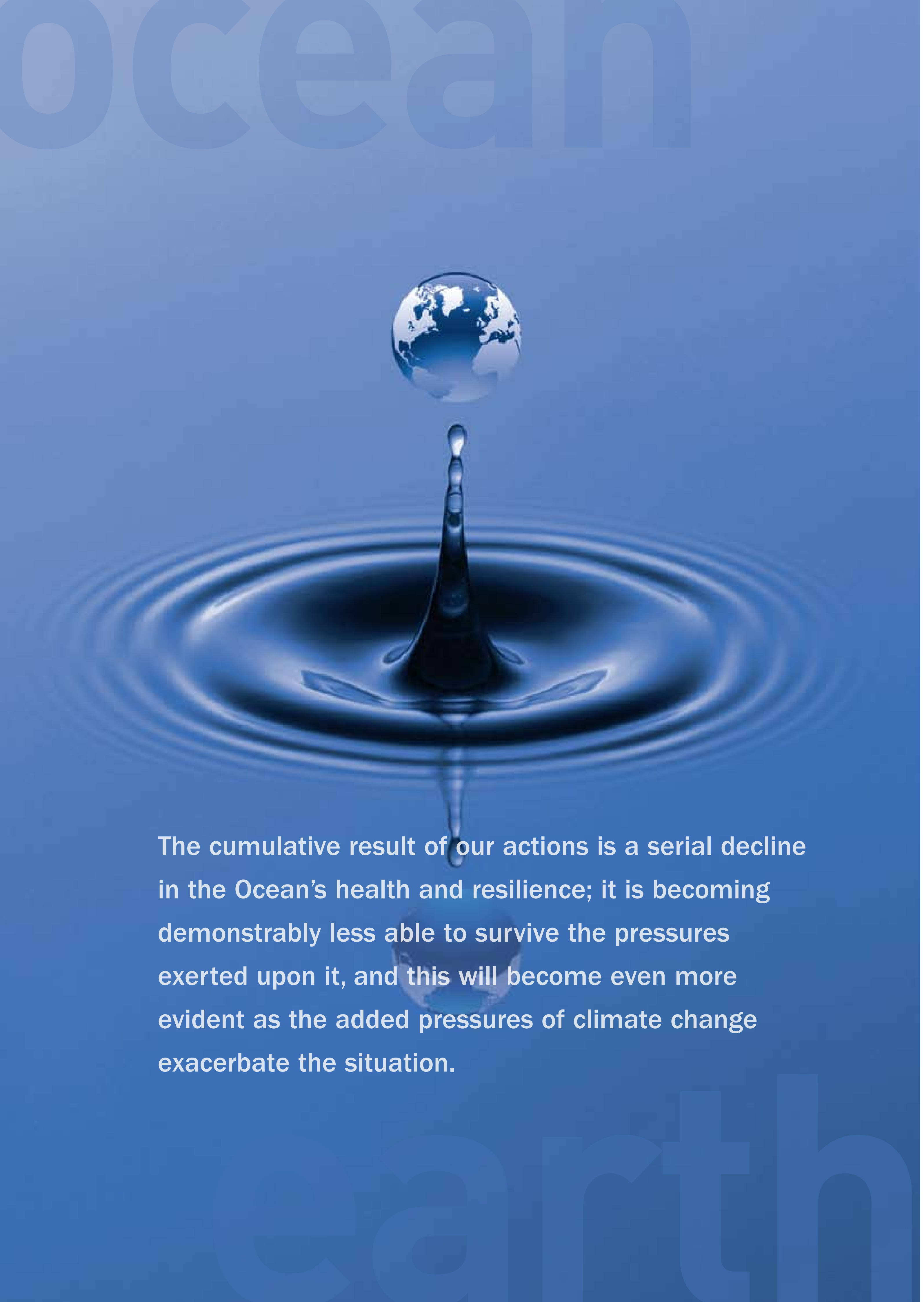
Implementing the Global State of the Oceans Report

World experts in the science, socioeconomics and governance of marine ecosystems to identify how humankind is changing the capacity of the Global Ocean to support life and human societies on Earth

save earth theocean theearthsystem

International Programme on the
ipso
STATE OF THE OCEAN



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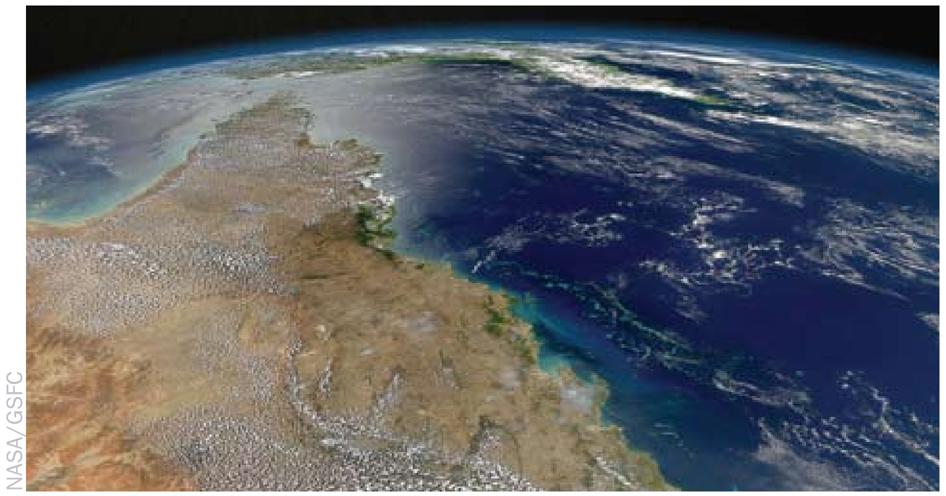

NASA/GSFC

The Great Barrier Reef, Queensland, Australia – a massive carbonate structure built by tiny gelatinous polyps. Corals here and everywhere else in Earth's tropical oceans are threatened by multiple factors.

The International Programme on the State of the Ocean

THE INTERNATIONAL PROGRAMME ON THE STATE OF THE OCEAN (IPSO) brings together world experts in the science, socioeconomics and governance of marine ecosystems to identify how humankind is changing the capacity of the Global Ocean to support life and human societies on Earth.

IPSO will use this knowledge to identify solutions to restore the health of the Ocean, so as to sustain environmental security and benefits for the present and future generations. The programme will communicate its findings to the public, industry and policymakers in order to impel the required changes in human behaviour needed to achieve these solutions.

Introduction
Every stretch of sea and ocean on the planet serves as part of the wider, Global Ocean. This network of marine life is linked by the Great Ocean Conveyor, which comprises the currents that work together to form one of the key operating systems of our planet – what scientists describe as the Earth System – and which in turn works to keep the planet habitable.

The Ocean creates more than half our oxygen; provides vital sources of protein, energy and minerals; drives weather systems and natural flows of energy and nutrients around the world; moderates the climate; modulates the chemical composition of the atmosphere; and transports water masses many times greater than all the rivers on land combined.

Yet at the Earth System level the Ocean is poorly understood and rarely considered.

Without a better understanding we cannot understand the true value of Ocean services to humankind – nor the full consequences of permitting widespread degradation to our Ocean's health.

ALEX D ROGERS

Section ONE

ON THE BRINK

As with terrestrial ecosystems, humankind has been expending the natural capitol of the Ocean with little restraint.

Although concealed beneath the waves, the evidence of wholesale degradation and destruction of the marine realm is clear, made manifest by the collapse of entire fisheries and the growth of deoxygenated dead zones, for example. The cumulative result of our actions is a serial decline in the Ocean's health and resilience; it is becoming demonstrably less able to survive the pressures exerted upon it, and this will become even more evident as the added pressures of climate change exacerbate the situation.

Without significant changes in the policies that influence human interactions with the marine environment, the current rate of ecosystem change and collapse will accelerate and direct consequences will be felt by all societies.

Without decisive and effective action, no region or country will be immune from the socioeconomic upheaval and environmental catastrophe that will take place – possibly within the span of the current generation and certainly by the end of the century. It is likely to be a disaster that challenges human civilisation.

A narrow window
Humankind faces an immediate and pressing choice between exerting ecological restraint and allowing global ecological catastrophe.

The belief among scientists is that the window of opportunity to take action is narrow. There is little time left in which we can still act to prevent irreversible, catastrophic changes to marine ecosystems as we see them today. Failure to do so will cause such large-scale changes to the Ocean, and to the overall planetary system it supports, that we may soon find ourselves without the natural capital and ecosystem services necessary to maintain sustainable economies and societies as we know them, even in affluent countries.

New scientific methods are emerging that enable us to understand the Ocean in ways we have never done before, from individual ecosystems to planet-wide functions and services. Critically, we can now undertake an entire Earth System assessment of the state of the Ocean and the impact of individual activities or policy decisions upon it.

We are able to open up a new understanding of how humankind impacts on the Ocean, how the stresses exerted upon it can be alleviated to restore Ocean health, and the consequences of a failure to do so.

IPSO
Although problems affecting the Ocean are serious, the intellectual capacity exists to tackle these global problems and to find solutions in the short timescale available to stave off potentially grave biological, ecological and economic consequences.

IPSO is an international programme formed by a consortium of marine scientists, experts in socioeconomics, ocean governance and other disciplines, to assess and project the present and future states of marine ecosystems. The aim is then to inform the public, industry and policymakers so as to impel policies to restore Ocean health and ecosystem services.

This programme is based on a uniquely holistic, global approach that investigates marine ecosystems at the Earth System level to achieve a breakthrough in human understanding of the Ocean. It will examine how marine ecosystems function, focusing on interactions and linkages and the mechanisms by which multiple stressors interact to impact the Ocean, the Earth System it sustains and, beyond that, humankind.

The central output of IPSO will be the Global State of the Ocean Report (GSOR).

The GSOR will, for the first time, synthesise existing marine and related science to provide a comprehensive overview of the health of the


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Ocean. It will take an ecosystem approach to marine science and conservation, observing the functioning of the Ocean at a planetary level in order to complement and move beyond the current issue-by-issue, species-by-species approach to marine management.

The report will summarise the current state of the Ocean, comparing it with the estimated intact state, and will outline what may be expected in the future given current climate change predictions, levels of fishing and other human exploitation, as well as the degradation of biological and non-biological resources and other impacts to marine ecosystems.

It will demonstrate the biological, economic and social costs of current management practices and clearly put forward the action required to redress the current critical states of many Ocean resources as well as the measures necessary to restore the integrity and function of marine ecosystems and of the Ocean at an Earth System level.

The GSOR will be submitted through appropriate governmental and intergovernmental channels, such as the UN Regular Process, to effectively engage IPSO with policymakers in order to impel change in management of activities that impact the Ocean. Coupled with this will be direct communication between IPSO scientists and experts with policymakers and key figures in industry through international fora, such as meetings (e.g. the Conference of Parties to Convention on Biological Diversity or the International Union for the Conservation of Nature Congress), presentations to regional governing bodies and governments and direct one-to-one meetings with key policymakers.

IPSO is an independent program driven by a global fellowship of scientists. It draws on the experience and information of other international and national programmes and assessments, the key differences being that IPSO is not restricted to one specific area of investigation and is focused on the identification of solutions. The sources of information include scientific programmes such as IMBER, SOLAS, LOICZ and CoML, global reports such as the Millennium Ecosystem Assessment, the Large Marine Ecosystems studies, the IPCC and the many datasets that pertain to physical or biological aspects of the Ocean (e.g. the Sea Around Us Project).

Through its holistic approach, IPSO will integrate the information arising from these and many other sources to attain the global view that is required to correctly assess problems in the Ocean, and to identify solutions.

IPSO is dynamic and responds to emerging issues, revelations and fields and, as a 'rolling programme', will contribute both regular and special reporting.

IPSO is independent and free from political or other influence. As such there are no areas that IPSO will not consider as long as they are ultimately concerned with solution building for Ocean system restoration and the sustainability of ecosystem health, security, and services.

The first full GSOR will be published in 2012, with a series of preliminary reports and findings being published from 2009 onwards.

Section TWO

IPSO AT WORK

A key innovation of the IPSO project is its consideration of the entire Global Ocean at the Earth System level and the cumulative impacts of stressors exerted on the Ocean; this is in order for us to better understand the consequences of feedback loops and the real cost of continued exploitation at the current rate.

This section sets out how IPSO will achieve this. The GSOR programme of work is comprised of three main modules: the Synthesis Module, where the main bulk of scientific work is undertaken; the Drivers Module, which examines the causes behind human exploitation of the Ocean; and the Solutions Module, which considers what needs to be done to address the problems.

SYNTHESIS MODULE

This module is undertaken by 11 working groups under the direction of IPSO's scientific director, Dr Alex David Rogers, and the ocean realms and stressors working groups leaders, drawn from the Scientific Steering Committee. This is the most complex module and it requires a highly integrated approach to enable the working groups to consider the major stressors on the Ocean, both across each ocean realm and cumulatively at the Global Ocean level.

The outcome will describe how the Ocean functions and what services it provides to the planet and humankind. By examining each stressor across the ocean realms, IPSO will be able to deduce both an Earth System-level understanding of the state of the Global Ocean and the state of individual realms, regions or ecosystems.

The work will be achieved through a synthesis of existing knowledge and involves all members of the Scientific Steering Committee.

Ocean realms – the x-axis

The world Global Ocean is continuous, but there are distinct realms, or ecosystem types, each with its own distinct sets of environments and communities of organisms. These realms are fundamentally interconnected at the interfaces between them and, coupled with the atmosphere and adjacent terrestrial and freshwater systems, they make up the Global Ocean (see Figure 1).

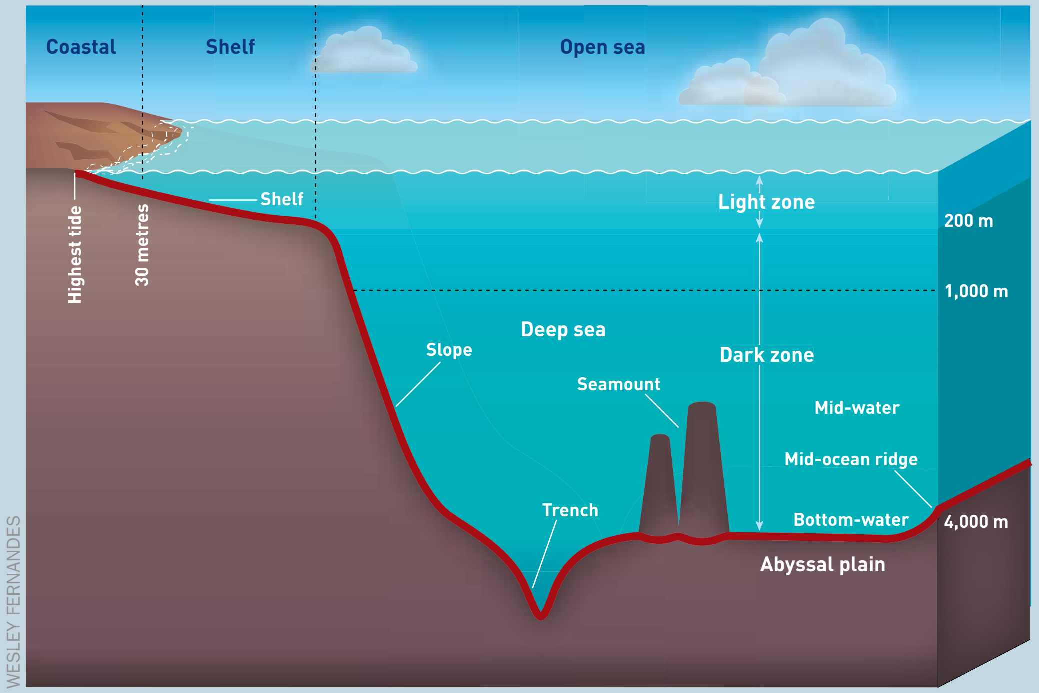

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Figure 1: The ocean realms forming the Global Ocean (Modified from: http://www.fao.org/docrep/009/a0210e/a0210e0a.jpg)

Four classical realms are distinguished for the purposes of IPSO.

- The coastal realm (0–30 metres depth): includes estuaries, mangrove forests, wetlands, rocky shores, beaches, and similar shallow sub-tidal habitats such as soft sediments, reefs and biogenic habitats.
- The shelf (30–200m): includes soft sediment, reef and biogenic habitats.
- The open sea (0–1,000m): the pelagic realm seaward of the continental shelf break, which includes the *epipelagic* and *mesopelagic zones*.
- The deep sea (more than 200m): this is seaward of the continental shelf break (continental margin and beyond) and includes the deeper bathypelagic, abyssopelagic, and hadopelagic zones as well as deep-sea floor habitats such as submarine canyons, seamounts, mid-ocean ridges, abyssal plains, and chemosynthetic communities such as deep-ocean vents and seeps.

Two additional, specially defined realms are also distinguished for the purposes of IPSO.

- Polar habitats of the Arctic and Antarctic, found at latitudes greater than 60 degrees north and south, respectively, at all depths.
- Tropical coral reefs, found throughout the world's tropical latitudes wherever appropriate habitat is available.

These ocean realms will be used as a framework for the IPSO project, which will focus expert working groups on their assessments of the:

- current and future effects of the human-induced causes of ecosystem change – known as anthropogenic drivers;
- socioeconomic implications of those changes; and
- development of effective solutions to the problems caused by these changes.

The ocean realms framework is critical to the success of the GSOR as many previous large-scale assessments of the state of global ecosystems have only dealt with specific realms, case studies or sectoral activities, or provided resolution at a very broad spatial scale. This has meant that results arising from these studies, which have included modelling of important ecosystem services and scenario building, have failed to be translated into policy-relevant forecasts of the future state of marine ecosystems at a global scale and especially at regional and local scales.

Such studies have therefore failed to impel policymakers to develop policies that protect the Ocean and the services it provides. Addressing these various relevant spatial scales using a consistent approach is both an objective and a challenge for IPSO, but it is what sets it apart from previous studies.

In addition to the ocean realm approach, some of the analyses conducted as part of the IPSO programme will be global at the outset or focused on realm interactions rather than on the identified realms.

For each ocean realm, an expert working group will characterise the effects of each identified impact on the biological communities and services of the ecosystems within that realm. They will also focus on assessing the combined effects of the various impacts that are expected to influence each ecosystem, and they will develop a range of alternative policy and management approaches to identify different future state scenarios for that system.

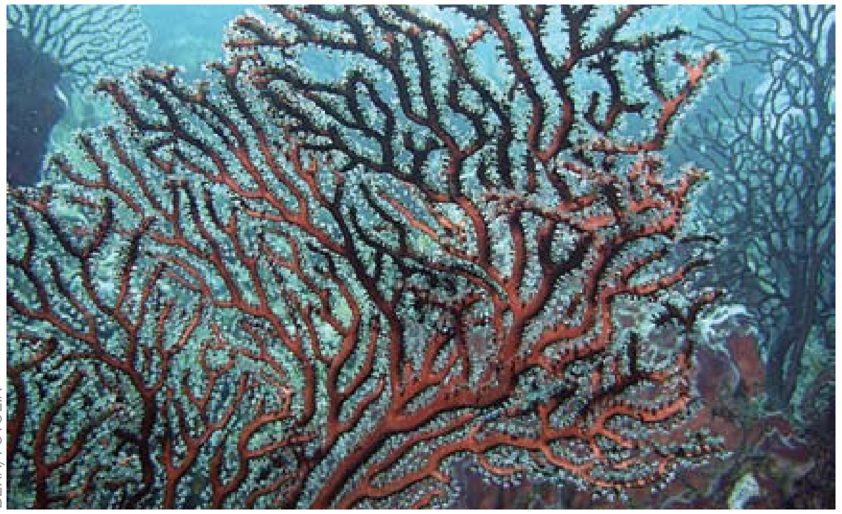
The working groups will:

- define the system structure, functions, and services;
- identify the main system drivers;
- identify links and interactions with other ocean realms and elements of the Earth System;
- assess the impacts of these drivers on scales of decades to centuries;
- identify useful indicators of the state of that system (e.g. aspects of diversity, community composition and structure, biogeochemical cycling, productivity, trophic structure) that are linked to ecosystem services from this realm;
- identify which data and models are to be used, and are available, and the gaps of information and research to be filled, in order to improve the overall assessment and development of solutions; and
- respond to new data and information on ocean realms and the impacts and pressure on them.

Each working group is led by a renowned authority on the ocean realm, and these leaders and groups are coordinated by the ocean realms working groups leader.

Key stressors – the y-axis

The main stressors on the Global Ocean can be organised into five categories. Some of these stressors are human activities and others are physical variables that are indirectly modified by human activities.



BERA/FOTOLIA

They are:

- climate change
- habitat destruction
- fishing and other extraction
- water pollution (chemical and radionuclide)
- introduced species.

Considering these stressors on the y-axis, across each ocean realm, is an important aspect of integration within IPSO. It is critical to the establishing of a chain of causal links between the socioeconomic drivers that lie behind human interaction with the marine environment and the impacts that result across a range of spatial and temporal scales, including where significant interactions or feedbacks occur between impacts and/or between components of the ecosystems within and between ocean realms.

Cutting across each of the expert working groups (for each ocean realm) are stressor groups and the whole y-axis is coordinated by the stressor working groups leader.

A description of the stressors and their major impacts is included in Appendix A.

DRIVERS MODULE

Critical to achieving the identification of effective solutions is a clear understanding of the causes and drivers which lie behind human interaction with the Ocean and the stressors exerted upon it.

The inclusion of this module is one of the main distinguishing features of the IPSO programme because it enables a range of future Ocean scenarios to be considered from very specific policy or culturally triggered starting points.

Through this module the GSOR will include truly comprehensive and quantitative analyses of the Ocean as a social-ecological system. Led by Dr Rashid Sumaila, this module will be undertaken by a special working group of economists, lawyers and social scientists but will also include participation by the representatives from each ocean realm working group.

The module will consider some of the following issues.

Socioeconomic implications

Current policy decisions are dictated by the goal of maximising discounted profit from the Ocean according to conventional economics. The working group will consider the implications for those policy decisions if the goal of securing healthy marine ecosystems for future generations is included, and identify the changes in policy this would require.

Fisheries contribute significant revenue to some developing countries and provide income to some of the poorest people in the world, who do not have alternative livelihoods. In addition, they have important social and cultural roles in many societies. Fisheries' access agreements, trade barriers and subsidies all impact on the ability of developing nations to benefit from fisheries, and are also important to the development of solutions that not only could improve the management of marine resources but could also alleviate poverty.

Marine ecosystems and their fisheries and fishers are subject to a range of climate-related variability, from extreme weather events, floods and droughts, through changes in aquatic ecosystem structure and productivity, to changing patterns and abundance of fish stocks (FAO, 2007). Climate change will increase the frequency and magnitude of such events and may also change patterns of primary productivity and production from fisheries. This important interaction between climate change and the Ocean must be anticipated and taken into consideration when planning the management of fisheries and marine ecosystems at local, national and international levels otherwise many of the world's development aims will be gravely compromised. Recent studies of the exposure of national economies and food supplies to climate change impacts on fisheries indicate that several African states are the most vulnerable (FAO, 2007).

Legal and governance implications

Governance of the Ocean is fragmented by national boundaries within the coastal zone and between coastal waters and the high seas (for a review of ocean governance see Kimball, 2003). Marine ecosystems are not consistent with the boundaries of legal regimes and even where they do to some degree match these boundaries (for example there is some congruence between the outer boundary of an EEZ and the continental margin for continental states), marine ecosystems are highly interconnected as a system in terms of exchange of waters, export of productivity and migration of species. This connectivity goes beyond the boundaries of the Ocean and includes adjacent terrestrial and freshwater ecosystems.

IPSO will develop principles of governance that are holistic and will allow humankind to manage the Ocean on local, regional or global scales. Such principles will steer the examination of current law applied to the Ocean (both in national and international waters) so as to understand whether the law is appropriate to the attainment of the goals of both sustainability and equitability while providing services to humankind and maintaining the function of the Ocean within the Earth System.

SOLUTIONS MODULE

Using the findings of the Synthesis Module – the definitive statement of Ocean services and health – as its baseline, the Solutions Module will collaborate with the drivers groups to project future scenarios of Ocean health across different time horizons. This will be based on a 'change nothing' approach to current Ocean exploitation.

Against this it will then examine different solutions in order to change the projections in Ocean health. The aim of this strand of work is to identify clear political and policy solutions and recommendations which are designed to impel action.

The forecasting of the state of the Ocean will be for 2035 and 2100, as these years have been identified as appropriate for near-term and long-term climate change scenarios by the IPCC (Moss et al., 2008). The forecasts will be compared with projections of alternative states that would occur if different management practices and policies (solutions) are adopted. This will enable IPSO to clearly communicate the consequences of alternative policy options with regards to the management of the Ocean and the ecosystem services it provides. It is critical that the models adopted to achieve the forecasts – which minimise uncertainty, or which can identify and quantify uncertainty – work from the same datasets with the same assumptions where possible. A prerequisite of such forecasting activities is, therefore, the design of future scenarios that will act as standards against which research can be focused throughout the entire program. These are 'integrated scenarios' in the sense that they include the drivers of human impacts (stressors), the ecological effects across all ocean realms, and then ultimately the integrated effects on the Earth System.

IPSO will aim to develop solutions to the problems of world fisheries that do not simply maintain current catches but improve them while increasing the health and resilience of marine ecosystems. If managed correctly the Ocean could provide a sustainable and important source of income, food and livelihood to the people of developing nations, while maintaining important aspects of culture linked with the Ocean. In addition, IPSO will examine the use of spatial protection measures; controls on fishing effort, including policies on discards, fishing technologies and their impacts on ecosystems; the role of subsidies in distorting the economics of fisheries; trade barriers; access agreements; and the relationship between fisheries management, industry and governments. The growing importance of aquaculture requires that sustainable practices within this industry are also considered in the context of the coastal zone in which such activities usually take place.

IPSO will take a holistic view of the processes and impacts within the coastal region, including watersheds, and the terrestrial activities that have an impact on rivers. Again, restoration will be an important aspect of this work and it is notable that the water quality of many rivers in the developed world has improved greatly in recent years. IPSO believes there are tremendous opportunities to restore the quality of estuaries, associated wetlands and other coastal ecosystems so as to directly restore the ecosystem services they have provided, including valuable fisheries resources and the ability to absorb huge quantities of nutrients, and to safeguard the important links that these ecosystems have with other marine ecosystems such as the open ocean.

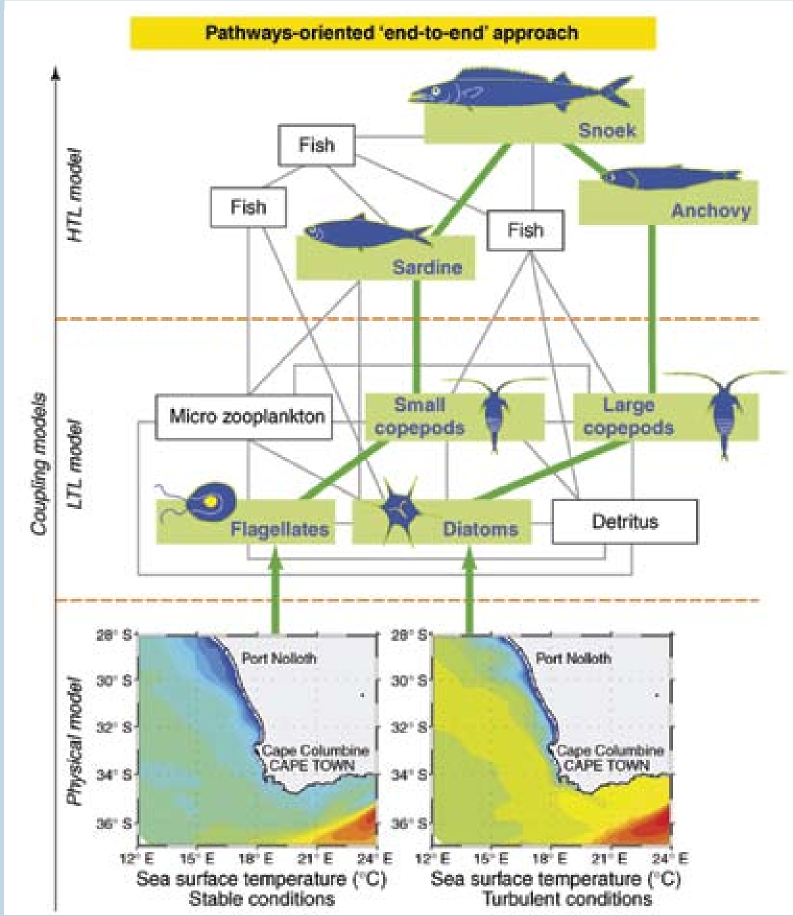


Figure 2: End-to-end models

End-to-end models can be built by coupling three types of models: high trophic level (HTL) models, low trophic level (LTL) models and physical models.

Key

Boxes: key species or groups of species.

Lines: trophic interactions (pathways).

Arrows: the forcing of hydrodynamic models on the LTL model.

(See Cury et al., 2008)

Some of the solutions considered and proposed by IPSO will be conventional but will be applied on a broader scale than has previously been considered (e.g. marine protected areas). However, IPSO will also encourage the evaluation of untried solutions to impacts on marine ecosystems as well as the development of entirely new solutions through advances in scientific understanding that will result from the programme. Regardless of the type proposed, all solutions will have to reflect the distribution of marine ecosystems and the life they contain and this will demand their application across political boundaries of management and governance in the Ocean. Identification of solutions and their application to the real world will require building capacity in international scientific, economic and political marine expertise so that the IPSO vision may be realised on local, regional and global scales.

INTEGRATION

A defining aspect of IPSO is its commitment to achieving integration across every aspect of its work; indeed, this integrative approach underpins the ability of IPSO to achieve an understanding of the Ocean at an Earth System level and of the current state of its health.

The task of integration is made up of three major components.

1. Inherent integration of the matrix approach in the Synthesis Module, which brings together working groups across each ocean realm and each stressor.

2. Synthesis of all relevant existing scientific research.

3. The integration of outcomes and findings across each of the three modules – this is particularly evident in the Solutions Module as it can only be delivered through an integration of the work of the other two modules.

MODELLING

Marine ecosystems should be managed in a manner that prevents both a loss of ecosystem services to humankind and a loss of function in the context of the Ocean and Earth System. This is very difficult to achieve without an understanding of the social-ecological systems of the Ocean. By definition, this includes dealing with dynamic ecosystem processes occurring within the physical, chemical and biological

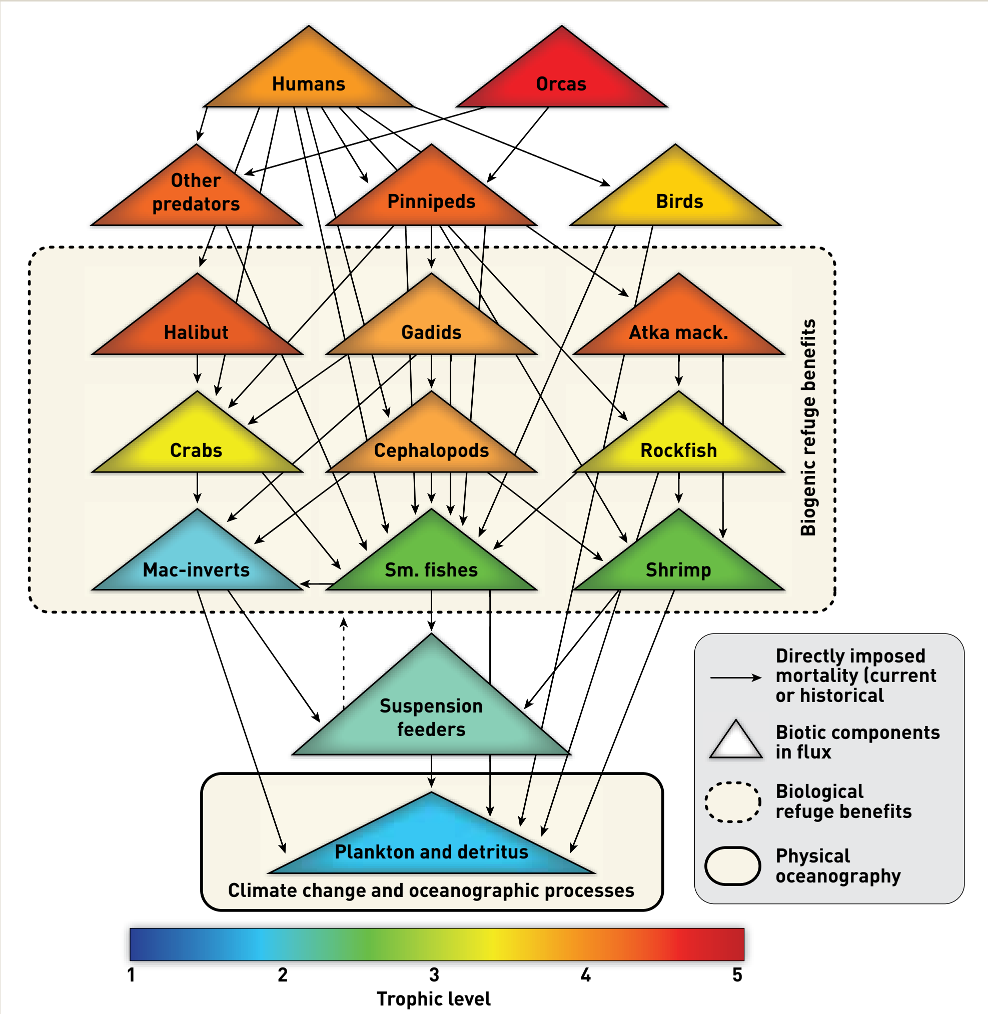


Figure 3: Conceptual model depicting trophic structure and gy flow in the Aleutian Islands octocoral gardens, North Pacific Ocean.

Key
Solid arrow s: directly imposed mortality (current or historical).
Triangles: biotic components in flux.
Dashed lines: biological refuge benefits.
Solid box: physical oceanography.
Colours: trophic level. (See George et al., 2007)

components of ecosystems and the interactions between them (George et al., 2007). Such interactions occur across a variety of temporal and spatial scales and often involve complex feedbacks as interactions between ecosystem components are not one way but bidirectional (Travers et al., 2007).

Because of the complexity of marine ecosystems, scientists have conventionally used models to try and understand specific interactions between biological and physical components of ecosystems in order to manage marine resources or to answer specific scientific questions related to the function of ecosystem components. Such simulations divide the components of marine ecosystems into model compartments (e.g. primary producers, zooplankton and fish) and examine the interactions between them. Models tend to fall into two categories: Lower Trophic Level models (LTLs) and Higher Trophic Level models (HTLs) (see Appendix E). LTLs focus on the tiny organisms that make up plankton communities (bacteria, phytoplankton and zooplankton) and the factors that influence their abundance and distribution. They tend to be explicitly linked to hydrodynamic models, simulating the behaviour of the ocean, and represent important biogeochemical processes such as nutrient cycling. HTLs have focused on single species or a few species, usually fish that are of economic importance, and look at the processes affecting abundance and the response of populations to exploitation.

The interaction between climate change and overexploitation of fisheries can lead to rapid and unforeseen changes in the Ocean, which arise from complex interactions between the biotic and abiotic components of marine ecosystems (see Appendix A). Examples include rapid regime shifts such as the collapse of cod in the north-west Atlantic or the massive proliferation of gelatinous zooplankton in ecosystems such as the Gulf of Mexico or Black Sea. Understanding why such catastrophic changes occur and adopting management strategies that can avoid them requires a new approach known as 'end-to-end' modelling (see Figure 2). Such an approach represents the entire food web and the physical environmental factors that influence it, coupling traditional LTL and HTL models. End-to-end modelling presents a number of significant challenges to the scientific community, for example it requires integration of biological and physical processes at different spatial and temporal scales. In addition, it has to reproduce the two-way interactions between different components of marine ecosystems, which cause the direct impacts of climate change or fishing pressure to propagate through food webs, and which can lead to the cascade effects within ecosystems by which regime shifts occur. End-to-end models must also include all stages of the life history of marine species, especially those at high trophic levels, and important aspects of the biology of marine species, such as the ability of marine predators to switch prey in response to changes in the relative abundance of species at lower trophic levels.

For many marine ecosystems there is a lack of data related to the structure, biodiversity, functions and interactions amongst species (e.g. most of the deep Ocean). But if we wait until all the necessary data for a detailed assessment of many ocean realms has been accumulated, it is likely that substantial degradation or collapse of these systems will have taken place before recommendations can be made to policymakers to enable them to make decisions that will protect marine ecosystems. IPSO will therefore use a stepped approach to modelling marine ecosystems that will depend on the quality and quantity of data available for them. Such an approach is extremely useful as it can not only be tailored to data availability but, on a regional scale, tailored to the pre-existing knowledge, infrastructure and expertise available to develop ecosystem models at an appropriate level of sophistication.

Where data are particularly scarce it is possible to develop simple conceptual models of ecosystems that include known essential structures, communities, species and functions, so that a simple understanding of the ecosystem and its functions can be attained. Such simple conceptual models can still be very effective in predicting the gross ecosystem-wide impacts of human activities and so can be extremely useful in enabling the development of proactive and precautionary management for the ocean realms and ecosystems they contain. An example of a conceptual model is illustrated in Figure 3. This is a simple trophic interaction model for recently explored octocoral gardens in the deep sea off the Aleutian Islands, North Pacific. The model represents the links between benthic suspension feeding animals, such as corals, with other components of the ecosystem including fish, cephalopods and crustaceans of commercial importance.

Where knowledge exists for some components of ecosystems, it may be possible to adopt a

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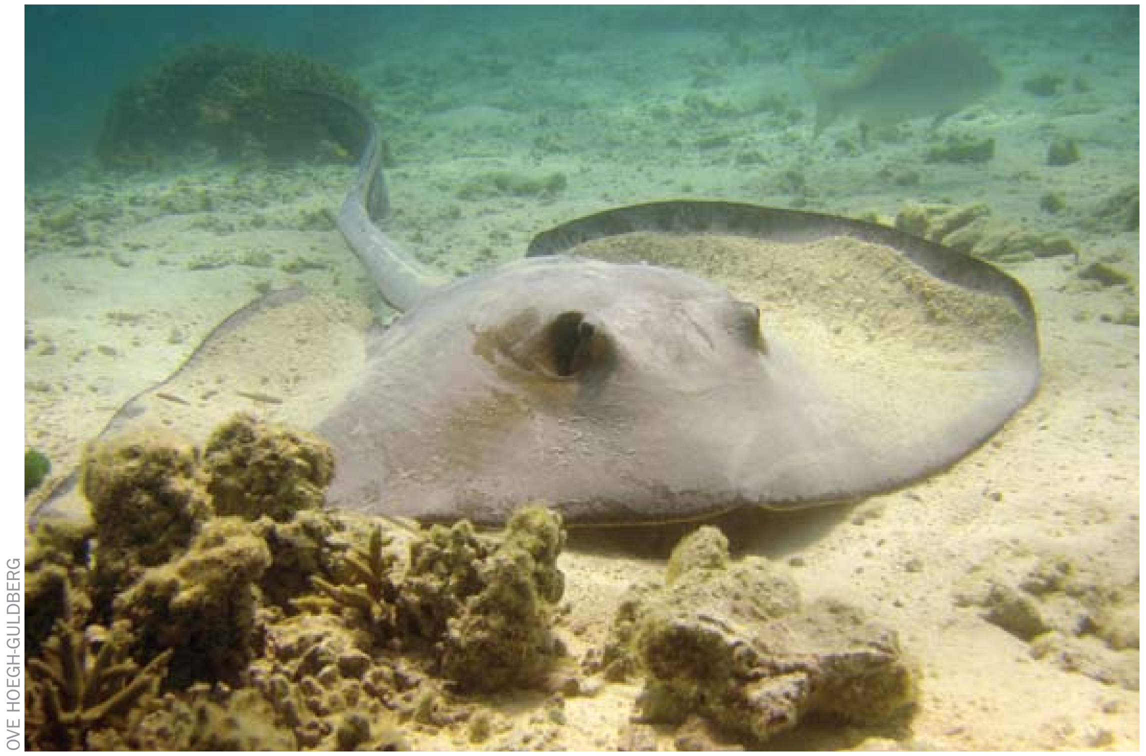

Reefs are home to a million species such as sting rays, which grow over a metre in diameter.

PHOTODISC

IPSO...
a unique initiative...
clear understanding...
Ocean works...
the consequences...
the solutions...
restorative action...
Ocean preservervation...

flexible approach to the discretisation of model compartments. For example, where data are lacking, parts of a marine ecosystem may be reduced to a single model compartment but other, better-characterised components, are represented in greater detail. Existing modelling approaches such as Ecopath with Ecosim, a dynamic model used to simulate marine food webs, have used such approaches to tackle specific fisheries-related questions in marine ecosystems successfully (Travers et al., 2007).

IPSO will promote the adoption of end-to-end models both as an important tool in understanding the impacts of climate change, fisheries and other human impacts on the Ocean and as a method of investigating the potential for changes in human behaviour to modify forecasts of the future of the Ocean, given current trends in exploitation and population growth. The development of end-to-end models is achievable either by linking existing models so that they can interact or by adding components to existing models so that they achieve the breadth required for an end-to-end approach. This represents a major scientific challenge that is now attracting considerable effort at an international level. It is important to point out that many such efforts, however, do not represent the human socioeconomic system at the detail required to transform such models to true integrated assessment models (IAMs), which currently do not exist for the Ocean. At a regional scale, coastal forecasting models have been developed, although these tend to be aimed at addressing specific questions (i.e. when toxic algal blooms may occur). In many cases these do not relate to human decision-making and do not provide information on a timescale that allows effective responses in management. IPSO will assist the development of a sophisticated understanding of social-ecological systems within ocean realms in order to apply them to end-to-end models and so reach fully integrated assessment approaches. The development of IAMs for marine ecosystems will be one of the major scientific outputs of the IPSO programme.

Conclusion

IPSO is a unique initiative designed to provide a clear understanding of how our Ocean works, the services it provides to humankind and the consequences of our interactions with it, as well as the solutions and steps necessary to restore and preserve Ocean services for current and future generations.

IPSO has been created, and is managed, to provide a holistic framework that is able to develop realistic and practical recommendations based on the current understanding of economics, governance and science, including knowledge developed within IPSO; the framework is applicable to global, regional and local scales. These solutions will be developed by world leaders in marine science, socioeconomics and Ocean governance working within IPSO, and will be rigorously peer-reviewed so that they have maximum credibility.

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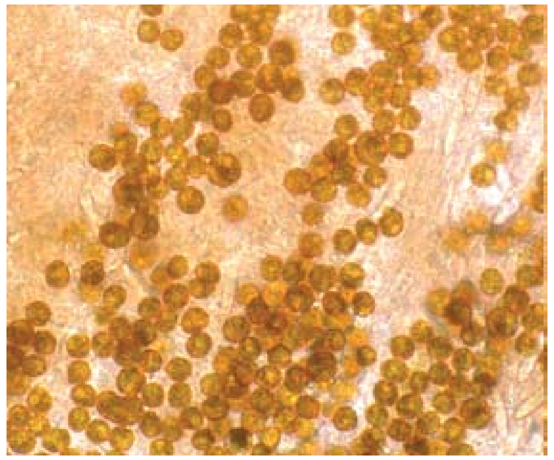
IPSO has been created, and is managed, to provide a holistic framework that is able to develop realistic and practical recommendations based on the current understanding of economics, governance and science, including knowledge developed within IPSO.



OVE HOEGH-GULDBERG

Reef-building corals form a symbiosis with tiny plant-like organisms called dinoflagellates (zooxanthellae). These plant-like organisms which are less than 1/10th of a millimeter across, trap sunlight and power the production of the limestone that makes up the reef framework.

APPENDIX A: Stressors on the Global Ocean

GLOBAL CLIMATE CHANGE

Global climate change affects the entire Earth System. The IPCC Climate Change 2007 report states that: "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level".

The increase of anthropogenic CO_2 in the atmosphere represents a direct threat to all marine ecosystems through changes in Ocean temperature, sea level rise, decreased sea ice cover, increased frequency of extreme events such as coral bleaching and storms, increased stratification of the Ocean – altering patterns of Ocean mixing, lowered oxygen levels and increased risks of eutrophication in coastal waters.

The Ocean naturally absorbs CO_2 from the atmosphere as one of its Earth System services but the excess overload now being absorbed is altering the natural chemical balance of the sea and leading to an increase in its acidity. This is a direct threat to marine organisms that build their skeletons out of calcium carbonate, especially reef-forming corals (Scleractinia).

Temperature increases and acidification alone may irreversibly destroy coral reefs, the most species-rich marine ecosystems in the Ocean, within 50 to 100 years if positive action is not taken now.

Summary of the effects of global climate change on the Ocean

+ = increase
 - = decrease

- Temperature (+).
- Sea level (+).
- pH (-).
- Aragonite saturation (-).
- Carbon enrichment (+).
- Sea ice cover (-).
- Light supply (+ and -).
- Precipitation and runoff (+ and -).
- Salinity (+ and -).
- Stratification (+).
- Winds (+ and -).
- Storm severity and frequency (+).
- Upwelling (+ and -).
- Oxygen (-).
- Nitrification (-).
- Denitrification (+).
- Nutrient delivery (-).
- Currents (Thermohaline Circulation) (+ and -).
- UV radiation (- from a current +).
- Disease (+).
- Plague (+).
- Introduced species (+).

HABITAT DESTRUCTION AND DEGRADATION

Habitat destruction is the elimination of the biophysical structure that supports species, communities and, ultimately, ecosystems.

In the Ocean it can occur as a result of direct removal of habitat – as in the clearance of mangrove forests or the destruction of biological structures such as coral reefs through the action of bottom trawling.

It also results from the alteration of the environment through activities that change the inputs of freshwater, nutrients and sediment principally to coastal areas, or interfere with the flow of currents, or disturb the thermal or acoustic environment of marine ecosystems. The destruction is often caused or accompanied by pollution.

Habitat destruction directly impacts marine biotic resources, such as fish, and damages other critical ecosystem services for humankind, such as protection from tsunamis.

Bleached corals are starving corals.

PROFESSOR OVE HOEGH-GULDBERG, ARC CENTRE OF EXCELLENCE FOR CORAL REEF STUDIES

Summary of the effects of habitat destruction and degradation on the Ocean

- Trawling or other disturbances on sea floor or biogenic habitat.
- Fragmentation.
- Watershed modification (freshwater input, sediment input, damming and engineering. of waterways).
- Coastal modification (freshwater input, sediment input, salinity, circulation, jetties, seawalls, coastal hardening).
- Direct habitat disturbance (e.g. from tourism).
- Direct habitat removal (e.g. from agriculture).
- Artificial reefs / benthic structures.
- Enhanced log disturbance.
- Thermal and noise pollution.
- Aquaculture effects.
- Mining.
- Disease.

EXTRACTION

The impacts of fisheries have been widespread and devastating both on the species targeted by fishing and on virtually every other marine creature from seabirds to coral.

The Ocean supplies large quantities of animal protein to humankind, especially populations within developing countries, and is a vital source of earnings and currency exchange for developing countries, now estimated to be responsible for 50% of exports in global fish trade at a value of US$92 billion. Current fisheries management, which is still dominated by modelling of single-species stocks, has failed to manage fishing sustainably, overseeing the collapse of some of the world's most abundant and valuable fisheries, including north-west Atlantic cod. It has also largely ignored wider impacts on marine ecosystems, with the result that many marine ecosystems now produce a fraction of the food and other services to humankind that they produced in the past.

Even relatively crude estimates of the production of global marine capture fisheries are indicating that catches are stagnating and going into decline, with just some of the shortfall being made up from aquaculture.

Oil and gas extraction from the sea releases hydrocarbons and other contaminants into the environment whilst transport of oil is associated with chronic oil pollution and catastrophic oil releases following grounding of vessels. Oil extraction is now occurring in waters greater than 2380m depth in the Gulf of Mexico, so it now potentially impacts deep-sea as well as shallow-water communities. Oil directly affects marine life (see Pollution, below) but oil extraction also produces fine sediments that are released onto the seabed and which may be contaminated with drilling muds (lubricants for the drill). The release of sediment and associated contaminants has been associated with reduced diversity of seabed communities occurring locally around oil wells (e.g. Olsgard & Gray, 1995), although now drilling muds are used that have a much lower toxicity than in the earlier days of marine oil exploitation. Surveys of the seabed using acoustic methods while prospecting for oil are another potential source of disturbance to marine ecosystems through impacts of sound on marine mammals and fish.

Plans to mine sediments of hydrothermal origin from seamounts in the south-western Pacific are currently being implemented. The first deposit, likely to be mined by the company Nautilus Minerals, is the Solwara 1 prospect on a seamount in the Bismark Sea off Papua New Guinea at a depth of about 1,600m. This is a seafloor massive ulphide deposit (SMS) that comprises consolidated hydrothermal deposits and active hydrothermal vents. It has been estimated that there is approximately 1,300kt of mining deposit comprising 7.5% copper, 0.8% zinc, 7.2 g/t gold and 37g/t silver (Golder Associates, 2008). Hydrothermal vent communities have a low diversity of species, but more than 90% of these do not occur outside of vent ecosystems and local to regional endemism is high (species do not occur elsewhere). Examination of photographs from the Solwara site seem to show high densities of gastropod molluscs on active vent chimneys at the site (Nautilus, 2008) that are likely to be vent-endemic species, raising concerns about the impacts of this operation on hydrothermal vent communities at this location. At present the identity of these gastropods is unknown and their geographic range is also therefore unknown. Further mining prospects are being and will be explored in the Solomon and Bismark Seas and off New Zealand, Tonga and Fiji.

The potential for mining of abyssal nodules from the equatorial Pacific and Indian Ocean and of cobalt crusts from equatorial Pacific seamounts is also being considered at present. These activities are regulated by the International Seabed Authority.

Summary of the effects of fishing and other extraction on the Ocean

- Depletion of targeted fish stocks.
- By-catch.
- Ghost fishing.
- IUU (illegal, unreported and unregulated) fishing.
- Whale strikes.
- Indirect trophic effects.
- Indirect non-trophic effects.
- Bio-prospecting.

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POLLUTION

By far the largest type of pollution, by volume and by impact, is nutrient enrichment or eutrophication.

The release of sewage and wastes from agriculture and industry into coastal ecosystems, often through estuaries, directly increases microbial activity through the provision of organic matter. Increased microbial respiration depletes oxygen in the water column and can lead to the development of dead zones in coastal waters.

The release can also lead to algal blooms both in the water column and on the seabed that result from the increased availability of nitrates and phosphates. These blooms can smother a seabed and all the life on it such as coral reefs, kill marine life in the water column, and pose a direct threat to human health through the consumption of contaminated seafood from direct exposure to, for example, cyanobacteria or indirect contact (e.g. estuary-associated syndrome).

Poor management of sewage is a global problem but is particularly severe in developing regions such as Africa and the Indo-Pacific where up to 80–90% of waste water may be released untreated into rivers, estuaries and the Ocean (Nelleman et al., 2008). The release of untreated sewage into coastal waters is also a source for the transmission of human disease, such as cholera.

Chemical pollutants enter marine ecosystems directly, through outfalls, rivers and estuaries and through use in the marine environment (e.g. antifouling paints such as tributyl tin), or indirectly via the atmosphere from which they enter via rain or particulate material (fall out). Some chemical pollutants are rapidly broken down and may only impact a local area (e.g. cyanide), whilst others are persistent (e.g. mercury, organo-chlorine compounds, polychlorinated biphenyls [PCBs]) and may be accumulated through food chains to reach high levels in the tissues of top predators such as tuna, whales, seals and humans (biomagnification).

Chemical pollutants can kill marine life through acute toxicity if present in sufficient quantities but usually their effects are chronic and sub-lethal, affecting the immune system, nervous system, reproduction and development, and damaging organs or causing tumours. These effects can be difficult to detect and attribute to a pollutant; consequently their impacts on marine species are hard to detect and interpret.

Oil is a common pollutant in the marine environment and it has been estimated that 1.3 million tonnes are released into the Ocean each year (NRC, 2002), although other estimates have put this figure as high as 8.3 million tonnes. Oil is a natural substance and about 46% of the oil released into the marine environment is thought to be from natural seepage. In addition, about 37% is released from shipping and from land-based sources in the course of using oil, while 12% comes from accidental spills and 3% from oil extraction (NRC, 2002). The impacts of oil on marine ecosystems depend on the type of oil, the quantity and the duration of release, and the sensitivity of the environment in which a spill or discharge occurs. Species of marine or aquatic animals are affected by contact with oil, as it may clog and damage fur or feathers; it may also smother animals and plants and has acute toxic effects and longer-term chronic effects

MARC CECCHETTI/FOTOLIA

on living organisms. Predicting the effects of an oil spill is, therefore, difficult but when serious incidents occur the impacts on marine ecosystems are usually serious and last for decades.

The intentional release of the micronutrient iron into the Ocean has recently been suggested as a means of increasing primary productivity and, through this, the draw down of CO_2 into the deep sea. Proposed as a method of decreasing the current rate of global climate change, the measure, known as iron fertilisation, is highly controversial because of uncertainty as to whether it would be effective, what its impacts would be on marine ecosystems and possible feedbacks to the Earth System (IMO, 2007). For example, some models suggest that iron fertilisation may cause the release of additional greenhouse gases into the atmosphere, such as nitrous oxide or methane, potentially increasing global warming (Sagarin et al., 2007). Iron fertilisation is currently an important subject of scientific study and political debate. Direct injection of liquid CO_2 into the deep ocean has also been suggested as a measure to reduce concentrations of atmospheric CO_2. It is known that liquid CO_2 kills marine organisms it comes into contact with, although the implications of large-scale injection of CO_2 into deep-sea ecosystems are uncertain.

Summary of the effects of water pollution on the Ocean

- Watershed (nutrients / eutrophication, organic / inorganic, point / non-point pollution sources).
- Coastal sewage and industrial outfalls.
- Atmospheric deposition (+).
- Debris (lost or abandoned vessels and cargo/ trash/ plastics/ lost fishing gear).
- Marine oil pollution.
- Aquaculture.
- Ocean fertilisation.
- Carbon sequestration.
- Disease (+).
- Hull antifouling paints and systems.

INTRODUCED SPECIES

Marine ecosystems have evolved over millions of years in different parts of the Ocean.

Isolated from each other by the continents, unsuitable environmental conditions (often a result of the latitudinal arrangement of belt-like climatic zones), hydrographic barriers or simply by sheer distance, these ecosystems comprise species that interact in a unique way with each other and with the environments in which they have evolved.

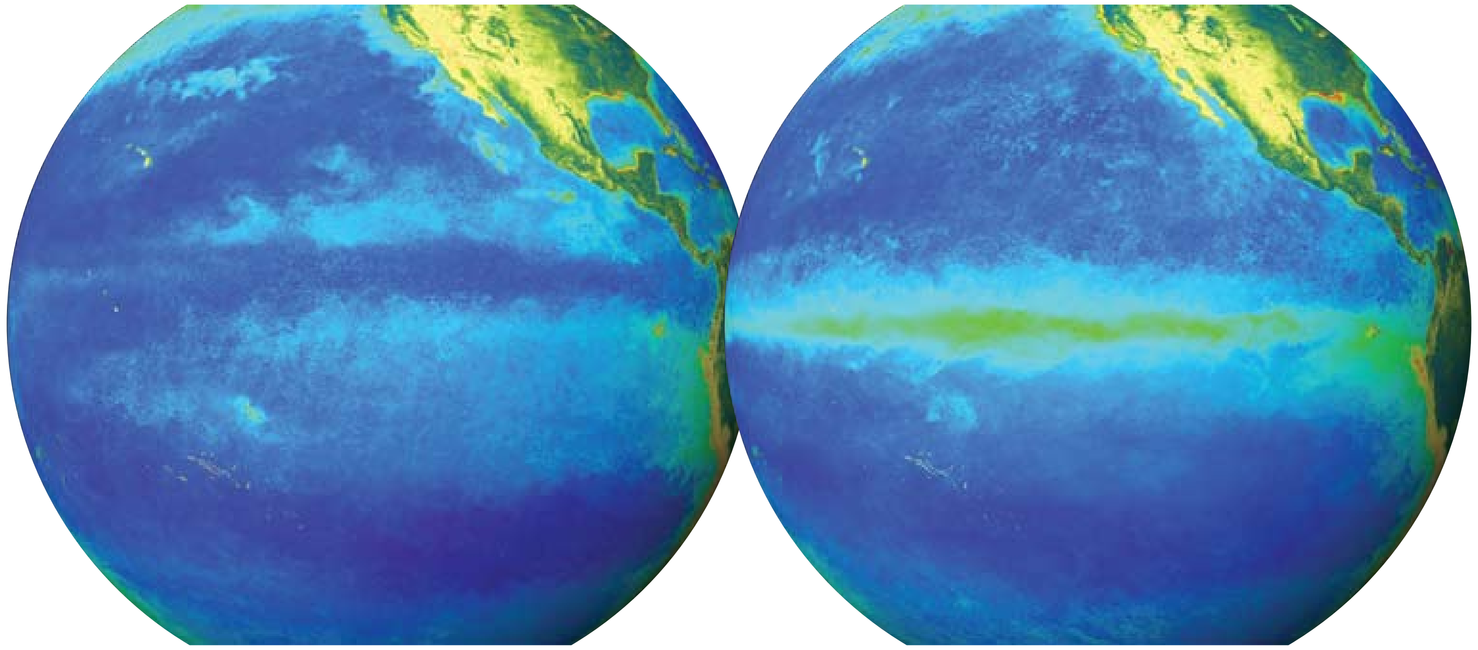
Humankind has and continues to transport marine species and their larvae or propagules over huge distances to introduce them to ecosystems in which they have never previously existed.

This is done deliberately, for example for use in aquaculture or as fisheries, and accidently, as fouling organisms on the hulls of vessels or in ballast water. Such species can wreak havoc on ecosystems to which they are not native through overgrowing native species, predating them or introducing exotic diseases to which native species have poor immunity.

In the worst cases, especially where other human impacts are already stressing marine ecosystems, this may lead to ecosystem collapse. For example, in the Black Sea fishing removed first the predatory fish and then impacted planktivorous fish species, causing significant cascades within the trophic structure of these ecosystems, which combined with eutrophication allowed a massive increase of an invasive comb jelly Mnemiopsis leidyi (Daskalov et al., 2007). This species fed upon the larvae of anchovies and the fishery for these collapsed with a reduction in profit from US$17 million per year to US$0.3 million per year (Knowler, 2007).

Interactions between different types of stressors in the Ocean – 'feedback loops'

The Ocean is degraded by human activities that impact it directly, such as pollution and fisheries, or by those that modify the systems connected to the Ocean, such as the atmosphere or



Satellite imagery from NASA's Sea-viewing Wide-Field-of-view Sensor (SeaWiFS) instrument showed nearly a complete lack of plankton along the equatorial Pacific during El Niño. The cool waters associated with La Niña brought nutrients from the below the surface and enabled an enormous plankton bloom (shown in green).

NASA/GODDARD SPACE FLIGHT CENTER/THE SEAWIFS PROJECT AND ORBIMAGE/SCIENCE VISUALIZATION STUDIO

river basins. Components of the Ocean are connected to each other and interconnected with other components of the broader Earth System. Modification of one component or aspect of the system may noticeably affect other components of the system, or they may have effects that are not noticeable (so-called 'feedback effects'). The effects of changing a single component may be strong or weak, and they may combine with other changes in additive, synergistic and antagonistic ways.

For example, the imposition of more than one stressor (e.g. fisheries and warming of the sea's surface temperature) on an indicator of the health of a particular ecosystem component may have effects that are more deleterious than the sum of the individual effects of each (synergistic effect). Adding an additional stressor (e.g. coastal deforestation) increases the complexity of the net effect and the challenge of understanding and distinguishing the mechanisms behind observed change. There are real examples of this in marine ecosystems across the world. For example, the combination of harvesting of predatory fish species and nutrient enrichment have led to the increasing occurrence of ecosystem collapse through combinations of harmful algal blooms, plagues of jellyfish (Ctenophora and Scyphozoa) and dead zones, which are areas of extreme oxygen depletion in the water column.

Particularly important in such interactions can be the synergistic combination of natural environmental variation in the Ocean and atmosphere and human activities. In the Pacific Ocean, fluctuation in air pressure between the east and west Pacific leads to episodes of weakening or reversal of the trade winds that in turn lead to a spread of warm waters from the western to the eastern Pacific, a phenomenon known as the El Niño Southern Oscillation. During such events warm water replaces the cold, nutrient-rich currents and upwelling along the Pacific coast of South America, having a dramatic impact on fish stocks. The combination of El Niño and fishing pressure has led to spectacular collapses of the world's most productive fisheries in this region. It is also likely that the combination of El Niño with increased global temperatures may have been responsible for global mass coral bleaching events, such as the 1998 event which may have destroyed 16% of the world's coral reefs. It is important to recognise that the effects of El Niño are transmitted across the globe, affecting the atmosphere and the marine environment and emphasising the need for an Earth System approach.

Examining the net effects of all the stressors on a whole community that contains a collection of strong and weak (and poorly known) interactions superimposed on natural environmental variation has, until recently, rendered the assessment of such effects practically intractable, but methods to estimate such whole community and whole ecosystem effects are now emerging.

APPENDIX B: A summary of the key drivers of stressors on the Ocean

ECONOMIC DRIVERS

- The profitability of Ocean activities – this is determined by the price of the products and services taken from the Ocean and the cost of undertaking these activities.
  - The cost of undertaking activities consists of:
    - fixed/capital cost of activity; and
    - operating cost of activity.
  - The price of products and services are usually assumed to be constant in real terms.
- Subsidies – these can either affect the price of fish by artificially increasing it or the cost of fishing by artificially decreasing it.
- Putting more weight on short-term profits through the process of discounting – this diminishes future profits and can therefore lead to the front-loading of benefits and the back-loading of costs, resulting in overfishing. For example:
  - the degree of poverty of a fishing community can increase the tendency to discount future benefits heavily, and
  - similarly, the level of debt carried by fishers can also lead to the front-loading of benefits.
- Using Ocean activities as employers of last resort.
- Lack of monitoring, control and monitoring tools – this is especially acute in developing countries, and is one reason why IUU fishing is still a significant activity.
- The lack of effective management, partly due to the high costs that this entails.
- The unwillingness to internalise external costs from activities dependent on Ocean resources (e.g. the cost of destroying Ocean habitats and bottom by trawlers).
- The inability, sometimes, to appreciate and quantify the total value of Ocean ecosystems in a meaningful way.
- The lack of management schemes that truly take the precautionary approach, such as incorporating marine protected areas in the management plan.
- The lack of joint management where, for example, fish stocks are shared by more than one country.

GOVERNANCE

The role and effectiveness of Ocean governance depends on a number of factors that create indirect drivers of marine ecosystem protection or degradation.

- The extent of coherence, coordination and consistency of management across diverse sectors and realms.
- The level of implementation of existing legal agreements.
- The extent of capacity and political will.
- Distance from shore (determines the applicable legal regime).
- The application or not of modern governance principles (e.g. precaution, ecosystem, adaptive management).
- The application or not of modern conservation tools (e.g.

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prior environmental assessment, strategic environmental assessment, MPAs and other area-based management tools).

- Sectoral approaches versus integrated approaches.
- The presence of an authority figure or institution.
- The existence of a strong or weak regulatory regime.
- A reliance on Flag State responsibility and/or other controls.
- Enforcement – the risk of detection and penalty levels.
- The extent of the rule of law versus corruption.
- The role of science in decision making.
- The accountability of decision makers.
- Transparency and participation in decision making.
- Peer pressure.
- The nimbleness of management institutions (response time of decision makers).
- The role of special interest groups.
- Civil society.
- Transboundary influences and impacts.

SOCIAL DRIVERS

- The role of fishing in culture.
- 'Roving bandits' concept.
- Public awareness.
- Scientific uncertainty.
- Educational attainment.
- Poverty level (mainly artisanal).

Lack of monitoring, control and monitoring tools – this is especially acute in developing countries, and is one reason why IUU fishing is still a significant activity.

ALEX D ROGERS

Fishery patrol boat.

APPENDIX C: A list of programmes of direct relevance to IPSO

INTERNATIONAL SCIENTIFIC COLLABORATION

IPSO must incorporate expertise from a wide range of disciplines as well as draw on input from other international programmes related to the oceans. In return IPSO will aim to influence what work is undertaken by such programmes to the extent of funding projects that specifically address the needs of the IPSO work programme. Collaboration with international programmes is a significant route to the communication of IPSO aims, ideals and outputs to relevant communities of interest, to the public and especially to policymakers. Listed here are some of the existing large programmes and organisations with which IPSO is likely to collaborate.

A database of marine projects, programmes, assessments and data-holding institutions is held by the GRAME programme at UNEP WCMC (http://www.unep-wcmc.org/GRAMED/). The Intergovernmental Panel on Climate Change and the Millenium Ecosystem Assessment are presented in some detail as the former will have a major input into IPSO and, in turn, will be a significant end user of IPSO science, while the latter was a large integrated assessment which identified many problems that IPSO will have to deal with.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)

Status: Active.

The IPCC was jointly established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to assess the scientific, technical and socioeconomic information relevant for the understanding of the risk of human-induced climate change. Work within the IPCC is based on three working groups.

WG1: Physical scientific basis
Synthesises and assesses the scientific information on climate change.

WG2: Impacts, adaptation and vulnerability,
Examines the environmental and socioeconomic impacts of climate change.

WG3: Mitigation
Formulates the potential response strategies to climate change.

Since its inception the IPCC has produced a series of comprehensive Assessment Reports on the state of understanding of causes of climate change, its potential impacts and options for response strategies. It also publishes Special Reports, Methodology Reports, Technical Papers and Supporting Material. These IPCC publications have become standard works of reference, widely used by policymakers, scientists and other experts.

In the sense that IPCC began as an initiative by scientists and that it is a rolling programme punctuated by period assessments as well as technical and special reports, it has been influential on the development of IPSO. In terms of the science to be undertaken in the IPSO programme, the IPCC Emissions Scenarios are particularly important in terms of predicting future temperature rises and atmospheric CO_2 levels. These scenarios can be fed into Oceanic or Coupled General Circulation Models and can form an important component of models predicting the impacts of climate change on marine ecosystems. The IPCC Special Report on Emissions Scenarios (SRES) describes scenarios used for modelling climate change that are based on four qualitative storylines. For each storyline, quantitative scenarios were developed using six models, each of which made different assumptions about driving forces causing emissions. In particular, SRES considered drivers associated with population size, GDP, energy production, land use and emissions of greenhouse gases and oxides of sulphur. This led to the development of 40 scenarios.

The storylines used for scenario building, as extracted from the Summary for Policymakers of SRES (IPCC, 2000), are as follows.

A1 describes a future world of very rapid economic growth, a global population that peaks in mid-century and declines thereafter, and with the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI); non-fossil energy sources (A1T); or a balance across all sources (A1B).

A2 describes a very heterogeneous world in which the underlying theme is self-reliance and preservation of local identities. Human fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

B1 describes a convergent world with a global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity but without additional climate initiatives.

B2 describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with a continuously increasing global population, but at a lower rate than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

No single set of scenarios were designed as a best guess as to how drivers and emissions will behave in the future. IPCC recommended that a variety of SRES scenarios should be used in analyses involving the prediction of emissions. Six scenario groups and four cumulative emissions categories are viewed as the smallest subset of SRES scenarios that capture the range of uncertainties associated with driving forces and emissions. These are the three scenario families A2, B1, and B2, plus three groups within the A1 scenario family, A1B, A1FI, and A1T. It is also important that different components of these scenarios are not mixed (see Figure AP1).

SRES considered drivers associated with population size, GDP, energy production, land use and emissions of greenhouse gases and oxides of sulphur. It did not specifically consider the marine environment except as a sink of greenhouse gases and in terms of its role in thermal regulation of the Earth System. Clearly, however, the predictions arising from the use of the IPCC SRES scenarios in terms of atmospheric CO_2 concentration and global sea temperatures will form an important component of scenario building in IPSO. Note that a new set of emissions scenarios are currently in development and will be released soon.

MILLENNIUM ECOSYSTEM ASSESSMENT (MEA)

Status: Complete.

The MEA represented a global-scale assessment of the relationship between human well-being and the provision of services by ecosystems. The assessment used Integrated Assessment Modelling (IAM) to project changes in the well-being of human populations and the state of ecosystems and the services they provide over the next 50 years. Integrated assessment models were described in the MEA as: "Frameworks to organise and structure various bits of scientific information to analyse cause and effect relationships of a specific problem." The term IAM refers to models that have components dealing with both socioeconomic systems and the environment and are often aimed at specific analyses that support decision making.

Because of the multidisciplinary nature of IAMs the assumptions used in making them become critical. To make sure that assumptions were

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Bleached corals from the southern Great Barrier Reef in January 2006. Hot still weather caused corals in this region to bleach, with the result that 40% had died by six months later.

uniform across different models used within the IAM framework for the MEA, four scenarios were developed to ensure consistency. These scenarios were as follows.

Global Orchestration

In this scenario there is increasing globalisation with emphasis on economic growth and provision of public goods. This includes the adoption of economic policies to improve the outlook for poorer nations, including the removal of trade barriers. Environmental degradation is addressed in an ad hoc manner, with some improvements in ecosystem services but degradation in other aspects of the environment.

Order from Strength

In this scenario increasing distrust of global institutions and the perceived increasing threat from terrorism leads to a world where rich nations become increasingly self-protective and isolated. The world becomes very regionalised, with an emphasis on national security and economic growth. The polarisation of the wealth of nations leads to major environmental problems.

Adapting Mosaic

There is a regionalised approach to governance and management, with an emphasis on local adaptation and flexibility. Local / regional approaches are adopted to deal with growing populations and the resultant environmental impacts. In some regions governments are successful at managing environmental problems and ecosystem services are maintained, but in other regions this does not happen. Increasing communications lead to a spreading of better practices but long-term damage to some ecosystems.

TechnoGarden

This is another globalised approach but one with a high dependence on technology to maximise ecosystem services and deal with environmental problems. Sometimes these efforts exceed the ability of the ecosystem to sustain itself, leading to surprise collapses of some ecosystem services.

A variety of models were used to predict the outcomes of the four scenarios for ecosystems, and include the following.

- The IMPACT model of the International Food Policy Research Institute in the US, which computes food supply, demand, trade, and international food prices for countries and regions (Rosegrant et al., 2002).
- The WaterGAP model of the University of Kassel in Germany, which computes global water use and availability on a watershed scale (Alcamo et al., 2003a, 2003b).
- The AIM global change integrated model of the National Institute for Environment Studies in Japan, which computes land cover and other

indicators of global change worldwide, with an emphasis on Asia (Kainuma et al., 2002).

- The IMAGE 2.2 global change model of the National Institute of Public Health and the Environment in the Netherlands, which computes climate and global land cover on a grid scale and several other indicators of global change (IMAGE-team 2001).

- The Ecopath with Ecosim model of the University of British Columbia in Canada, which computes dynamic changes in selected marine ecosystems as a function of fishing efforts (Pauly et al., 2000).

The MEA encountered several significant problems that were particularly pertinent to dealing with marine ecosystems and which are also significant challenges in end-to-end modelling.
These were as follows:

- Processes occurring at different spatial and temporal scales.

- The inability of the existing models used to incorporate spatially explicit data.

- The combination of complex interactions among a large number of components with the variable nature of ecosystems and their driving forces meant that the MEA (and other) models were very poor in dealing with feedbacks. Such feedbacks become more serious sources of inaccuracy the further in the future that predictions are made.

- Identification of the potential occurrence of tipping points. Changes within ecosystems that are driven by a combination of human pressures, climate change and natural environmental variation may not be incremental but can reach tipping points. These are situations where there are major ecological shifts where reversibility is biologically unlikely or restoration is prohibitively expensive and are often associated with major declines in ecosystem services. Such irreversible change is called hysteresis. The vulnerability of marine ecosystems to such catastrophic changes in structure and function has been associated with a history of multiple human impacts that may appear to cause 'smaller' incremental changes within ecosystems but which significantly decrease resilience to natural or anomalous environmental variation. The MEA concluded that current models were extremely poor at predicting the occurrence of such 'surprises'.

- The MEA tended not to deal with the oceans beyond 50m depth or beyond 100km off the coast. Under-representation of marine ecosystems was particularly acute in the sub-global components of the MEA (Capistrano et al., 2004), contributing to problems associated with assessment at multiple spatial scales.

- When dealing with the marine ecosystem, the MEA emphasised fisheries in terms of the yields of fish as an ecosystem service under the four scenarios (e.g. Alcamo et al., 2005; Pauly et al., 2005). There was no detailed consideration of the influence of human-driven environmental changes on the diversity of species within marine ecosystems or ecosystem function, even in terms of its influence on other ecosystem services, even at the Earth System level. The impact of fisheries was assessed through the use of Ecopath with Ecosim and the IMPACT models. A specific biodiversity component, 'Kempton's Q', or biomass diversity, was considered within Ecopath but only for species at or above trophic level 3, essentially those targeted by fishing. The lack of quantitative methods for examining changes in marine biodiversity at the ecosystem scale is limited by methods and robust, broad-scale data. According to the MEA, there are no global models for marine ecosystems but there are more than 130 Ecopath with Ecosim models worldwide, raising the prospect of meta-analyses (Travers et al., 2007).

- The MEA concluded that to date fisheries management had emphatically relied on single species assessments. Such models were associated with uncertainty arising from a number of processes including observational uncertainty, process uncertainty, model uncertainty and institutional uncertainty. For example, errors in stock-size estimates were often in the order of 30% but could be as high as 200% when there were serious flaws in methodology. Some of these errors have arisen from the reliance on fishery-dependent data such as catch per unit effort, which can be very problematic when used as an index of stock abundance. Also many stock histories are depletion trajectories and do not allow a variation in effort versus abundance to fine tune the response of populations to exploitation. Furthermore, the unexploited elements of marine ecosystems are not dealt with at all in such High Trophic Level (HTL) models and they cannot be used to address ecosystem-level questions.

NASA/GSFC

The northern part of the Caspian Sea showing widespread eutrophication – agricultural run-off rich in fertilizers stimulates growth of algae in the water. The death and decay of the algae robs the water of oxygen, with obvious negative consequences for aquatic life.

Fisheries models within the MEA showed a marked variation in fisheries yields over time within the different scenarios. One of the significant conclusions from these analyses, however, was that there was a trade-off between fisheries yields and the diversity of the harvested species. Three contrasting marine ecosystems were examined in detail – the Gulf of Thailand, the North Pacific and the Benguela Current. Of these, the high-diversity Gulf of Thailand ecosystem showed the most marked response of species diversity to harvesting. This demonstrates that there can be substantial regional differences in ecosystem responses to harvesting, reflecting differences in trophic complexity and species diversity.

The MEA concluded that there were approaches to undertake biodiversity analyses at large scales, although these had largely only been undertaken for terrestrial species. These approaches included expert-based surveys, an approach recently adopted by Halpern et al. (2008) but developed originally for terrestrial ecosystems by Sala et al. (2000). The problem identified with this approach was that it is qualitative and also has major problems in matching the scale of analysis to those at which biodiversity loss is occurring. An alternative approach is habitat envelope modelling. This approach can be very useful for single species or groups of organisms but can suffer from a number of statistical problems (i.e. overfit). These approaches also have difficulty in taking into account the connectivity of populations or biogeographic history of species, both of which can lead to 'suitable habitat' being empty of the subject taxon. Species area curves use a simple method to estimate the number of species in an area. They can be used to estimate species loss on a regional basis as habitat loss approximately correlates to species loss. However, a particular problem with this method is that not all species are lost when habitat is changed and, particularly in marine ecosystems where extinctions are rare, species can undergo major declines in abundance but still be present. There has been limited effort to apply species area curves to marine ecosystems so one additional problem here is estimating the correct value for the z parameter. Population viability analysis can be undertaken but requires a very large quantity of data and tends only to be useful for single species, as in fisheries assessments.

Coastal ecosystems were discussed in the context of modelling within the MEA. Human impacts that were considered to affect ecosystem services in the coastal region included eutrophication, habitat modification, hydrologic and hydrodynamic disruption, exploitation of resources, toxic effects, invasive species, climate change and variability, shoreline extension, hazardous storms, and pathogens and toxins that may affect human health. Coastal forecasting systems have been developed that involve a metadata portal linked to an analysis system. Analyses may be interactive or coupled multimodels aimed at addressing a specific question (e.g. when are harmful algal blooms likely to occur?). These models may also be empirical, based on observations or experience in a particular place, or mechanistic, based on theories which explain phenomena in physical terms. The main problems, identified by the MEA, with such models were that many do not include human decision making and operate over too short timescales to allow effective responses to problems as they arise.

The MEA specifically dealt with eutrophication through examining the cycling of phosphorus and nitrogen through ecosystems. This was done at a very broad scale for marine ecosystems and was only relevant to the coastal zone. It was pointed out that there are many feedbacks involved with looking at nutrient cycling. For example, phosphorus can be underestimated as a result of recycling from sediment, a situation which is enhanced in conditions of anoxia. Thus there can be a feedback effect leading to stable eutrophication where the presence of high nutrient loads lead to algal blooms which die and sink. Microbial degradation decreases oxygen in the water column resulting in increased availability of phosphorus. The MEA pointed out that there

EAN-LUC COCHONNEAU/FOTOLIA

were major problems with applying models of transport of phosphorus to marine ecosystems, especially in terms of estimating impact. Empirical models neglect recycling and food web effects on phosphorus availability and therefore underestimate effects on eutrophication. Sulphate input exacerbates problems of phosphorus release from sediments. Particular problem areas are those where there is a long history of phosphorus input, warm temperatures, and food web interactions.

Nitrogen is a key regulator of the Earth System. The MEA pointed out that nitrogen levels more than doubled as a result of human activities and loads in rivers have doubled, leading to a doubling of input to coastal ecosystems. Perturbations in N cycle lead to leaching into rivers and eutrophication in coastal ecosystems and are associated with the development of dead zones. There may be direct feedbacks to the Earth System as enhanced delivery of nitrogen to the coastal zone can lead to increased production of NH3 and N2O (greenhouse gases). Significant fractions of NH3 and NOx compounds volatalised from soil and released by combustion end up in the open ocean. Acidification also affects the availability of nitrogen in the open ocean. Increased stratification can lead to lower oxygen in the water column and increased denitrification. One very interesting aspect of nitrogen cycling described in the MEA is the effect of iron fertilisation. It was stated that although this may lead to increased primary productivity, utilising CO_2, it is also potentially associated with increased remineralisation and nitrification. In this situation, release of the greenhouse gas N2O may have an effect that equals or exceeds the positive effects of CO_2 uptake. Nitrogen inputs were examined through modelling in the MEA and in three out of four scenarios N input to coastal zone increased. Primary sources were agriculture and sewerage with a general decrease in the rate of increase of atmospheric emissions or even a decrease in these. Large feedbacks involved in the cycling of nitrogen and other nutrients means that there is a need for a whole Earth System approach to modelling.

GLOBAL ENVIRONMENT FACILITY (GEF)

STATUS: Intergovernmental organisation.

The GEF is a global partnership among 178 countries, international institutions, non-governmental organisations (NGOs) and the private sector to address global environmental issues while supporting national sustainable development initiatives.

The GEF is the designated financial mechanism for a number of multilateral environmental agreements (MEAs) or conventions; as such the GEF assists countries in meeting their obligations under the conventions that they have signed and ratified. These conventions and MEAs provide guidance to the two governing bodies of the GEF, the GEF Council and the GEF Assembly. They are the:
- Convention on Biological Diversity (CBD)
- United Nations Framework Convention on Climate Change (UNFCCC)
- Stockholm Convention on Persistent Organic Pollutants (POPs)
- UN Convention to Combat Desertification (UNCCD)

The GEF is also associated with many global and regional MEAs that deal with international waters or transboundary water systems. The GEF is not a financial mechanism for the Montreal Protocol on Ozone-Depleting Substances, however, its activities complement and enhance the work of the Montreal Protocol.

Today the GEF is the largest funder of projects to improve the global environment. Since 1991, GEF has achieved a strong track record with developing countries and countries with economies in transition, providing $7.6 billion in grants and leveraging US$30.6 billion in co-financing for more than 2,000 projects in over 165 countries.

GEF provides grants for projects related to the following six focal areas: biodiversity; climate change; international waters; land degradation; the ozone layer; and persistent organic pollutants. As such the organisation is of interest to IPSO as a potential funding agency.

The GEF international waters focal area is particularly relevant to IPSO and targets transboundary water systems, such as river basins with water flowing from one country to another, groundwater resources shared by several countries, or marine ecosystems bounded by more than one nation. Some of the issues addressed are:
- transboundary water pollution
- over-extraction of groundwater resources
- unsustainable exploitation of fisheries
- protection of fisheries habitats
- invasive species
- balancing competing uses of water resources.

The GEF helps countries to collaborate with their neighbours to modify human activities that place stress on these transboundary water systems and interfere with downstream uses of those resources. In this way, water use conflicts can be prevented, security improved, and sustainable resource use fostered in support of global goals.
GEF international waters projects help countries to deal with concerns about all types of transboundary water systems, ranging from river basins, lake basins, and groundwater systems, to coasts and large marine ecosystems where most fisheries are harvested, to the open ocean. GEF funds many of the current Large Marine Ecosystem projects.

INTERNATIONAL GEOSPHERE-BIOSPHERE PROGRAMME (IGBP)

STATUS: Active.

IGBP aims to study the interactions between biological, chemical and physical processes and how they impact (and are impacted by) human systems. It is essentially an umbrella for coordinating and integrating research in this area across the international community. Activities include development of international frameworks and networks for collaborative research, standardisation of methodologies, promoting long-time series monitoring programmes, data management and modelling and capacity building. IGBP is funded by governments (60–70%), with the remainder of funds coming from project-specific funding sources.

JOINT GLOBAL OCEAN FLUX STUDY (JGOFS)

STATUS: Complete.

JGOFS was an IGBP programme that grew from a 1984 National Academy of Sciences Workshop. The aims of the JGOFS programme were to:
- understand at the global scale the time varying fluxes of carbon and associated biogenic elements in the ocean and to evaluate exchanges with the atmosphere, sea floor and continental margins, and
- develop the capability to predict the global-scale response of oceanic biogeochemical processes to human perturbations, especially climate change.

The programme generated many valuable datasets for ocean science and produced many significant discoveries, including:
- ocean sinks and sources of CO_2
- reducing ocean capacity to take up CO_2 with progressive climate change
- the importance of the continental margins in uptake of CO_2
- the impact of the dynamics and structure of planktonic food webs on the magnitude and partitioning of carbon flux among organic, inorganic, dissolved and particulate forms
- the domination of the carbon cycle by microorganisms
- the influence of micronutrients (iron) on primary production.

JGOFS science has had a major influence on the development of the concepts of IPSO and archived datasets are likely to be of significant use in the programme of science. The programme was largely funded through national research agencies, especially from the US government.

GLOBAL OCEAN ECOSYSTEM DYNAMICS (GLOBEC)

STATUS: Integration and synthesis stage.

GLOBEC is an IGBP science programme that succeeded but overlapped with JGOFS.

The aim of the programme is to advance the understanding of the structure and functioning of the global ocean ecosystem – its major sub-systems and its response to physical forcing

– so that the responses of ecosystems to global change may be forecast.

In the GLOBEC Synthesis Plan it is stated that: "Understanding the role of variability in the function of marine ecosystems is essential if we are to effectively manage global marine living resources such as fisheries during this period of tremendously increased human impact and concurrent dependence on these resources."

In line with this, the programme has tended to focus on ecosystem dynamics and trophic structure of marine ecosystems, especially at the top end and often directly related to fisheries (zooplankton, fish, top predators). The programme has six regional foci, including:

- North Atlantic (International Council for the Exploration of the Seas – ICES)
- North Pacific (North Pacific Marine Science Organisation – PICES)
- Southern Ocean
- small pelagic fish and climate change
- climate impacts on top ocean predators*
- sub-Arctic seas ecosystem studies*.

* New projects in the planning stage.

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GLOBEC's objectives are to determine:

- how multiscale environmental processes force large-scale changes in marine ecosystems
- the relationship between structure and dynamics in a variety of oceanic ecosystems that typify the global ocean ecosystem with an emphasis on food webs
- the impacts of global change on stock dynamics using coupled physical, biological and chemical models to predict future impacts
- how changing marine ecosystems will affect the global Earth System by identifying and quantifying feedback mechanisms.

Among GLOBEC's approaches to addressing these objectives are two of direct interest to IPSO, the development of marine ecosystem typologies and the synthesis of data relating to responses of characteristic 'ecosystem types' to large-scale global change. Clearly GLOBEC science aims and objectives are in line with the work of IPSO and there is clear ground for significant collaboration with this programme, which is due for completion in 2010.

LAND-OCEAN INTERACTIONS IN THE COASTAL ZONE (LOICZ)

STATUS: Running until 2012.

LOICZ is an IGBP programme and part of the International Human Dimensions Programme on Global Environmental Change (IHDP).

- The aims of the LOICZ programme are:
- to provide the knowledge, understanding and prediction needed to allow coastal communities to assess, anticipate and respond to the interaction of global change and local pressures which determine coastal change

to develop the capacity to assess, model and predict: (i) change in the global coastal zone under multiple forcings (including human activity); and (ii) the consequences for human welfare.

The programme concentrates on the coastal zone as this plays a key role in the life-support systems of most societies. Research is focused on biogeochemical fluxes into and within the coastal zone. There are strong elements of synthesis and outreach to policymakers in the programme and this is promoted through the production of technical reports that are highly focused on specific regions (e.g. African Basins, Russian Arctic Basins). Identification of proxies that can be used to describe the state of coastal systems under existing conditions and change scenarios is also a feature of the programme. Coastal typologies are used for areas where data are lacking.

- The LOICZ themes are: vulnerability of coastal systems and hazards to society
- implications of global change for coastal ecosystems and sustainable development
- human influences on river basin-coastal zone interactions
- biogeochemical cycles of coastal and shelf waters
- towards coastal system sustainability by managing land-ocean interactions.

Clearly there is large scope for the use of LOICZ data and reports for the coastal and shelf ecosystem components of IPSO work packages. As the programme enters a synthesis and modelling phase there is also scope for direct collaboration between LOICZ and IPSO in these areas.

INTEGRATED MARINE BIOGEOCHEMISTRY AND ECOSYSTEM RESEARCH (IMBER)

STATUS: Newly initiated programme with minimum 10-year life span.

IMBER is an IGBP programme initiated in 2003. Its vision is to provide a comprehensive understanding of, and accurate predictive capacity for, ocean responses to accelerating global change and the consequent effects on the Earth System and humankind.

The main aim of the programme is to investigate the sensitivity of marine biogeochemical cycles and ecosystems to global change, on timescales ranging from years to decades.

IMBER will identify key interactions between marine biogeochemical cycles and ecosystems, and will assess how these interactions respond to complex natural and anthropogenic forcings. These forcings/drivers include: large-scale climate variation; changing physical and biological dynamics; changing carbon cycle chemistry and nutrient fluxes; marine harvesting.

The IMBER themes are as follows.

Interactions between biogeochemical cycles and marine food webs
QUESTION: What are the key marine biogeochemical cycles and related ecosystem processes that will be impacted by global change? The theme concentrates on transformations of organic matter, transfers of organic matter across ocean interfaces, and material flows through end-to-end food webs.

Sensitivity to global change
QUESTION: What are the responses of key marine biogeochemical cycles and ecosystems and their interactions to global change? This is the main predictive theme and concentrates on responses to climate change in: physical dynamics of the ocean; effects of increased CO_2 and decreased pH; changes in nutrient inputs into the oceans; and impacts of marine harvesting.

Feedbacks to the Earth System
QUESTION: What are the roles of ocean biogeochemistry and ecosystems in regulating climate change? Essentially this theme looks at the capacity of the ocean to affect the climate system; in particular it addresses the capacity of the oceans to store CO_2 ecosystem feedbacks to physics and climate and how changes in low oxygen zones affect the nitrogen cycle.

Responses of society
QUESTION: What are the relationships between marine biogeochemical cycles, ecosystems and the human system? This is the least developed IMBER theme and aims to understand feedbacks between the ocean and human systems and what human institutions can do to mitigate or adapt to climate change.

IMBER is the closest international research programme to IPSO in terms of its overall vision, although at present the human dimension is very poorly developed. Clearly there is excellent scope for a wide range of collaborations between IPSO and IMBER and links should be established with the programme at this early stage in its development.

SURFACE OCEAN-LOWER ATMOSPHERE STUDY (SOLAS)

STATUS: Recently initiated programme with life span of 10 years.

The aim of SOLAS is to achieve quantitative understanding of the key biogeochemical-physical interactions and feedbacks between the ocean and atmosphere, as well as how this coupled system affects and is affected by climate and environmental change. SOLAS is largely a biogeochemical / physical programme with a special emphasis on collaboration between atmospheric and marine scientists. The programme contains a large effort in observations from ships, aircraft and satellites and will comprise a large effort in modelling as well. The programme has three research foci:

- biogeochemical interactions and feedbacks between the ocean and atmosphere
- exchange processes at the air-sea interface and the role of transport and transformation in the atmosphere and oceanic boundary layers, and
- air-sea flux of CO_2 and other long-lived radiatively active gases.

As with IMBER, the human dimension of SOLAS is poorly developed but there is clear scope for interaction with IPSO in terms of understanding the role of the oceans in the Earth System.

PAST GLOBAL CHANGES (PAGES)

STATUS: Running since 1991.

PAGES supports research aimed at understanding the Earth's past environment in order to help make predictions about the future effects of climate change. The scope covers the physical climate system, biogeochemical cycles, ecosystem processes, biodiversity, and the human dimension, across a range of timescales including the Pleistocene, Holocene, last millennium and the recent past. The programme includes a range of databases and various links to publications, meetings and offers support for workshops or meetings. Obvious links to IPSO are with the ocean realms work packages.

EUR-OCEANS

STATUS: Running since 2005.

EUR-OCEANS is a Network of Excellence co-funded under the European Commission's Sixth Framework Programme for Research and Technological Development (FP6). The overall networking objective of EUR-OCEANS is to achieve lasting integration of European research organisations on global change and pelagic marine ecosystems and the relevant scientific disciplines. Presently, the 160 EUR-OCEANS Principal Investigators (PIs) are scattered in 66 Member Organisations, located in 25 countries. The PIs belong to three research communities, which have traditionally often worked independently on: pelagic ecosystems, biogeochemistry and ecosystem approach to marine resources.

The overall scientific objective of EUR-OCEANS is to develop models for assessing and forecasting the impacts of climate and anthropogenic forcing on food-web dynamics (structure, functioning, diversity and stability) of pelagic ecosystems in the open ocean. For this reason the EUR-OCEANS programme is of direct interest to IPSO. To reach this goal, EUR-OCEANS will favour the progressive integration of research programmes and facilities of major research institutes in Europe. The Joint Programme of Activities of EUR-OCEANS comprises the following.

- Integrating activities on networking, data, and model integration.
- Jointly executed research, organised around four broad modelling tasks (together with observations and experiments) on: (i) pelagic ecosystems end-to-end; (ii) biogeochemistry; (iii) ecosystem approach to marine resources; and (iv) within-system integration.
- Activities to spread excellence, targeted at three different groups: (i) researchers: training and education; (ii) socioeconomic users of the knowledge resulting from the Network's research activities (these include the community of climate modellers involved in the IPCC, and the marine resources management community); and (iii) the European public – public outreach through the Association of Aquaria for EUR-OCEANS public outreach, which is a Member Organisation of the EUR-OCEANS Network.

The research activities of EUR-OCEANS are conducted in seven marine systems of interest to the EU. This suite of systems is of major relevance to the global change perspective (e.g. Arctic and Nordic seas, North Atlantic and Southern Oceans) and fisheries (e.g. Arctic and Nordic seas, Baltic Sea, North Atlantic shelves and upwelling systems). It represents a wide range of environmental conditions, covering a gradient from low-production conditions (e.g. Mediterranean) to highly productive waters (e.g. North Atlantic shelves). This gradient provides the range of trophic conditions necessary to develop and test the EUR-OCEANS models, especially where time series have existed for decades (e.g. Arctic and Nordic seas, North Atlantic Ocean and shelves, Baltic and Mediterranean Seas), or are being developed (e.g. Southern Ocean).

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CENSUS OF MARINE LIFE (COML)

STATUS: Running until 2010 in its present form.

CoML is a large international programme aimed at discovering:

- What lived in the oceans?
- What lives in the oceans?
- What will live in the oceans?

The focus is research to describe marine biodiversity, communities and ecosystems, both in the past and present. There is also an increasing emphasis on predicting the future shape of the oceans, although this is poorly developed at present in most projects (apart from FMAP, see below).

Current projects:

- Arctic Ocean Biodiversity (ARCOD)
- Census of Antarctic Marine Life (CAML)
- Census of the Diversity of Abyssal Marine Life (CeDAMAR)
- Census of seamounts (CenSeam)
- Biogeography of Deep-Water Chemosynthetic Ecosystems (ChEss)
- Census of Marine Zooplankton (CMarZ)
- Continental Margins (CoMargE)
- Census of Coral Reefs (CReefs)
- Gulf of Maine Programme (GoMA)
- International Census of Marine Microbes (ICoMM)
- Mid-Atlantic Ridge Ecosystem Project (MAR-ECO)
- Natural Geography in Shore Areas (NaGISA)
- Pacific Ocean Shelf Tracking Programme (POST)
- Tagging of Pacific Predators (TOPP)
- Future of Marine Animal Populations (FMAP)
- History of Marine Animal Populations (HMAP).

The programme also runs a large marine species database called the Ocean Biographic Information System (OBIS).

COML programmes run from a regional to global scale and overall have had a significant impact on our knowledge of the distribution of marine biodiversity. COML projects are likely to provide important data for IPSO and in return IPSO may be able to act as a significant agent of synthesis of COML data. IPSO personnel are heavily involved in several COML projects.

THE SEA AROUND US PROJECT (SAUP)

STATUS: Running since 1999.

SAUP aims to provide an integrated documentation and analysis of the impacts of fisheries on marine ecosystems and to devise policies that can mitigate and reverse harmful trends whilst ensuring the social and economic benefits of sustainable fisheries. The project maintains an extensive, publicly available database of fisheries and biodiversity information, including data on catches, values, biodiversity, ecosystems and governance. Specific information is given on coral reefs, seamounts and primary production. SAUP is a valuable resource for IPSO and clearly IPSO has the capacity to contribute to this already well-known database.

THE INTERNATIONAL UNION FOR CONSERVATION OF NATURE (IUCN)

STATUS: Intergovernmental organisation.

IUCN is comprises of a range of member / affiliate organisations as well as members from national governments. It has a well-established marine programme which is currently in the process of establishing a new plan of action. The programme tends to be focused on specific campaigns and issues, many of which are in line with IPSO objectives. The IUCN Species Survival Commission (SSC) also runs the Red List of Threatened Species, the world-wide database. Until recently this has had a poor marine component, but this has been recognised and there is an emphasis on assessment of marine species, especially invertebrates at the present time (Alex Rogers) is the Marine Invertebrate

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Red List Authority). Assessments for the Red List are often global, although regional assessments are carried out for speciose groups. Red List data can form one source of information for assessing how disturbed a particular region or ecosystem is.

IUCN creates a major forum for contact, discussion and planning of action with other NGOs and policymakers. IPSO should, at the earliest opportunity, seek affiliation with IUCN so as to place itself within this forum.

UNITED NATIONS ENVIRONMENTAL PROGRAMME WORLD CONSERVATION MONITORING CENTRE (UNEP-WCMC)

STATUS: Intergovernmental organisation.

UNEP-WCMC is centred in Cambridge, UK. Its work includes significant effort in assembling databases related to conservation, threatened species, human impacts, etc. The organisation is also involved in the IUCN Red List and CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora). The Cambridge centre also houses the Coral Reef Unit, which covers both tropical coral reefs and cold-water corals; it also runs a coral database. UNEP-WCMC is involved in the Millennium Ecosystem Assessment, including the so called Marine Assessment of Assessments or UN Regular Process, see below. Collaboration may be possible between IPSO and UNEP-WCMC both in terms of data sharing and joint Geographic Information System analysis, as well as through the Coral Reef Unit and the Global Reporting and Assessment of the State of the Marine Environment.

GLOBAL REPORTING AND ASSESSMENT OF THE STATE OF THE MARINE ENVIRONMENT, INCLUDING SOCIO-ECONOMIC ASPECTS (ASSESSMENT OF ASSESSMENTS – GRAME OR THE UN REGULAR PROCESS)

STATUS: Programme is in the initiation phase and is planned to last two years (initial planning phase ends 2008/2009).

GRAME is a UN programme essentially run or backed by Member States and a number of UN organisations, including UNEP, UNESCO, ISA, IMO, IOC and others. The programme is currently under-budgeted (US$2.11 million) and is at the stage of scoping its mission. The GRAME programme has the following remit.

- GRAME is not intended to alter the competence of any other organisation to undertake marine assessments within its field of competence. It should respect the sovereign rights and jurisdiction of coastal States over maritime zones under their jurisdiction. It is not intended that the 'Assessment of Assessments' should make recommendations about the management of human activities that affect the oceans.

- The programme should be essentially science-based. It should not require any original scientific research or any new marine observations but will involve the integration of existing scientific and technical data and information.

- It should cover assessments of the state of the marine environment, including socioeconomic aspects. The latter might include, for example, existing assessments of underlying trends in the employment and economic value of activities affecting the marine environment, but should not encompass policy evaluations. Time, resources and professional judgment will determine the range of activities that can be covered.

- GRAME will not involve making any new assessments about the state of the oceans or about the state of any particular component. It is intended that it should bring together and review existing assessments.

- It will need to acknowledge uncertainties and identify gaps in scientific knowledge and data.

Furthermore, the aims of the Assessment of Assessments should be to:

- assemble information about assessments relevant to the regular process, which have already been carried out under the purview of United Nations bodies and global treaty organisations, regional organisations, national governments, and by any other relevant organisation, where appropriate

- make a constructive appraisal of those assessments, for example, by comparing methodologies, data sources and coverage, in order to identify, collate and synthesise best practices in assessment methodologies and to identify what thematic and other gaps and uncertainties exist in current scientific knowledge and assessment processes

- establish how those assessments have been communicated to policymakers at the national, regional and global levels.

The report of the Assessment of Assessments should identify:

- available assessments on the marine environment and an evaluation of their potential contribution to the regular process

- available data and how that information might be incorporated into the regular process

- the usefulness and constraints posed by organising assessment components of the regular process on different scales

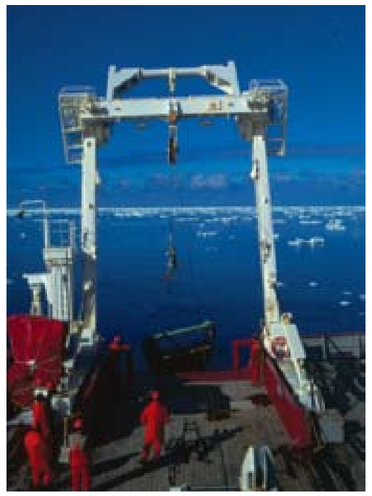
- how organising assessment components on different scales could relate to integrated assessments

- what gaps exist and their implications for the regular process

- the need for capacity-building to support the regular process, and

- a framework and options for building the regular process, including potential costs.

GRAME is likely to become a programme that will condense information from a range of regional marine assessments and communicate these to policy makers on an annual basis. The programme intends to produce separate scientific and policy-relevant documents and during its course it is likely to be an important conduit for the communication of IPSO documents to governments and international governmental organisations. The programme currently centres on the work of a group of 15–20 senior experts and is led by Professor J McGlade of the European Environmental Agency.



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Collaboration with international programmes is a significant route to the communication of IPSO aims, ideals and outputs to relevant communities of interest, to the public and especially to policymakers.

APPENDIX D:

Ecosystem modelling and stock assessment approaches with the potential for use in evaluating and forecasting climate change impacts. (Okey et al., in press)

Acronym	Name: Description	Example host organisation	Host country
Whole ecosystem approaches			
ECOPATH with ECOSIM, and other full ecosystem food-web models	Various: Trophodynamic fisheries ecosystem model with temporal and spatially explicit dynamics, non-trophic mediation, physical and production forcing, economics, policy analysis, etc.	Fisheries Centre, University of British Columbia; and CEFAS, CSIRO, NMFS, OGS, SAMS, etc.	Canada; UK; Australia; USA; Italy
ATLANTIS	Atlantis: Simulation modelling approach that integrates physical, chemical, ecological, and fisheries dynamics in a three-dimensional, spatially explicit domain.	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	Australia
IGBEM	Integrated Generic Bay Ecosystem Model.	CSIRO	Australia
INVITRO	InVitro: Whole ecosystem agent-based modelling approach.	CSIRO	Australia
GEEM	General Equilibrium Ecosystem Model.	University of Wyoming	USA
APESCOM	Apex Predators Ecosystem Model: Spatially explicit size based model of open ocean ecosystems. Dynamic energy budget based.	Fundación AZTI ; Institut de Recherche pour le Développement (IRD)	Spain; France
SKEBUB	Skeleton Bulk Biomass Ecosystem Model.	National Marine Fisheries Service, National Oceanic & Atmospheric Admin. (NMFS, NOAA)	USA
End-to-end models	Various: Coupling 3D hydrodynamic, biogeochemical, bioenergetic and Ecopath with Ecosim models in coastal areas.	Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS)	Italy
Biophysical dynamic system approaches			
SEAPODYM	Spatial Ecosystem and Population Dynamics Model.	CLS, Centre National d'Etudes Spatiales (CNES)	France
OSMOSE	Object-oriented Simulator of Marine ecOsystems Exploitation: Individual-based model.	IRD; Fisheries and Oceans Canada	France; Canada
SYSTMOD	System Model for Norwegian and Barents Seas: Piscivores and small pelagics with climate driver.	Montefiore Institute, University of Liege	Belgium
NPZ – fish approaches / *coupled hydrodynamic models with nutrients, plankton, and fish*			
ERSEM II	European Regional Seas Ecosystem Model.	Plymouth Marine Laboratory	UK
SSEM	Shallow Seas Ecological Model.	Yamaguchi University	Japan
NEMURO-FISH & CCSR COCO	North Pacific Ecosystem Model for Understanding Regional Oceanography (with fish) coupled to the Center for Climate System Research Ocean Component Model.	Hokkaido University 2, Frontier Research Center for Global Change JAMSTEC; NMFS, NOAA	Japan; USA
ESMF	Earth System Modeling Framework: In which the NEMURO suite of plankton and coupled fish bioenergetics models will be adapted.	NMFS, NOAA	USA
BIMS	Black Sea Integrated Modelling System: Dynamic mass flux model for the prey/predator interactions of pelagic fishes.	Institute of Marine Sciences, Middle East Technical University	Turkey
NPZ approaches / *coupled hydrodynamic models with Nutrient-Phytoplankton-Zooplankton*			
ROMS-NPZD	Regional Ocean Model System-Nutrient Phytoplankton Zooplankton Detritus: 3D pelagic ecosystem model coupled to a 3D ROMS split-explicit free surface oceanic model.	Fundación AZTI; IRD; Institute of Ocean Sciences, Fisheries and Oceans Canada	Spain; France; Canada
ROMS- CoSINE	Regional Ocean Modeling System – Carbon, Si(OH)4, Nitrogen Ecosystem model: Ocean circulation and coupled Nutrient-Phytoplankton-Zooplankton-Detritus (NPZD) model.	NMFS, NOAA	USA
PISCES v1	Pisces v1: A Biogeochemical component coupled to OPA v9 hydrodynamics.	IRD	France
POLCOMS	Proudman Oceanographic Laboratory Coastal Ocean Modelling system.	Proudman Oceanographic Laboratory (POL)	UK
GCOMS	Global coastal oceans modelling system.	POL	UK
ERGOM	Ergom: A biogeochemical component coupled to MOM31 hydrodynamics	Baltic Sea Research Institute (IOW)	Germany
ECOSMO	Ecosystem Model of the Hamburg Shelf Ocean Model.	University of Bergen	Norway
NORWECOM	Norwegian Ecological Model (coupled to ROMS model).	Institute of Marine Research	Norway
POM-BFM	Pelagic model and benthic model coupled to Princeton Ocean Model.	Università di Bologna	Italy
OPA-BFM MITGCM-BFM	Pelagic model and benthic model coupled to OPA and MIT General Circulation Models	OGS	Italy
GOTM-GETM	General Ocean Turbulence Model – General Estuarine Transport Model: 3D coupled physical/biogeochemical modelling system based on modular exchangeable model components	Bolding & Burchard Hydrodynamics	Germany
NEMO-PISCES	Nucleus for European Modelling of the Ocean – Pelagic Interaction Scheme for Carbon and Ecosystem Studies: 3D global biogeochemical model. Coupled to IPSL climate model	Institut Pierre-Simon Laplace	France
Dynamic green ocean models / global climate models representing Plankton Functional Types			
PlankTOM	Plankton Type Ocean Model	University of East Anglia	UK
Global predictions of communities and ecosystems from simple ecological theory			
n/a	Global-scale predictions of community and ecosystem properties from simple ecological theory	Centre for Environment, Fisheries & Aquaculture Science (CEFAS)	UK
n/a	Application of macroecological theory to predict effects of climate change on global fisheries potential	Fisheries Centre, University of British Columbia	Canada
n/a	Coupled dynamic size-spectrum modelling	CEFAS	UK
Bioclimatic envelope (niche-based) approaches			
n/a	Dynamic bioclimate envelope model for projecting distributions of marine fish and invertebrates	Fisheries Centre, University of British Columbia	Canada
MARCLIM	Multinomial logistic regression models matching categorical multispecies abundance data to best climate-related predictors (SST, wave fetch) and local site occupancy	Scottish Association for Marine Sciences (SAMS)	UK
Minimally realistic models / *key parts of the system to understand the essential dynamics*			
MRM	Minimally Realistic Model	University of Washington	USA
GADGET	Globally Applicable Area-disaggregated General Ecosystem Toolbox	Institute of Marine Research	Norway
BORMICON	Boreal Migration and Consumption Model	n/a	n/a

Acronym	Name: Description	Example host organisation	Host country
MULTSPEC	Multi-species model for the Barents Sea	Institute of Marine Research	Norway
MSVPA and MSFOR	Multi-species Virtual Population Analysis and Multi-species Forecasting Model		
MSM	Multi-species Statistical Model	NMFS, NOAA	USA
Bioenergetic / allometric	Parameterising a model using power functions of individual body mass		
DisMELS	Dispersal Model for Early Life Stages: Coupled biophysical individual-based model that incorporates ontogenetic changes in early life stage parameters and simulates egg and larval dispersal under 3D oceanographic currents	NMFS, NOAA	USA
FOOSA	Formerly krill-predator-fishery model: A minimally realistic and spatially explicit predator-prey model	NMFS, NOAA	USA
EPOC	Ecosystem Productivity Ocean Climate Model	Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR)	Australia
SMOM	Spatial Multi-species Operating Model	CCAMLR	Australia
4M	Multi-species, multi-fleet, multi-area model package: MSVPA derivate, including fleets/areas covering top-predators, piscivores fish and small pelagics	Danish Institute for Fisheries Research	Denmark
SMS	Stochastic multispecies model: Fish and fisheries	Danish Institute for Fisheries Research	Denmark
KPFM	Krill-Predator Fishery Model	NMFS, NOAA	USA
SMS	Stochastic multispecies model: Fish and fisheries	Danish Institute for Fisheries Research	Denmark
KPFM	Krill-Predator Fishery Model	NMFS, NOAA	USA
MSYPR	Multispecies yield-per-recruit model	NMFS, NOAA	USA
MOOVES	Marine object-oriented virtual ecosystem simulator: A multi-species individual-based model for assessing the response of trophodynamic and size-based indicators of change	IRD	France
Competition in recruitment-driven open populations	Stage-structured model of space-use by competing benthic species (barnacles) with climate-sensitive population processes	SAMS	UK
Extended single species approaches			
ESAM	Extended Single-species Assessment Models	NMFS, NOAA	USA
SEASTAR	Stock Estimation with Adjustable Survey Observation Model and Tag-Return Data	Institute of Marine Research	Norway
MLMAK	MLMAK: Single-species age class model that can include the effects of predation	NMFS, NOAA	USA
MSPROD	Maximum Sustainable Production	NMFS, NOAA	USA
Statistical approaches			
MAR-1	Multivariate auto-regressive first-order models: E.g. to describe interaction strengths	NMFS, NOAA	USA
EMAX	Energy Modeling and Analysis eXercise	NMFS, NOAA	USA
EcoGoMAgg	Ecosystem Gulf of Maine Aggregate	NMFS, NOAA	USA

Acronym	Name: Description	Example host organisation	Host country
Water quality and habitat approaches			
SHIRAZ	Shiraz: Chinook metapopulation dynamics and upland/freshwater habitat quality in estuarine/marine realms	NMFS, NOAA	USA
CBWQM and FEM	Chesapeake Bay coupled Water Quality Model and Fisheries Ecosystem Model	NMFS, NOAA	USA
Habitat and water quality related models	Various	NMFS, NOAA	USA
Spatial planning			
ECOSIM with MARXAN	Ecosim with Marxan: Linking a dynamic whole ecosystem model with spatial management site selection tool to manage for resilience	The Nature Conservancy	USA

Notes: Information from EUR-OCEANS Model Shopping Tool (MOST), Allen (2007); Plagányi (2007); DFO (2008); Hollowed et al. (2008a); Okey et al. (2008a, 2008b); Okey (2008); and Townsend et al. (2008).

NASA/GSFC

A break in the clouds over the Barents Sea revealing a large, dense phytoplankton bloom. The visible portion of this bloom covers about 150,000 square kilometers (57,000 square miles).

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level.

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The belief among scientists is that the window of opportunity to take action is narrow. There is little time left in which we can still act to prevent irreversible, catastrophic changes to marine ecosystems as we see them today.

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we all need to get on the
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