Plymouth Marine Laboratory is within a few minutes’ walk of the famous Plymouth Hoe and coast. This location provides easy access to coastal and shallow sea environments, in particular the Western English Channel, which has been the subject of long-term study for over a century. Regular data recording through PML’s data buoys, stationed in the Channel, and frequent monitoring and collecting trips using PML’s research vessels ensure detailed surveillance of the local marine environment, which informs studies at national and regional scales.
Plymouth Marine Laboratory (PML) science remains globally significant, as evidenced by the quality of its publication record, often in high impact journals. During this year further recognition for PML science came through a Research Council commissioned analysis, which showed that PML outperforms other UK environmental science providers in terms of its impact.

Terence Lewis
Chair of the PML Board of Trustees

“It has been a difficult year for UK and European finances and, consequently, for many research organizations. These difficult times are not yet over; however, PML has continued to do very well, a direct result of its track record of delivering excellent and relevant science on time and to budget, which bodes well for the future.”

Prof. Stephen de Mora
PML Chief Executive

“Plymouth Marine Laboratory is an independent institute, with a globally recognised reputation for scientific excellence, working on challenging science and related societal issues. PML’s strength comes from good teamwork linking its marine observations and experiments to remote sensing and ecosystem modelling.

Benefiting from diverse funding opportunities in the UK and Europe, PML builds on the foundations of its long-term science, which comprises a notable PML contribution to Natural Environment Research Council (NERC) National Capability. Working together and in a network of highly valued partner institutes at home and abroad, PML is able to tackle perplexing societal issues including: ocean acidification, food security and marine planning.

Through sharing a passion for the marine environment and to unravel its scientific mysteries, ‘Listen to the Ocean’ will be a guiding mantra in PML’s future, ensuring PML continues to learn what it can of the global seas and act for the benefit of future generations.”

For more information about PML please visit www.pml.ac.uk or follow us on Twitter @PlymouthMarine
PML’s major strength is vested in its science, support and technical staff. With an almost equal split between male and female amongst its staff of 146 and about 20% of its workforce originating from outside the UK, PML can draw upon a vast range of experience and expertise to create multidisciplinary teams to address the issues facing today’s society. With a special blend of continuity, from its experienced Heads of Science, the dedication of its science staff and the opportunity to inject fresh ideas from a rolling programme of PhD studentships, PML is perfectly equipped to face the challenges facing the marine environment.

Prof. Bess Ward – visiting scientist from Princeton, USA: “PML is one of the premier marine laboratories in the UK, and I had already established collaborations over the last few years working on aspects of biogeochemistry and ocean acidification, and as a Trustee, so Plymouth was a natural choice for me.”

Dave Smith – Head of Technical Services: “My career has taken me down many paths but some of the work that I do at PML is probably the most rewarding, as it’s kind of a payback for the many years that I made a good living from sailing the oceans and paid little heed to the ecological damage caused through uncontrolled working practices.”

Dr Peter Claridge – Deputy Chief Executive and Director of Operations (retiring): “During my time at PML I’ve seen and been part of many changes, not only in response to external drivers but also proactively to enhance the relevance and delivery of excellent science for the benefit of our customers and stakeholders.”

Dr Steve Widdicombe – Head of Science, Marine Life Support Systems: “The huge variety of marine organisms living in coastal waters creates some of the most complex, productive and beautiful ecosystems on the planet. By studying everything from tiny bacteria and plankton to large animals and plants we are increasingly able to understand how these ecosystems work and how human activities are impacting upon them.”
Stephanie Sergeant - PhD student: “I am looking at bacterial uptake of methanol in the marine environment. I came to PML, because it’s one of the leading academic institutes for my science and it has a great research reputation.”

Dr Phil Nightingale - Head of Science, Cycling in the Sunlit Ocean: “It’s a great time to be a Head of Science. We’re conducting world-leading research on methanol in seawater, on the processes controlling air-sea exchange and on the impact of ocean acidification on biogeochemistry in the Arctic and Antarctic.”

Chris Taysom - Director of Finance and Operations: “Having recently joined I am amazed at the diversity of the marine science areas covered by PML and impressed by the dedication and enthusiasm of the scientists and support staff.”

Dr Melanie Austen - Head of Science, Sea and Society: “We are at the cutting edge of undertaking and leading UK and European research into why people should and do value marine ecosystems, what affects these values, and how society can take this into account in managing and sustainably exploiting our use of our seas and their natural products.”

Jeroen Ingels - Marie Curie Fellow: “I am a marine benthic ecologist and I chose PML, for various reasons. Firstly the opportunity to broaden my skill set into new scientific and managerial disciplines. Secondly to work in an environment that regards people as its most valuable resource. Thirdly I was tempted by the expertise, knowledge and understanding of how anthropogenic stressors affect marine ecosystem health and functions.”

Steve Groom - Head of Science, Sea from Space: “PML has the largest marine remote sensing group in the UK and its reputation for innovation, research and services ensures it remains at the forefront of Earth observation through leading and participating in a growing number of UK, European and globally focused projects.”

Matthew Cole - PhD student: “I’m doing a PhD with PML and Exeter University, looking at impacts of microplastics on the marine food web. Having access to regular zooplankton trawls, modelling data, a range of laboratory analysis equipment, and zooplankton experts, has allowed me to further my research in a number of new and exciting directions.”

Prof. Manuel Barange - Director of Science: “A recent UK Research Council assessment revealed that the science conducted at PML outperforms other environmental science providers in terms of its scientific impact. This gives us confidence that our science implementation strategies have the right balance on innovation and quality assurance to succeed.”

Dr Icarus Allen - Head of Science, Today’s Models, Tomorrow’s Futures: “PML has one of largest and most energetic marine ecosystem modelling groups in the world. Our models provide a means of investigating the interactions between human activity and climate impact on different parts of the ecosystem.”
Above: The QICS experiment involved benthic-deployed gas sensors, sediment and organism sampling and direct observation by divers. (Courtesy Scottish Association for Marine Science [SAMS]).

Laboratory and, increasingly, in situ studies by PML scientists and their collaborators have already demonstrated that CO₂ can lead to ocean acidification, with consequences for marine life.
Increasing levels of carbon dioxide (CO₂) from human activities threaten the global climate and are moving the chemistry of the world ocean towards acidity, a phenomenon known as ocean acidification (OA). CO₂ capture and storage (CCS) is one method of removing CO₂ before it enters the atmosphere and, ultimately, the ocean.

PML has been at the forefront of research trying to establish how marine life might be affected, which organisms might be susceptible or resilient to the changes and under what timescales impacts might manifest themselves.

Measuring the impacts of a CO₂ leak
Growing levels of atmospheric CO₂, resulting in global warming and climate change, and in seawater OA, has led to an imperative to mitigate these effects.

One obvious strategy is to reduce the amount of CO₂ being produced as a by-product of human industry and fossil fuel usage, although this has not met with universal political support. Another obvious action is to prevent the CO₂ that is produced from reaching the atmosphere, where it can continue to contribute to potentially globally damaging consequences.

Amongst the suggested approaches is the use of Carbon Dioxide Capture and Storage (CCS), which collects CO₂ at source, usually transports it to another location and finally injects it into deep geological strata where it becomes effectively locked away from the atmosphere, out of harm’s way. The process may sound simple and the technology for each stage of the process is tried and tested, but it has still to be accepted as a preferred mitigation strategy.

Already there are a number of large-scale pilot projects in parts of the world where depleted oil or gas reservoirs are being used as the final storage sites for our excess CO₂ and, by their nature, many of these are located in sub-seabed strata.

But, what happens if the stored gas seeps through the strata and leaks out onto the seabed? Laboratory and, increasingly, in situ studies by PML scientists and their collaborators have already demonstrated that CO₂ can lead to ocean acidification, with consequences for marine life. A CO₂ leak from a sub-seabed reservoir can be thought of as a localised, but potentially more rapid and more concentrated OA event. PML is playing a leading role in a number of research projects looking at the implications of a CO₂ leak into seabed ecosystems.

QICS off the mark
One of this year’s great successes in CCS studies has been a PML managed project, working with the Scottish Association for Marine Sciences, the British Geological Survey and other UK research institutes and colleagues from Japan.

The project Quantifying and Monitoring Potential Ecosystem Impacts of Geological Carbon Storage (QICS), led by PML, is a world-first controlled CO₂ release, beneath a Scottish sea loch.
The Experiment...
Prior to drilling, Scottish colleagues gathered a wealth of data on all aspects of the loch bed and the sediments, and undertook wide-ranging consultations with governmental, licensing and other interested groups and individuals to introduce the experiment and address any concerns they may have had.

The carefully controlled release of CO₂ into the sand and mud sediments took place over a period of 36 days beginning in May 2012; this was followed by a 90 day period of monitoring recovery. A comprehensive set of carefully timed, physical, chemical and biological properties of the sediment and the overlying water were measured during and after the controlled leak event. These measurements were made at distances; for comparative purposes, similar measurements were made at of the CO₂ natural variations that might have occurred within the experimental period. The mass of data that resulted from the experiment is now being analysed and will further inform future predictive models.

RISCS – Research into Impacts and Safety in CO₂ Storage
RISCS is a multi-institute research project which brings together various expertise to predict what might happen if a leak takes place. PML’s crucial role is to apply its modelling experience and knowledge to hypothetical situations by building all appropriate available data into its models to gain the most accurate picture possible.

Each potential leak scenario will, of course, be unique and how the resulting plumes behave will depend on variables such as flux rates, tidal state and season. The Finite Volume Coastal Model (FVCOM) coupled to a carbonate system model, that shows chemical changes when a CO₂ influx takes place at depth, is being applied to a set of generic scenarios to gain the best possible idea of likely plume dispersions.

Another modelling exercise took hypothetical scenarios of seawater ecology and benthic (seabed) species in order to inform impact studies in the event of a leak. The model used the conversion of pelagic particulate matter, which is produced by plankton and seagrass, into detritus reaching the seafloor. Because the nutrient cycles interact with dissolved oxygen it is possible to estimate the amount of oxygen being produced by the seagrasses.

Four target species: fish, meiobenthos, deposit feeders and suspension feeders were used as a simple foodweb to populate the conceptual food web. The model’s simulations, with an emissions flux set at a steady rate over a 62 day period, predicted that, while the biomass of the deposit and suspension feeders was reduced to almost zero, the seagrass biomass actually increased due to a reduction in grazing. Encouragingly, collaborating researchers have shown that measurements at natural analogue sites support the predictions of the models and underline the highly variable nature of leakage scenarios, but do demonstrate rapid dilution of CO₂ with distance from the ‘large source’.

Impacts of CO₂
PML continues as a lead partner in the Europe-wide ECO₂ project, which brings together expertise from a wide range of scientific disciplines, industry knowledge and experience to assess the full range of impacts that might accrue from a CO₂ leak and their implications.

PML is involved in three aspects of this project: firstly, leading a work package on modelling the behaviour of any escaping gases from a storage site beneath the seabed to ascertain whether they pose serious threats to marine life, and, if they do, how extensive and long-lasting they may be.
The global oil and gas company, Statoil, is an industry partner in the ECO2 project and studies of their existing storage facility at Sleipner in the North Sea are providing a background of reality to any model predictions. Another work package builds upon the expertise that PML has gained from its ocean acidification research to determine how, in the event of a leak, benthic marine life will be affected. Laboratory and in situ experiments and measurements have been developed to look at effects upon individual species over a long time period, as well as more broadly across seabed communities.

Apart from the research being carried out at PML, its scientists are also co-ordinating complementary work being carried out in a range of other laboratories. A third element of the ECO2 project concerns how the wider public and other stakeholders will accept or reject the potential of sub-seabed storage as a mitigation technology for climate change.

Working with social scientists from the Universities of Rome and Edinburgh a series of ‘focus groups’ and other interviews have taken place, while a second strand is to produce a final glossary of CCS terminology for use across this and other projects.

Shellfish motives

Following a series of high profile international meetings and a general acceptance that it is real, the OA problem has become the subject of concern for stakeholders beyond the scientific community. Marine molluscs, which form calcareous shells, have always been seen as potentially at risk as ocean pH continues to drop. As existing food resources, which are predicted to become more important globally, any impact on molluscs threatens to have widespread consequences on human food security.

Those who are directly involved with marine based food products have begun to ask what the future holds for them. PML, with its multi-disciplinary approach to such questions, was able to send a marine chemist and an environmental economist to present a summary of OA knowledge and potential impacts to the annual meeting of the Association of Scottish Shellfish Growers at a workshop that attracted much interest from growers.

Speaking from first-hand experience of the research carried out at PML, which is directly relevant to the shellfish industry, the speakers succeeded in opening a dialogue with professional shellfish growers, and discussed opportunities for future collaborative work between PML science and the shellfish industry. The industry perspective is that this is a three to four generation problem, but they did recognise the need to be kept informed of any specific research that demonstrates sensitivities of individual species as it becomes available.
Maintaining long time-series of data has always been regarded as essential to an understanding of the wider scale workings of the marine environment, and is key to establishing the reliability of trends that may be useful in projecting forwards any implications of global changes. Indeed, the Natural Environment Research Council (NERC) has identified this requirement as part of National Capability.

Climate change and ocean acidification, for example, are likely to have ecological consequences that in turn impact upon marine goods and services and ultimately affect human populations economically and societally. In recognition of the importance of gaining such knowledge and as a key component of building National Capability and preparedness, PML maintains the Western Channel Observatory (WCO) – an oceanographic time-series and marine biodiversity reference site in the Western English Channel. Autonomous data buoys collect data on an increasing range of chemical, physical and biological aspects of the Western Channel.

The WCO provides an ideal platform for collaborative projects and supports the work of many other organizations, notably the UK Met Office, who are working with PML to provide a new data buoy at the E1 site.
In situ measurements, including light, temperature, salinity and nutrients, are undertaken weekly at coastal station L4, which has some of the longest time-series in the world for zooplankton and phytoplankton, and fish trawls going back a century. At the open shelf station E1, which has a hydrographic series dating back to 1903, measurements are taken fortnightly. These long series are complemented by hourly measurements, transmitted back 'to base', made at PML’s autonomous data buoys moored at both stations, so enhancing the ability to capture changes not seen in a weekly sampling. Complementing this unique data series is PML’s recognised excellence in ecosystem modelling and satellite remote sensing science.

Plankton trends
Weekly seawater samples collected at the L4 station are examined microscopically for phytoplankton and microzooplankton species composition, while other samples are analysed via analytical flow cytometry for smaller phytoplankton, bacteria and heterotrophic flagellates. Such a regular and comparable time-series has allowed analysis of seasonality, composition and abundance at a fine scale over a long period of time – an ideal tool for establishing the presence of trends and detecting changes.

The picture that has emerged is that the L4 phytoplankton community exhibits strong seasonal and interannual patterns of composition and abundance. Surface chlorophyll-a, for example, shows lowest values during autumn and winter, with distinct peaks in spring and late summer. Phytoplankton are also less abundant during autumn and winter but become more abundant, and show a greater variation in species composition, at the onset of the spring bloom.

The observed patterns reflect the measured nutrient availability, being highest in winter so feeding the spring bloom which then depletes the resource, for it to recover during the following winter.

Whilst there are difficulties in establishing long-term trends, because of interannual variability of the species composition, there does appear to be a decline in diatoms and an increase in coccolithophores and dinoflagellates. This appears to be linked to an observed 0.5°C increase in sea surface temperature over the last 50 years, which would naturally favour dinoflagellates.

Such changes in timing, composition and abundance of the phytoplankton communities may impact the zooplankton communities, as well as affecting carbon export to seabed communities. In turn, this might lead to negative impacts on commercial fisheries and ultimately human health, potential conclusions that can only be drawn from long-time-series.

Measuring aerosols
Aerosols, minute particles suspended in the atmosphere, play a vital role in the Earth’s energy budget. They can scatter and absorb sunlight and act as condensation nuclei and so are important in cloud formation and hence are important in climate change studies. Atmospheric aerosol observations have formed part of the activities of the WCO since 2000 when an automatic sun-sky photometer was deployed to take measurements every ten minutes.

The weather in Plymouth is variable, often preventing optical aerosol retrieval, but the frequency of measurements taken over an eight year period ensured the best possible opportunity to take advantage of cloudless intervals. In all a total of 314 daily averages were obtained, sufficient to enable a thorough characterisation of the aerosol optical properties for the site.

Sun photometric data from maritime sites, such as the WCO, around the North Atlantic are scarce, so this long series of data will be instrumental in understanding how aerosols affect global sea surface temperatures and ultimately land temperature. Piecing together an aerosol climatology of European Atlantic shores should prove of immense value when it comes to refining climate models for future predictions of global change.
The most recent Atlantic Meridional Transect (AMT) research cruise took place during October and November adding significant knowledge to the long-term dataset that has already been collected.

Since it began in 1995, AMT has provided a platform to undertake important open ocean observations for 223 scientists from more than 60 research institutes in 18 countries; has produced 220 significant scientific papers to date, and contributed to 75 PhD studies. AMT science is co-ordinated by PML as a key part of UK National Capability, and a perfect example of facilitating collaborative research to address questions of national concern.

Long-term studies are especially important when considering issues of global importance. The AMT has, over the years, contributed huge amounts of data which are especially valuable as they relate to areas of the ocean which are otherwise little known. Whilst much of the data appears in scientific papers, 220 since AMT began, its value does not end after initial research results are published. Indeed such is the nature of the long-term studies that some scientific results reviewing trends on a number of scientific fronts can take decades to collect, collate, analyse and publish. The real worth of this huge amount of data is its longevity and the unique information it can generate to answer new questions.

Unique collaborations

The latest AMT cruise aboard the NERC vessel, RRS James Cook (pictured right) followed a course from Southampton to Chile, in the South Atlantic. AMT continues to build its unique database of key scientific readings and measurements, including those around microbial and planktonic distributions, activities and interactions, and is adding to its extensive database of measurements concerning the mechanisms, rates and nature of how gases move between air and sea.

Impact

Since 2002 AMT data has been lodged with, and managed by, the British Oceanographic Data Centre (BODC), which makes it available to a wide range of researchers. Over this period 1200 requests for data have been received from NERC Research Centres, UK and overseas universities, the UK Met Office, hydrographic offices (UK and overseas), members of the public and consultancies – in total 123 organizations from 29 countries across
North and South America, Europe, the Middle East, Africa and Australasia. In 2010 and 2011 nearly 300 requests for data were received and in the first seven months of 2012 almost 80 requests had been received. Apart from use by the immediate AMT community and cruise participants, the data is widely used, across the academic community, for validation of satellite algorithms; parameterisation of biogeochemical models; validation of biogeochemical models; as part of university undergraduate courses where data analysis is being demonstrated, and in postgraduate studies.

Other research projects using AMT data include: studying the relationship between nutrient concentration and nitrogen fixation; investigating long-term global trends in dissolved organic carbon and, investigating the relationship between biodiversity and community size structure in copepods on an ocean-wide scale. The vast amount of data has also been incorporated into meta-analyses of datasets from a number of projects and cruises.

4. Carefully collected and recorded AMT data is lodged with the British Oceanographic Data Centre (BODC), which has received 1,200 access requests for the data in the last ten years.

AMT is unique
The AMT programme is unique for a number of reasons. It is the longest series of observational cruises of its type; it covers 100° of latitude of rarely recorded ocean and above all it encourages international collaborations by providing opportunities for established and early career scientists to carry out world-class research in situ, so adding to global knowledge in an era when knowing how the ocean works is crucial to its sustainable management.
Modelling the future

Atmosphere

Pelagic

Phytoplankton

Particulates

Dissolved

Bacteria

Pico-f

Micro-

Meso-

Heterotrophs

Suspension

Feeder

Mesobenthos

Deposit

feeders

Aerobic

Bacteria

Anaerobic

Bacteria

Redox

Discontinuity

Layer

Reduced

Layer

Oxygenated

Layer

Benthic

Redox

Discontinuity

Layer

Reduced

Layer

Above: The ERSEM model can be modified to increase the detail of inputs, hence the accuracy of outputs.
PML’s interdisciplinary approach which brings together knowledge, expertise and rigorous research across an impressive range of marine topics is best demonstrated through its world-renowned modelling group.

Now recognised as the largest group of its kind in Europe, and therefore one of the largest in the world, the group does not just apply modelling techniques to solve problems and predict future scenarios; it is a global leader in developing innovative modelling applications, and refining them for precision and accuracy. As such the group continues to expand to meet the demand for its skills and experience and is a leader or significant partner in many UK-based and international projects.

Ultimately such modelling is a servant of humankind, providing valuable information crucial to understanding the marine environment now, managing it in the future, so ensuring sustainability of marine systems, and informing predictability of health issues, ocean-based food resources and other goods and services.

**Single cell to global ocean**

The impacts of climate change and its related phenomena on marine systems present a complex challenge when taken in the context of other pressures faced by the ocean. Sophisticated and often coupled modelling approaches offer the only reliable way of including all of the parameters necessary to begin to understand how the intricate web of marine life interacts, and how it might be affected by natural and anthropogenic changes.

Modelling can, however, be applied at the microscopic scale, predicting how single-celled organisms might react to changes, or across ecosystems to assess how they may be impacted by installation of marine energy devices, for example.

PML has been especially successful in developing models that work across a range of scales so enabling the detail of microorganisms and their activities to be included in broader scale investigations on environmental consequences of change.

**Model refinement**

Coastal waters are not just ecologically interesting, they also have a crucial socio-economic role and are thus of great relevance to human societies. It is thus important to understand how they function and how they may be altered in the face of wider global changes such as ocean acidification.

A key role of the ocean is in climate control and particularly acting as a sink for CO₂, which perturbs the carbonate system and results in a lowering of ocean pH. However, the coastal waters are inherently complex and require sophisticated approaches if we are to understand them and begin to predict how they may be affected into the future.

Complex hydrodynamic and ecosystem models can be brought together to capture the significant heterogeneity of such areas, but rigorous validation is essential to ensure that such model combinations are reliable. By coupling the POLCOMS and ERSEM models together, which brings together the physical and ecological characteristics of an area, it is possible to produce a much clearer picture of what is happening, or through forcing, what might happen under any given conditions.
Further refinement...

PML scientists have further refined the coupled model by parameterising it specifically to take into account the effects of riverine inputs and the influence of biological processes on alkalinity. Whilst the new model has been validated showing good to reasonable agreement on principal variables, and so will be useful as a tool to provide information on some ocean acidification (OA) scenarios, there is still a need for further reduction of uncertainties concerning pH and partial pressure of CO₂ if impacts of OA on ecosystem functions are to be included.

Modelling photoprotection in plankton

In the marine environment light levels can fluctuate wildly over periods of seconds or hours to seasons, and from dark to intense light. Phytoplankton, reliant upon sunlight for photosynthesis, can thus experience conditions from light-limited to light supra-saturated. Too much light can be damaging and actually lead to a reduction in the photosynthetic rate of cells - so-called photo-inhibition which can compromise cell survival. Hence mechanisms have evolved to protect plankton cells from, and acclimatise to, increasing light conditions; often such photoprotection is a rapid process, on a time-scale of minutes, allowing cells to react to changing conditions.

Simply, the mechanism, which is reversible, causes one form of the pigment xanthophyll to change into another form which is more or less resistant to increasing light levels - this is known as the xanthophyll cycle. Despite the importance of this mechanism in marine algae, to date no model has been generated that can describe the changes that take place under a range of scenarios.

PML modellers, using existing experimental data, have now developed a numerical model which, for the first time, describes the observed xanthophyll dynamics involved in phytoplankton photoprotection and photo-inhibition.

This shows that it is possible to model the pigment dynamics under changing light conditions so that light-dependent photosynthetic pigments are converted to photoprotective pigments: a pathway that could protect the cell from photo-inhibition under sudden and steep increases in light. Such a model has the potential for being used in studies of the consequences of xanthophyll dynamics for competition and succession in phytoplankton communities.

Modelling for energy

PML modelling experience and skill lends itself to a wide range of applications wherever diverse and interacting parameters have to be balanced to ensure reliable interpretation of future scenarios. One such area is marine renewable energy which, while still in its youth in this country, is rapidly moving towards maturity, not least through economic and political drivers in the light of increasing amounts of carbon dioxide from fossil fuels entering the atmosphere.

PML’s applied ecosystem modelling offers great potential for assessing not just the immediate impacts of installation of devices, but also the less obvious effects on surrounding waters. These devices extract energy from the currents or waves so modifying the energetic balance; currents and mixing will also be affected with the potential for ecosystem impacts down the line. PML modellers are involved in a number of projects which aim to extrapolate from single device installations. One of these is Flow and Benthic Ecology 4D (FLOWBEC), a three-year, £1.2 million project, that brings together a consortium of researchers (including PML scientists) to investigate the effects of devices which harness tidal and wave energy. It is funded by NERC and the Department for Environment, Food and Rural Affairs (Defra).
GreenSeas

Global challenges require global partnerships and GreenSeas is one such project which brings PML scientists into a close working worldwide collaboration with partners from as far afield as South Africa, Brazil, Russia, Australia, Norway and Italy.

The GreenSeas project is a recognition that climate and other changes will affect the distributions, composition and timing of plankton. This, potentially, has an impact further along food chains and could affect world food supplies.

The project aims to uncover how phytoplankton, bacterioplankton, and zooplankton might be affected and draws together a combination of observation data, numerical simulations and a cross-disciplinary synthesis to develop a high quality, harmonised and standardised plankton and plankton ecology, long time-series, data inventory and information service. It is building on historical data-sets, and ongoing multidisciplinary ocean planktonic ecosystem monitoring programmes, enhanced where possible.

The heart of the GreenSeas concept is establishing a ‘core’ service. PML’s significant contribution to the project is to apply its expertise and experience, to improve the ability to model and project future marine ecosystem states, and to identify a list of environmental indicators that can be used in a predictive manner through models. Such an exercise will be of great importance for policy makers, as well as the wider scientific community.

PML’s significant contribution to the project is to apply its expertise and experience, to improve the ability to model and project future marine ecosystem states.
Satellites for marine science

Working with colleagues in the UK and across the world PML has increased its reputation and influence to become a global leader in the use of Earth observation.
The use of satellite remote sensing for Earth observation is a proven method of gaining data about and insight into, wide-scale phenomena which are of importance and concern globally.

PML remains at the forefront of developing and refining the techniques, improving the accuracy and validating the precision of the information that can be gained.

Working with colleagues in the UK and across the world, PML has increased its reputation and influence to become a world leader in the use of Earth observation, especially as it pertains to the global ocean; how it functions; how it interacts with the atmosphere and the terrestrial environment, and how it is being affected by global change.

Ocean colour detected from plankton across the ocean is a powerful tool for analysing the distributions and even the make-up of phytoplankton blooms. Gaining detailed information is of great interest to the studies of climate change, fisheries’ management and the early detection of harmful algal blooms.

Global plankton
Phytoplankton phenology, the timings of bloom and quiescence, has in recent years been proposed as an indicator of the state of the pelagic marine environment and, in the event of perturbation of environmental conditions, as a useful monitor of change.


The ocean colour data obtained showed that the growing period in the tropics and sub-tropics while long, at 15-20 weeks, was also of low amplitude. In the high latitudes the opposite occurred with a short growing period of less than 10 weeks but at higher amplitude.

Further analysis showed that this was closely coupled to seasonal increases in insolation in the high latitudes where seasonality was a stronger influence; in the tropics and sub-tropics where variability in light levels is less marked, nutrient availability due to increased mixing was the controlling factor. Anomalies linked to El Niño and La Niña events were also apparent, while warmer sea surface temperature resulted in extended growing periods over the summer months at high latitudes, but a shorter growing period in the tropics and sub-tropics, indicating an increase in stratification.

This PML investigation has demonstrated that the phenology of the phytoplankton can be measured using remotely sensed ocean colour data at a weekly resolution; that it differs across the latitudes; that it is sensitive to environmental changes and that it can influence wider ecological changes, such as food supply to higher trophic levels. The overall conclusion is that this method is useful in analysing and monitoring the pelagic environment.
Plankton growth and primary production

Further study of the plankton phenology around Iceland and the Faroes, by PML scientists with colleagues from Canada and Iceland, is providing information that can be utilized in analyses of the survival and growth of plankton grazers and scavengers.

Correlations between plankton growth and primary production that can be useful in understanding the variations that occur in harvestable marine organisms and provide good advice to managers of marine food resources.

The use of satellite remotely sensed data to provide a valuable tool for studying phytoplankton phenology. The results gained are consistent with those obtained from more conventional cruise-based research, but go much further in terms of spatial and temporal coverage.

Assessing microbes from space

Observations from space provide unique information which greatly assists the successful understanding and management of climate change.

Over the course of the last few years a robust and formalised dialogue between the bodies with responsibility for the specification of climate observations and space agencies has led to a coherent set of requirements, agreed globally.

“Climate change is arguably the greatest challenge facing mankind in the twenty-first century. Its importance has been recognised in recent reports from the IPCC and from UNFCCC, and the overwhelming economic consequences are set out in the Stern Report.” (European Space Agency)
The European Space Agency (ESA) has responded to this requirement through its Climate Change Initiative Programme (CCI), intended to make best use of ESA archived data alongside other datasets in a coherent way, available to all. Of the fourteen essential climate variables (ECV) that were identified, PML, working in collaboration with an international team including participants from France, Germany, Italy and the UK in Europe, as well as Canada, USA and Japan, has taken the lead on the part of the project which concentrates on the ocean colour ECV.

A key aim of the PML-led team is to develop and validate algorithms to meet the requirement for consistency across multi-sensor data archives. This in turn will be used to produce the most complete, validated time-series of multi-sensor global satellite data products for climate research and modelling.

Currently there are a wide range of algorithms that perform better or worse in particular circumstances; the first part of this project will take existing algorithms that interpret the ‘water leaving radiance’ within the visible domain and compare them to assess which are the most appropriate. Data from ESA’s MERIS, and NASA’s SeaWiFS and MODIS sensors are being utilised.

So far, a ‘round robin’ comparison of algorithms currently used showed that there are differences between the categories of algorithm and analytical models being assessed.

As a result of this assessment an objective classification has been created which is able to rank the performance of a suite of bio-optical models. A key conclusion is that performance varies depending on the product and the wavelength of interest.

**Ocean truthing**

Refining the interpretation of ocean colour measured from satellites requires accurate measurement of *in situ* properties taken from actual samples, often collected at sea.

PML’s cross-disciplinary methods of working ensure that groups of scientists can address the same questions from a range of expertise.

One recent research project involved seawater sampling near the Mid-Atlantic Ridge, Charlie Gibbs Fracture Zone. Optical casts and simultaneous water samples enabled analysis of the contents of the water and its optical properties, especially its back-scattering coefficient - which would be detected by satellite sensors.

Such detailed investigation *in situ* from the RRS Discovery was carried out across the frontal zone, which represented a range of microbe habitats and, hence, an ideal series of comparisons in a relatively short transect.

By using pigments, flow cytometry and microscopy techniques the distributions of phytoplankton and bacteria were studied. This allowed a bio-optical analysis between the backscattering coefficient and the abundance of phytoplankton, bacteria and detrital matter. Bacteria accounted for the greatest amount of back scattering but the variation on the ‘background’ could be related to changes in phytoplankton abundance and size.

This is an early step in refining the analysis of backscattering signals received by satellite sensors and a significant contribution to gaining data on the plankton classes being remotely sensed.

‘Sea, Satellites and CO₂’ is the first in PML’s new ‘Coffee Break Science’ series of podcasts – which aims to bring PML’s world-class science to a wide audience. Thanks to support from NERC to make the short film, this first podcast explains PML’s work in the OceanFlux Greenhouse Gases project, a two year European Space Agency funded investigation that aims to improve the quantification of air-sea gas exchanges of greenhouse gases. By using remotely sensed data from ESA satellite sensors the PML scientists can combine the measured ‘roughness’ of the sea and its surface temperature as a proxy for the amount of CO₂ being absorbed across different locations in the world ocean.

To watch this podcast please visit www.coffee-break-science.info
The Arctic Ocean is thought to account for 5-14% of total oceanic sink of CO$_2$, despite only contributing about 1% of global ocean volume.

Biogeochemistry is the study of biological, chemical, physical and geological processes and their interactions within and upon their environment.

The cycling of carbon, nitrogen and other elements is essential to the efficient functioning of the biosphere and is the controlling mechanism that regulates the Earth environment, making it suitable for life.

It has, however, in recent decades, become apparent that the Earth and its ocean are under threat from anthropogenic forcing at global and local scales. These pressures include amongst others: eutrophication, warming, deoxygenation and acidification, and have the potential to alter biological, chemical and physical characteristics of the ocean.

PML biogeochemists, working in collaboration within the UK marine science community and in international partnerships, are at the vanguard of facing the challenge of understanding the complex chemistry of the oceans; how it is being affected by humankind’s activities; and the ramifications for ocean health, marine resources and the need for science-based policy generation.
Climate change impacts sink

A PML-led team used satellite sensors on board ESA’s Envisat to characterise environmental conditions and net sea-air fluxes of CO₂ in three Arctic seas (Greenland, Barents, Kara) to assess the sensitivity of the CO₂ sinks to changes in temperature, salinity, and sea ice duration arising from future climate scenarios. The Arctic Ocean is especially important in such studies as it is thought to account for 5-14% of total oceanic sink of CO₂, despite only contributing about 1% of global ocean volume. This disproportionate contribution and the Arctic Ocean’s susceptibility to environmental changes highlight it as having an important role in future ocean CO₂ uptake.

The results of the study show that all three seas are strongly sensitive to changes in temperature and salinity but less so to changes in sea ice duration. All become smaller CO₂ sinks at higher temperatures, but larger sinks at lower salinities. Predictions of the relative magnitudes of these changes up to 2020 suggest that temperature effects will dominate leading to a decrease in the collective function of the seas as a sink. The predicted effect of a 23% reduction in the overall sink to 2020 would, if it continued at the same rate, lead to the region ceasing to be a net sink by 2060 with serious implications for global climate and ecosystems.

Halocarbons respond to climate change

Volatile marine halocarbons are produced via a range of biological and photochemical processes at the sea surface, resulting in the most important flux of natural halocarbons to the atmosphere. These halocarbons are rapidly oxidised in the atmosphere to produce reactive radicals that are important in ozone control as well as acting as nuclei for the growth of larger particles and clouds, with the potential to influence global climate.

In a study in the Arctic PML scientists carried out whole ecosystem mesocosm investigations to determine how marine halocarbon net production from phytoplankton and subsequent sea-to-air flux may be affected in future climate change scenarios, which alter the composition and abundance of phytoplankton and bacteria. The results of this first Arctic ocean acidification (OA) mesocosm experiment demonstrated strong associations with the biological communities. Some significant effects were observed indicating that the role of halocarbons in Arctic atmospheric chemistry may increase in importance as a result of climate change.

Methanol uptake

Methanol is the predominant oxygen-containing volatile organic species (OVOCS) in the troposphere and the second most abundant organic gas after methane, yet there is still considerable uncertainty about OVOCS sources and how the oceans control their abundance in marine air. Methanol is an essential nutrient for some microbial marine organism which use it for energy and growth. PML biogeochemists have, in recent years, pushed forward the understanding of OVOCS and studies on methanol are at the heart of their research. Previous studies have concentrated on bulk surface waters so knowing how microbes assimilate methanol carbon and oxidise it to carbon dioxide at different depth profiles and at finer scales has been the subject of PML research.

The researchers found that loss of methanol close to the sea surface is highly variable, so having an impact on both seawater concentrations and air-sea flux. Further investigations will look at which marine organisms use methanol for energy and/or carbon assimilation. This research direction should inform an understanding of methanol loss patterns and even the magnitude and direction of methanol flux across the sea surface.

1. Shipborne 3-D sonic anemometer deployed on RRS James Cook during the latest AMT research cruise. This sensitive apparatus measures wind speed in three dimensions to help unravel the complexities of air-sea gas fluxes.
2. Conductivity, temperature and depth apparatus (CTD) readings provide the background for other environmental monitoring on local and trans-oceanic surveys.
PML is at the forefront of socio-economic analysis and valuation of our seas, and is providing advice to marine managers on many aspects of the marine environment from renewable to fisheries’ futures.
Our coastal waters are amongst the most productive on the planet not just for food, but also for energy, recreational areas and transport. As the pressures on coastal waters increase, so our ability to manage them in a sustainable way is strained. Weighing up the relative values of differing and often competing ways of using the seas is now an essential rather than a luxury. 

Amongst the multiple demands on our waters are the unseen benefits we gain including the oxygen we breathe or simply a feeling of wellbeing through proximity to a healthy ocean. Measuring such intangibles and balancing them with the obvious economic benefits is a relatively new approach.

PML is at the forefront of socio-economic analysis and valuation of our seas, and is providing advice to marine managers on many aspects of the marine environment from renewable energy to fisheries’ futures.

Marine renewable energy

As concern about the implications of dwindling hydrocarbon reserves and rising levels of CO$_2$ in the atmosphere and ocean grow, the search for ‘alternative’ sources of power is accelerating.

Britain, as an island nation, is surrounded by seas that are some of the most energetic on Earth and thus a natural area of interest for those seeking to power our homes and factories from renewable energy sources. But while the energy seems endless and free, there are inherent challenges with harnessing it. Marine-based technologies face testing and often harsh conditions and, whilst economic and environmental arguments might favour one course of action, environmental concerns and socio-historic aspects might favour another.

PML research is applicable across a range of issues surrounding the implementation of marine renewable energy devices and arrays from the impacts during construction and operation of marine renewable energy devices, to the ways their performance might be impaired by growth of biofouling organisms, and the wider, if less obviously tangible, socio-economic aspects of offshore wind, wave and tidal installations. Working in partnerships with other research institutions and industry to find sustainable solutions to the challenges is an important aspect of PML’s mission.
The value of mud

Harnessing the energy of the ebbing and flowing tides is a logical source of power of known strength and reliability, but economic arguments are only one element of the challenge facing those that decide whether to permit such large-scale ventures. Perhaps the best known proposal is that for the Severn Estuary where a tidal barrage is planned that could generate 5% of UK energy needs. Opposition to this and other similar barrages often hinges upon ecological and hydrological concerns, whilst supporters point to the huge advantages of using renewable energies in a world facing increasing levels of CO₂ and its consequences, seeing it as an essential infrastructure project to provide electricity to many homes.

Often arguments come down to points of view which are not always based on fact or logic, but on less easily measured values and emotions, such as aesthetics or feelings of wellbeing. But, in the balance between rising energy costs and protection of the environment, how much would people be willing to pay?

Virtual value

Socio-economists from PML conducted a study using the Taw-Torridge Estuary on the North Devon coast as a virtual example of an estuary which might have the potential for tidal barrages, is of great wildlife value, is a recreational area and has intrinsic beauty and hence aesthetic value.

The question being addressed was - ‘Are members of the public willing to pay a premium on their electricity bills in order to reduce the intertidal habitat loss associated with tidal barrages?’

By means of online surveys, face-to-face interviews and the collation of background information the trade-off between attributes, including such things as flood protection and the potential for increased watersports, against mudflat loss and cost of electricity were assessed.

Preliminary results show that estuaries are important to ordinary people and that trade-offs, including some habitat loss, are acceptable in exchange for social benefits, especially flood protection. Moreover, people are willing to sacrifice income to reduce habitat loss, this includes people who remain remote from the site, although there was a noticeable decrease with distance.

Energy and environment

The benefits of renewable energy technologies are often measured as a positive step towards reducing carbon footprints, especially in the move away from hydrocarbon-based fuels. However, critics often point out that, whilst a marine energy device might at face value look to be a good option, whilst a marine energy device might at face value look to be a good option, the benefits diminish when the whole lifecycle of any device is analysed.

Working closely with colleagues at the University of Aberdeen on a UK Energy Research Council (UKERC) project, PML socio-economists have begun to look at the real carbon cost of a range of energy sources including oil and gas, wind and nuclear on land and in the marine environment.

The project is divided into two sections with PML looking at the local costs during construction and operation. In particular a detailed literature search is compiling the known facts on how each power source affects the benthic and pelagic communities in the marine environment.

Negative impacts might include noise, loss of habitat, leaks leading to pollution, boat traffic for maintenance, amongst other effects. Impacts do not always have to be detrimental to the marine environment so benefits are also being investigated; these might include the creation of artificial reefs or lead to no-take zones around and amongst installations, for example.
The aim is to produce a matrix detailing the various threats and benefits for each technology at each stage of its life from construction to dismantling. With such a matrix it should be possible to weigh up the negative and positive effects and make informed decisions about the timings, and positioning of any new offshore energy projects. Such an approach has never been followed previously, so PML is once more at the cutting edge of understanding how we can safely and sustainably exploit the ocean.

Biofoulants and the marine energy sector

Biofouling has been of great concern to the shipping industry where it seriously impacts the efficiency of vessels, raises costs and increases exhaust emissions, and so further adds to greenhouse gases and other pollutants. In the early stages of development of the marine renewable energy industry there was little concern and even less information about the impacts that biofouling organisms could have. Countermeasures were often regarded as costly and unnecessary, largely due to a lack of data on performance impairment.

As the relatively new marine renewables industry continues to develop, and energy devices move from the demonstration phase to proof of concept and actual installation and operation, biofouling organisms are being taken far more seriously and studies are being undertaken to establish how biofouling can impact efficiency of operation and frequency of maintenance.

PML is now working through an Energy Technologies Institute (ETI) private/public partnership to clarify just what these impacts may be and how they can be managed or avoided.

A public/private partnership

The Reliable Data Acquisition Platform for Tidal (ReDAPT) is a £12 million project funded through the ETI partnership of UK government departments with industrial partners: BP, Caterpillar, E-ON, EDF, Rolls-Royce and Shell. PML’s role is to reveal biofouling problems at device scale before scaling up to fully functioning arrays. An extensive literature review formed the basis for further experimental work at the European Marine Energy Centre (EMEC) in the Orkney Islands.

The first stage is to establish the rate and extent of biofouling in the conditions where renewable energy devices might be located – usually high energy areas. Experimental test panels were designed and fitted to ‘panel arrays’ and benthic landers, as well as renewable energy devices, to mimic the variety of surfaces of actual devices. Monitoring is undertaken regularly and will continue over a two year period. Testing existing anti-foulants from the shipping industry is a key part of the research.

PML uniquely skilled

PML is already testing a range of market leading biocidal and non-biocidal coatings on control surfaces under a range of conditions, including on actual energy devices, to establish their performance against rigorous industry requirements (see box).

A crucial element of the appraisal process recognises that test devices are taken in and out of the water frequently to allow modifications and other activities to take place. It is essential that PML’s ongoing biofouling studies are not compromised, so special measures that ensure continuity of monitoring and conditions are put in place.

PML has become uniquely skilled in applying superior analytical replication and redundancy techniques, as well as all aspects of the safety, engineering, installation and monitoring required, ensuring that results are a true reflection of the impacts of biofouling organisms upon an actual 1 MW scale tidal turbine device.

Meeting the marine renewable energy sector’s needs.

The ultimate aim of PML’s research in this sector is to provide guidance on the choice of an effective anti-foulant coating that meets the exacting standards required by the marine renewable industry and its regulators. An ideal coating must:

1. Work in dynamic water – up to 7 knots.
2. Also work in static water in internal niche areas.
3. Be highly resistant to scour and abrasion.
4. Ensure long periods (5-7 years) between maintenance.
5. Facilitate easy cleaning with jets, scrubbers and remotely operated vehicles.
6. Be made with high visibility materials.
7. Be cost effective.
8. Be environmentally benign.
PML scientists shared their knowledge of the search for bioproducts from algae at a recent EnAlgae workshop.
Photobioreactor steps up search for biofuels. In the search for a replacement for dwindling and damaging fossil fuels, biofuels have become the focus of much research.

Some terrestrial 'biofuel crops' have been accompanied by controversy surrounding their sustainability, and science is therefore increasingly turning to aquatic algae as a potential, renewable source of hydrocarbons.

PML scientists have wide experience of growing algae in photobioreactors. More recently their attention has turned to the challenge of moving experiments from bench top to semi-industrial scales in the hunt for sustainable biofuels.

Through working alongside chemical engineers from EDTE Contracting Limited under a Technology Strategy Board (TSB) funded project, PML has taken existing photobioreactor technology and modified it to produce a semi-industrial scale test-bed, capable of growing large enough quantities of algae for assessment in a totally closed system.

This PML innovation has resulted in a 500 litre capacity apparatus, which can generate one kilo of dried (five kilos wet weight) algal product from which metabolite can be extracted. It is thought to be the largest of its kind in Europe and its unique modular design means that it can be increased in size to accommodate even larger scale growth 'runs', potentially up to industrial scale. Specifically designed and built for the TSB funded project, the new photobioreactor will continue to be updated and future proofed so ensuring its use is maximised as similar projects come on stream internally and external to PML.

Purity no longer a problem
Purity has always been a challenge in large-scale algal culture, which is traditionally grown in outside ponds. This state-of-the-art apparatus provides a totally closed system to reduce impurities to virtually zero.

A further advantage of being self-contained is that it can be used to grow and assess genetically modified strains safely with no danger of contamination into the wider environment. Further guarantees of purity and security are enhanced by the careful attention paid to the design to ensure that it can be quickly, easily and thoroughly cleaned between experimental 'runs'. It also has the advantage of being capable of being charged with either salt or freshwater species for different experiments and is thus a very flexible system.

Coupled reactors
The initial experimental programme for the PML photobioreactor is to produce enough biomass for lipid extraction, using algae known to produce lipids in significant amounts. Extraction of the lipids from the dried biomass is normally achieved by the use of solvents or biofuel, but another PML innovation is being developed and improved alongside the photobioreactor. The Vortex Reactor takes the simple principle that oil and water do not mix and applies it to 'spin out' the oil from the algae without the need for drying first; any remaining material can also be used in other processes such as fertilisers or a source of sugars. By coupling the two reactors together, an elegant 'one-stop' process of seeding with algae, growing its biomass and producing oil as a final product is made much easier.

The PML photobioreactor makes a perfect complement to other algae related research at PML, which is investigating the use of selective stressors and genetic modification to encourage greater lipid production, or production of better lipids, and the continuing search for more lipid-productive algal species.

Above: PML modified semi-industrial scale photobioreactor, thought to be the largest in Europe, will deliver one kilo (dry weight) of algal product each run.
Bicycle driven recycling

Whilst the vortex bioreactor was originally designed to work alongside the PML photobioreactor as a one stop process for culturing algae and extracting their lipids, it soon became apparent that the technology had other applications. With funding from the Grand Challenges Exploration Fund, an initiative created by the Bill & Melinda Gates Foundation, the PML developers modified the vortex bioreactor so that wastewater could be separated into two output streams - liquid and solid. Further, low cost chemical and biological agents could also be added to reduce the activity and viability of pathogenic organisms.

This innovative equipment is now designed to work by hand or by being attached to a bicycle. This low-cost approach not only reduces the health risks from untreated sewage, it also produces a solid fraction for use as fertilizer and the liquid fraction as a source of much needed irrigation water. The equipment was recently demonstrated at the ‘Reinvent the Toilet Fair’ in Seattle.
Fish with a future?

As global demand for protein keeps pace with the rapidly increasing world human population the pressure on fisheries is growing.

Fish protein from wild stocks and aquaculture forms a significant percentage of the protein intake for billions of people and for millions it forms their main source of food. Yet with the human population set to pass the 9 billion mark by 2050 there are serious doubts about whether fisheries and aquaculture can supply the accelerating demand, and remain economically and ecologically viable.

Global fisheries are constrained by the productivity of ecosystems and the way we manage them, so can we do so in a way that can feed the growing human population? An international team led by PML scientists concludes that we can, but only if aquaculture makes an increasing contribution to the volume and stability of global fish supplies.

They reached this conclusion after drawing together the most up-to-date predictions on climate change, marine ecosystems and fisheries’ production estimates, human population size estimates, fishmeal and price estimations, as well as projections of technological developments in aquaculture feed technology, and applying the best available modelling techniques.

The results demonstrate that current and increased consumption rates are sustainable even as the population grows and climate change affects production. However, they also identified that the essential contribution of future aquaculture could be compromised by inefficient management and a rise in fishmeal prices.

What is clear from this study is that while climate change and population growth may have an impact, it is efficient management of global fisheries and a requirement for aquaculture to grow in a sustainable manner by becoming technologically efficient that are the real keys to success.

In parallel is the need for improved environmental standards in aquaculture and commitments to address weaknesses in the governance of capture fisheries.

Can copepods cope?

At the base of the Arctic food web three species of copepods totally dominate the zooplankton. The three Calanus species comprising two Arctic species, Calanus glacialis and Calanus hyperboreus and a smaller Atlantic species, Calanus finmarchicus play an important role and are responsible for the accumulation and transfer of essential lipids up the food chain to fish, birds, seals and whales.

As part of an EU programme, EUROBASIN, PML scientists, together with colleagues from Aarhus University, are investigating the response of the three Calanus species to a range of temperature increases in the Disko Bay area of Greenland. The aim is to determine which species may better be able to adapt to, or survive, future warming of the ocean. Detailed work includes counting eggs and fecal pellets, as measures of reproductive success and growth, and the collection of samples for transcriptomic analysis to determine which genes are being actively expressed at any given time and how they will vary with external environmental conditions. Such analysis will help determine which species are most stressed at different temperatures and which species have the potential to adapt to the changing environmental conditions: essential knowledge as changes will have implications further up foodwebs and ultimately impact on human food resources.
Impacts

PML takes great pride in the relevance of its science to today’s marine-based societal challenges, and takes seriously the need to make it as impactful as possible. PML’s publication record remains very strong and a recent Research Council commissioned analysis showed that PML consistently outperforms other research providers in the quality of its research outputs.

Policy advice continues to be an important method of transferring science to where it can have the greatest impact and PML takes every opportunity to share its research with decision makers at local, national and international levels. Engaging the wider public through presentations, work with schools and the recently instigated ‘Coffee Break Science’ podcasts remain a priority.

PML remains a first point of call on marine environmental matters for the press and media who know they can rely upon accurate and timely information. Perhaps the greatest measure of impact is the increasing number of national and international projects in which PML is invited to take part, or in a growing number of cases, takes the lead.

PML has an active policy to engage with the wider community through press and media contacts and events.

PML scientists are in demand as speakers at international conferences. Prof. Manuel Barange, PML Director of Science, addresses the Yeosu Expo, Korea, where an important declaration on the oceans was formulated with the input of PML scientists.

Ensuring policy makers have the facts at their fingertips is an essential output for PML and a real justification for the relevance of its science. Dr Carol Turley explains the work of the UK Ocean Acidification Research Programme (UKOA) to Deputy Prime Minister Nick Clegg MP.

Taking scientific messages to a global audience is an important method of transferring knowledge to the broadest range of stakeholders. PML leads an international partnership at ‘Planet Under Pressure’, in London.
Dr Melanie Austen was called to Brussels to present the successful outputs of the VECTORS project to the European Marine Strategy Framework Directive (MSFD); likewise, Dr Icarus Allen presented on the use of models to the Marine Strategy Co-ordination Group – policy makers from all EU member states.

PML Chief Executive, Prof. Stephen de Mora and Oliver Colvile MP. PML is a magnet for politicians and other stakeholders keen to grasp some of the challenges facing our marine environment.

The FP7 Integrated Project – Marine Ecosystem Evolution in a Changing Environment (MEECE) – has been brought to a successful conclusion during 2012 under the leadership of PML. It has produced models that combine both climate drivers and human induced drivers, such as fishing, pollution, invasive species and eutrophication.

PML expertise makes significant contributions to policy decisions. Dr Steve Widdicombe chaired the Expert Review Group assessing the quality of available marine science used in ministerial decisions regarding the establishment of Marine Conservation Zones in England.

A PML event at the House of Commons showcased the relevance of our science to the challenges faced by and the opportunities available from today’s ocean.

Sharing PML science and raising capacity in countries across the globe is an important measure of impact for PML. Dr Shubha Sathyendranath, from PML’s remote sensing group, addresses the East Asian Seas Congress.

“A special aspect of PML’s research is its great impact value and relevance to policy formers and decision makers, across a wide range of societally important topics.”

(Prof. Stephen de Mora, PML Chief Executive)
New projects

A continuing measure of PML success and standing within the international marine science community is the number of new projects with which the organization becomes involved or leads. During this year 24 new significant research projects have been initiated, or accepted for commencement in 2013. Success in gaining funding for research projects is a reflection of the quality and reliability of PML outputs and the reputation of its science groups, along with its ability to bring together multidisciplinary teams to address questions. As well as its crucial role in UK marine science, an essential ingredient leading to PML success is its ability, with internal support staff, to co-ordinate large-scale projects across a number of countries and a wide range of disciplines. Such recognition places PML firmly at the centre of international marine research. Only a small selection of PML projects can be included here; others are in the body of this Annual Review, a broader selection can be accessed via the PML website - www.pml.ac.uk.

The EC-funded OPEC project (OPerational ECology) is developing and evaluating ecosystem forecast tools to help assess and manage the risks posed by human activities on the marine environment, helping to improve the ability to predict the ‘health’ of ecosystems. Such information will then help inform the Common Fisheries Policy, the European Marine Strategy Framework Directive and other cross-border policies. Apart from co-ordinating this project, which involves scientists from Italy, Denmark, Greece, Germany and Turkey and colleagues from the Centre for Environment, Fisheries and Aquaculture Science (Cefas) in the UK, PML will be generating hindcasts for validation of any predictive tools being created.

MyOcean2, an EC-funded project which began in April, will operate a rigorous, robust and sustainable Ocean Monitoring and Forecasting component of the Global Monitoring for Environment and Security (GMES) Marine Service, delivering ocean physical state and ecosystem information to users in the areas of marine safety, marine resources, marine and coastal environment and climate, and seasonal and weather forecasting.

GloboLakes is a NERC-funded, five year research programme that will investigate the state of lakes and their response to climatic and other environmental drivers of change at a global scale through the realisation of a near-real time satellite based observatory with archive data processing to produce a 20-year time-series, of observed ecological parameters and lake temperature supported by linked auxiliary data on catchment land-use and meteorological forcing. PML Earth observation scientists are inputting into this project. PML is a major partner in one work package and leads another. Both rely on PML expertise in benchmarking algorithms and retrieving functional indicators learned from the marine environment, and its flexibility in relating these to freshwater habitats.

CANDYFLOSS: Following a successful submission the NERC-funded CArbon/Nutrient DYnamics and Fluxes of the Shelf System project was given the go-ahead to begin in 2013. This project aims to quantify the role of the NW European shelf seas in the global nutrient and carbon cycle, and how this role is sustained.

Another NERC-funded project due to begin in 2013 is Radioactively Active Gases from the North Atlantic Region and Climate Change (RAGNARoCC). PML will investigate concentrations and fluxes of CO2, N2O and CH4 (greenhouse gases) in the North Atlantic by direct shipboard measurements and Earth observation extrapolations over time and space.
Financial performance and governance

Financial performance

Whilst PML’s current financial year ends on 31 March 2013, all indications are that PML is continuing to perform well, having won significant new commissioned research contracts during the year. Notable recent successes have been with the Natural Environment Research Council (NERC) funded Shelf Sea Biogeochemistry research programme and the European Commission under Framework 7. Funding was also won from other UK Research Councils, as well as new customers, which is an important aspect for PML’s future.

Competitively won National Capability funding from NERC supports _inter alia_ the Atlantic Meridional Transect (AMT), the Western Channel Observatory (WCO), modelling and the NERC Earth Observation Data Acquisition and Analysis Service (NEODAAS).

Total turnover for the year is likely to exceed £10m and income for this financial year in percentage terms, based on our current forecast, is shown below:

**Income 2012-13**

- NERC National Capability funding: 27%
- Commissioned/Other Research income: 64%
- Miscellaneous income: 9%

Governance

PML is governed by a Board of Trustees, in accordance with charity law, and the Board currently comprises 9 Trustees (the maximum permitted by PML’s Articles is 11). In addition to the main Board, there are a number of sub-committees which deal with audit and financial matters, review of the science, remuneration of employees and promotion of PML’s activities.

For further information on PML’s governance structure, please visit our website at [www.pml.ac.uk/about_us/overview/governance.aspx](http://www.pml.ac.uk/about_us/overview/governance.aspx)

---

This Annual Review introduces some of the science highlights of 2012; there are many other projects in various stages of development, activity and publication. For the first time an interactive version of this Annual Review can be accessed at [www.pml-ar2012.org](http://www.pml-ar2012.org), where further up-to-date, detailed information about all of PML’s activities can be found.