HOW CAN SCIENCE HELP TO SAVE THE MARINE ENVIRONMENT?

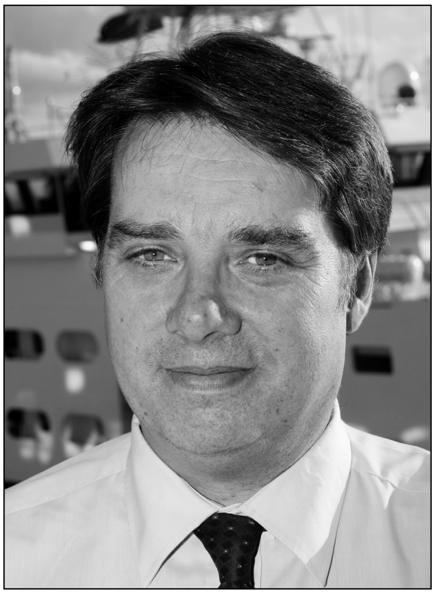
MEETING OF THE PARLIAMENTARY AND SCIENTIFIC COMMITTEE ON MONDAY, 23RD OCTOBER

The effort to protect and preserve marine life is the "second biggest environmental challenge the world faces after climate change" – Ben Bradshaw, Fisheries Minister, on the Today programme. The oceans have been under attack from a massive influx of carbon dioxide and toxic elements derived from burning fossil fuels since the beginning of the industrial revolution.

The Marine Bill currently in preparation will attempt to address and reconcile the multitude of overlapping and conflicting interests of government departments, devolved administrations, public bodies, defence, energy from renewables, oil and gas, environmental, fishing, shipping, ports, aggregates and recreation. The UK is the world-leading centre of marine renewables technology and home to the greatest concentration of wave and tidal stream technology developers with plans for offshore power generation. Scientific advice on effective environmental monitoring and fisheries management is an essential basis for a sustainable marine fisheries policy.

How then can science help to provide a rational basis for preservation in the longer term of the marine environment combined with effective economic management of this strategic resource on which we all ultimately depend?

How can Science Help Protect the Marine Environment?



Professor Edward Hill
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The marine environment is the subject of growing public interest. It is now widely recognised that the oceans are integral to the regulation of our planet as the major reservoirs of carbon and heat, and so understanding our oceans is key to better prediction of future climate scenarios. We also expect that the largest impacts on people arising from climate change will be the increased exposure to flood risk from the sea.

There is a progressive international trend towards more integrated policies for maritime activities and the marine environment (eg Australia's Ocean Policy; Canada's Oceans Act 1997; USA's Oceans Act 2000). The European Commission is presently consulting on a broad-ranging Maritime Policy Green Paper. The Marine Thematic Strategy Directive (intended as the environmental pillar of the proposed Maritime Policy) is presently being negotiated. In the UK, the proposed "Marine Bill" is part of the Government's proposed response to this wider call for a more integrated approach to marine regulation which has for some time been perceived as complex and confusing.

The underlying vision is that of achieving sustainable development, namely striving for a balance between social, economic and environmental considerations whilst ensuring that we live within environmental limits. A move towards an "ecosystem-based" approach to management of human activities in the marine environment is a common thread through all proposals.

The result should lead to much more sophisticated approaches to management of the marine environment. Any regulation must be based on robust science if it is to be proportionate to the risks posed; consistently applied; transparent and defendable in its underlying basis, and is targeted on the real issues. A robust scientific underpinning gives the best prospect of challenging vested interests, winning public confidence for unpopular measures that may be required and enabling those whose role is to enforce measures to demonstrate their accountability.

The fundamental context for management of the marine environment is global change, including climate change. Our planet is out of range compared to its natural "self regulating state" before human influence. In the 21st century marine science is fundamentally concerned with decadal scale variability (and the science integral to observing on these scales) and its interaction with shorter and longer time scale phenomena in the marine environment. We increasingly view the marine environment as part of the larger earth system. There is consequently strong interest in the interfaces between the ocean and other parts of the earth system (land-ocean, atmosphere-ocean and ice-ocean interactions).

Within this context the key roles for science are three fold:

gain deeper understanding of fundamental earth system processes (so we know what is going on);

develop better prediction and scenario testing systems (models) and sustained and properly specified global and regionally observing systems – so we are more continually aware of changes in the earth system – and can predict what might happen next;

inform and guide public policy, regulation and management and help find the innovative solutions and opportunities to live and do business in a changing world.

Sustained observation is central to the science of decadal variability – if the object of 20th century (environmental) science was to understand better the processes at work on our planet, then the goal of 21st century science is to enable us *to be more continually aware* of those processes. This is because living on a planet that is well outside its normal range of behaviour than has prevailed for all human existence, and probably much longer, calls for us to be much more in tune with changes taking place so we can rapidly assess their significance and adapt and respond accordingly.

The key roles for marine science in helping formulate practical policy and regulations such as those under consideration in the UK and Europe include:

identifying and filling key knowledge gaps;

investigating the non-linearities (possible "tipping points") in the marine system;

contributing to developing a definition of "good environmental status" that is more than just a "value judgement by society" and one that can be turned into a sound basis for effective monitoring and assessment and recognises the inherent variability in natural systems;

designing, optimising and reviewing the effectiveness of monitoring programmes;

developing novel technologies for reliable measurements in the parts of the marine system that matter;

providing the techniques to include the fourth dimension (time) into marine spatial planning systems;

developing next-generation modelling and simulation tools for marine spatial planning and ecosystem based management;

putting the marine system in its wider earth system context with better knowledge of the key earth system interfaces;

horizon scanning, evaluating and rapidly communicating to policy-makers new knowledge (eg ocean acidification was not fully appreciated until a couple of years ago);

In order to be effective the role that science can play in the policy making process must be acknowledged and well structured routes and linkages established to ensure that timely, broadly based independent science input feeds into the policy process (IPCC for the seas).

It is noted that in developing new legislation and regulation, the UK seeks to apply the following tests. Is the measure (a) proportionate – relative to risk; (b) accountable – can decisions can be justified objectively; (c) consistent – joined-up and fair, (d) transparent – open and user friendly (e) targeted – focused on the real problems. Robust science, well communicated, can provide the evidence and information base necessary to support the above objectives by underpinning sensible, defensible risk-based approaches.

In the UK, Europe and globally the marine science community is becoming progressively more "self organised" as it strives to rise to the major challenges ahead through more coordinated approaches and address the science challenges that cannot be undertaken by a single institution or nation on its own. For example, in the UK, seven major marine science institutions have joined forces to develop "Oceans 2025" a 5-year programme of strategic research to run from 2007-2012, funded by the Natural Environment Research Council (www.oceans2025.org). Oceans 2025 will address the key science challenges outlined above, embracing knowledge transfer to the wider stakeholder community, and provide the basic underpinning to ensure that the best UK science is available to protect our marine environment.

The big science challenges:

Climate variability and long-term change (now the context for all long term management)
The role of the oceans in fundamental earth system (the earth's life support systems)
Marine biodiversity and ecosystem function (the diversity of life)
The deep oceans and continental margins (where life on earth originated, but the last frontier to be explored)
Coastal and shallow continental shelf seas (our backyard)
Natural hazards (all disasters are global in a global economy)
Environment and human health (health of people and the environment are intertwined)
Pollution and waste (a problem solved or a legacy waiting to bite?)
Sustainable use of natural resources (energy, bioresources, water)
Technology (giving us the capacity to measure new things in new ways)
Ocean predicting and forecasting (science is ultimately valued by its ability to make reliable predictions – that we can act on)
Sustained observing (continually taking the pulse of the oceans)

Ocean Acidification – the Other Half of the CO_2 Problem

Dr Carol Turley
Plymouth Marine Laboratory

Marine ecosystems make up approximately two thirds of the Earth's surface, carry out about 50% of global primary production and support a great biodiversity. Oceans also play an important role in transfer of heat around the planet and in determining weather systems and climate at sea and on land. Oceans are also key in the cycling and storage of the Earth's elements. For example, the oceans are the largest reservoir of carbon (other than that in rocks) on the planet, around 19 and 54 times greater than that in the terrestrial biosphere or in the atmosphere, respectively. Marine ecosystems also provide livelihoods for millions of people through fisheries, aquaculture, transport, tourism and recreation. In essence, marine ecosystems play a large role in providing the Earth's life support system.

Marine ecosystems are already being affected by climate change through ocean warming. For example, long term records from Plymouth, of microscopic animals called plankton which are the food of many fish show substantial geographical shifts in their distribution in European Shelf water in response to the ~1.5ºC rise in seawater temperature.

That same manmade CO_2 that we observe to be the major greenhouse gas causing climate change is also altering the chemical balance of the oceans. This – "the other half of the CO_2 problem" – has received little attention until quite recently, but it may turn out to be as serious as the more familiar one.

The surface waters of the oceans have already taken up over 500 thousand million tonnes of CO_2 (500 Gt CO_2), about half of all that generated by human activities since 1800. By absorbing all this additional CO_2 the oceans have buffered the effects of atmospheric climate change. But there is a cost. CO_2 reacts with seawater to form a weak acid (carbonic acid) and results in a greater seawater acidity (expressed as a reduction in pH). Surface ocean pH has already declined by about 0.1 since pre-industrial times which may not sound much but as pH is measured on a logarithmic scale and measures the amount of hydrogen ions (H^+) in the water it means that the amount of H^+ has increased by 30%. If this trend continues and we burn all available fossil-fuel reserves, ocean pH will fall further (and acidity increase) by as much as 0.4 units from its current level of around pH 8.1 by the year 2100 and 0.67 by 2300. It will take tens of thousands of years for ocean chemistry to return to that of pre-industrial times because it will take this long for the surface oceans to mix with deep waters and react with the calcium carbonate sediments and through their dissolution raise pH again.

Such a reduction in pH is far greater than the annual variation that organisms currently experience and has not occurred for at least 420,000 years and probably for the past tens of millions of years. Marine organisms have therefore had a constant pH environment to evolve in. About 55 million years ago ocean pH did decline to levels we can expect to see at 2300 and this resulted in the extinction of many marine bottom dwelling calcifying (shell producing) organisms even though it took thousands of years for the pH to fall. The current decline in ocean pH will happen far more rapidly, over decades to a couple of centuries. It is not then surprising that scientists are concerned with not only the level of decline in ocean pH but also the speed at which it will happen.

Increase in seawater CO_2 results in a decrease in the amount of carbonate ions which are used by calcifying organisms to make calcium carbonate shells, skeletons and liths (small platelets). Currently most surface waters of the world's oceans are saturated with carbonate ions. However, the lower the concentration of carbonate ions, the harder it will be for calcifying organisms to make their shells or skeletons. In waters undersaturated in carbonate ions the shells of organisms will dissolve. Recent studies predicting future carbonate ion concentration using the IPCC "business as usual" scenario of fossil fuel burning show that the carbonate ion in aragonite, used by corals to make their hard skeletal reefs, will be so low in tropical waters with a doubling of CO_2 that coral calcification will be reduced by 20-60% so the framework of the reefs may be weakened and more erodible. Warm water corals also suffer from another climate change impact, coral bleaching, through rising sea surface temperature caused by global warming. Our current understanding would suggest that corals could become rare on tropical and sub tropical reefs by around 2050 because of raised sea temperature and declining aragonite concentrations. Coral reef ecosystems harbour a huge number of species and are the most diverse of marine habitats. They are also important socio-economically through tourism, fishing and their role in protection of shores from waves.

In polar and sub-polar waters the aragonite concentration is predicted to become marginal or undersaturated (so low that it will become corrosive to shells and they will dissolve) by 2100. All of the Southern Ocean, the ocean around the Antarctic, and large parts of the Arctic will suffer from aragonite undersaturation. Organisms that use aragonite to make their shells such as pteropods (the sea butterfly) and shellfish, which form an important part of the food web, in some areas as important as krill, will not be able to live there. Whales and salmon are amongst the animals that eat pteropods while mammals such as walruses feed on shellfish.

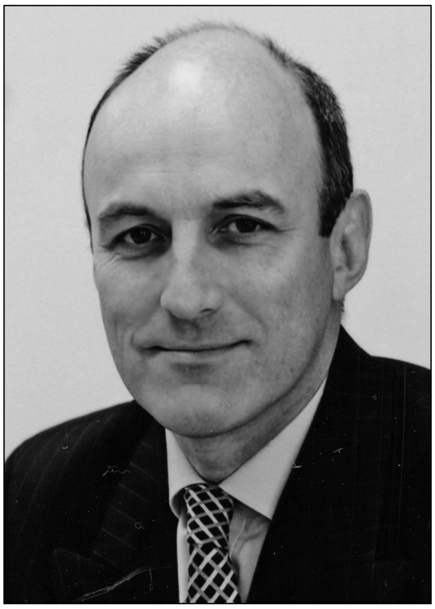
The importance of cold water corals as a habitat and their substantial geographic distribution is only just emerging as is concern over their vulnerability to the rising of the aragonite saturation horizon. Below this horizon aragonite is undersaturated, above it aragonite is saturated. This horizon is currently 100's to 1000's of meters deep but as the surface oceans take up more and more CO_2 it will move upwards towards the sea surface. In high latitudes, it may even surface this century so that those waters will be undersaturated and corrosive to organisms such as the deep cold water corals.

Microscopic plants called coccolithophores produce blooms that are so extensive they can be seen from space. They are currently thought to be the largest producers of calcite on the planet. When they die their calcium carbonate platelets, which are known as liths rain down to the ocean floor where over geological time they are buried and can form vast structures such as the white cliffs of Dover. The liths also act as "ballast" making the aggregates sink faster to the deep sea bed and thus transferring carbon before it has time to be recycled and respired to CO_2 in the surface of the ocean. This "biological pump" helps to control the exchange of carbon between the oceans, atmosphere and sediment. Without it, there could be large changes in the Earth's carbon cycle. Scientists have shown that one important coccolithophore species' ability to form calcite (calcium carbonate) liths is impaired when grown at CO_2 concentrations expected by the end of the century so much so that the calcification is reduced and liths deformed. The impact of this on the extent of the biological pump is of concern.

The study of the impact of altered ocean chemistry on these organisms is still in its infancy and scientists are currently using seawater and seabed mesocosms (large volume natural enclosures) dosed with future CO_2 concentrations as well as complex ecosystem models to predict future impacts. At Plymouth Marine Laboratory mesocosms are being used to look at the impact of a high CO_2 ocean on animals that live on the seabed and within the sediments and their biodiversity and biogeochemistry. Some of these animals (eg starfish, sea urchins and shellfish), which burrow and plough through the sediments, play a key role in maintaining the biodiversity and important chemical feedback processes to the overlying seawater that help sustain primary production.

Ocean acidification is now a mainstream scientific concern for the majority of international marine research organisations. As the research of impacts of ocean acidification is just emerging or still in the planning stage there will undoubtedly be impacts and adaptations that have not been addressed here. Understanding these and predicting what future marine ecosystems will look like and determining the feedbacks to the functioning of the Earth's life support system will undoubtedly be one of the biggest challenges for marine scientists in future decades.

Surface ocean acidification is happening now and will continue as humans put more CO_2 into the atmosphere. It is happening at the same time as the world is warming. Organisms and ecosystems are going to have to deal with a number of major rapid global changes at once – unless we urgently introduce effective ways to reduce CO_2 emissions. These changes are happening on human time scales so that our children and grandchildren will experience them. Avoiding even more serious ocean acidification is a powerful additional argument to that of future dangerous climate change for the urgent reduction of global CO_2 emissions. It is for this reason that Plymouth Marine Laboratory has also worked to bring this issue to the attention of stakeholders and policy makers at the national and international level (eg English Nature, Environment Agency, Royal Society, Defra, Dti, NERC Intergovernmental Panel on Climate Change, OSPAR, The London Convention, UNFCCC, UNEP, EU, IGBP, SCOR, IWC, GECC).



Sustaining our Marine Inheritance

Mark Farrar
Chief Executive, Centre for Environment, Fisheries and Aquaculture Science (Cefas)

Living on an island should provide ample reason for all of us to pay close attention to the surrounding marine environment. The marine inheritance we pass on to future generations will partly depend on how we provide for clean, safe and healthy seas whist ensuring effective economic management of a strategic resource that dominates many aspects of our lives.

Marine science has a particularly important role to play in providing an underpinning evidence base to aid understanding of an environment that is constantly changing, where access is both difficult and costly and our current knowledge is far from complete.

However, if science is to provide solutions and help influence our actions, it cannot act alone. To succeed it must align with the policy needs of Government and work alongside the many individual and commercial stakeholders with an interest in marine resources.

The scale of the task is immense, requiring an understanding of long-term trends and changes in global terms at one end of the spectrum, through to a need for detailed monitoring, assessment and advice on more localised issues at the other.

The challenge is to harness the wide range of skills and knowledge across the UK Marine Science base, to provide such assessment and advice. For example, at Cefas we have developed our strategy recognising Government priorities for future science and technologies and partnering with other research organisations to provide integrated science across Europe. Our science covers analysis of the wider ecosystem interactions, understanding of organism health and input to how resource managers utilise both the biological and non-biological resources available to them.

The following examples provide an insight into how Cefas and other UK marine scientists can provide a pivotal role in advising Government and others on the best course of action in particular circumstances.

Firstly, at a global level, it can be shown that fish provide more than 50% of the essential protein and mineral intake for c400 million people around the world. Initial research carried out for DfID suggests that some countries, particularly those in Africa, will face difficulties in adapting to the impacts of climate change on their fisheries. Further work is now needed to examine on a finer scale how policy levers and working practices might best be adjusted to support local communities.

Closer to home, managing the high profile nature of the European fishing industry requires a thorough understanding of an extremely complex food web and associated distribution changes in the whereabouts of fish. Data from research cruises and other industry sources is utilised to support complex models and simulations and so predict the impact of future management actions.

This is not without its challenges. The complexity of the food web needs to take account not just of man's interaction, but the fact that fish eat other fish. And of course there is also the interaction with the bird population. Acoustic surveys, hard sampling and modelling all help to supplement reported catch information and aid interpretation and prediction.

Through a Defra-funded programme the fishing industry is now engaged in ongoing surveys, gear and catch studies. Harmonising the power and buy-in of industry knowledge alongside scientific skills has proved a powerful, positive benefit.

Recent work in the Irish Sea has examined spawning and settlement locations underpinning Plaice distribution. This is a response to the need to understand which pathways Plaice followed and which behavioural processes were important to the settlement distribution. Once it was understood how the larvae moved vertically in the water column, this understanding combined with tidal, wind and other environmental information enabled fine-scale models to be developed. Without an ability to interpret information at this level it would not be possible accurately to predict movement and, in turn, link this to control of man's interaction in fisheries.

Studies to reduce the environmental impacts of trawling perhaps provide a particularly tangible example of how science can make a positive difference. Working with the fishing industry, one programme of work examined beam trawling with a view to ensuring nets released non-target, bottom-dwelling invertebrates rapidly, unharmed and close to the point of capture. The practical solutions used to amend traditional net mesh panels produced a 75% release rate with over 90% survival.

Equally important is the need to understand and influence man's interaction with the wider marine environment as offshore energy and other sectors are further developed.

This encompasses aggregate extraction sites, disposal grounds, windfarms, oil and gas platforms, wells, pipelines and cables for example. Scientists are not only involved in the initial environmental impact assessments but also have a continuing role in ongoing monitoring to ensure that lessons learnt are incorporated in the planning and licensing of future developments.

Of course, operating in a difficult environment provides challenges of its own in data collection. Here science and industry can assist by developing new methods for better (and cheaper) data capture. A network of "Smartbuoys" around the UK coastline now collects increasing amounts of information on key indicators, enabling models to be refined still further and support policy needs and decision-making.

Studies using small electronic data storage tags on Rays have dramatically changed our understanding of their movement during the year, in turn suggesting different actions were required to ensure this safe management. Historic measures aimed at sustaining this pressured species went so far, but science has now shown that more effective measures are possible.

Looking to the future, there is a need to ensure marine science adapts to changes in the environment and mankind's evolving behaviours. The UK's Marine Monitoring Assessment Strategy must ensure that sufficient comparable data are available to underpin our knowledge of climate change and a wide swathe of ecology. New compounds we do not even know about may be influencing the marine environment and the impact of nanotechnology needs to be better understood. As information becomes more complete in one area, attention needs to turn to others where activity may have been traditionally less comprehensive.

All of this underpins the need both to maintain and develop the UK's marine science skill base. There is a need to ensure strong linkages to coherent policy architecture, and orchestrate our science resource appropriately. The recent European green paper on Marine Policy will draw our European partners into the debate and the UK's own Marine Bill is seeking to provide a common spatial planning and licensing framework for the marine environment. The UK's marine science base will need to ensure it is positioned appropriately.

For all of us, whether scientist or not, perhaps the importance of the marine environment is best underlined by the opening quotation, attributed to Arthur C Clarke, in the European Commission's recent green paper. "How inappropriate to call this planet Earth when it is quite clearly Ocean".

In discussion the following points were made:

The present organisational structure underpinning marine science in the UK came in for strong criticism as being a rather unusual and poorly defined mixture comprising a Research Council, University based Institutes and a Government Agency. It is therefore not easy for anyone to identify areas of responsibility and the roles of the various components of the structure and the nature of formal linkages to other topics such as the atmospheric science community, for example. Indeed the National Oceanic and Atmospheric Administration (NOAA), a highly regarded Government Agency in the USA, was hailed as an exemplary model for the UK to follow compared with the UK muddle in the organisation of marine science. It was also pointed out however that the NOAA also lacked satisfactory linkages to other Government Agencies and Universities. Marine science is highly technology dependent and therefore depends on close relationships being developed between Government funded organisations and SMEs who develop and manufacture the innovative technology required for marine research. However there has been a notable decline in the introduction of innovative technology, which suggests that collaboration between Regional Development Agencies (RDAs) and SMEs is not all that it should be in order to ensure that academia, Research Councils and SMEs and Defra will have access in future to the technology required to undertake state of the art science in the marine environment. These will be important issues for the Marine Bill to consider.