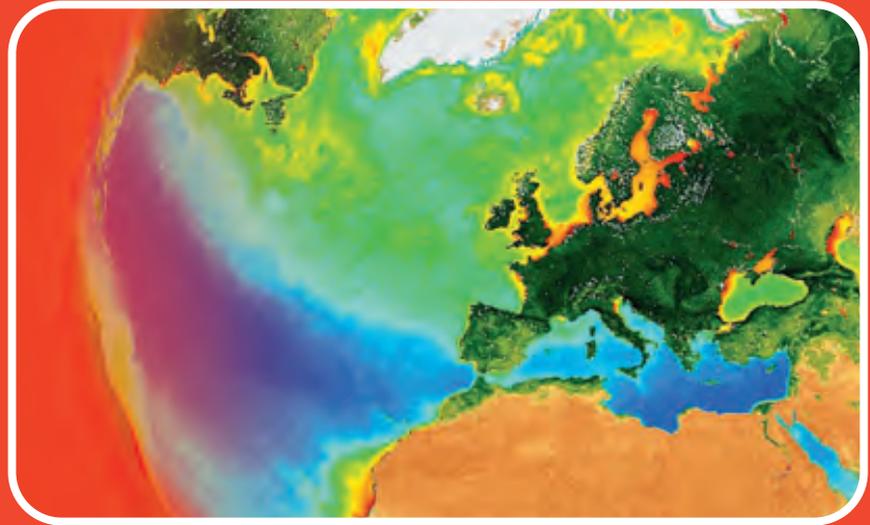


Why are the oceans important?

The oceans cover over 70% of the Earth's surface, carry out about 50% of global primary production and support the greatest biodiversity on the planet. They are also one of the largest carbon reservoirs in the Earth system, holding up to 54 times more carbon than the atmosphere.

The oceans therefore:



Regulate the Earth system

Transferring heat around the world
Driving climate and weather systems
Playing a key role in the global carbon cycle

Supply living and non-living resources

From fisheries to marine biotechnology
Minerals to renewable energy

Provide social and economic goods and services

Tourism and recreation
Marine transport and security
Coastal protection



Why are the oceans important?



Regulate the Earth system

In the North Atlantic Ocean wind-driven surface currents head poleward from the equator, cooling all the while and eventually sinking at high latitudes into the ocean basins (thermohaline circulation). Extensive mixing takes place across ocean basins, reducing differences between them and making the Earth's ocean a global system. On their journey, the water masses transport heat, gas and matter around the globe. This circulation has a large impact on the climate of our planet.

Ocean currents transport large amounts of heat and water around the world and constantly interact with the atmosphere, which enables the ocean to act as a heat sink to delay the full effects of climate change.

Carbon is continuously cycled between reservoirs in the ocean, on land and in the atmosphere, where it occurs primarily as CO₂. In the ocean, CO₂ dissolves in seawater forming carbonic acid and is ultimately removed from the marine system through processes such as the formation of calcium carbonate and the creation of limestone.

Carbon exists in many forms in the ocean, mainly as dissolved CO₂ and organic matter in the form of small creatures, such as plankton. The largest reservoir is the deep ocean, which contains close to 40,000 Gt C. The exchange of carbon between the deep ocean and the fast-responding system above takes several hundred years.

Microalgae are responsible for greater than 50% of global primary production. In doing so, they play a major role in the global carbon cycle by consuming CO₂ from the atmosphere and positively influencing climate change.

Supply living and non-living resources

The oceans are a major source of food. Worldwide approximately half of the population live in coastal zones and about a billion people rely on fish as their main source of protein.

Blue (marine) biotechnology is an emerging sector with huge potential to use marine biological systems and living organisms or derivatives to produce innovative products and services for the health and beauty and medical industries.

Apart from harvesting food from the sea, many industrial processes worldwide rely on the marine environment for resources, such as oil, gas and marine aggregates.

The oceans offer enormous potential for renewable energy technologies, such as offshore wind farms, tidal or wave energy devices.

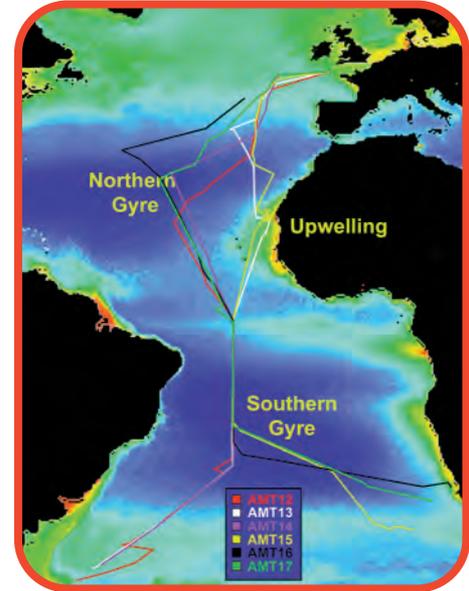
Provide social and economic goods and services

Coastal and marine tourism is a large global industry supporting regional economies as coastal and marine environments become more accessible. Eco-tourism in particular is a fast growing sector.

International seaborne trade relies on regular and safe routes for freight and passengers. World seaborne trade is estimated at approximately 28,000bn tonne miles¹. 90% of EU external trade and 40% of EU internal trade is carried by sea and in the UK the shipping sector employs over 30,000 people².

Approximately half of the world's population live and work within 100km of the sea and 100 million people live less than 1 metre above present sea level.

Marine habitats such as coral reefs and salt marshes provide natural coastal defences and nursery grounds for fisheries as well as diverse ecosystems.



CASE study:

Atlantic Meridional Transect

A child born in 2007 will be an adult by 2025 - "within one generation we want to have made a difference"

Safeguarding Our Seas - UK Government.

The UK Natural Environment Research Council (NERC) has approved funding for a 5-year marine science & technology core programme called Oceans 2025, which is being delivered by 7 research centres across the UK, including 3 in Plymouth. Oceans 2025 will make a major contribution to our understanding of oceans and climate change impacts through projects like the Atlantic Meridional Transect (AMT) which has been investigating the links between oceans and climate for over 10 years.

CONTACT details:

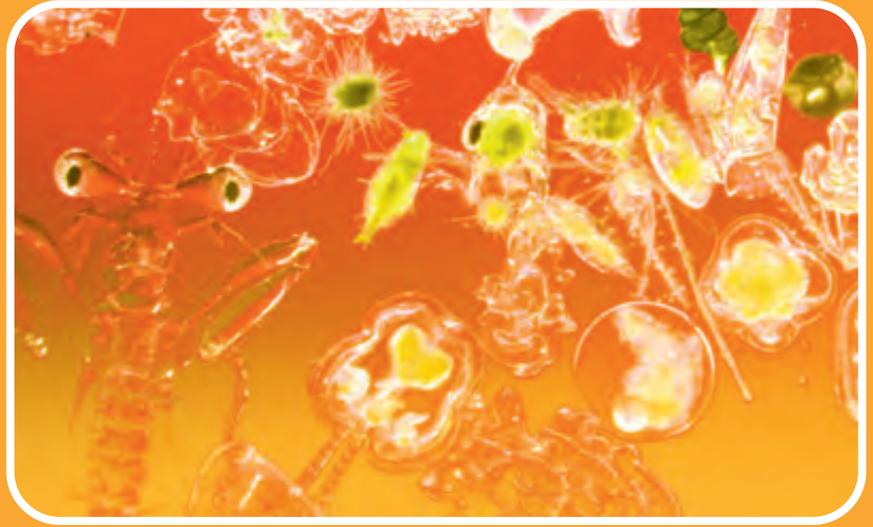
Plymouth Marine Sciences Partnership
c/o The Laboratory
Citadel Hill
Plymouth
PL1 2PB
Tel: +44 (0)1752 633 234
enquiries@pmsp.org.uk
www.pmsp.org.uk

¹ estimate from Fearnley 2005

² Sea Vision UK 2004

What will be the impacts of climate change on the oceans?

Climate change will impact on the way ocean ecosystems function. Better knowledge of climate impacts on the marine environment is vital for improved forecasts of future changes and for informing climate change policy. This is essential for our broader economic prosperity, security and well-being. Impacts will include:



Physical processes

- Increased frequency and severity of storm events
- Sea level rise
- Changes to ocean currents

Biological changes

- Massive shifts in global distribution of marine species
- Disruption to marine life cycles
- Rapid changes and losses in marine biodiversity

Changes to biological and chemical processes

- Combined temperature rise and lower pH will affect biogeochemical processes
- Changing ecosystem structures and function



What will be the impacts of climate change on the oceans?



Physical processes

Escalating natural disturbance events, including sea level rise and storms, will increase damage to coastal infrastructure, housing, transport (including ports and major coastal cities), as well as have a significant impact upon vulnerable habitats, such as corals and salt marshes, which provide natural coastal protection and important marine environments.

There will be serious risks and increasing pressures on coastal protection in South East Asia, small islands in the Caribbean and the Pacific, and large coastal cities, such as Tokyo, New York, Cairo and London. Rising sea levels will result in tens of millions more people flooded each year with 3-4°C warming¹.

Changing sea level, ocean currents, extreme weather events and other changes to climatic processes, will impact on aquaculture, shipping, food production, tourism and recreational industries.

Increased rainfall, melting of sea ice, glaciers and the Greenland ice sheet are all possible consequences of higher temperatures and could reduce North Atlantic surface water salinity sufficiently to slow down, or even stop, the thermohaline circulation which gives the UK its mild climate. Once stopped, the consequences would be a cooling of northwest Europe.

Changes to biological and chemical processes

Ocean biogeochemistry (i.e. the cycling of elements like carbon and nitrogen) is driven by activity in the ocean surface where sufficient light exists to stimulate photosynthesis. This process converts CO₂ and other nutrients into living biomass, on which all subsequent ocean productivity depends. Research has shown that the most significant changes in seawater temperature and pH levels so far have been observed in the surface layers of the oceans where the base of the marine food web is most active.

Phytoplankton, microscopic oceanic plants which live in the surface waters, take in CO₂ during growth and convert it into complex organic compounds. During biological cycles, some of the carbon is broken down and transported to the depths by faecal matter and dead organisms, creating a net transfer of carbon from the surface to the deep ocean in a process known as the 'biological pump'. The combination of increased levels of CO₂ and reduced productivity of phytoplankton will reduce the oceans' ability to process the carbon.

Biological changes

There will be major poleward shifts in species' distributions. Over the past 30 years, a 10° latitude northward shift in the distribution of many plankton and fish species has already been observed.

There will be changes to the seasonal timing of plankton production with consequences for plankton predator species, such as fish, whose own life cycles are timed according to the seasonal production of particular prey species.

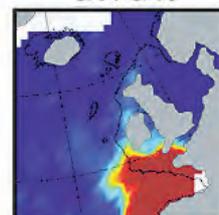
Many organisms, such as corals, urchins and species at the base of the food chain, will be impaired in their ability to digest, reproduce and grow due to the effects of ocean acidification.

Declining productivity at the base of the food chain will cause changes or loss of food resources for marine species. This will impact on the availability and accessibility of many commercially exploited fish (e.g. decline in stocks of cold water species such as cod).

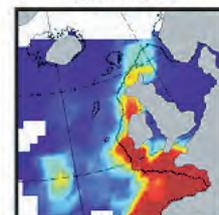
A 2°C warming could cause loss of 15-40% of biodiversity¹.

The decline in populations of native species may be caused by an increased invasion of non-native species.

Warm-temperate pseudo-oceanic species
1958-1981



1982-1999



0.00 0.02 0.04 0.06 0.08 0.10

CASE study:

Plankton distribution shifts

The image shows biogeographical changes in plankton assemblages spanning five decades. Warm water plankton are moving north and cold water plankton are moving out of the North Sea².

Researchers use long-term monitoring programmes to monitor changes in abundance, population structure and biogeographic distributions of a range of species.

Evidence suggests that species range expansion in response to climate warming is occurring quicker in marine systems (plankton, fish, intertidal species) than terrestrial systems.

CONTACT details:

Plymouth Marine Sciences Partnership
c/o The Laboratory
Citadel Hill
Plymouth
PL1 2PB
Tel: +44 (0)1752 633 234
enquiries@pmosp.org.uk
www.pmosp.org.uk

¹ Stern Report 2006

² Beaugrand et al SAHFOS ecological status report 2004/2005.

How will climate change impacts on the oceans affect our economy?

**“Climate change presents a unique challenge for economics: it is the greatest and widest-ranging market failure ever seen.”
(Stern Report)**

As a maritime nation, much of our social and economic activity relies on the marine environment, in addition to traditional goods and services, we increasingly understand the ‘value’ of less obvious ‘goods and services’.
Examples of climate impacts on both include:



Traditional goods and services

Increased costs of coastal protection
Implications for commercial fishing
Reduced access to raw materials
Changes in tourism and recreation opportunities

Less obvious goods and services

Loss of biodiversity and potential for biotechnology
Changes to trade, shipping and security
Increased potential and risks for renewable energy
Changes to physical-chemical-biological processes (e.g. nutrient cycles)



How will climate change impacts on the oceans affect our economy?



Traditional goods and services

Increased costs of coastal protection

Costs of man-made coastal protection will increase not only for low lying countries and island states but also for large coastal cities including London, New York and Tokyo.

The predictions are that the costs of flooding in the UK could increase by 15 fold by 2080, which would result in losses of over £20bn¹.

Disturbance prevention provided by natural regulating services such as saltmarshes could create cost savings of tens of millions of pounds.

Implications for commercial fishing

Impacts of reduced marine productivity at the base of the food chain will affect marine populations including commercially valuable species of fish.

The harvesting of marine organisms for human consumption is valued at £513m p.a. (2004) in the UK but this figure does not include the added value of fish processing and unreported catches.

Reduced access to raw materials

Risks and costs of extracting raw materials in more unpredictable environments will increase. UK offshore oil and gas sales amounted to £28.7bn in 2005, providing revenues and taxes of nearly £10bn back to the UK in 2005-06.

Changes in tourism and recreation opportunities

Loss of important ecological habitats such as cold and warm water corals could result in £billions lost from important sectors of the marine tourism and recreational industries.

Marine recreational services in the UK have been valued at £11.77bn p.a (2004).

Less obvious goods and services

Loss of biodiversity and potential for biotechnology

UK Marine biodiversity is extremely valuable and it has been estimated to provide services which are valued over £800bn p.a². Services within this figure include food provision, storm protection and climate regulation but many of the services provided could not be valued and are thus not included in this estimate.

Blue biotechnology is one of the most exciting emerging technology sectors with potential to provide innovative solutions in a number of industry sectors. The current global market is worth \$2.4bn which is projected to grow at more than 10% p.a.

Changes to trade, shipping and security

Costs and threats to world shipping due to increased risk of extreme weather events will increase. Worldwide merchant ships contribute \$380bn³ in freight costs. Shipping services used to carry cargo and passengers as well as vessel charter are worth £5bn⁴ to the UK economy.

Increased potential and risks for renewable energy

Costs of damage repair and maintenance of offshore installations, including renewable energy devices, will increase as severe weather events and wave size increase.

World industry in offshore renewables was valued at about £100m in 2004 and is forecast to grow to about £4bn by 2009. The UK has one of the largest wave energy resources, which by 2020 could be worth £0.2bn.

Changes to physical-chemical-biological processes (e.g. nutrient cycles)

The nutrient cycling support services provided by the oceans is invaluable and this service could not be replaced by any human designed process.

Gas and climate regulation services provided by the oceans are valued between £420m - £8.47bn p.a. (2004).



CASE study:

Economic impacts

Researchers in Plymouth were commissioned by Defra to produce a report on 'An Economic Valuation of UK Marine Biodiversity' to support and guide the Marine Bill.

Researchers have developed a goods and services approach to look at the economic, cultural and biological value of marine biodiversity.

These methods are being tested at case study sites across Europe, including the Isles of Scilly and Flamborough Head in the UK.

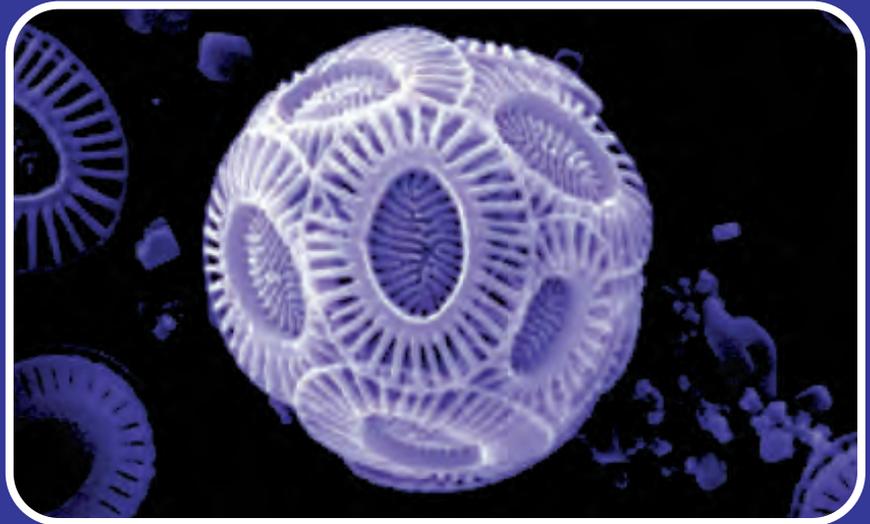
CONTACT details:

Plymouth Marine Sciences Partnership
c/o The Laboratory
Citadel Hill
Plymouth
PL1 2PB
Tel: +44 (0)1752 633 234
enquiries@pmssp.org.uk
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¹ Association of British Insurers. Financial Risks of Climate Change. Summary Report, June 2005
² Marine Biodiversity. An economic evaluation. Building the evidence base for the Marine Bill. Defra 2006. This value is subject to considerable limitations, see Beaumont et al. 2006
³ UNCTAD Maritime Transport
⁴ Sea Vision UK

What is ocean acidification?

The oceans have already absorbed 50% of CO₂ emissions since the industrial revolution. Whilst this has buffered climate change it is changing the chemistry of the oceans by reducing pH. This process will continue as we increase our emissions through burning fossil fuels, so that by 2050 pH will fall below levels experienced by marine ecosystems for around 20 million years. This rapid input of CO₂ is happening much faster than the slower neutralisation processes. Implications for the marine environment are:



Severe biological disruptions to marine life (e.g. shellfish and corals)

Effects on biological systems, processes and reactions

Reduced productivity for many important organisms

Alterations to the interactions between organisms

Reduction in the ocean's ability to absorb further atmospheric CO₂

Surface ocean acidification is happening now and will continue, as humans put more CO₂ into the atmosphere



610
VEGETATION

ATMOSPHERE 750

CO₂



What is ocean acidification?



The same man-made CO₂ 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 CO₂ problem” has received little attention until quite recently but it may turn out to be as serious as the more familiar global warming issue.

The world's oceans currently absorb on average about one metric tonne of CO₂ produced by each person every year. It is estimated that the surface waters of the oceans have taken up over 500,000 million tonnes of CO₂ (500 Gt CO₂), about half of all that generated by human activities since 1800. By absorbing all this additional CO₂ the oceans have buffered the effects of atmospheric climate change.

In the ocean, CO₂ reacts with seawater to form a weak (carbonic) acid and results in greater seawater acidity (expressed as a reduction in pH). As levels of CO₂ in the oceans increases so pH declines. Surface ocean pH has already rapidly declined by about 0.1 pH unit since pre-industrial times. This represents a 30% reduction in (alkaline) hydrogen ions.

If current CO₂ emission trends continue ocean pH will fall further by as much as 0.4 pH 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. These levels have not been experienced for at least the past 20 million years.

We do not fully understand the consequences of this acidification for the productivity of the oceans but scientific forecasts include the following impacts:

Severe biological disruptions to marine life (e.g. shellfish and corals)

The ability to produce calcium carbonate skeletons in marine organisms (such as certain species of plankton, sea urchins and corals) will be reduced or even stopped altogether.

Effects on biological systems, processes and reactions

Increased ocean acidity will have a detrimental effect upon the internal organs (digestive system, reproductive organs) of many marine organisms and will therefore reduce populations and even severely impact marine biodiversity.

Reduced productivity

The growth of phytoplankton (the basis of the marine food chain and an important element in the global carbon cycle) will be reduced by more than 20%, with a similar reduction in the production of oxygen, which could lead to an insufficient food supply from the sea.

Alterations to the interactions between organisms

Interactions between organisms will change and therefore alter the marine ecosystem. This may impair the oceans' ability to deliver the functions that benefit humans.

Reduction in the oceans' ability to absorb further atmospheric CO₂

Atmospheric CO₂ is absorbed in surface waters by phytoplankton, in particular coccolithophores (which are thought to be the largest producers of calcite on the planet). When these organisms die their calcium carbonate platelets, known as liths, rain down to the ocean floor where over geological time they are buried. This locks away carbon in the ocean sediments and in time can form vast geological formations such as the white cliffs of Dover.

Changes to biological systems, their productivity and the interactions between marine organisms are being observed and will impair the oceans' ability to absorb atmospheric CO₂.

Since the scientific 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 yet been addressed or considered. Understanding the impacts, predicting what future marine ecosystems will look like and determining 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.



CASE study:

Ocean Acidification Bergen Experiment

Plymouth scientists travelled to Bergen, Norway to undertake investigations into the effect of ocean acidification on the productivity of our oceans as part of Plymouth's research programme into ocean acidification.

The 3-week, large-scale mesocosm experiment was organised to manipulate the CO₂ concentration in the sea and explore how the marine microalgae and bacteria will respond to this more acidic environment.

Preliminary results show evidence of how vulnerable key food web organisms are to small and large changes in ocean pH.

CONTACT details:

Plymouth Marine Sciences Partnership
c/o The Laboratory
Citadel Hill
Plymouth
PL1 2PB
Tel: +44 (0)1752 633 234
enquiries@pmssp.org.uk
www.pmssp.org.uk

What are the future challenges?

There are conflicting views as to whether we can avoid the worst impacts of climate change or whether we now need to adapt to changes beyond our control. The complexity of Earth's changing climate, affecting various regions of the globe differently, presents a formidable challenge to society and science. Some challenges we need to address are:



Understand changes caused by human activity as opposed to natural trends

Recognise the certainty of ocean acidification, but the uncertainty of its effect

Quantify the nature, rate and distribution of climate change impacts in the ocean

Invest in sustainable approaches to flood and coastal management

Build on long-term monitoring

Improve models and future predictions to reduce uncertainty

Investigate risks and costs of carbon capture and storage

Organisms and ecosystems are going to have to deal with a number of major rapid global changes at once!



What are the future challenges?



Understand changes caused by human activity as opposed to natural trends

We are increasingly concerned about the influence of human activity on marine ecosystems. However, it is often difficult to separate man-made impacts from 'natural' trends. Long-term monitoring programmes can help to solve these difficulties and to enable us to identify local and broad-scale changes. For example, we need to investigate the separate effects of climate and fishing on UK fish stocks and ecosystems.

Recognise the certainty of ocean acidification, but the uncertainty of its effect

The study of altered ocean chemistry on marine organisms is still in its infancy and scientists are currently using mesocosms (large volume natural seawater enclosures) dosed with future CO₂ concentrations to study growth, physiology and production of important climate gases by these organisms.

We know quite a lot about the short-term impact of low pH on fish physiology, however, we know nothing about the long-term impact of pH reductions of 0.4-0.8 pH units.

The chemical changes that occur through ocean uptake of CO₂ may also indirectly affect fish through impacting the planktonic and benthic organisms which they rely on for food. The consequences for marine food webs are not yet well understood but could be very serious.

Quantify the nature, rate and distribution of climate change impacts in the sea, we need to:

Accurately assess the current state of marine ecosystems

Determine quantitatively how marine ecosystems are changing

Identify 'hotspots' for future change [in the UK]

Identify the most vulnerable species and ecosystems

Design dynamic marine protected areas to account for climate change

Invest in sustainable approaches to flood and coastal management

Improve understanding of changes in the offshore wave regime in terms of magnitude, frequency and direction.

Improve understanding of changes in the magnitude and frequency of extreme events.

Develop new techniques for reducing uncertainties in determining the behaviour of coastal morphology beyond that currently observed.

Build on long-term monitoring

In view of global change predictions there is a pressing need for long-term monitoring to continue, in order to provide baselines from which to assess the scale of future change and predict potential consequences for biodiversity and marine environmental 'goods and services'.

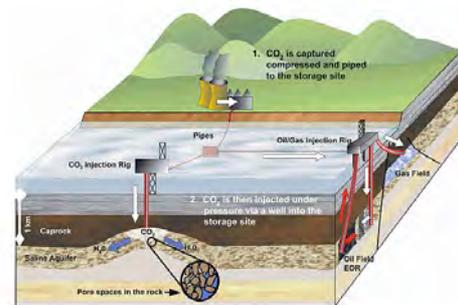
Long-term changes, such as those of climate change, can best be understood using long-term data sets, which can be costly and require long-term investment (POST 2004).

Will over-exploited fish stocks ever fully recover against a backdrop of climate change impacts, or will gelatinous organisms (like jellyfish) come to permanently dominate the UK's shelf sea ecosystems?

Improve models and future predictions to reduce uncertainty

We need to develop probabilistic forecasts for future sea levels, as opposed to the scenarios currently available.

We also need to develop new and improved ecosystem models to help us forecast future climate change impacts. These models will also help in developing better climate models which can then incorporate the role and impact of ocean biota into future climate change scenarios.



CASE study:

Carbon capture and storage

Researchers in Plymouth are working with the DTI and Defra to investigate the ecosystem risks associated with carbon capture and storage in the marine environment.

For the UK the strata hundreds of metres below the North Sea are a prime site for CO₂ storage. Studies will look at potential impacts on marine ecosystems and compare them to similar studies of the impact of increasing CO₂ on marine ecosystems to help inform UK policy makers.

Neither the UK, nor the international community, currently possess the capacity to answer these questions. Researchers from Plymouth are involved in a programme which aims to create this capacity.

CONTACT details:

Plymouth Marine Sciences Partnership
c/o The Laboratory
Citadel Hill
Plymouth
PL1 2PB
Tel: +44 (0)1752 633 234
enquiries@pmsp.org.uk
www.pmsp.org.uk

What opportunities are available?

The oceans play a critical role in climate change, but they also represent the largest living space on the planet and contain valuable resources. In taking steps to adapt to a changing world we can also take advantage of new opportunities that the oceans offer and make the most of these to support a sustainable future. Opportunities we are exploring include:



Carbon capture and storage

Working with the DTI and Defra to investigate the ecosystem risks associated with carbon capture and storage in the marine environment

Potential of aquaculture

Developing an ecosystem approach to sustainability of food production involving studies in Europe and China

Energy from offshore renewables

Wave Hub is a groundbreaking project in SW England to create the UK's first offshore facility for the testing and operation of wave energy generation devices

Marine biotechnology

We are working with industrial partners to identify sustainable and environmentally friendly alternatives to health and beauty products

Novel Technology

Collaborating with industry to develop autonomous sensors for measuring and monitoring marine environmental impacts and climate change



What opportunities are available?



Carbon capture and storage

Our scientists are developing a UK experimental facility and modelling capacity for exploring the effects of high CO₂ (including lowered pH) on UK shelf waters and to make an initial exploration of marine ecosystem response to elevated CO₂ either through ocean uptake of atmospheric CO₂ or through leakage from geological stores.

Potential of aquaculture

Researchers in Plymouth have long-standing working relationships with colleagues in Europe and China. Work in China is helping to develop better understanding of the interaction between the Chinese (marine) aquaculture industry and the ecosystems that sustain the resources.

Researchers are also working with colleagues in Portugal to apply new interdisciplinary approaches which combine natural and social sciences. These programmes address the complex scaling issues inherent in integrated management within a framework that accounts for watershed interactions, ecological structure and human activities.

Energy from offshore renewables

The South West of England Regional Development Agency supported Wave Hub project, involving researchers from Plymouth and Exeter, will enable the testing of wave energy generation devices through an electrical infrastructure under the sea. The wave hub is essential in helping to bridge the gap between production prototypes and full commercial wave farms. The project will support the UK's drive to meet the challenges and achieve the goals of the new energy policy including a 60% reduction in carbon emissions by 2050. Researchers in Plymouth and Exeter will use the facility to support further research into wave energy generation and associated impacts.

Marine (blue) biotechnology

Microscopic plants and bacteria in the sea contain unique suites of compounds of benefit to humans. One suite of compounds provides protection against the sun's intense rays in the surface of the oceans and has

potential in a range of healthcare products. Researchers in Plymouth are working to identify the most suitable conditions for high productivity of these microalgae and bacteria. Collaboration with industry will facilitate transfer of this knowledge and developments to healthcare and energy sectors.

Researchers in Plymouth are also developing innovative ways of solving the dual issues of managing excess CO₂ outputs and increasing supply of energy from renewable sources. Current studies are looking at removal of CO₂ from flue gases and converting it on site into a continuous supply of biofuels.

Novel Technology

Among a range of novel autonomous sensors researchers in Plymouth have developed and deployed two novel sampling systems to help characterise surface layers in the oceans' a novel near surface sampling device (NSSD) and a microlayer sampling device (MLSD). New instruments are now being developed that will allow us to map the fluxes of CO₂ between the sea and the atmosphere. This is essential for the next generation of climate models being developed by the UK Met Office's Hadley Centre for Climate Change.

Ocean and human health

An opportunity to develop a regional Centre of Excellence

There is increasing awareness that the environment plays an essential role in ensuring good human health. According to the World Health Organization, the major risks include "...climate change, stratospheric ozone depletion, loss of biodiversity... and stresses on food-producing systems." Interactions between living things and the environment are incredibly complex and we are only now beginning to comprehend the magnitude of the problems for our future well-being that human activities have created. There are continued pressures from human development of the coastal zones and from our use of these areas for leisure and tourism. Overall, we have a very poor understanding of how future climate change will affect the behaviour of pathogens and pollutants in the seas around the UK.

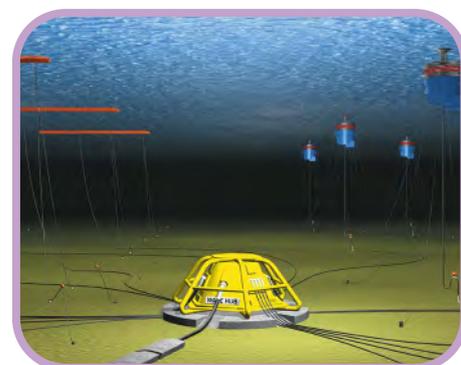


Illustration by Industrial Art Studio - www.ind-art.co.uk

CASE study:

Wave Hub

Wave Hub is a groundbreaking renewable energy project in SW England to create the UK's first offshore facility for the testing and operation of wave energy generation devices. Wave hub will provide an electrical infrastructure under the sea into which wave energy generation devices can be plugged and their outputs and efficiencies tested.

The project will support the UK's drive to meet the challenges and achieve goals of the new energy policy including a 60% reduction in carbon emissions by 2050.

Wave Hub is supported by the South West of England Regional Development Agency (SWRDA) and will involve researchers from Plymouth and Exeter who will use the facility to support further research into wave energy generation and impacts.

CONTACT details:

Plymouth Marine Sciences Partnership
c/o The Laboratory
Citadel Hill
Plymouth
PL1 2PB
Tel: +44 (0)1752 633 234
enquiries@pmsp.org.uk
www.pmsp.org.uk