Challenge to Solution

Millions of people living in coastal communities rely on the ocean directly for food, their livelihood and culture; all of us benefit from the services it provides, including half the oxygen we breathe, much of the protein we consume, and as a source of minerals and energy to underpin our economies and well-being. One estimate suggests the ocean is worth US$24 trillion and provides an annual product that totals at least US$2.5 trillion - if the ocean was a country it would boast the world’s seventh largest economy.

If we are to use the ocean’s resources wisely, meeting future demands while maintaining the integrity of its ecosystems, we need to understand its strengths, weaknesses and potential, what it does for us and what we need to do for it.

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Please share your comments via email to commss@pml.ac.uk

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or follow us on Twitter @PlymouthMarine, Facebook, LinkedIn and YouTube (PMLAdministrator)
Harnessing the ocean’s potential, while ensuring the health of its ecosystems, is the huge challenge faced by society. PML’s world-class expertise and unique, combined approach of observation, experimentation and modelling is targeted towards finding solutions to the issues faced by the ocean and society.

It does this through a pragmatic choice of topics where PML has developed areas of proficiency and experience. This, in turn, informs the choice of projects that PML leads, or contributes to, which generate understanding and evidence for downstream decision making for potential solutions.
OUR CHANGING WORLD

PML’s unique combination of Observation, Experimentation and Modelling of the marine environment enhances its ability to understand how it functions, and to forecast the effects of global changes. PML has been at the forefront of research into the impacts of growing CO₂ levels in the atmosphere and how the combinations of ocean acidification, climate change and deoxygenated zones work independently or together. Untangling the complex relationships, alongside the more obvious impacts of over-fishing and pollution, and how they will alter ecosystem structure, function and services, including the essential services they provide to food security and nature-based solutions, is at the core of PML’s science.

Time series and climate change

The Western Channel Observatory (WCO) has been monitoring phytoplankton and other components of the plankton community in parallel with hydrographic measurements and processes, so providing a unique time series of data of immense value in gauging climate and other environmental changes in the world ocean.

Station L4 in the western English Channel is a very dynamic site which makes it especially important when attempting to discern trends or changes in plankton communities and their seasonality. Nano- and picoplankton samples from L4, collected between 2007 and 2013 were scrutinised by flow cytometry to quantify abundance and investigate seasonality. Some, such as Synechococcus showed a bimodal (two abundance peaks) over the year, while others, Phaeocystis for example, had only one discernible peak. Abundance peaks for the different groups varied through the year, while some picoeukaryotes showed no seasonality at the surface at all. Time series data applied through models is a useful means of identifying repeating cycles so enabling detection of trends and cycles on timescales of months to years, and providing a gauge of climate change, its effect on natural environments and impacts on the human environment. The study also identified the need for better understanding of the complexity down through the water column.
Low oxygen affects brittle star functions

Coastal hypoxia, low concentrations of oxygen in seawater which are deleterious to marine life, affects almost a quarter of a million square kilometres of the world's ocean and appears to be a growing problem associated with global warming.

Hypoxic conditions threaten the survivability of a wide range of marine organisms and thus have the potential to impact benthic (bodied) communities and modify the biogeochemical cycles in which they play a major role, with wider ramifications in the marine environment. Effects, depending on the duration of a hypoxic event, can range from short-term behavioural changes to longer term species absences through migration or local extinctions.

Inevitably long-term or repeated seasonality could impact the sustainability and biodiversity of coastal ecosystems and are thus of concern. Experiments carried out in PML’s mesocosm facility investigated the impacts of a short-term hypoxic event and organism density on the metabolism and reproduction of the brittlestar *Amphiura filiformis*, a key sediment-inhabiting species. Organism density did not appear to have any effect but the hypoxic conditions did result in reduced metabolic rates and delayed recovery once conditions were restored to normal. Also female reproductive cell development was impacted.

Such disruptions, the scientists conclude, could cause major alterations to the quality and quantity of planktonic stages of the brittlestars which, in turn, could affect community diversity and coupling between the benthic and pelagic realms.

PML and COP21

PML has actively participated in every United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties (COP) meeting since Copenhagen in 2009. It has made valuable contributions throughout, working with a large international partnership coordinated by PML in collaboration with Scripps Institution of Oceanography and the UK Ocean Acidification Research Programme.

PML’s activities included taking part in official UNFCCC side events and exhibition stands, press interviews and Q&A sessions, as well as co-organising Oceans Day which attracted high level country representatives.

Such focus has raised awareness of the ocean stressors (ocean acidification, deoxygenation and warming) on the international stage at high level and has received support from many international bodies including the World Bank; European Union and UN bodies.

The UNFCCC COP21 Paris Agreement commits, for the first time, all nations to reduce their rates of greenhouse gas emissions to "well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 degrees Celsius above pre-industrial levels." Importantly steps have been made to recognize the central role of the oceans noting "the importance of ensuring the integrity of all ecosystems, including oceans, when taking action to address climate change." PML has been key in achieving this recognition of the oceans.
**Risk of eutrophication**

Shelf seas are the most highly productive areas of the world ocean, supporting biodiversity and hence marine ecosystems and the goods and services they provide.

Direct anthropogenic drivers, such as fishing and eutrophication, are having impacts at many levels from individual organism, through population to ecosystems, potentially exacerbating any effects brought about by climate change. Eutrophication is the phenomenon resulting from increased nutrient inputs from rivers and other sources, which can lead to increased growth of algae, leading to oxygen depletion with knock-on effects for benthic and other marine life. It is a key topic of concern, and eutrophication status is embraced in the European Union’s Marine Strategy Framework Directive as a potential threat to ‘Good Environmental Status’.

PML computer modellers used a combination of the European Regional Seas Ecosystem Model (ERSEM) and the Proudman Oceanographic Laboratory Coastal-Ocean Model (POLCOMS) outputs with in situ data to assess the risk of eutrophication in the coastal areas of the North Sea. The resulting methodology is generic but could be refined to more local areas, especially if required in policy contexts. The results show that the model tools can be used in operational ecology and marine assessment, including evaluations of management strategies. Eutrophication risk can be predicted under scenarios of the future state of the ecosystem, while allowing exploration of the sensitivity of the ecosystem to combinations of climate and management strategies. It is therefore a positive step forward in predicting eutrophication risk and hence beneficial to policy development and ecosystem-based management.

**Models for policy and management**

The pressures on the marine environment continue to increase and its management for sustainability becomes more complex.

In many walks of life computer models are increasingly used to find a way through such complexity and, in the light of global environmental changes, it is surprising that the uptake of ecosystem models for policy decisions and management within the shelf-sea zone has been limited in Europe and the UK. Currently there are some 14 models that help explain, in more or less detail, how ecosystems function and provide goods and services. There are, however, none that directly address the needs of policy makers and managers. PML modellers and socio-economists are at the forefront of their disciplines and so were invited to take part in a workshop that brought together other modellers, advisors, assessors, biologists, social scientists, economists, statisticians, policy makers and funders.

They concluded that some models already addressed some policy requirements without the need for further developments. Multi-model ensembles that could address some of the needs are already available, but they are very diverse. This makes a standardised approach, which combined outputs, very challenging. They also recognized the need for new methodologies for describing, analysing and visualising uncertainties. Key to ensuring models are relevant to policy and decision making is the requirement for ecosystem, economic and social systems to link in a more coherent manner, only then, with improved communication between modellers and policy, will the models take their place in the tool-box of shelf seas management.
Fish for 21st Century Bangladesh?

A crucial part of the Bangladesh economy is fisheries which accounts for 4.4% of GDP and 22.8% of production in the agricultural sector. Since the 1980s the number of people living close to the coast has doubled and now stands at 16 million, to them fish is vital for their survival.

But as changes in global consumption patterns change and populations continue to rise the demands of fish will increase accordingly. With global environmental changes, to which Bangladesh is especially vulnerable, what are the prospects for the long-term productivity of fisheries, and how might they be managed to keep pace with growing demand? PML modelers along with colleagues at the University of Southampton, the University of British Columbia and in-country, at the Bangladesh Agricultural University took a global climate model which they downscaled and added in river flow and nutrient loading estimates to project more detailed changes in physical and oceanographic properties. This enabled them to project fish production and catch potential under different fishing mortality targets. The modelers concentrated on two key target species: the Hilsa Shad (Tenualosa ilisha) which accounts for more than 11% of total catch; and the Bombay Duck (Harbadon nehereus) the second highest catch, and low priced so appealing to low income communities. The models predicted that overall the total Bangladesh potential fish production is likely to be reduced by less than 10%.

However, the Hilsa Shad could decline by as much as 95% by 2060 if over-exploitation is allowed to continue, but sustainable management practices could reduce this to a ‘minor decline’ by 2030 with a significant decline of around 35% by 2060. For Bombay Duck the potential catch estimate by 2060 under sustainable scenarios would not face collapse. This is likely a function of differing distributional, behavioural and developmental characteristics of the two species. When models combine environmental change with management considerations it becomes clear that in the face of climate change management can mitigate or exacerbate changes to ecosystem productivity, and that management choices are crucial for the sustainability of fisheries as a nutritional and economic resource for Bangladesh. Declines in fish stocks have wider implications than purely food supply and can impact employment, fishing is the second most important source of livelihood in coastal Bangladesh, and cultural identity within communities. The results of this work will be integrated into the Ecosystem Services of Poverty Alleviation in Populous Deltas (ESPA Deltas) project.

PML leads ecosystem research programme

Ensuring models are competent is highly dependent upon the data which feeds them and there are gaps yet to be filled in the marine environment. The Marine Ecosystems Research Programme (MERP) which will address key knowledge gaps in marine ecosystem research is a UK programme, funded by the Natural Environment Research Council (NERC) and the Department for Environment, Food and Rural Affairs (DEFRA), and led by PML. By bringing together existing data and targeted new data, the programme scientists will integrate these data with current models and knowledge of ecosystem services within a common framework, in order to improve our understanding of the whole UK marine ecosystem. This will facilitate the development of a more accurate suite of marine ecosystem models and provide vital evidence, tools and advice to policymakers and environmental managers, including the development and implementation of the Marine Strategy Framework Directive (MSFD), the Marine and Coastal Access Act, Marine (Scotland) Act, Common Fisheries Policy and the OSPAR Joint Assessment and Monitoring Programme.

Bringing observations and models together
Offshore wind explored

PML socio-economists carried out two reviews on behalf of The Crown Estate: ‘Understanding the impacts of offshore wind on well-being’, and ‘Public perceptions of offshore wind farms’.

In the first review they explored the positive and negative impacts arising from the UK offshore wind industry in terms of well-being. Positive impacts were seen on the economy in terms of investments, for manufacturing and the development of relevant infrastructure, and in terms of jobs and skills development. Social and environmental impacts were more mixed or less clear. In general people were positive about offshore wind energy, but there were concerns about the planning process for offshore wind farms (OWFs), which led to some distrust in developers. Understanding the complex nature of people's perceptions of the offshore wind industry was something that needs exploring in more detail, they concluded.

Perceptions of the UK public to offshore wind farms were explored in a second report which aimed to further understanding of how individual well-being is affected by OWFs, as well as the wider opinions held by the general public on the industry. It found that offshore wind was the third most favourable electricity source after solar and hydro. 83% of survey respondents view offshore wind energy as favourable or very favourable and more than a third would like to see at least 30% of their electricity produced by offshore wind. A clear majority of respondents felt that OWFs do not harm human health, are an efficient way to generate electricity, contribute significantly to the UK economy, create local jobs and do not affect fishermen's incomes. Opinion was more evenly divided as to whether OWFs have a positive effect on coastal tourism, benefit local communities, harm wildlife or spoil the view. On a more negative note, the perceived minimal environmental impact of OWFs is not sufficient to compensate for a perceived lack of reliability. Respondents identified a lack of public support as the most significant barrier to OWF development.

As the world human population continues to grow, the pressures on the marine environment are also increasing. Our coastal zones, in particular, are facing unprecedented demands upon their resources. Balancing the competing demands is a burgeoning challenge for managers of the marine environment, who are faced with prioritising activities that maximise financial gain whilst ensuring the ecosystems on which we depend are sustainable in the longer term. Understanding impacts on delicate and vulnerable marine ecosystems is crucial in achieving such a balance, but economic considerations versus ecological sustainability is only a part of the equation. Human health and well-being are also important aspects. PML’s socio-economic group, the largest of its kind in Europe, is at the forefront of bringing together evidence from natural and social sciences in order to understand the consequences and benefits of the interactions between society and the marine environment.
Offshore wind, ecology and marine planning

Installation of offshore wind farms creates ecological and, by affecting the seascape view, social impacts and is one of an increasing range of activities in the marine environment that needs to be addressed in integrated marine planning. PML socio-economists carried out an online survey to assess how people's welfare might be affected by jointly considering changes in ecology and amenity resulting from the installation of an offshore wind farm.

They used the scenario of a proposed wind farm in the Irish Sea and found that respondents expressed preferences for ecological improvements emanating from the installations – protected areas, for example, but had less clear preferences regarding height and visibility of turbines. Concern about the visual impact of turbines diminished amongst respondents further away from the proposed location. The research demonstrates that responses to individual features can be different when two or more features are valued together. The study concludes that ‘trade-offs’ might be at work and that generalizing between different locations may not provide real reflections of values, and such considerations should be included in marine planning.

Marine ecosystem services and energy impacts

The link between the burning of fossil fuels and climate change has prompted interest and investment in lower carbon (gas and nuclear) and renewable (e.g. wind) energy sources.

The marine environment will play a key role in hosting and supporting some of these renewables, yet it remains unclear how the construction, operation and eventual decommissioning of necessary infrastructure will impact the marine environment and the services it provides, and the benefits that accrue for human well-being. This lack of clarity is due to a paucity of research and the resulting absence of a common currency synthesising the effects of these energy sectors on the marine environment. PML socio-economists have drawn together evidence of impacts on the marine ecosystem and, for the first time, translated them into ecosystem services impacts. The results show that differences exist between the energy sectors in the way they impact ecosystem services. Nuclear has a predominantly negative impact on cultural ecosystem services; oil and gas a predominantly negative impact on cultural, provisioning, regulating and supporting ecosystem services; while wind has a mix of impacts on the same services, while the researchers noted an absence of studies for regulating services. Indeed, the study identified large gaps in the available information regarding the full impacts of the energy sectors. It concludes that filling these information gaps will become more pressing as world economies seek new energy supplies with the aim of curbing emissions.
Health benefits and the marine environment

Marine spatial planning requires understanding of the human health and welfare benefits alongside any ecological or financial considerations.

One benefit which has proven difficult to quantify is the health benefit of engaging with the marine environment. PML researchers and their colleagues have developed an approach which can estimate the contribution of aquatic physical activities to quality adjusted life year (QALYs) in monetary and non-monetary terms. They estimated that there is a total gain of 24,853 QALYs, nationally worth £176 million. Such estimates could be applied in comparisons of alternative spatial plans. The researchers caution that these figures result from scaling-up and any uncertainties would be reduced with access to larger databases concerning marine physical activities. However, they point out that their approach shows that health benefits from marine-based activity and reconnecting people with nature should be considered in national, regional and local decisions.

Benefits undermined by litter

While beneficial effects to human health of engaging with the marine environment are now clearer, the litter we leave behind is negating our enjoyment.

Working with colleagues at Plymouth University, the team of scientists and psychologists assessed public reactions to the differing conditions along coastlines. They showed participants images of clean beaches, including some with natural seaweed debris; others with fishing industry related debris (ropes, netting, packaging) and ‘public litter’, such as drinks cans, plastic bottles, sweet and crisp wrappers. As might be expected, clean condition was consistently rated more positively, but the littered beaches elicited different reactions with the ‘public litter’ condition being rated the worst. So, it is not simply litter that undermines the psychological benefits of engaging with the marine environment it is the type and origin of the litter that increases the impact on beach visitors. There are knock-on effects to local economies which carry the cost of cleaning beaches of litter, as well as suffering from the impact of potential loss of tourism.

Towards better ecosystem management

Assessing the impacts of human activities on the direct and indirect contributions that ecosystems make to human well-being (ecosystem services), enables a better understanding of the trade-offs between them, so leading to more informed management strategies.

This approach calls for a clear understanding of what is meant by ecosystem services, how they are categorized and what should be assessed. Typical assessments rarely focus on the full complement of ecosystem services, the functions that create them and benefits that they provide. Following a review of existing ecosystem classifications, all of which have advantages and drawbacks, a team of scientists and socio-economists, led by PML, has taken elements from them to develop a generic ecosystem service classification. After applying it to a real life situation, the Dogger Bank, the team managed to derive indicators for the full suite of ecosystem services. However, they point out that the relevance and uncertainty of the indicators will vary from site to site, so indicators will need to be tailored to be effective. They also concluded that simply assessing on ecosystem service, function or benefit indicator alone may misrepresent the system as a whole and could lead to counterproductive management interventions.
Microplastics and plankton

Building upon a developing research theme, which had already showed that various types of zooplankton were capable of ingesting microplastic particles, PML scientists carried out further exposure experiments on the copepod Calanus helgolandicus. They tested the hypothesis that exposure to the microplastics could alter ingestion of algal prey to determine the impacts on the copepod’s reproductive and metabolic function. The results show that exposure to microplastics can indeed have a significant impact on copepod feeding which, in turn, can lead to notable impacts on health of the individuals. The scientists suspect that in order to avoid ingesting the microplastics, the copepods shifted to smaller prey size which in turn reduced the amount of nutrients (carbon biomass) ingested. After long exposure smaller eggs with reduced hatching success were produced, although egg production rate was not affected in this study. It is further speculated that if microplastic ingestion in the wild is compromising ingestion rate there is an expectation that lipid reserves will be rapidly depleted, affecting the health of the individuals and having ramifications further up food chains.

Fish on the menu

Fish provides an average of 15% of the animal protein consumed by 4.5 billion people and its unique nutritional properties are essential to the health of billions of consumers. Fish and fishing related activities contribute substantially to the income, and therefore indirectly to food security, of more than 1.0% of the global human population. But what will be the contribution of fish when it comes to feeding an increased human population that is projected to reach 9 billion by 2050. PML scientists working with colleagues in Europe, Australia, the USA and South America have been looking at why fish, as a key element in food security and nutrition strategies, has been overlooked at national level or in wider development discussions. They found that most fisheries’ specialists have been concerned with biological sustainability and economic efficiency; whilst most non-specialists appear to be unaware of the critical contribution fish can make in the future. Also when it comes to making food systems more nutrition sensitive, fish are overlooked again, with many programmes not recognizing or building the potential of fish for reducing micronutrient deficiency. The scientists make the case that fish deserves more attention in food policies due to its importance as a food source, its unique nutritional properties, its higher production efficiency and lower carbon footprint when compared to other animal protein production. Whilst there are some inherent challenges in ensuring fish is available to the poor, and inequalities in supply and benefit, the research shows that the best available projections for fish supply and demand are relatively positive, although climate change impacts remain uncertain. However, there is no doubt that fish should stay on the menu.

As this Annual Review goes to press we are pleased to announce the successful outcome of a research proposal supporting the Ellen MacArthur Foundation ‘New Plastics Economy’ initiative which was funded by the People’s Postcode Lottery. PML will bring to the initiative its deep scientific expertise of the socio-economic impacts of plastics in the marine environment.
ADDING THE PAST TO THE FUTURE

Climate change reference signal established

Knowledge of the structure, seasonality, interannual variability and long-term trends of ocean currents is vital to understanding the physical processes producing change and its implications for marine systems.

The western edge of the European continental shelf, which extends from the Iberian Peninsula, via the Bay of Biscay to the western edge of Ireland and onwards to Scotland, is marked by a sharp depth change from 200m to over 2000m. Bathymetric changes of this scale limit flow across the shelf and direct deep or bottom currents. An example of this is the extension of the North Atlantic Current (NAC), along with the poleward flowing European Slope Current (SC) and Eastern Boundary Flow, which together provide the warm saline waters flowing from the Atlantic to the Arctic. It is this flow that keeps northern areas much warmer than they would otherwise be at these latitudes. These warmer conditions are favourable for plankton and fish, bringing economic benefit to Europe, and moderate our climate. Any change in the behaviour of these currents, therefore, is of concern and the subject of study to understand how, when and where they function.

PML Earth observation scientists investigated the SC using a 20-year satellite altimeter dataset, combined with in situ drogued buoy data, which allowed them to make a more comprehensive appraisal of the currents, including four branches of the North Atlantic Current as well as the positions of five permanent/semi-permanent eddies. Not only did the research show distinct regional and seasonal variation, with maximum poleward flow in winter and minimum in the summer, it also provided new insights into the interannual variability, showing a peak during 1995-1997. As far as long-term trends are concerned the rate of the SC has been decreasing by an average of 1% per year over the 20 year study; there was no significant decrease in the flow rate of the NAC. The results from the study now provide a climate change reference signal for the SC and the NAC, which can be used as a standard for model simulations.

PML is part of a global network of leading marine organizations that observe, measure, monitor and interpret ocean processes through high quality scientific research. Marine observations are undertaken at a range of scales from the molecular to ocean basin and across varying time periods stretching into decades. PML’s approach to science brings together expertise across a range of disciplines to address particular issues and questions of interest to wider society through the use of techniques and technologies best suited to the challenges faced. Long-term observations are especially important in providing base lines and trends that help unravel the changes the ocean, and the Earth as a whole, are currently experiencing. During this year the Atlantic Meridional Transect (AMT) celebrated 20 years of globally significant oceanographic observations, while the 10 years span of the Western Channel Observatory (WCO) has added to, co-ordinated and improved the century-long time-series of data from the Western Channel.
The Western Channel Observatory (WCO) was established in 2005 to bring together, under a single umbrella, time series from the marine environment of Plymouth, south-west England, which cover a period of more than a century.

Presently sampling, data collection and monitoring continue at a number of sites, including key reference stations at L4 and E1, respectively 13km and 40km off Plymouth. The wide range of observations includes levels of detail from photons to fish and at all depths from surface to seabed.

Two autonomous databuoys, relaying data back to PML at hourly intervals, and a surface atmospheric station further increase the coverage of the WCO and specifically facilitate the implementation of an Earth System Science approach, which links atmosphere to sea surface to seabed. The WCO gives the ideal opportunity for contextualised process studies, to develop and validate ecosystem models and remote sensing algorithms. The WCO has really come into its own in identifying the relative impacts of natural and anthropogenic drivers on marine ecosystem change, which are of national and international interest.

Plankton resilient to shifts in seasonal timing

Change in phenology, the timing of natural and cyclic phenomena, is a fundamental ecological response to climate change. In a warming climate, differential shifts in the seasonal appearance of predators and prey have been suggested to lead to timing mismatches.

On land, for example, the emergence of insects in spring and the arrival of migrant birds that eat them can become out of step, and in the sea, the timing of larval fish and their zooplankton prey may be out of kilter. This decoupling between the trophic levels could have far-reaching consequences which may be social and economic as well as environmental. PML researchers tested the so-called ‘match-mismatch’ hypothesis by analysing a 25-year time series of weekly plankton samples from PML’s long-term monitoring site L4, just south of Plymouth. This site is undergoing warming and some of the spring species did indeed appear earlier in warm years, just as they do on land. Likewise the autumn species lingered later in warm years.

However the success of the species, measured in terms of their abundance or egg production rates, was not affected by these timing changes. They found a series of traits among this productive inshore fauna that gave it resilience to phenology shifts. The researchers acknowledged that ‘trophic mismatches’ could be important in some systems such as at high latitudes, or for specialist feeders such as some seabirds. However they suggest that the concept is being over-extended to many other marine plankton systems, where multiple factors compensate and the food web has more resilience to climatic variability. The importance of this research resulted in the scientific paper announcing it as a ‘Hot paper’ in Web of Science, placing it in the top 0.1% of papers in its field.
No effect on egg production

The L4 sampling station of the Western Channel Observatory (WCO) is especially suited to understanding how species may respond to environmental variability.

As an inshore site it already experiences variability from year to year in temperature, stratification, and food quantity, quality and timing. Also it is sampled weekly and has produced valuable time series over long periods including specifically for the copepod Calanus helgolandicus, 21 years of egg production measurements.

Sea surface records show that the waters of the L4 site have warmed over the last 25 years, yet the egg output of C. helgolandicus does not appear to be at all depressed, even in years where there was an apparent mismatch with the phytoplankton bloom. Abundance of C. helgolandicus can vary from year to year but the researchers suggest this is due to other mortality factors including the timing of stratification early in the season that might result in egg losses. C. helgolandicus, at this site at least, is highly resilient.

New technique reveals microbe interactions

Metabolomics is the study of the unique chemical fingerprints that specific cellular processes leave behind. It is a useful technique for understanding organism-environment interactions and for assessing organism function and health at molecular levels.

It is useful for understanding the interactions between biota and for studying responses of organisms to abiotic pressures. Using non-targeted metabolomics techniques has revealed hitherto unexpected metabolites in some microbes, while community metabolomics, applied to whole systems or communities, has shown how an entire soil microbial community responds to factors such as pollution or climate change.

The technique has not previously been used to study natural populations of marine microorganisms. Now for the first time in the Western Channel the particulate organic matter (POM) has been characterised in a 'proof of concept' for the technique in discriminating and characterising a variety of metabolite patterns in the POM. POM is crucial in global carbon cycling, turning over organic metabolites driving the biological pump and generating climatically active gases. Its composition is largely driven by microbes, particularly carbon-fixing phytoplankton. The technique has the potential to greatly enhance our understanding of the metabolic processes through which microbes interact with their environment.
Summer rain drives increase in plankton abundance

Harmful Algal Blooms (HABs), when large concentrations of toxic or otherwise harmful algae occur, can have dramatic effects on coastal and seabed communities and have become of concern due to their impacts on fisheries, aquaculture facilities and human health.

However, such blooms appear to be unpredictable so understanding the underlying factors that cause them is a matter of urgency. Karenia mikimotoi is one such HAB species that occurs in the English Channel. PML researchers analysed a 19-year coastal time series from the Western Channel Observatory to determine any interannual variability or seasonality in K. mikimotoi to discover the primary drivers for blooms, and how they affected phytoplankton productivity and oxygen conditions. Although no long-term trends in timings or magnitude of blooms were found, persistent summertime rain, resulting low salinity, and high nutrient river water input was identified as a driver. For example the largest bloom in the time series, in 2009, followed a short period of high rainfall and associated low salinity and high nutrient river water entering Plymouth Sound. So, the researchers conclude, K. mikimotoi blooms can be potentially predicted from knowledge of rainfall and river discharge.

The 2009 HAB, as part of a time series was also the focus of the Algarisk system which was developed, on behalf of the European Environment Agency, to provide a demonstrator portal for forecasting bathing water quality. It brought together in-situ, Earth observation and modelling data as a decision-making tool for national agencies. The occurrence of the bloom helped to prove the concept.

Blooming diatoms less palatable

One of the advantages of modelling work is that it can highlight gaps and inconsistencies in current knowledge and datasets and thence inform future experimental research.

By coupling a modified ERSEM model with the general Ocean Turbulence Model and running it through a 10 year simulation, PML researchers were able to investigate the role of phytoplankton nutritional status in the formation of the ‘spring bloom’ that is regularly observed at the Western Channel Observatory L4 sampling station. They tested the idea that an increase in sunlight from winter to spring would cause a decrease in the nutritional status of diatoms, reducing their palatability and thus making them less attractive to predatory zooplankton and so free to ‘bloom’. Measured by the ratio between cellular carbon and nutrients, the researchers indeed found this to be the case and conclude that conditions necessary for a bloom are therefore a compromise between attaining high nutrient content, which invites predation, and low nutrient content that deters predators but is too poor for growth, even though they may ‘escape’ zooplankton grazing. The former state occurs in winter, the latter in summer, the ideal conditions occur in spring when growth is positive and palatability is reduced — perfect bloom conditions.

The models have emphasized the need for further studies on grazing impact and carbon:nutrient ratio in phytoplankton to validate these mechanisms.
The Atlantic Meridional Transect (AMT) marked two milestones in the year by reaching the 20th anniversary of this unique ocean going programme and celebrating its 25th cruise.

The AMT programme has been supported from the beginning with funding from the UK Natural Environment Research Council (NERC) and has stayed close to its original aims including providing a collaborative programme; it has involved 242 sea-going scientists from 66 institutes in 22 countries, a truly multi-national initiative that the UK can be proud of. During the 25 cruises the research ships covered over 200,000 miles in 958 ship days, providing 17,704 scientist days at sea. This truly unique programme has resulted in 243 refereed scientific publications and led to 70 PhD theses. AMT has become a co-ordinated study of ocean biodiversity, biogeochemistry, and ocean/atmosphere interactions, and has made major contributions to other multi-national initiatives including the Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) and the Surface Ocean — Lower Atmosphere Study (SOLAS) projects. It is difficult to select highlights from such a successful programme but of note are the first ocean basin-scale measurements of two marine cyanobacteria that informed the extent of distinct biogeographical provinces in the Atlantic, and the first ocean basin-scale description of plankton net community production and other processes. Feedbacks between the atmosphere and the ocean have been an important area of study including establishing evidence of a marine ammonia source. The data relating to dimethyl sulphide (DMS) and dimethylsulphoniopropionate (DMSP) showed a strong correlation with primary production, thought to be important in global prediction of these climate relevant compounds. AMT continues to provide a successful and highly impactful science programme of global significance.

More Arctic Ocean study needed

A mainstay of PML science is concerned with identifying critical gaps in knowledge of how the marine environment functions and the part it plays in global processes, so informing future research in the most relevant and efficient way.

The Arctic Ocean is being altered faster than others under climate change, yet it is one of the most difficult to study, being often hostile and largely impenetrable for long periods of the year. How the Arctic functions geophysically and ecologically can have significant consequences for the internal cycling of carbon, influencing carbon export, atmospheric CO2 uptake and productivity of food chains. Yet observations and measurements can be sparse or non-existent. In a workshop led by PML early career scientists got together to assess and summarize the current level of knowledge on carbon pools and their associated processes. They looked at data availability and the ranges of rates and values in four geophysical domains in the Arctic Ocean and assessed the current state of models, and how they might be used or improved to project existing and future functioning when observational data are limited or missing. This enabled the researchers to link physical oceanographic aspects, productivity and carbon cycling within the ecosystem, that are likely to change under future scenarios. Importantly they identified those pan-Arctic research areas that should be prioritised.

They noted that there is much less information about carbon cycling through microbial food webs and how heterotrophs (organisms that obtain carbon from the food they eat) contribute to secondary cycling in the Arctic Ocean. They also noted the seasonality of observations, with very little data being collected during the winter and suggest that new technologies such as Argo floats and gliders should be deployed in future. Organic matter measurements have been restricted to export studies which are not very informative in understanding residence time and their contribution to the microbial carbon cycle. Further field studies and controlled experiments are needed.

When it comes to the responses of small zooplankton and other heterotrophs to temperature and other stressors, such as ocean acidification and increased organic input, many uncertainties remain. Further studies on how these vary through the seasons and across geophysical gradients are required.

The major controlling factor in the Arctic Ocean is sea-ice distribution, thickness and cover, and any changes in these parameters are likely to have repercussions on the timings of spring ice algal blooms and how they couple with zooplankton communities. Light levels, which will impact processes such as photosynthesis, are likely to change and have concomitant influences on carbon cycling; these should be subject to further investigation.

The lack of experimental and direct observational data specific to the cold Arctic waters is a severe limitation on understanding key processes, but also on any attempts to model future scenarios. As interest in the Arctic Ocean, politically and economically, increases opportunities should arise for studying the region. Join efforts between the modelling and observational communities are essential and should be encouraged through international, multidisciplinary and co-ordinated efforts in the future.
Gas exchange

The exchange of gases across the ocean-atmosphere interface influences the abundance of many compounds of importance to climate and air quality.

These may include greenhouse gases which accumulate and contribute to global warming and climate change, the precursors of aerosols which may play a part in cloud formation, and stratospheric ozone-depleting substances, as well as a wide range of volatile organic carbon compounds which can also influence ozone. In a changing world it is essential to understand the quantity of these compounds and the mechanism by which they are exchanged in order to provide meaningful data for climate models. However, there is still much uncertainty concerning this sea-air exchange, largely due to a paucity of measurements. A central activity of PML is concerned with increasing the number and quality of measurements of these important gases. Oceanographic research cruises offer one platform for gaining data, especially in more remote locations across the global ocean.

During the Surface Ocean Aerosol Production (SOAP) study the fluxes and bulk air-sea gradients of dimethylsulfide (DMS), an important compound associated with cloud formation and a product of phytoplankton activity, were measured in the Southern Ocean. The Southern Ocean is very important in determining the global supply of DMS, as well as the global uptake of atmospheric carbon dioxide by the ocean. Not only is land area minimal, there is also a unique wind and wave environment providing ideal challenges for determining fluxes and how they are affected by changing physical conditions. The cruise targeted areas of high biological activity including three phytoplankton blooms; two of these had moderate DMS levels while the third, a high biomass dinoflagellate bloom, had high seawater DMS levels. Measurements obtained were in sound agreement with previous studies which showed that gas transfer across the ocean-atmosphere interface is a linear function of low and moderate wind speed, but that it appears to weaken at higher velocities, although data is limited. One cruise transect offered a unique opportunity to attempt to measure the extent of the flux footprint. The result was much greater than predicted, possibly because the model used assumes homogeneity in the DMS concentrations within the footprint. The researchers suggest that a flux footprint model developed for marine air-sea gas flux measurements would be an invaluable tool for those attempting to quantify ocean-atmosphere gas exchange. The study again shows that refining measurements of gas transfer will provide a much clearer idea of how global chemical cycles work and may be affected by phenomena such as climate change.

Citizen surf monitors

The coastal zone may be one of our most treasured environments due to its provision of a wide range of social and economic benefits, yet it remains vulnerable to anthropogenic pressures and changing climate.

Coastal management is one way of mitigating these threats through an approach which balances societal and economic needs while maintaining the integrity of ecosystems. However, even though pressures increase there remains a sparsity of near-shore data on which to build effective management strategies. The inadequate sampling of suitable environmental indicators, at least partly reflects the cost of collecting the data. In an innovative project to harness one of the many groups of people that visit the coast for recreational purposes PML scientists are targeting surfers as platforms to carry sensors to help fill some of the gaps. In a proof of concept trial a surfer was fitted with a global positioning system (GPS) device and temperature sensor during 85 surfing sessions over twelve months. While the temperature sensor provided sea surface temperature readings, the GPS pinpointed locations. The acquired data were compared with a data from an oceanographic station and from satellite observations and proved that high quality data could be collected autonomously by surfers. An extrapolation that took into account the UK surfer population and the frequency of surfing forays indicates that around 40 million such readings could be taken each year by surfers around the UK coast. Such a quantity of data would greatly enhance coastal monitoring and hence management in the UK and, as surfing is a world-wide pastime, could be expanded globally. Having established that the principle is sound the researchers are actively seeking further funding for a larger-scale study.
EARTH OBSERVATION

PML is internationally recognized as a global leader in Earth observation (EO) science and enjoys an excellent, proven, track record in a wide range of research areas, including extensive work on ocean colour and phytoplankton dynamics. PML is not simply a user of existing techniques but is constantly improving existing methods and developing new ways to use satellite and aerial observation to unravel the complexities of ocean processes in particular, and has also applied its expertise to include estuarine, fresh water lakes and some terrestrial observations and monitoring. Linking satellite observations with in situ measurements and modelling places PML at the forefront of validation and exploitation of EO data, which are then used for the provision of services and products to others. Over the last year, PML has strengthened links with existing partners and collaborators, supporting National Capability in the UK through the Natural Environment Research Council (NERC) and in Europe via a number of significant programmes, including with the European Space Agency and the Copernicus Programme.

Loggerheads to the fronts

PML’s Earth observation scientists have previously demonstrated the importance of persistent ocean fronts to basking sharks, feeding where the interface between two water masses can lead to pelagic biodiversity ‘hotspots’, also known to attract fish, whales and seabirds. By bringing together satellite tracking with high resolution composite front mapping, and working with colleagues at the Universities of Exeter and Las Palmas de Gran Canaria, loggerhead turtles can now be added, with certainty, to the list of charismatic marine megafauna exploiting the rich oceanic foraging opportunities the fronts provide. Coupling the two satellite technologies enabled the scientists to relate turtle movements and frontal zones in both time and space, so providing a rare glimpse into the lives of these highly migratory and enigmatic creatures and establishing the importance of fronts to the turtles. Such insights into pelagic ecosystem functioning has great potential to improve biodiversity conservation; front mapping could inform wider scale management efforts designed to incorporate the needs of highly mobile marine vertebrates whilst away from their better known breeding and nursery grounds.
Salinity from Space

Ocean acidification (OA), which results from decreasing pH and carbonate ion concentration brought about by an increased net influx of carbon dioxide into the ocean, is of growing concern. Currently, OA monitoring efforts are dominated by in situ observations from moored buoys, ships, and more recently the Argo float network. Whilst each provides valuable data, they all have disadvantages. Ships are expensive while Argo floats, for example, do not provide data for shallow water or enclosed seas and only measure below 5 metres from the surface. The need to monitor and study large areas of the Earth has led to the development of satellite sensors, which are used extensively for measuring many ocean parameters, including sea surface temperature (SST) and chlorophyll concentrations, only recently have sensors been developed that can estimate sea surface salinity (SSS). Salinity data are key for assessing the marine carbonate system and so the SSS data from these new sensors will enable the development of space-based OA assessment. PML Earth observation scientists have reviewed the potential for using SSS with other parameters to assess OA, identified areas of the global ocean which would provide rigorous case studies and highlight the future opportunities as a new generation of satellites are launched into orbit. They conclude that supported by good in situ measurements, satellite measurements are likely to become a key element in assessing and understanding OA.

Water quality bulletins for shellfish farms.

Environmental events that reduce the quality of the water in and around aquaculture farms can have significant impacts, ultimately preventing products reaching end consumers and so causing significant financial losses to growers.

Shellfisheries have the potential for increased growth in coming decades but face the barrier of reduced and changing water quality from sewage pollution and eutrophication when increased nutrients from land sources cause accelerated algal growth followed by oxygen depletion. Contamination from Escherichia coli and Aeromonas and the build-up of toxins from harmful algal blooms are threats to shellfish harvesting and subject to EU hygiene regulations to ensure consumer safety by maintaining levels below particular limits. Should a site be downgraded, leading to temporary closure, the costs to operators can be significant – one estimate suggests as much as £162k per closure; such closures also result in loss of consumer confidence.

The ShellEye project, funded by the Natural Environment Research Council and the Biotechnology and Biological Sciences Research Council and led by PML with partners at the University of Exeter and the Centre for Environment, Fisheries and Aquaculture Science, is exploiting Earth observation data and modelling techniques to extend satellite-based harmful algal bloom early warnings for shellfish farms and to develop early warning indicators of microbiological hazards. The project is working towards providing advanced hazard bulletins for the shellfish industry. Partners within the industry are providing case-study sites, and the project is collaborating with colleagues to ensure meteorological data is included for short-term forecasting of microbiological hazards.
Fit for industry
PML Applications Ltd is the commercial arm of PML.

Over a number of years of working with industrial partners, it has built a reputation for its flexible and pragmatic approach whilst maintaining discretion and confidentiality throughout its working practices. Along with a broad range of relevant experience and its ability to harness the globally recognised excellence of PML’s scientific research, PML Applications has become a partner of choice for commercial companies looking to solve some of the challenges of working in the marine environment.

Testing ballast water treatment technology
Impending legislation will require vessel owners to comply with rigorous ballast water regulations.

Investment in shipboard ballast water treatment (BWT) technologies represents a significant operating cost, while installation of inappropriate BWT technologies, not matched to operational conditions or not functioning correctly, can result in further unnecessary cost and potentially delay schedules. PML Applications’ Ballast Water Centre has been working with ship owners to fill the gap in in-house expertise by carrying out shipboard assessments of BWT technologies to ensure they are functioning correctly. Operators who comply with the legislation will be able to keep a full range of destination ports available for their fleets, and promote a positive environmental image.

There may be several thousand different species in a ballast water tank

The ocean’s bounty seems infinite. It is a source of essential animal protein to large swathes of the global human population; it provides mineral wealth, energy and the world’s most important transport network, as well as regulating our climate and supplying around half the oxygen we breathe. Exploitation of the ocean per se need not be always harmful or destructive but managing the ocean for the goods and services it provides while maintaining its sustainability for the wider environment is now paramount. This is a principal tenet of the Blue Economy. A key priority for PML is recognizing the potential of the ocean, finding ways to harness that potential for food, energy or biotechnology, and ensuring that in doing so there is no risk to its future.
Aquaculture risks and opportunities

The aquaculture of suspension feeding bivalve species is an important contributor to the UK and especially local economies.

The current value is in excess of £33 million and is one of the fastest growing food-producing sectors and it is showing all the signs of even greater growth in the next decade. Despite its importance there is no clear national roadmap that describes how to optimise this growth and how it should be integrated with other demands on the coastal zone. Aquaculture operators are required to conform to strict controls which include any impacts on the natural environment.

In order for the industry to grow sustainably the PML-led Risks and Opportunities for Sustainable Aquaculture (ROSA) project sets out to develop management strategies that allow development, promotion and societal acceptance of the industry, while balancing potential benefits with possible risks. Successful shellfish farming is dependent upon having the right species in suitable conditions which provide the correct growth rate, production costs, accessible location and resistance to disease which meet market pricing.

However, shellfish are notoriously responsive to fluctuations in temperature, salinity and food availability and composition, all of which are subject to rapid change in coastal areas, and potentially even more so as global environmental changes gather momentum. Future impacts might accrue from increased storminess with exposure to wind and waves, rising temperatures and harmful algal blooms. PML scientists, working with colleagues at Discovery Software Ltd, are bringing together aquaculture data into models to produce a desk-based information tool tailored to the needs of individual growers and managers in the industry. For the first time this will enable the projection of likely risks resulting from interrelationships between habitat suitability and culture practice at scales ranging from individual farms to regional waters.

Remote biofouling monitor

Managing biofouling on marine infrastructure often relies on conducting costly and potentially disruptive surveys or maintenance on difficult to access sub-sea areas, frequently in high energy offshore environments where there are significant health and safety issues.

PML Applications’ Centre for Biofouling & Corrosion, together with the Offshore Renewable Energy Catapult, Scottish Association for Marine Science, and coatings company AkzoNobel, have been investigating the feasibility of producing a biofouling sensor that would monitor and measure biofouling levels on remote structures and report back to a monitoring station in real time. Such technology would provide information that would enable optimum programming of maintenance to keep costs down and minimise downtime.

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Novel antifouling coating technology

Biofouling on marine infrastructure often inhibits the efficient operation of many marine industries and may also lead to negative impacts on the environment.

Currently anti-fouling coatings are used to manage biofouling, but some release biocides into the marine environment while others may fail when used outside their design criteria; a coating that is designed to slough from a ship’s hull as it moves will fail to work in static applications, for example. Currently there is no ‘silver bullet’ in terms of antifouling coatings so research continues to look to develop an anti-fouling coating which is suitable across a range of applications including static use, high energy environments or where mechanical damage is expected. PML Applications is working with the coatings industry in developing anti-fouling coatings which combine low surface energy coating technology with active antifouling compounds from natural sources, through thorough testing in real environments. Such technology should last longer, be more widely applicable and save operators re-coating and hull management costs compared to traditional biocidal technologies.

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PERFORMANCE & COMMUNICATIONS

PML enjoys a worldwide reputation for the excellence of its science and the uniqueness of its approach, which brings together observation, experimentation and modelling from across its science areas to target the most effective and efficient marine research for societal good.

Performance & Evaluation

The performance of any organization is measured in a number of ways; whilst financial performance is critical to future sustainability, for PML the quality, relevance and impact of its research are crucial to long-term success.

Indications are that PML’s turnover in this financial year will be of the order of £10m. Significant effort into the development of proposals for the EU Horizon 2020 programme has already begun to yield positive results, with PML enjoying an average success rate of 50% on full proposal submissions. Capital funding success included a grant won from the Wolfson Foundation to match funding awarded by NERC in December 2014 for an Environmental Single Cell Genomics facility.

A principal output from research is scientific publications and in 2015 PML scientists produced 150 peer-reviewed publications. Of particular note was a PML first-authored paper produced as part of the Western Channel Observatory special issue, which has been classified as a ‘hot paper’, meaning that it received enough citations within a certain timeframe to place it in the top 0.1% of papers in its academic field.

Other accolades which recognise the quality, relevance and impact of PML’s research included:

- PML was ranked top UK organisation for climate economics and policy by the International Center for Climate Governance in their Climate Think Tank Ranking.
- Global recognition for PML’s Earth observation science in a report by the Committee on Earth Observation Satellites.

At the heart of evaluating organisational performance is PML’s Board of Trustees and during the year there were a number of changes in its membership, notably the retirement of its Chairman, Prof. Terence Lewis FRCS, who had served as a Trustee since 2002 and Chairman since 2009. The Trustees and staff would like to thank him for his significant contribution to PML’s success. PML’s new Chairman is Admiral Sir James Burnell-Nugent KCB CBE MA.

PML’s success in winning competitive funding calls, entering into collaborations and building new partnerships is testament to its standing in scientific and governmental arenas; this is further reflected in its continuing level of scientific publications, many in high impact journals. Behind the science is a pyramid of supporting activities including administrative, financial, human resources, communications, and the more technical laboratory maintenance, research vessel and equipment management, and computational provision. It is this blend of skills and abilities, and the desire to work together in relevant teams that lead to PML being a partner of choice, and often the lead partner in research projects of global importance.
Communicating the science

Scientific publications are the mainstay of any research organization, sharing results and gained knowledge with peers across the globe through the medium of research papers in scientific journals is the bread and butter of science.

Once again PML has maintained its level of publications at around 150 during the year, an astounding feat. However, getting the messages out, reporting the conclusions and sharing the knowledge amongst non-scientific ‘stakeholders’ is another challenge and one that is growing as funders require more impactful and relevant science from the research community. PML has always held societal benefit at the core of its research and so has adapted to the requests for meaningful and applicable science with ease. PML scientists continue to share their expertise and experience at many key meetings, conferences and workshops at home and further afield. Professor Stephen de Mora, for example, represents PML and the UK scientific community on a number of international boards and committees, and this year was appointed as a member of the Sargasso Sea Commission, and is much further reflected in the demands for them to be included in a wide range of advisory roles for government, often providing evidence to parliamentary inquiries. Communicating science to wider groups is now an essential output from research and is increasingly being seen as an important marker of the relevance and impact of science. PML’s Communications Group works closely with the research scientists to build impact plans and then deliver on them, increasingly taking the communications lead in multi-institute projects.

A picture is worth a thousand words

Short videos are a simple and effective way of sharing the ideas behind projects as well as summarising the results.

Towards the close of the Marine Operational Ecology for European Regional Seas Project (OPEC) a short video was created to show the interactive computer-based tools it created could be used. A second large EU project also drew to a close during the year, the VECTORS of change project was concerned with ecosystem services and how they may be impacted in future. The opportunity was taken during a workshop held in PML to interview participants, the resulting film explains what ecosystem services are and how they can be used in marine management. Also funded from Europe through the European Space Agency is the GlobCurrent Project; another opportunism allowed collecting material for a film during the 1st User Consultation Meeting, held in Plymouth. The sources and sinks of CO₂, is a complex research area; the importance of increasing our knowledge of how it fits into the great chemical cycles and how it may be affected by climate change, was the subject of another film concerning the Radiative Gases of the North Atlantic Region and Climate Change (RAGNARoCC) project. During the year these and other videos, available through PML’s website, were viewed over 7000 times.

Electronic media

PML’s website is a key portal between the wider public and its science and other activities.

The completely renewed and reinvigorated website attracted more than 77000 visitors who between them viewed nearly 238000 pages, remaining on average over three minutes. PML embraces electronic media and is constantly updating its successful Twitter feeds, Facebook posts and e-alerts, while always on the lookout for new trends and better ways of communicating with as many interest groups and individuals as possible.

Electronic media continue to develop but traditional methods are still important. PML has an extensive contacts list, built up over many years, to which it regularly sends press releases and submits more popular articles. National and local TV and radio coverage is still a useful conduit for getting the news out. Apart from many appearances on domestic channels PML was especially pleased to host Al Jazeera as they made a film about the Western Channel Observatory and how modern marine science monitors and observes the ocean. This was transmitted for a whole day every hour on the hour.

Still important

Scientific publications are the backbone of our output but the so-called grey literature can also be effective and PML has maintained its commitment to share science through articles in many non-specialist magazines and newspapers.

A major contribution was to a Food and Agriculture Organization (FAO) publication produced on behalf of the Youth and United Nations Global Alliance (YUNGA). ‘The Youth Guide to the Ocean’ was co-ordinated through PML and more than a third of its chapter authors are PML staff.

Further details of all of PML’s activities, outputs and publications can be accessed through the website: www.pml.ac.uk
At the organisational level, PML actively seeks to develop strategic relationships with global, national and regional partners, and is itself sought after by other organizations keen to partner a world-leading institute, not only to address the challenges facing the ocean, but also to contribute towards developing solutions and the next generation of scientists.

In 2015 we forged new partnerships with a number of global organizations, including:

- Commonwealth Scientific and Industrial Research Organisation, CSIRO, Australia to develop opportunities for collaboration and share expertise, strengthening our collective footprint in national and international marine and coastal postgraduate training.
- Korea Institute of Marine Science and Technology Promotion (KIMST), Korea to explore opportunities for enhancing collaboration and sharing experiences, networks and knowledge with the aim of transferring scientific knowledge and supporting marine policy development.
- Nansen Environmental Research Centre, (NERCI), India in order to develop co-operation in research and education, focusing on marine ecosystem studies, monsoon and ocean variability, climate change, coastal zone management and societal issues.

In addition to these new strategic alliances, PML has built upon existing relationships, and amongst these are its involvement in a number of Natural Environment Research Council (NERC) Doctoral Training Partnerships (DTPs), which resulted in six new PhD students having started at PML in October 2015, adding to an existing cohort of 70 students and 81 visiting researchers across the year, thus strengthening PML’s collaborations worldwide.

The DTP initiative is designed to provide excellent postgraduate research opportunities within the NERC science remit and is delivered in collaboration with partners from a wide range of backgrounds, including academic institutions and specialist research organizations; its intent is to ensure students are equipped with the skills and experiences to allow them to become world-leaders in their chosen careers. PML is currently a partner in three DTP consortia:

- The Great Western 4+ (Gw4+) consortium in association with the Universities of Bristol, Exeter, Cardiff, and Bath
- The Southampton Partnership for Innovative training of Future Investigators Researching the Environment (SPITFIRE) with the University of Southampton
- EnvEast consortium includes the Universities of East Anglia, Essex and Kent.

The range of topics covered by postgraduate students at PML reflects the organization’s expertise and interests, including: ocean CO2 uptake measurements; predicting European fish distribution and abundance under climate change; valuing the marine environment and human well-being; microplastics in the ocean; microbial communities and carbon cycling; satellites for ocean-atmosphere CO2 exchange; variability, health, physiology and function of marine benthic invertebrates; halocarbons and atmospheric chemistry; the ocean carbon pump; the marine oxygen cycle; viruses and methanol cycling.

Next generation scientists

Early career scientists add to PML’s dynamic and innovative approach to marine science.
PROJECT DEFINITIONS

ABC Fluxes Atlantic Biological Chemical Fluxes project
ADVENT Addressing Valuation of Energy and Nature Together
ALGAE/ALGO Environmental and Biotechnological Risk Assessment
AQUA USER AQUACulture USER driven operational remote sensing Information Services
ARMS Atlantic Meridional Transect
ASBIT Airborne Research Survey Facility
ATLAS Optimising and Enhancing The Integrated ATLANTIC Ocean Observing Systems
BATMAN Biological carbon pump Assessment using the Transport Method And global Nutrient distributions
CAYNAMIC Carbon/Nutrient Dynamics and FLUXES Of the Shelf System
CERES Climate change and European aquatic RESources
CMEMS Copernicus Marine Environment Monitoring Service
Crown Estate The Crown Estate renewables projects
C2X Extreme Case 2 Waters
DECCMA DEpartments of Environment and Climate Change Migration and Adaptation
DeVALPP Development of an Agri Crop Protection Programme
DEVOTES Development Of Innovative Tools for Understanding Marine Biodiversity and Assessing Good Environmental Status

DGMSO Microbial degradation of Dimethylsulphoxide in the sunlit ocean
Earth2Observe Global Earth Observation for Integrated Water Resource Assessment
Earth Server the marine data service developed by PML makes use of the European Space Agency Ocean Colour - Climate Change Initiative data contributing to PML’s ‘big data’ strategy
ECO2 Sub-sea C02 Storage Impact on Marine Ecosystems
EnAlgae ENergetic ALGAE
ERSEM European Regional Seas Ecosystems Model
ESPA Assessing health, livelihoods, Ecosystem Services and Poverty Aversion in populous deltas
Globemod estimation of ocean surface currents from satellite sensors
GlobeLakes GLOBal Observatory of LAKE Responses to Environmental Change
INFORM Improved monitoring and forecasting of ecological status of European INland waters by combining Future earth Observation data and Models
MERL Marine Ecosystem Research Programme
MARS Maximising Yield of FISHERies whilst Balancing Ecosystem, Economic and Social Concerns
NCEO National Centre for Earth Observation
NERC/NGA the NERC Earth Observation Data Acquisition and Analysis Service
NITCYTE Short cuts in the oceanic NITrogen CYcle in the Twilight Zone
O-Bioanalysis Biological cycling of N and P in the surface ocean
LUCAS-LMPA North-West European Shelf Monitoring and Prediction Service
OASIS Ocean Acidification in Arctic Fjords
OCCLIV Ocean Colour Climate Change Initiative project
OceanFluxGINS Ocean Flux Greenhouse Gases project
PAULER Pilot Algal Lipoxygenase Manufacture in the UK
RadInOpt OA an ESA project to exploit Earth Observation data to quantify parameters required for OA research
RESEUS Policy-Oriented Marine Environmental Research in the Southern European Seas
REPOPOs of Carbon in the Ocean project
RECOPII Quantifying and monitoring potential ecosystem Impacts of geological Carbon Storage
RAGNAR The Radiatively Active Gases from the North Atlantic Region and Climate Change
RECOIL Resolving Climate Impacts on shelf and Coastal Ecosystems
RISHER Risks and Opportunities for Sustainable Aquaculture
SeaMOSAIC to produce and validate a Sea Level Essential Climate Variable (ECV) product

Sentinel-3/MOPS assessment of new ESA satellite data quality
SheEyes will use Earth observation and environmental data to monitor and forecast water quality for the aquaculture industry
StELLAS Surface Mixed Layer Evolution at Submesoscales project
STOLAS Sustainable Pathways to Low Carbon Emissions
STRESS Shelf Seas Biogeochemistry research programme
STEMM-CCS Strategies for Environmental Monitoring of Marine Carbon Capture and Storage
TAPAS Tools for Assessment and Planning of Aquaculture Sustainability
UKERES UK Energy Research Centre
UKOA UK Ocean Acidification Research project
VALMER Valuing Marine Ecosystem Services in Europe
VECTORS Vectors of Change in Oceans and Seas Marine Life, Impact on Economic Sectors
WCO Western Channel Observatory
WindWaves - Minimising the risk of harm to aquaculture and human health from advective HABs through early warning
W26 Wastewater to produce biomass for Biorefinery

This list relates to the bubble diagram inside the front cover. It is only a selection of projects undertaken by PML.
Millions of people living in coastal communities rely on the ocean directly for food, their livelihood and culture; all of us benefit from the services it provides, including half the oxygen we breathe, much of the protein we consume, and as a source of minerals and energy to underpin our economies and well being. One estimate suggests the ocean is worth US$24 trillion and provides an annual product that totals at least US$2.5 trillion – if the ocean was a country it would boast the world’s seventh largest economy.

If we are to use the ocean’s resources wisely, meeting future demands while maintaining the integrity of its ecosystems, we need to understand its strengths, weaknesses and potential, what it does for us and what we need to do for it.

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For more information about PML please visit www.pml.ac.uk or follow us on Twitter @PlymouthMarine, Facebook, LinkedIn and YouTube (PMLAdministrator)

We welcome your feedback about this Annual Review. Please share your comments via email to comms@pml.ac.uk