreed procedures and quality standards for data and information included;
- guidelines for the treatment of a lack of consensus among experts;
- clear treatment of uncertainty;
- peer review;
- effective communication including appropriate products for each target audience;
- capacity-building and networking;
- post-assessment evaluation; and
- clear institutional arrangements.

The assessment will have a coordinator and secretariat based at the IOC, advised by an expert oversight panel balanced between natural science, social science, and economic and legal experts; as well as a representative of the GEF, and ideally representatives of the UN intergovernmental process focused on the open oceans. This expert panel will be responsible for ratifying the assessment outline and the final reports, and will be a subset of the scientific and governance assessment panels described below in Section 6.2. The expert oversight panel will be named by the partners in the TWAP open ocean assessment and GEF.

[45] UNEP and IOC-UNESCO, 2009. An Assessment of Assessments, Findings of the Group of Experts. Start-up Phase of a Regular Process for Global Reporting and Assessment of the State of the Marine Environment including Socio-economic Aspects. ISBN 978-92-807-2976-4. Available at http://www-unga-regular-process.org

6.1 IMPLEMENTATION OF MAPPING OF INDICATORS

The mapping of the indicators identified in Part 3 will be the responsibility of the IOC, whose technical capacity will be augmented by a strong co-financing investment by the European Commission in the GEOWOW project (see Section 5.1). The mappings will be freely and publicly available, to allow those outside the TWAP open ocean assessment process to profit from the assessment outputs. These could then be used for specific regional or thematic assessments, or for the purposes of other projects.

The extension of the methodology to mapping cumulative human impacts described in Section 5.2 will be the responsibility of the Centre for Marine Assessment and Planning (CMAP). Efforts will be made during the implementation of the assessment to ensure the interoperability of these two mapping exercises.

6.2 IMPLEMENTATION OF THE EXPERT ASSESSMENTS

The working group developing the TWAP open ocean methodology emphasized that an assessment approach exclusively based on metrics, indicators, and indices was not feasible for the open ocean due to a lack of data. A successful model for a complementary approach is the Intergovernmental Panel for Climate Change, whose goal is to review and assess the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change (see an overview of their procedures in Figure 29).

The goal of the expert assessment segment of the TWAP assessment is similarly to review and assess the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of human well-being connected to the open oceans through ecosystem services and direct impacts.

Two groups of expert authors will be formed, nominated in an open call to GEF, TWAP partners, and UN-Oceans members. The first will focus on open ocean natural environment issues, the second on a broad definition of governance concerning the open oceans, including government, markets, and civil society, and including economic expertise. The experts in the two groups will be selected from the nominations by the expert oversight panel for the TWAP open ocean assessment.

Support will need to be provided for a number of the authors who will not be able to come to the assessment process with institutional support for their time.

The groups will meet, sometimes all together, to share experiences and ensure coherence in their work.

6.2.1 High uncertainty but potentially high-impact natural environment issues

In the presentation of the four major themes of the open ocean assessment (Part 3) a number of the themes raised were noted as having high uncertainty in elements of linking the entire conceptual framework from human activity that has impacts on the open ocean, to effects on human well-being. These areas of high uncertainty but potentially high impact are noted in Table 1 by asterisks. It is on these areas that the natural environment open ocean expert team will focus.

6.2.2 Governance of human system interaction with the open ocean environment, including understanding of ecosystem service valuation

A separate expert sub-panel will focus on a broadly-defined governance assessment defined in Section 3.5. This group will have to represent many cultural and political points of view, as governance is viewed through many filters.

A second sub-panel will be responsible for an assessment of the emergent literature on the valuation of global ocean ecosystem services. This sub-panel will have to pay particular attention to how different human cultural settings in developed and developing countries (including particular attention to Small Island Developing States where appropriate) will change interpretations of economic valuation.

6.2.3 Reporting

The assessment secretariat will develop the high-level summary of the metrics, indicators and indices, which will be approved by both natural science and governance expert groups.

The expert teams of authors will collectively be responsible for the production of the designated sections of the technical summary on the basis of the best scientific, technical and socio-economic information available.

All elements of the report will go out for expert review. These experts will be selected through an open nomination process.

To the extent feasible, full engagement of stakeholders in the review process and in the final review of the high-level summary will be attempted. This will increase ownership of the results of the report, and help in its wide dissemination.

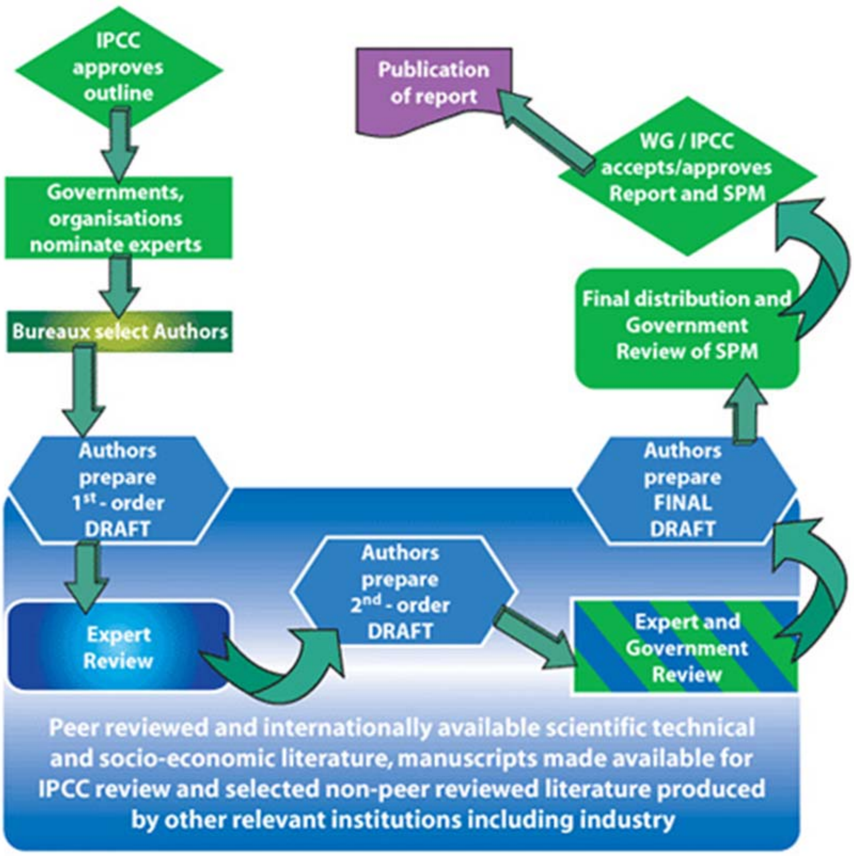

Figure 29. IPCC procedures for the generation of assessment reports[46]. The TWAP open ocean assessment will follow a number of these procedures, where the expert oversight panel will play the role of the IPCC, its member governments and its Bureau.

[46] http://ipcc.ch/publications_and_data/publications_and_data.shtml, detailed in 'Procedures For The Preparation, Review, Acceptance, Adoption, Approval And Publication Of IPCC Reports' adopted at IPCC-15 (1999) and last revised in 2008.

6.3 LEVEL 2 ASSESSMENT

The strategy for the Level 2 assessment is laid out in Section 1.3.2. Given the limited financing (about 10 per cent of the assessment cost) for the Level 2 assessment, it will be performed as a consultant desk study of existing literature. The region will be chosen in coordination with the other water system assessments, in order to provide a consistent story across all water systems for the particular region(s) selected for Level 2 analysis.

6.4 COMMUNICATIONS STRATEGY

The TWAP open ocean assessment will embed a science journalist in the expert oversight panel and in the work of the two expert teams from an early stage, to help guide how communication materials are developed in order to have the best impact.

High quality graphical expressions of the mapping of the metrics, indicators, and indices that are a key part of the assessment will also help carry key messages. The assessment effort will put significant emphasis on the high level summary for policymakers and these graphics.

The target audience for these will be the GEF, its Council members, and the UN-Oceans family of agencies and their Member State representatives.

The web will be used as much as is feasible for transparency in the assessment process and the data upon which it is based.

A key partner in the TWAP open ocean assessment for these purposes will be UNEP/GRID-Arendal.

6.5 PARTNERS AND GEF INCREMENTAL COST

The partners in the TWAP open ocean assessment consortium will have collective responsibility for producing the assessment products and reports. Their roles are defined on the basis of their comparative advantages in terms of ongoing work for other purposes, and their willingness to co-invest in the production of the assessment.

Partners are defined separately from data providers as having an active role in the production of the assessment.

The partners for the TWAP open ocean full-sized assessment are listed in Table 2 and shown graphically in Figure 30.

The total cost of the TWAP open ocean assessment has been estimated to be US$7.3 million, with $5.4 million in co-financing and a $1.88 million GEF incremental cost.

Table 2. Proposed partners, their comparative advantage, and their proposed role in the TWAP full-sized open ocean assessment.

PARTNER	COMPARATIVE ADVANTAGE	ROLE	MAIN CONTACTS
Intergovernmental Oceanographic Commission of UNESCO (**IOC**)	Coordination of ocean observations (GOOS, JCOMM) data systems (IODE, OBIS), and research (WCRP, IOCCP and other programmes), link to governments on marine science and observations issues,	Coordinating partner; convening the expert panels; ultimately responsible for producing reports. Data management and mapping with co-financing from EC GEOWOW project.	K. Alverson, A. Fischer
European Commission Seventh Framework Programme (**EU** FP7) GEOWOW project	Data interoperability funding call	Funding for GEOSS interoperability for Weather, Ocean, and Water (GEOWOW) project	K. Alverson, A. Fischer
Center for Marine Assessment and Planning (**CMAP**)	Mapping of cumulative human impact on ocean ecosystems, ecosystem valuation links, scenario generation, interaction with policy process	development of extended cumulative human impact mapping, supporting role for ecosystem valuation	B. Halpern
GRID-Arendal (a UNEP collaborating centre)	mapping, visualization, communication and data management	supporting role for coordinating partner	J.-N. Poussart
United Nations Environment Programme (**UNEP**), Division for Early Warning and Assessment (DEWA) and Marine and Coastal Ecosystems Branch	link to Regional Seas Conventions and Action Plans, large range of environmental assessments including ecosystem services valuation	supporting role for coordinating partner	S. Diop
Food and Agriculture Organization (**FAO**)	Governance of fisheries in the open ocean, assembly and collection of source data	expert assessment of fisheries governance arrangements	K. Cochrane J. Sanders
Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (**GESAMP**)	Assessment of marine pollution-related issues	expert assessment of pollution as a natural system stress	T. Bowmer
US National Oceanic and Atmospheric Administration (**NOAA**)	World Ocean Database (physical and chemical data), sea ice and coral data and indices	data assembly and provisioning	S. Levitus, N. Cyr
Plymouth Marine Lab (**PML**)	Ocean colour analysis, ESA Climate Initiative to create a consistent historical data set of primary productivity and other ocean colour environmental parameters	data assembly and provisioning	T. Platt S. Sathyendranath
Sir Alister Hardy Foundation for Ocean Science (**SAHFOS**)	Zooplankton analysis and data collection	data assembly and provisioning	S. Batten
Sea Around Us project	Fisheries analysis and research, value added on FAO data	data assembly and provisioning	V. Christensen
World Conservation Monitoring Centre (**UNEP-WCMC**)	Collected data on conservation effort	data assembly and provisioning	L. Woods
WMO-ICSU-IOC World Climate Research Programme (**WCRP**)	climate projections: projections of how open ocean conditions affect rainfall and drought patterns	data assembly and provisioning	V. Detemmermann
International Union for Conservation of Nature (IUCN) Global Ocean Biodiversity Initiative (**GOBI**)	work in identifying open ocean areas proposed to CBD as candidate EBSAs using defined criteria	advisory	P. Bernal

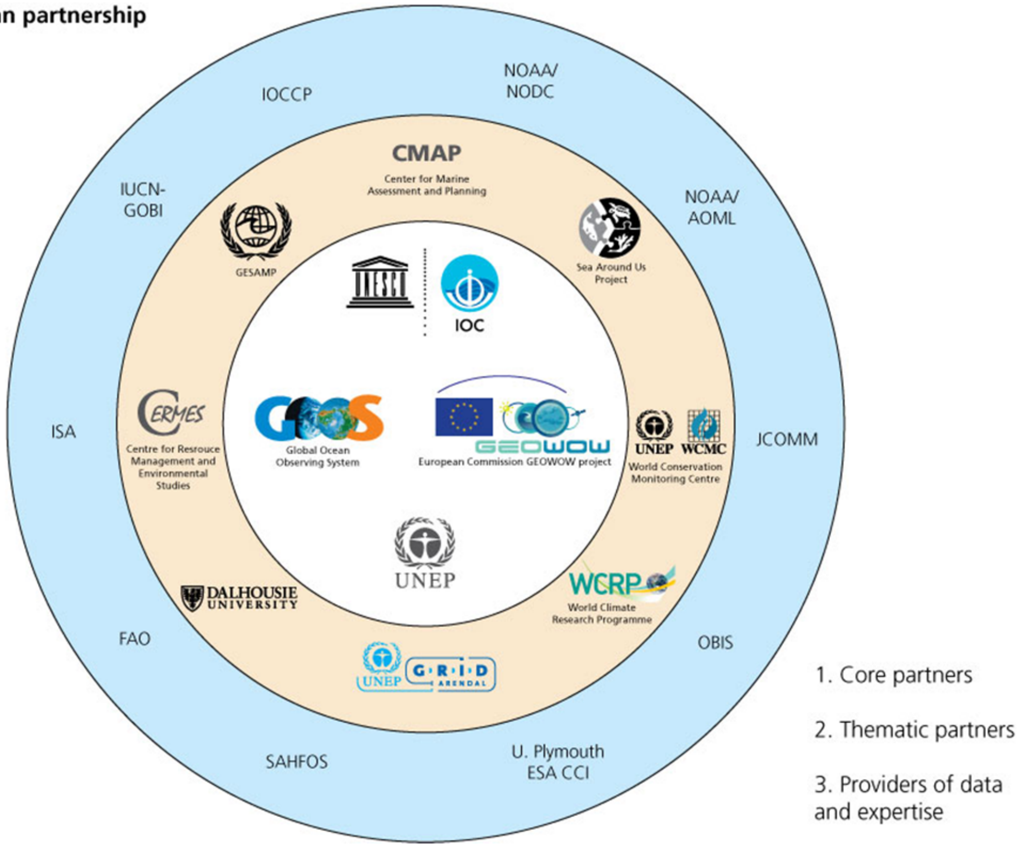

Figure 30. The TWAP Open Ocean assessment partnership

6.6 REPEATING THE ASSESSMENT

The initial baseline assessment will involve a heavy investment from GEF and the partners in the TWAP open ocean assessment. It will be a strong contribution to the developing UN Regular Process, and serve the various thematic governance arrangements in place for the open oceans.

Repeat assessments may attempt to assess all themes, or could concentrate on particular areas of concern identified by policymakers.

Assessment of the metrics, indicators and indices will be the easiest component to implement again, and this is likely to be done by many of the TWAP open ocean assessment partners on an ongoing basis as the open ocean monitoring system develops.

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ANNEX 2
INDICATOR TEMPLATES

Overview

The metrics, indicators, and global indices in the methodology are presented below in a standard shortened template. Extensive source material including further detail, caveats, and references for a number of these indicators was developed by working group members, and can be found online at: http://ioc-unesco.org/twap-oo-supplementary-material.

As stated elsewhere in the report, these metrics, indicators, and global indices are in some cases derived from ocean data, and in others from model projections. The main text indicates where expert assessment of the latest scientific literature is needed to supplement an indicator-based approach (see Table 1 above).

Climate change, variability, and impacts

Indicator **SEA LEVEL** *mapped, time series to present and projected*	
In the *conceptual framework*, this is a natural system stress (2)	
Definition	Observed and projected sea-level rise changes from baseline state, in mm, relative to the fixed geoid (not taking into account land movement)
Relevance	Direct threat to human well-being caused by human drivers (greenhouse gas emissions and climate change) with an inhomogeneous geographic distribution, also a contribution from groundwater extraction (link to groundwater assessment)
Methodology	Observed quantity (from satellite altimetry and tide gauge observations) for past and present value, projections from coupled climate models developed for IPCC assessment under the coordination of the WCRP
Data source	AVISO (http://www.aviso.oceanobs.com/) for current/past analysis of sea-level rise, WCRP (http://wcrp-climate.org) for projections
Partners	WCRP

Metric **HUMAN POPULATION IN LOW-LYING AREAS** *mapped, present value and projected*	
In the *conceptual framework*, this is a human system vulnerability (5)	
Definition	Quantified projections of human population in areas exposed to flooding from global ocean sea-level rise: based on land topography, population projections, and IPCC sea-level rise projection scenarios.
Relevance	Quantification of vulnerability to combine with natural system indicators and other human system metrics
Methodology	Scientific analysis (natural and social science)
Data source	Published analysis and projections (see references below)
Partners	—
References	Ericson, J.P., C.J. Vorosmarty, S.L. Dingman, L.G. Ward and M. Meybeck, 2006: Effective sea-level rise and deltas: causes of change and human dimension implications. *Global Planet. Change* ,**50**, 63-82, doi:10.1016/j.gloplacha.2005.07.004 Nicholls, R.J., 2004: Coastal flooding and wetland loss in the 21st century: changes under the SRES climate and socio-economic scenarios. *Glob. Environ. Change*, **14**, 69-86.

Metric **GROSS DOMESTIC PRODUCT PER CAPITA** *by country, present value*	
In the *conceptual framework*, this is a proxy for a human system vulnerability (5)	
Definition	Total income of a country divided by its population, a metric for how much people money earn on average, in US$
Relevance	A proxy for the adaptive capacity of the population to climate change or other changes in ecosystem services provided
Methodology	Observed quantity
Data source	World Bank World Development Indicators (public domain)
Partners	—

Global Index **VULNERABILITY TO SEA-LEVEL RISE** *single quantity, present value and projected*	
In the *conceptual framework*, this is combines a natural system stress (2) with human vulnerability (5)	
Definition	Single global index that combines sea level, human population in low-lying areas, and gross domestic product per capita (inverse normalized so that low GDP/capita is a metric of high vulnerability and low resilience), in persons. The Small Island Developing State populations might be singled out as particularly vulnerable to sea-level rise.
Relevance	Shows the link between open ocean climate change (heating and sea-level rise) and human populations at the coast
Methodology	Analysis based on natural system indicators and human system metrics
Data source	see indicators and metrics above
Partners	—

Indicator and Global Index **OCEAN HEAT CONTENT CHANGE** *mapped and single quantity, time series to present*	
In the *conceptual framework*, this is a natural system stress (2)	
Definition	Volume integral of changes in potential temperature over the upper 700 m of the ocean, in Joules
Relevance	General indicator of global ocean change due to climate change, relevant in derived indicators below as a natural system stress (2)
Methodology	Observed/analysed quantity, calculated from changes in ocean temperature measured from Argo profiling floats and expendable bathythermograph (XBT) profiles
Data source	World Ocean Atlas
Partners	NOAA National Oceanographic Data Center (NODC)
References	Locarnini, R. A., A. V. Mishonov, J. I. Antonov, T. P. Boyer, H. E. Garcia, O. K. Baranova, M. M. Zweng, and D. R. Johnson, 2010. World Ocean Atlas 2009, Volume 1: Temperature. S. Levitus, Ed. NOAA Atlas NESDIS 68, U.S. Government Printing Office, Washington, D.C., 184 pp Levitus, S., J. I. Antonov, T. P. Boyer, R. A. Locarnini, H. E. Garcia, and A. V. Mishonov (2009), Global ocean heat content 1955–2008 in light of recently revealed instrumentation problems, Geophys. Res. Lett., 36, L07608, doi:10.1029/2008GL037155

Indicator **CORAL DEGREE HEATING WEEKS** *mapped, present value and projected*	
In the *conceptual framework*, this is a natural system stress (2)	
Definition	Cumulative degree-weeks above maximum expected summertime temperature in °C weeks
Relevance	A measure of cumulative stress from ocean temperatures on coral reefs (in coastal and open ocean waters, although relevant only for near-surface corals)
Methodology	Analysis based on observed Sea Surface Temperature from satellite observations calibrated by surface drifters
Data source	Coral Reef Watch, NOAA National Environmental Satellite, Data and Information Service (NESDIS)
Partners	NOAA
References	Liu G, A. E. Strong, W. Skirving, and L. F. Arzayus, 2005. Overview of NOAA coral reef watch programme's near-real time satellite global coral bleaching monitoring activities. Proc 10th Int Coral Reef Symp, Okinawa, Japan, 2004. 1:1783-1793.

Indicator and Global Index **TROPICAL CYCLONE HEAT POTENTIAL** *mapped and single quantity, time series to present and projected*	
In the *conceptual framework*, this is a natural system stress (2)	
Definition	The mapped quantity is integrated vertical temperature from the sea surface to the depth of the 26°C isotherm, estimated from satellite sea surface temperature and altimetry, in KJ cm^{-2}. The global index is the annual and spatial integral of this quantity, in KJ year, and will be compared to baseline and historic values. Projected values will be calculated from IPCC coupled climate model projections coordinated by the WCRP.
Relevance	Relates open ocean conditions with impact on extreme rainfall events at the coast and inland, with direct relevance to human well-being
Methodology	Scientific analysis from observed quantities
Data source	NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML) for past and present values
Partners	NOAA, WCRP
References	Willis, J. K., D. Roemmich, and B. Cornuelle, Interannual variability in upper-ocean heat content, temperature and thermosteric expansion on global scales, J. Geophys. Res., 109 (C12036), 2004. Goni, G., S. Kamholz, S. Garzoli, and D. Olson, Dynamics of the Brazil-Malvinas Confluence based on inverted echo sounders and altimetry, J. Geophys. Res., 101(C7), 16,273-16,289, 1996.

Indicator **OPEN OCEAN STRATIFICATION STRENGTH AND TIMING** *mapped and gyre-based units, time series to present and projected*	
In the *conceptual framework*, this is a natural system stress (2)	
Definition	Vertical stratification of temperature as expressed by mixed layer depth, in m, and timing as expressed by Julian Day of first mixed layer depth below critical depth of mean light that allows phytoplankton growth
Relevance	These are basic quantities that control open ocean primary productivity, and are changing due to climate change and natural variability
Methodology	Analysis from observed quantities: open ocean temperature profiles from Argo profiling floats and XBTs, climatology of ocean light for calculation of critical depth.
Data source	Ocean mixed layer depth climatology (LOCEAN, open access), Coriolis ocean analysis (open access) for past and present value, projected values from coupled climate models developed for IPCC assessment and coordinated by the WCRP
Partners	—, WCRP
References	de Boyer Montégut, C., G. Madec, A. S. Fischer, A. Lazar, and D. Iudicone (2004), Mixed layer depth over the global ocean: an examination of profile data and a profile-based climatology, J. Geophys. Res., 109, C12003, doi:10.1029/2004JC002378

Indicator (link) **RAINFALL AND DROUGHT PROJECTIONS** *mapped, projected*	
In the *conceptual framework*, this is a change in ecosystem service (4) related to changes in the open ocean, and a major input for the other TWAP water systems	
Definition	Projected change in rainfall from coupled climate models
Relevance	When related to projected changes in ocean heat content, this shows the relevance of open ocean conditions to the global human population, as well as being the major link between the open ocean and the other TWAP water systems
Methodology	Coupled model projection ensembles
Data source	Coupled climate model projections developed for IPCC assessments and coordinated by the WCRP
Partners	WCRP

Indicator (link) **AREAS OF WATER STRESS** *mapped*	
In the *conceptual framework*, this is a human system vulnerability (5)	
Definition	These are defined by the other water system methodologies and by other assessments
Relevance	In linking open ocean changes driving rainfall and drought projections, for mapping of particularly vulnerable areas
Methodology	Socio-economic and expert assessment
Partners	Other TWAP water system assessments, UNESCO/UN-Water World Water Assessment Programme (WWAP)

Indicator and Global Index **SEA ICE EXTENT** *mapped and single quantity, present*	
In the *conceptual framework*, this is a natural system stress (2)	
Definition	Summertime minimum sea ice coverage in the Arctic and Antarctic, in km^2
Relevance	An indicator of changing ocean habitat, as well as an indicator of the possibility of increased human stress through shipping in a largely pristine environment
Methodology	Observed quantity, from satellite remote sensing
Data source	(US NASA/NSF/NOAA) National Snow and Ice Data Center (NSIDC), open access
Partners	—
References	Fetterer, F., K. Knowles, W. Meier, and M. Savoie. 2002, updated 2009. Sea Ice Index. Boulder, CO: National Snow and Ice Data Center. Digital media.

Indicator and Global Index **OCEAN DEOXYGENATION** *mapped and single quantity, present and projected*	
In the *conceptual framework*, this is a natural system stress (2)	
Definition	Oxygen minimum zones are ocean areas with oxygen concentration below O_2 < 10 µmol kg^{-1}, and can be mapped and collapsed to a single global volume expressed in km^3. Since oxygen observations are sparse, this will be based on model projections and expert assessment of the latest scientific literature.
Relevance	Oxygen minimum zones limit the range of many fish species and are expanding as ocean circulation changes with climate change
Methodology	Scientific analysis from model projections and expert assessment of the latest scientific literature
Data source	Model projection (see reference below)
Partners	—
References	Gruber, N. & Co-Authors (2010). 'Towards An Integrated Observing System For Ocean Carbon and Biogeochemistry At a Time of Change' in Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society (Vol. 1), Venice, Italy, 21-25 September 2009, Hall, J., Harrison, D.E. & Stammer, D., Eds., ESA Publication WPP-306, doi:10.5270/OceanObs09.pp.18

Indicator and Global Index **OCEAN UPTAKE OF ANTHROPOGENIC CO_2** *mapped and single quantity, present value and projected*	
In the *conceptual framework*, this is an ecosystem service (4)	
Definition	Changes in flux of anthropogenic CO_2 across the air-sea interface, in mol m^{-2} yr^{-1}, mapped and as an average over the entire open ocean
Relevance	This is a key ecosystem service the open oceans play in the climate system, reducing the amount of atmospheric greenhouse warming while causing ocean acidification. Projections show this ecosystem service is reducing with climate change.
Methodology	Scientific analysis from observations, climate projection models, and expert assessment of the latest scientific literature
Data source	see reference below
Partners	—
References	Takahashi, T., and co-authors. (2009). Climatological mean and decadal change in surface ocean pCO_2, and net sea-air CO_2 flux over the global oceans. Deep-Sea Res II 56, 554–577, doi:10.1016/j.dsr2.2008.12.009.

Indicator **ARAGONITE SATURATION STATE** *mapped, present value and projected*	
In the *conceptual framework*, this is a natural system stress (2)	
Definition	Aragonite is a mineral form of calcium carbonate, a basic building block of corals and many forms of zooplankton. The aragonite saturation state decreases with increasing acidity of ocean water. Below a certain threshold calcifying organisms using aragonite cannot produce shells or skeletons effectively.
Relevance	A broad-scale ocean ecosystem stress that will affect a large set of organisms
Methodology	Scientific analysis from observed quantities and model projections, augmented by expert assessment of the latest scientific literature.
Data source	see reference below
Partners	—
References	Cao, L., and K. Caldeira (2008), Atmospheric CO_2 stabilization and ocean acidification, Geophys. Res. Lett., 35, L19609, doi:10.1029/2008GL035072

Global Index **CORAL REEFS AT RISK FROM OCEAN ACIDIFICATION** *single quantity, present value and projected*	
In the *conceptual framework*, this is a natural system stress (2) combined with an ecosystem vulnerability (3)	
Definition	Histogram of distribution of coral reef locations in different aragonite saturation states, projected for different ocean acidification / climate-change scenarios
Relevance	Projects global ocean acidification onto one vulnerable ocean ecosystem which represents 25 per cent of known fish species and is a hotspot for biodiversity (IPCC, 2007)
Methodology	Scientific analysis based on coral reef locations and projections of aragonite saturation state (see above).
Data source	see reference below
Partners	—
References	Cao, L., and K. Caldeira (2008), Atmospheric CO_2 stabilization and ocean acidification, Geophys. Res. Lett., 35, L19609, doi:10.1029/2008GL035072

Ocean ecosystems, habitats, and biodiversity

Metric and Global Index **OPEN OCEAN AREA COVERED BY MARINE PROTECTED AREAS** *mapped and single quantity, present value*	
In the *conceptual framework*, this is a governance measure (6)	
Definition	Area in km^2 of the ocean Areas Beyond National Jurisdiction (ABNJ) that are conserved as Marine Protected Areas, and as a percentage of total ocean ABNJ.
Relevance	Marine protected areas conserve certain place-based areas from human-driven stresses other than those induced by climate change or other remote effects. The CBD in 2010 increased the target, to protect 10 per cent (up from 1 per cent) of the oceans by 2020.
Methodology	Data submitted by national governments or approved NGOs, converted to a standard GIS format
Data source	Convention for Biological Diversity (CBD), UNEP-WCMC
Partners	UNEP-WCMC, IUCN-WCPA
References	IUCN and UNEP-WCMC (2010), The World Database on Protected Areas (WDPA): Annual Release [On-line]. Cambridge, UK: UNEP-WCMC. Available at: www.wdpa.org

Indicator and Global Index **PRIMARY PRODUCTIVITY** *mapped, gyre, and single quantity, time series to present*	
In the *conceptual framework*, this is a change in ecosystem state (3)	
Definition	Primary productivity is the rate of organic matter production by the growth of planktonic plants, in mg C m^{-2} $days^{-1}$
Relevance	All ocean life is ultimately dependent on the oceanic primary production of phytoplankton, which is at the base of the food web. It is a limiting factor for the production of commercially-fished open ocean species.
Methodology	Estimated from satellite-derived ocean colour measurements. The ESA Climate Initiative will over 2010-2012 create long time series of ocean primary productivity, creating a calibrated and consistent record. Global maps of change, as well as gyre-based and global averages will be generated.
Data source	Plymouth Marine Lab-led ESA Climate Initiative for Ocean Colour
Partners	Plymouth Marine Lab
References	Platt, T, and S. Sathyendranath, 2008. Ecological indicators for the pelagic zone of the ocean from remote sensing. In Remote Sensing of the Environment 112 3426-3436, doi:10.1016/j.rse.2007.10.016

Indicator **ZOOPLANKTON ABUNDANCE, COMPOSITION AND TIMING** *mapped, time series to present*	
In the *conceptual framework*, this is a change in ecosystem state (3)	
Definition	This indicator is a combination of three zooplankton variables: abundance (biomass in dry weight m^{-3}), composition/diversity (a species richness index) and timing (Julian day of peak biomass), which is weighted evenly among each variable, normalized to a ranking amongst years in the historical record.
Relevance	
Methodology	Derived from observations taken by Continuous Plankton Recorders towed behind commercial ships, as well as other net, optical, or acoustic measurements from research ships.
Data source	SAHFOS Database
Partners	Sir Alistair Hardy Foundation for Ocean Science (SAHFOS)
References	Burkill, P. and Reid, P., (2010). 'Plankton Biodiversity of the North Atlantic: Changing Patterns Revealed by the Continuous Plankton Recorder Survey' in Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society (Vol. 1), Venice, Italy, 21-25 September 2009, Hall, J., Harrison, D.E. & Stammer, D., Eds., ESA Publication WPP-306, doi:10.5270/OceanObs09.pp.09

Indicator **CANDIDATE ECOLOGICALLY AND BIOLOGICALLY SENSITIVE AREAS (EBSAS) IDENTIFIED** *mapped, present value*	
In the *conceptual framework*, this is a governance measure (6) related strongly to an ecosystem state vulnerability (3)	
Definition	The seven CBD EBSA criteria adopted include: 1. uniqueness or rarity 2. special importance for life history of species 3. importance for threatened, endangered or declining species and/or habitats 4. vulnerability, fragility, sensitivity, slow recovery 5. biological productivity 6. biological diversity 7. naturalness The indicator is a mapping of the EBSAs proposed to and/or identified by the CBD
Relevance	Definition of candidate EBSAs is a precursor to the development of protected areas
Methodology	Expert assessment based on ocean observations
Data source	Data for the expert assessment of candidate EBSAs is sparse, and encompasses all available physical, chemical, and biological data from a region - the lack of data is acute
Partners	IUCN-GOBI and CBD
References	CBD Decision IX/20

Indicator and Global Index **SEAMOUNTS AT RISK** *mapped and single quantity, present value*	
In the *conceptual framework*, this is a combination of natural system stress (2) from demersal fishing and ecosystem vulnerability (3) in the seamount locations	
Definition	Mapping and number of seamount observations
Relevance	Using the demersal fishing indicator, this is an attempt, in the face of a lack of data, to map vulnerabilities with stress. Seamounts are hotspots of open ocean biodiversity, providing habitat for deep sea corals and commercial fish species. Seamounts are disproportionately targeted by destructive fishing practices, such as bottom trawling.
Methodology	Scientific analysis of the number of observations available from seamounts, cross-referenced with known demersal fishing activity
Data source	SeamountsOnline, Sea Around Us project
Partners	Sea Around Us, UNEP-WCMC
References	Stocks, K. (2009). SeamountsOnline: an online information system for seamount biology. Version 2009-1. World Wide Web electronic publication. http://seamounts.sdsc.edu

Open ocean fisheries

Indicator and Global Index **DEMERSAL FISHING EFFORT** *mapped and single quantity, time series to present*	
In the *conceptual framework*, this is a natural system stress (2)	
Definition	Catch by bottom water trawls, mapped and averaged over all ocean areas beyond national jurisdiction
Relevance	A proxy for habitat-destructive fishing practices, a major stress on ocean bottom habitats
Methodology	Reported quantity from FAO statistics and other sources
Data source	Sea Around Us project
Partners	FAO, Sea Around Us project

Indicator and Global Index **MARINE TROPHIC INDEX** *mapped and single quantity, time series to present*	
In the *conceptual framework*, this is an indicator of ecosystem state (3)	
Definition	The FAO landings database is used to assign a trophic level to all catches which is then averaged. Units range from 1 (primary producers) to 5 (top predators).
Relevance	Provides a measure of ecosystem integrity, as declining trophic levels reflect depletion of the largest fish and fisheries turning to less desirable smaller species. Adopted by the CBD as an indicator of policy relevance.
Methodology	Scientific analysis from reported fisheries observations
Data source	Sea Around Us project (FAO landings database and FishBase for assigning trophic level)
Partners	FAO, Sea Around Us project
References	Pauly, D., Watson, R. and Alder, J. (2005) Global trends in world fisheries: impacts on marine ecosystems and food security. Philosophical Transactions of The Royal Society: Biological Sciences 360: 5-12.

Indicator and Global Index **FISHING IN BALANCE INDEX** *mapped and single quantity, time series to present*	
In the *conceptual framework*, this is an indicator of ecosystem state (3)	
Definition	The rate of biological production is much greater at lower trophic levels, and the Fishing-in-Balance (FiB) index is defined to stay constant (zero) when changes in trophic level are matched by appropriate changes in catch size.
Relevance	Provides a measure of the 'ecological correctness' of changes in catch. It will increase as fish catches increase, including if the geographical range of fish catches expands. It decreases if the fisheries remove so much biomass that its functioning is impaired. It is a complement to the Marine trophic index.
Methodology	Scientific analysis from reported fisheries observations
Data source	Sea Around Us project (FAO landings database and FishBase for assigning trophic level)
Partners	FAO, Sea Around Us project
References	Pauly, D., Watson, R. and Alder, J. (2005) Global trends in world fisheries: impacts on marine ecosystems and food security. Philosophical Transactions of The Royal Society: Biological Sciences 360: 5-12.

Indicator **CATCH POTENTIAL** *mapped, projected*	
In the *conceptual framework*, this is a projection of changing ecosystem state (3)	
Definition	Maximum exploitable catch over species combined, assuming that geographic range and selectivity of fisheries remain unchanged from present (referenced to 2005).
Relevance	Marine fisheries productivity is likely to be affected by the alteration of ocean conditions related to climate change.
Methodology	Scientific analysis based on an analysis of the 1 066 major commercially exploited fish species. Future distributions of these species are projected using a dynamic bioclimate envelope model, while primary production is projected by empirical models. The model is run on a 0.5° resolution global grid. This indicator will need to be augmented by expert assessment of the latest scientific literature, as the method is based on a large number of assumptions, and does not take into account the changes in the food web caused by different species bioclimate envelopes.
Data source	Model: see reference below
Partners	Sea Around Us project
References	Cheung, W.W.L., V.W.Y. Lam, J.L. Sarmiento, K. Kearney, R. Watson, D. Zeller and D. Pauly. 2010. Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. Global Change Biology 16: 24-35.

Metric **VALUE OF REPORTED LANDINGS BY COUNTRY** *single quantity, time series to present*	
In the *conceptual framework*, this is an ecosystem service (4)	
Definition	Catch value by country from FAO landings database for ocean areas beyond national jurisdiction, complemented by additional catch information and economic aspects from other sources.
Relevance	The governance assessment will look at social factors including current and intergenerational equity in governance arrangements. The value of reported landings by country, compared to their population, will provide an interesting if simplified metric of equity.
Methodology	Derived from the FAO fisheries landings database and the Global Ocean Economics Project of UBC
Data source	Sea Around Us project
Partners	Sea Around Us project

Pollution as a stressor of marine ecosystems

Metric and Global Index **SHIPPING INTENSITY** *mapped and single quantity, time series to present*	
In the *conceptual framework*, this is a natural system stress (2)	
Definition	Gridded reports of VOS ship presence, in number per month per gridbox.
Relevance	Ocean-based pollution in the open ocean is assumed to derive mainly from commercial shipping activity.
Methodology	Estimated from reports of Voluntary Observing Ships, a Global Ocean Observing System platform based on commercial ships for measuring marine meteorology and surface ocean variables - about 4 000 ships participate in VOS.
Data source	JCOMMOPS (Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology in situ Observing Platform Support centre)

Indicator **PLASTIC MARINE DEBRIS CONCENTRATION** *mapped, present value (time series where available)*	
In the *conceptual framework*, this is a natural system stress (2)	
Definition	Concentration of plastic marine debris collected in plankton net tows, in pieces km^{-2}
Relevance	While firm scientific knowledge of the negative environmental impacts of marine plastic debris is lacking, it is an issue in marine pollution that is gathering both political and public attention.
Methodology	Observed through counts of marine plastic debris in plankton net tows and with Continuous Plankton Recorders. Scientific data is largely restricted to the North Atlantic, but all the subtropical gyres (convergent) are expected to have large levels of marine plastic debris. This indicator needs to be complemented by an expert assessment of the consequences of this natural system stress on the marine environment, taking advantage of the latest scientific literature.
Data source	see reference, SAHFOS
Partners	SAHFOS, GESAMP
References	Law, K.L., S. Morét-Furgeson, N.A. Maximenko, G. Proskurowski, E.E. Peacock, J. Hafner, C.M. Reddy, 2010. Plastic Accumulation in the North Atlantic Subtropical Gyre. Science 329, 1185, doi: 10.1126/science.1192321

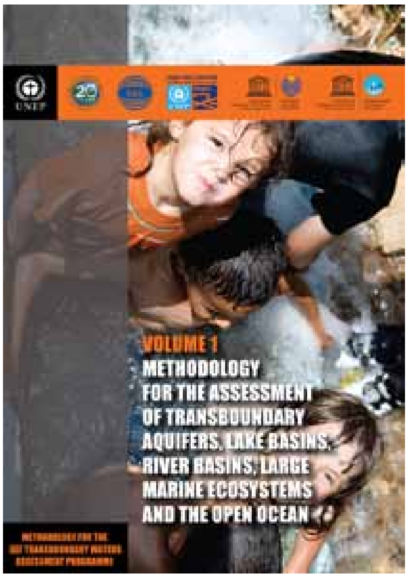
Metric and Global Index **SEABED MINING CLAIMS** *mapped and single quantity, time series to present*	
In the *conceptual framework*, this is a potential natural system stress (2) related to governance (6)	
Definition	Area of open ocean areas beyond national jurisdiction (in km^2) with current contracts with the International Seabed Authority for seabed areas where mining exploration is permitted.
Relevance	While none of the deep seabed mining claims filed with the International Seabed Authority have been exploited, their exploitation could lead to significant demersal habitat destruction.
Methodology	Survey of ISA database.
Data source	International Seabed Authority (ISA)
Partners	—

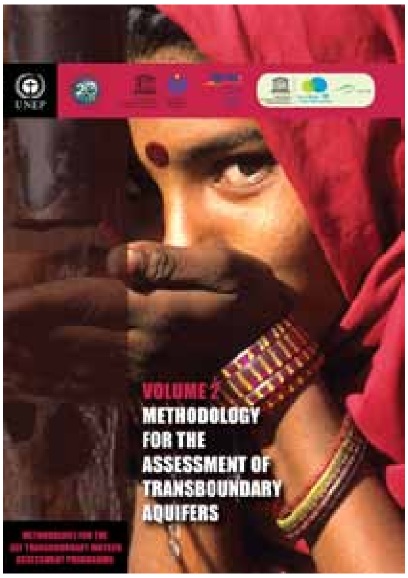
Indicator **ATMOSPHERIC NITROGEN DEPOSITION** *mapped, present value and projected*	
In the *conceptual framework*, this is a natural system stress (2)	
Definition	Atmospheric deposition of total inorganic nitrogen (N), NHx (NH_3 and NH_{4+}), and NOy (all oxidized forms of nitrogen other than N_2O), in mg N m^{-2} $year^{-1}$
Relevance	Nitrogen is a limiting factor in many cases for ocean primary productivity, and unlike in the coastal ocean, where river input and runoff from agricultural sources are a major factor, in the open oceans atmospheric deposition of nitrogen is the largest anthropogenic nutrient input.
Methodology	Model based on IPCC historic data and scenarios of emissions and a global three-dimensional chemistry-transport model, to produce global maps of atmospheric nitrogen deposition for 1860, 1993, and 2050.
Data source	See reference for data, deposition maps, flux calculations, etc. as well as other references.
Partners	GESAMP, JRC Ispra
References	Duce, R.A., J. LaRoche, K. Altieri, K. Arrigo, A. Baker, D. G. Capone, S. Cornell, F. Dentener, J. Galloway, R. S. Ganeshram, R. J. Geider, T. Jickells, M. M. Kuypers, R. Langlois, P. S. Liss, S. M. Liu, J. J. Middelburg, C. M. Moore, S. Nickovic, A. Oschlies, T. Pedersen, J. Prospero, R. Schlitzer, S. Seitzinger, L. L. Sorensen, M. Uematsu, O. Ulloa, M. Voss, B. Ward, L. Zamora, 'Impacts of atmospheric anthropogenic nitrogen on the open ocean', Science, 320, 893-897 (2008).

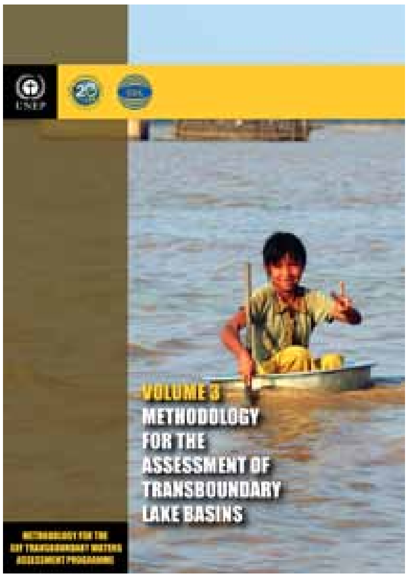
Indicator **ATMOSPHERIC MERCURY DEPOSITION** *mapped, present value*	
In the *conceptual framework*, this is a natural system stress (2) which persists in the environment (3), and can be concentrated in predatory fish species which are consumed (4) by humans (5).	
Definition	Model of global deposition of mercury to the ocean surface for the present day, in micrograms·m^{-2}
Relevance	Mercury is ubiquitous in the environment, originating from industrial and combustion processes as well as natural sources. It is subject to long-range atmospheric transport and cycling. It is therefore relevant to all five TWAP water modules. '*Mercury is a chemical of global concern owing to its long-range atmospheric transport, its persistence in the environment once anthropogenically introduced, its ability to bioaccumulate in ecosystems and its significant negative effects on human health and the environment*' (UNEP, 2002). Mercury will most likely become subject of an international treaty (2013), intended to reduce the risks, primarily to human health but also to the environment
Methodology	The model accounts for 'prompt' recycling, whereby 20 per cent of the Hg^{++} upon deposition to land and 60 per cent upon deposition to snow surfaces is quickly re-volatilized into the atmosphere. These amounts are not included in the deposition fields and have the largest effect in polar regions.
Data source	see reference
Partners	GESAMP
References	Selin, N. E., Jacob, D. J., Yantosca, R. M., Strode, S., Jaeglé, L., and Sunderland, E. M. (2008). Global 3-D land-ocean-atmosphere model for mercury: Present-day versus preindustrial cycles and anthropogenic enrichment factors for deposition. Global Biogeochemical Cycles, 22, GB2011, doi:10.1029/2007GB003040

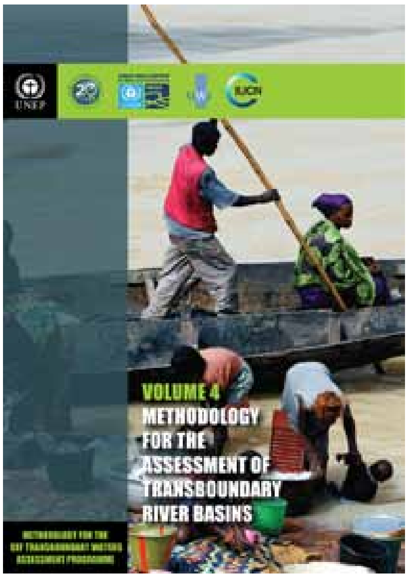
METHODOLOGY FOR THE GEF TRANSBOUNDARY WATERS ASSESSMENT PROGRAMME

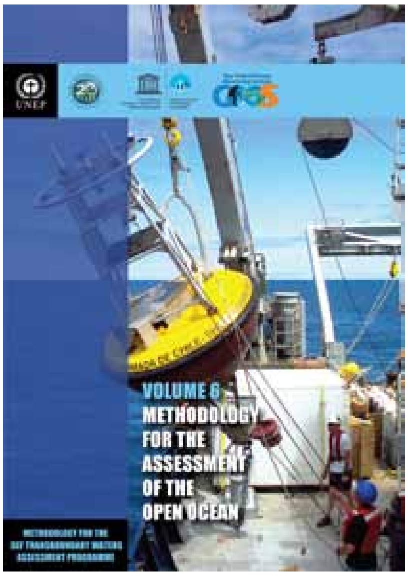
Volumes 1-6











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The water systems of the world - aquifers, lakes, rivers, large marine ecosystems, and open ocean - support the socioeconomic development and wellbeing of the world's population. Many of these systems are shared by two or more nations and these transboundary resources are interlinked by a complex web of environmental, political, economic and security interdependencies. In order to address this challenge UNEP, under the auspices of the GEF, coordinated over a 2 years period from 2009 to 2011 the implementation of the Medium Size Project (MSP) entitled "Development of the Methodology and Arrangements for the GEF Transboundary Waters Assessment Programme (TWAP)".

This Project produced methodologies for transboundary water systems. The final results of this Project are presented in the following six volumes:

Volume 1 - Methodology for the Assessment of Transboundary Aquifers, Lake Basins, River Basins, Large Marine Ecosystems and the Open Ocean;
Volume 2 - Methodology for the Assessment of Transboundary Aquifers;
Volume 3 - Methodology for the Assessment of Transboundary Lake Basins;
Volume 4 - Methodology for the Assessment of Transboundary River Basins;
Volume 5 - Methodology for the Assessment of Large Marine Ecosystems; and
Volume 6 - Methodology for the Assessment of the Open Ocean.

This Project has been implemented by UNEP in partnership with the following lead agencies for each of the water systems: the International Hydrological Programme (IHP) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) for transboundary aquifers including aquifers in small island developing states (SIDS); the International Lake Environment Committee (ILEC) for lake basins; UNEP-DHI Centre for Water and Environment (UNEP-DHI) for river basins; and Intergovernmental Oceanographic Commission (IOC) of UNESCO for large marine ecosystems and the open ocean.

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