

**PML**

Plymouth Marine  
Laboratory

# MARINE SCIENCE FOR PEOPLE

Annual Review 2017



# PLYMOUTH MARINE LABORATORY - MARINE SCIENCE RELEVANT FOR SOCIETY

Plymouth Marine Laboratory specialises in investigating the coastal and sunlit seas of our planet.

► It is in these areas, where the majority of productivity takes place, where the ocean is at its most dynamic and where research informs us how it functions and how humans may be changing it. These highly productive areas impact directly on human populations, in a good way by providing food and other resources, but sometimes negatively through storms and inundation, for example. It is, therefore, only right that PML research in these zones is directly relevant to not only local, but also the global human population. Increasingly, through

international partnerships and funding, and as a result of PML's reputation for delivering high quality, relevant research directly of benefit to the human race, much of our research has important societal impact. In the following pages we can only highlight some of PML's impressive annual research output. We hope this will provide a taste of the variety, depth and excellence of our research, and would encourage you to visit the PML website for further information or get in touch to learn more.

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# SCIENCE SERVING SOCIETY

► Plymouth Marine Laboratory's science has direct relevance to society and contributes to achieving targets and aspirations set out in national and international directives and goals for a sustainable future for our planet, including:

## UNITED NATIONS SDGs

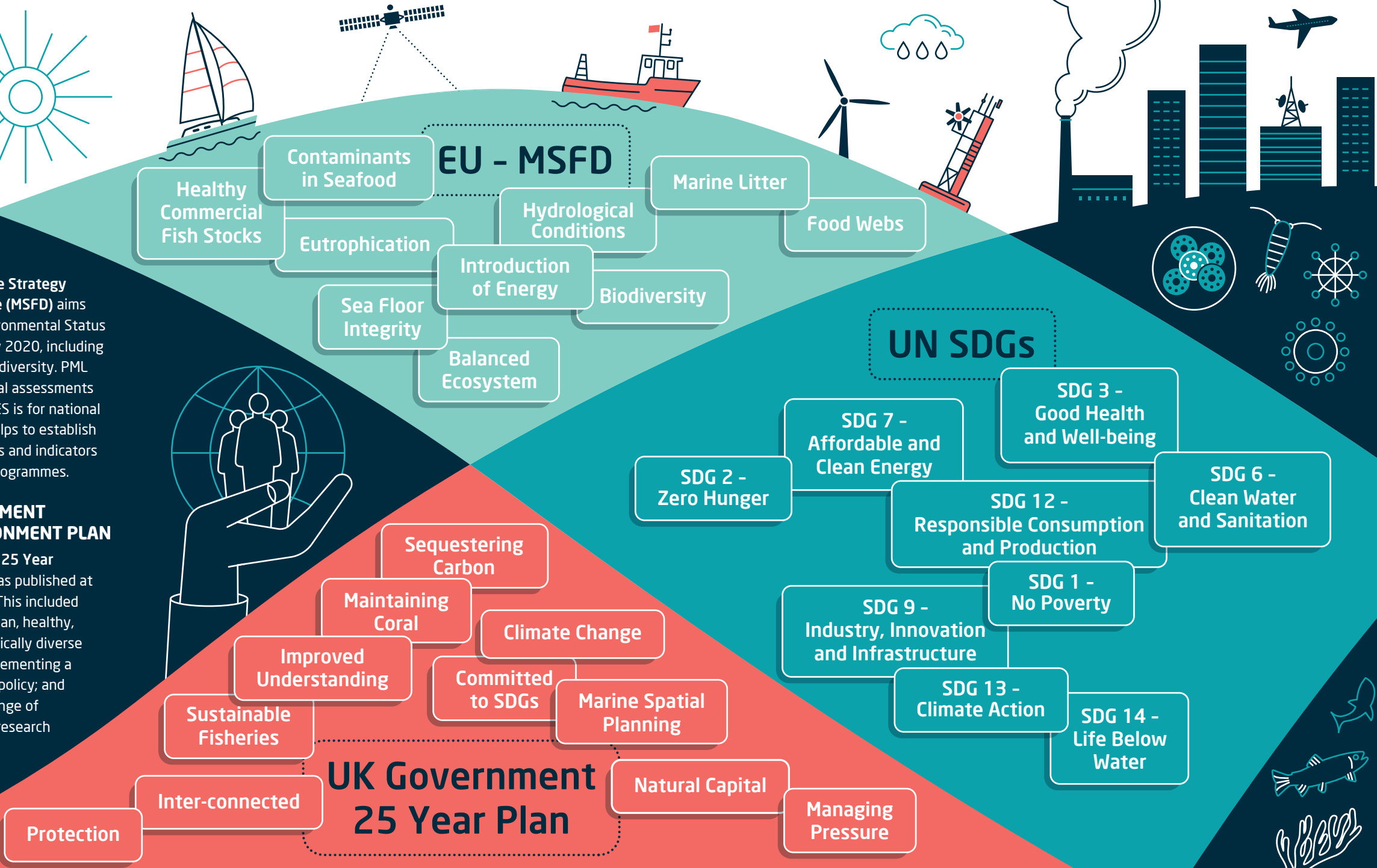
The 17 UN Sustainable Development Goals that aim to end poverty, protect the planet and ensure prosperity for all. PML science addresses 8 of these goals, aimed at ensuring food resources, improving human health and well-being, addressing climate change and maintaining a healthy and productive marine environment.

## EU - MSFD

The European Marine Strategy Framework Directive (MSFD) aims to achieve Good Environmental Status (GES) of EU waters by 2020, including protecting marine biodiversity. PML research informs initial assessments to determine what GES is for national marine waters and helps to establish environmental targets and indicators through its science programmes.

## THE UK GOVERNMENT 25 YEAR ENVIRONMENT PLAN

The UK Government 25 Year Environment Plan was published at the turn of the year. This included plans for: securing clean, healthy, productive and biologically diverse seas and oceans; implementing a sustainable fisheries policy; and addressing the challenge of climate change. PML research is already aligned to such aims.



# WELCOME



► **Admiral Sir James Burnell-Nugent KCB CBE MA,**  
**Chair of the PML Board of Trustees**

**Welcome to PML's Annual Review 2017 which captures some of our exciting science, and related activities, over the twelve month period.**

► This year we focus on People, encompassing the research we undertake which delivers societal benefit, and the achievements of our staff and students.

Investment in our staff is critical for future success; such investment can take the form of training and development, or investment in the equipment and infrastructure our scientists need to deliver cutting-edge research. We were therefore delighted to announce in September that we were embarking on a major £5.4M building refurbishment programme, primarily funded by the Natural Environment Research Council, to create a suite of state-of-the-art laboratories to boost PML's capacity as a leader in pioneering marine science. The project has commenced, and is on schedule, with the aim to complete in early 2019.



► **Prof. Stephen de Mora CChem, FRSC, FRSB, FRSA,**  
**Chief Executive**

Another cause for celebration this year has been our scientists' success in winning new contracts, the value of which already (and before our financial year end) at £8.4M is at a record level in PML's history. Such success demonstrates the excellence and relevance of PML's research, as well as the dedication of our staff. Amongst these contracts are research projects which have a strong societal focus. One such project, funded through the Research Councils UK's Global Challenges Research Fund (GCRF), is Blue Communities, led by PML, and which aims to support coastal communities in Southeast Asia that depend on healthy and diverse marine ecosystems for food, livelihoods, their health and well-being.

The capability and flexibility of our staff, and their resilience against an ever-changing external landscape stands PML in good stead for the future.

We hope you enjoy reading this Annual Review and discover more about how our research makes a difference.

## BUILDING FOR THE FUTURE

► PML enjoys a global reputation for its world-class marine science research; this success is highly dependent upon the calibre of its scientific and support staff, but underpinning all of this are modern laboratories and the equipment they contain. This year has provided an opportunity to further improve these facilities thanks to a generous grant of £5 million from the Natural Environment Research Council, matched with £400k invested by PML.

The building project has got off to an excellent start and will create a suite of showcase laboratories over the coming months, and further boost PML's capacity as a leader in pioneering marine science. The exciting new laboratories will enable PML to build on its excellence in interdisciplinary marine research, and include facilities to investigate the impacts of plastics on our environment and the marine life within it, from our coasts and beaches to the seafood we eat, and to develop cutting-edge technology, while also testing the technology of others, to help us better understand the marine environment.

The new laboratories and equipment reflect the relevance and emphasis of PML research aspirations and will provide state-of-the-art microscopy that enables the identification of some of the tiniest life – plankton – in the waters surrounding Plymouth, while using the unique and globally-important data provided by the

Western Channel Observatory. Other facilities are designed so that multiple stressors, including noise pollution and the now recognised threat from light pollution, can be investigated. Alongside these facilities are constant-temperature rooms that replicate diverse marine environments, from polar to tropical. These are especially important in the investigation of climate change and the complex relationships of gas exchange between the ocean and the atmosphere. Quite unique is the “Molecular Matrix” – a one-stop laboratory for the analysis of DNA and dedicated to the study and culture of marine organisms. The next generation is not forgotten and a new teaching laboratory for training the marine scientists of tomorrow will further enhance PML's commitment to sharing its science and welcoming young career scientists from across the world, to work alongside our renowned researchers. The work has progressed at a pace and (as this is written) Phase 1 is open, thanks to the efforts of the main contractor Devon Contractors Ltd, and their sub-contractors and the enthusiasm and collaboration of staff at PML.



# 1 ENGAGING WITH COMMUNITIES

► PML scientists continue to work with many communities across the globe, helping to build local capacity for understanding and managing marine resources, such as coral reefs and mangrove swamps. Closer to home citizen scientists in the surfing community are gathering marine environmental data which contributes to understanding our coastal waters.



## CORAL COMMUNITIES - BUILDING RESILIENCE

► Coral Communities was a Global Challenges Research Fund (GCRF) project which engaged with stakeholders from across the Western Indian Ocean (WIO) and from the UK to discuss the concept of resilience and the strategies used in practice to help build social and ecological resilience in coastal locations. The Coral Communities team comprised an interdisciplinary partnership between academics, NGOs, a development consultant and a creative art and film-making team.

The overall aims of Coral Communities were two-fold: to identify and critically assess the effectiveness and potential of management and development strategies to build resilience of coral reefs and dependent communities in the Western Indian Ocean (WIO), and to understand to what extent ecosystem services language and approaches facilitate development and implementation of such strategies.

The project included stakeholder workshops in both the UK and Mauritius to identify possibilities for future collaboration and assess the extent to which the initiatives currently used to manage coral reefs are successful in building community and reef resilience. A novel, arts-based approach for assessing perception of the environment and socio-cultural risk associated with different resilience strategies took place in Mauritius and with local people. Coral Communities also undertook a review of the literature to assess the evidence available on the social and ecological implications of strategies that have been used in the WIO region to help build both social and ecological resilience to the drivers of coral reef decline and which resulted in a series of 14 factsheets in both English and French and a video outlining the aims and achievements of the project, which are available via the PML website.

► **SHARING  
EXPERTISE AND  
EXPERIENCE  
FOR COMMUNITY  
RESILIENCE**







## CITIZEN SCIENCE DATA ANALYSIS REVEALS PLASTICS TREND

► The problem of plastics littering beaches and the wider marine environment has gained much publicity over the last few years. PML, often collaborating with other partners, has been assessing various aspects of the 'plastic problem'; one thread has been to analyse the data collected from a decade of Marine Conservation Society beach litter surveys to determine the composition, spatial distribution and temporal trends of coastal debris. The analysis confirmed that the majority of marine anthropogenic litter was plastics of one sort or another and that most of this came from land-based sources, specifically public littering. The researchers also detected regional

differences, with the Western English Channel and the Celtic Sea experiencing the highest relative litter levels. Over the ten-year period litter abundance (the number of items collected per person per minute of effort) did not change significantly but six common litter items showed increases: small plastic items, plastic food packaging, wet wipes, polystyrene foam, balloons and large fishing nets. All European nations have an obligation to monitor anthropogenic litter in their marine waters and using volunteers as citizen scientists is an effective way of gathering data at a much lower cost. The analysis of the MCS data further demonstrates that volunteer beach cleans and surveys result in the removal of large amounts of litter, reduce the cost of

sampling, enhance public awareness and generate useful data.

► THE MAJORITY OF MARINE LITTER IS PLASTICS



## A DIP IN THE OCEAN CAN FILL GAPS

► The large number of people engaging in sea-based activities presents a huge and growing resource of citizen scientists. They can make useful contributions to our understanding of how the ocean works by collecting important, long-term data during their recreational activities. One such opportunity is afforded by surfers, who spend significant time in coastal waters, often throughout the year. One essential variable that provides crucial data for our understanding of how the ocean might be changing is sea surface temperature (SST), which can be measured remotely and over large areas by Earth observation (EO), satellite-borne sensors. However, it is crucial to be able to have confidence in the accuracy and precision of such data, so ground-truthing is essential. Across the open ocean there is a good understanding of SST. Perversely, closer to shore, where conditions are less uniform and there is greater seasonal

change, dynamism and complexity, the performance of EO techniques is less well established. PML scientists came up with the idea of engaging the surfing community to take ground-truthing measurements, via small board-borne sensors, while they pursue their sport at the coastline. Initial results indicate that using such communities as data-collectors has great potential. Indeed, other studies involving anglers and SCUBA divers have shown similar utility, and such engagement could be expanded to wherever coastal recreation takes place. One estimate concludes that each year in just the US and UK combined there are 1.25 billion participant interactions with the marine environment. If only 1% of those could be harnessed to gather data, 12.5 million independent measurements of environmental indicators could be gained each year.



## INVOLVING COMMUNITIES

► **South West Partnership for Environment & Economic Prosperity (SWEEP)** is a new initiative that will help deliver economic and community benefits to the South West of England, whilst also protecting and enhancing the area's natural resources, including in the marine realm. Funded by the Natural Environment Research Council's Regional Impact from Science of the Environment programme for 5 years, SWEEP will bring academic experts, businesses and policy makers together to solve some of the challenges involved in managing, utilising and improving the natural environment. Together with our partners in industry and the community, SWEEP will develop bespoke tools and solutions that will aid decision-making, and support the management of our natural environment. SWEEP will drive sustainable economic growth, create new products and services, safeguard jobs, generate new employment, improve policies, and enhance the health and well-being of people living in the South West.



► **SWEEP brings academics, business and policy makers together.**

► **Addressing Challenges of Coastal Communities through Ocean Research for Developing Economies (ACCORD).**

The coastal and marine environments of South East Asia and the Western Indian Ocean are rich and diverse, possessing high levels of biodiversity and productivity. However, the coastal ecosystems and the services they provide are under threat from growth in human activities, global markets, the desire for economic growth, and the less direct impact of global climate change. This affects both the resilience of living resources to pressures and the ecosystem services we derive from them. Many coastal communities depend on nearby coastal and marine resources for their livelihoods and welfare yet lack alternatives when these services deteriorate due to over-exploitation or adverse effects of climate change. At the same time coastal developing nations are looking to the ocean to provide opportunities for sustainable economic growth through resource exploitation (e.g. mineral extraction) and livelihood diversification (e.g. tourism, aquaculture, and blue carbon initiatives) and to support food security (e.g. fisheries and aquaculture).

Scientists from PML and the National Oceanography Centre will work together on the ACCORD project to increase our understanding of the mechanisms and processes that determine the potential sensitivity or resilience of marine ecosystems to both globally and locally induced environmental change.

## BLUE COMMUNITIES - WORKING WITH STAKEHOLDER COMMUNITIES FOR SUSTAINABILITY



► Blue Communities is a 4 year research capacity building programme for marine planning in East and South-East Asia. Millions of people across the globe rely on marine and coastal ecosystems for their livelihoods: food, employment and their general well-being. However, the marine environment is under immense pressure from the multiple, and often conflicting, needs of the people that use it. In E/SE Asia, where marine activities are important contributors to Gross Domestic Product (GDP), marine spatial planning involving co-ordinated decision-making has been highlighted as a key requirement for a sustainable future. One of the most important aspects of this Blue Communities programme is effective and culturally-sensitive relationship building with the wide-ranging stakeholders. Through academic-stakeholder collaborations, community co-creation and co-delivery, Blue Communities will support the development, implementation and ongoing

management of initiatives that promote the sustainable use of marine resources by multiple users, whilst protecting the fragile marine ecosystems and supporting the livelihoods food security, health and well-being of the people in these coastal communities.

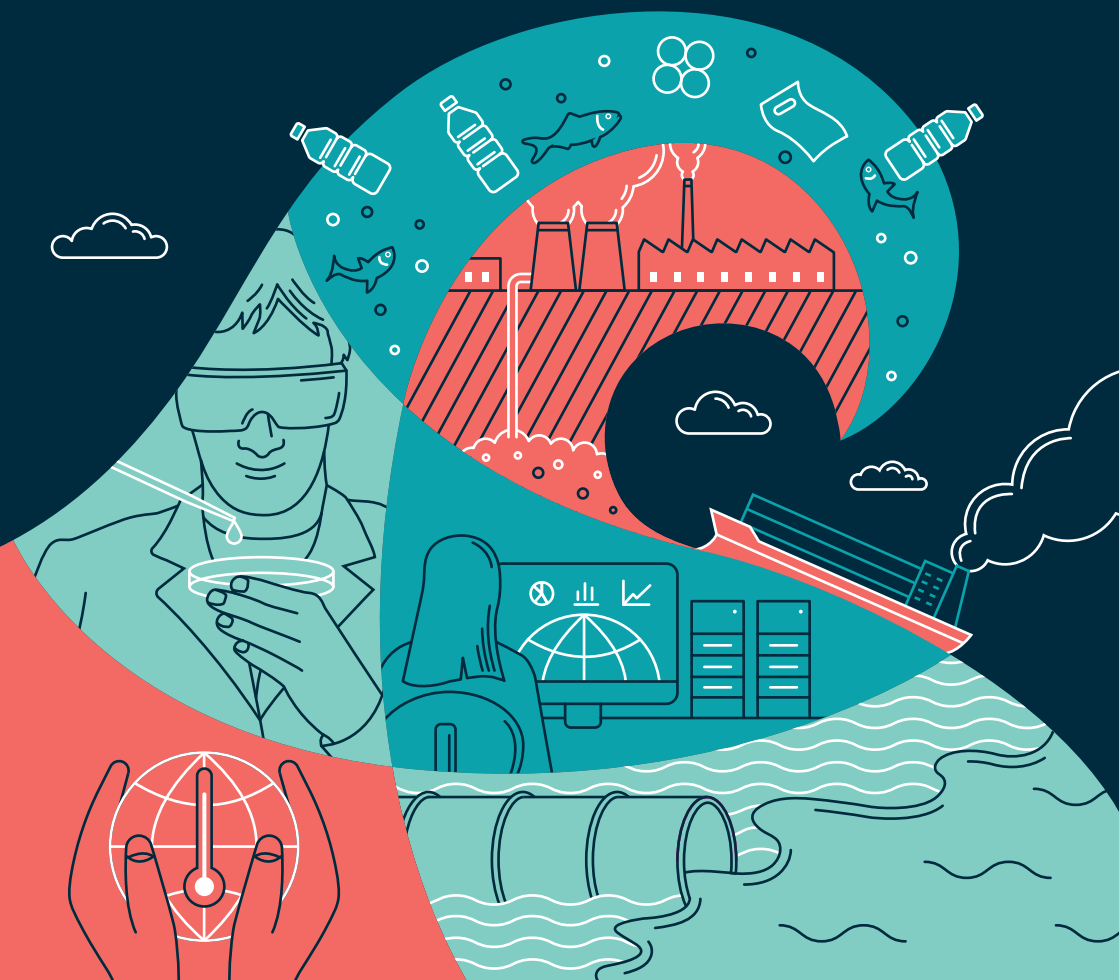


### BLUE COMMUNITIES

► The Blue Communities 'kick off' meeting in Kuala Lumpur, Malaysia attracted delegates from Malaysia, UK, Indonesia, Vietnam and the Philippines.

# 2 RESEARCH FOR A CHANGING OCEAN

► Climate change is almost universally recognized as a reality that is likely to have profound impacts on the environment and consequently on society. PML research continues to look into how rising temperatures and the carbon dioxide-related phenomena of ocean acidification and oxygen depletion, working alone or in combination, are affecting marine life, and how these affects might be mitigated.





## BETTER EXPERIMENTS FOR BETTER UNDERSTANDING OF OCEAN ACIDIFICATION

► Changing ocean chemistry as a result of ocean acidification (OA) will have wide implications for marine life, especially for organisms that require calcium carbonate to build shells or skeletons. Over the last 15 years, many OA studies have been conducted, usually altering the pH (or  $\text{CO}_2$  concentration) of seawater to simulate future ocean conditions and thereby determine what the impacts on marine organisms might be. However, many previous OA experiments of this kind did not wholly take into account species' own natural resilience to changes in their environment; particularly in the highly variable environment of coastal areas where pH/p $\text{CO}_2$  levels fluctuate far more dramatically than in the open ocean. The highly variable conditions found along the Chilean coast, for example, are an ideal home for organisms more resilient to stress and


changes in climate, due to its changeable seawater carbonate chemistry. It is likely that the estimated impact of OA on the different physiological traits of coastal organisms has been inaccurate. PML scientists working with colleagues in Chile concluded that, in order to better understand the impacts of OA on marine ecosystems, future studies should use more realistic scenarios in experiments. This would include changes in how OA experiments are designed, to simulate situations that better represent both present and future pH/p $\text{CO}_2$  conditions, including the extreme scenarios posed by progressive OA. From this our understanding can be improved of how flexibility changes across traits, populations and species, and how results obtained can be interpreted, communicated and utilized elsewhere.



## OA AND MARINE LIFE DISTRIBUTION

► Working alongside researchers from Quebec and Plymouth, PML scientists have discovered that some populations of periwinkles (*Littorina littorea*), a marine gastropod found across a wide geographical range, are vulnerable to the effects of ocean acidification. When exposed to low pH conditions based on predictions of future ocean warming, these small sea snails experience higher levels of shell degradation. The effects are more pronounced in the populations from sub-polar regions, found near the northern edge of their range and thus more suited to colder climes. More differences between populations were found when investigating metabolic responses and their effects on growth: periwinkles

from the northern and southern edges of their range were both found to adjust their metabolism in the lower pH waters. This led to inhibited growth in both populations, as more energy was used to maintain their health. Nearer the centre of their range, the periwinkle population in cold, temperate waters seemed to fare much better – they were able to respond to ocean acidification by increasing their metabolic rate to a level where they could not only take care of their shells but still had enough resources to continue their growth. Ocean acidification is likely to have an influence on the distribution of marine life as the waters of the world warm, but some populations will be more sensitive than others.



► **OCEAN  
ACIDIFICATION AND  
WARMING WATERS  
ARE LIKELY TO AFFECT  
MARINE LIFE**



## OA AND EARLY-LIFE STAGES



► Early-life stages are thought to be more vulnerable to changing climate and increased acidification, but there may be some room for species to recover as they age. For the first time, PML scientists have demonstrated how the multiple stresses of exposure to warmer waters and elevated  $p\text{CO}_2$  impact upon the development of young marine gastropods. The dog whelk (*Nucella lapillus*) is an important predator of the intertidal zone, but their early-life stages feel the effects of ocean acidification in a way that may harm their own chances of survival. Young dog whelks were found to have weaker shells when exposed to conditions simulating future ocean temperature and pH levels – a vulnerability that could increase their own risk of predation and have repercussions throughout the rocky shore ecosystem. As some individuals aged, however, there appeared to be some compensation. Over time, the dog whelks' shells showed signs of reversing the effects of the warmer,

more acidic waters, a trait that could suggest the species has the ability to counteract the damaging effects of future conditions, should they survive their early weakness.



### MARINE ECOLOGY AND BIODIVERSITY GROUP

► The Marine Ecology and Biodiversity group at PML uses its expertise to measure and investigate biodiversity across a range of biological scales, and explore the ecological processes and interactions that support biologically diverse and productive marine ecosystems.

## DETECTING SEA FLOOR CARBON DIOXIDE ANOMALIES

► Sub-seabed carbon dioxide capture and storage (CCS) is one strategy which could help to control greenhouse gas emissions from fossil fuel plants and other industries, that contribute to climate change and ocean acidification. Storage beneath the sea floor is not without challenges, however, and the integrity of the geological storage sites must be demonstrated to ensure confidence that no CO<sub>2</sub> will leak into the atmosphere. To be confident that leaks are not occurring, any leaks that do occur need to be detected accurately and promptly. Storage monitoring using seismic techniques to produce images of geologically stored CO<sub>2</sub> is an expensive method. Instead, a chemical way of checking for emissions at the sea floor could be more suitable. However, this process in itself is complex and what to measure remains open to debate. Added to this is the fact that CO<sub>2</sub> levels in seawater are naturally variable and increases in CO<sub>2</sub> could be a result of other factors, such as rivers, circulation patterns, changes in temperature, biological activity and ocean acidification.

► CO<sub>2</sub> LEVELS  
IN SEAWATER  
ARE NATURALLY  
VARIABLE

Now a team of PML scientists has developed an effective strategy for assuring the absence of leaks by first characterising natural variability of CO<sub>2</sub> in their North Sea study area using sophisticated computer

models of the marine system. They have shown that by taking measurements of seawater acidity (pH) several times an hour, they can be certain that changes as small as 0.01pH unit (representing a tiny amount of additional CO<sub>2</sub>) would indicate an anomaly, or possible leak, rather than natural variability. As a

result monitoring strategies can be recommended that will give assurance that stored CO<sub>2</sub> is secure and, in the very unlikely event of leakage, enable rapid detection and management. Detecting anomalies and potential CO<sub>2</sub> leaks in this way is cost-effective, practical and highly sensitive. Thus PML's modelling expertise will contribute to an increase in confidence for carbon capture and storage.

CO<sub>2</sub>

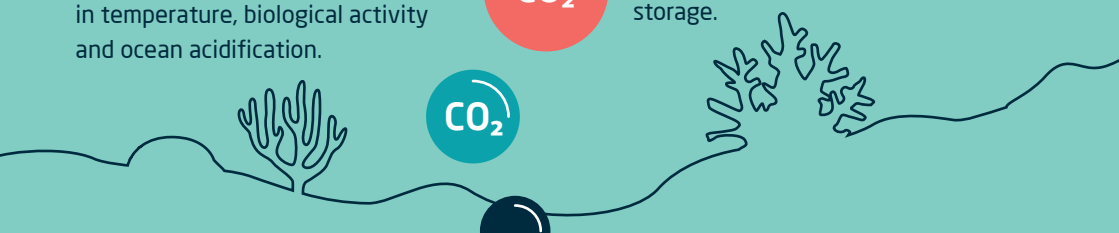
CO<sub>2</sub>

CO<sub>2</sub>

CO<sub>2</sub>

CO<sub>2</sub>

CO<sub>2</sub>



## SURVIVING IN NATURAL FLUCTUATIONS

► Simulating future conditions has already revealed a great deal about how marine species may respond to ocean acidification. But what about species that inhabit coastal regions, where the environment is constantly changing, and where predictions of static ocean conditions may not paint a full picture? By studying the mussel (*Mytilus edulis*) PML scientists have demonstrated that an environment that naturally fluctuates in pH levels appears to be more demanding to live in. Mussels faced with variable conditions were found to have higher metabolic rates and elevated stress responses than those experiencing levels of ocean acidification at current and near-future, but static, conditions. Living in an environment with natural fluctuations appears to be more energetically demanding for some species, and will be an important consideration for future understanding and management of coastal regions as the climate continues to change.



## LIGHT POLLUTION AND COASTAL ANIMALS



► Light pollution from buildings, vehicles and street lights is widely recognised as having detrimental effects on many animal groups. Now a team of scientists from PML and the University of Exeter has designed experiments that show that lowlier creatures along the seashore can be affected too, and this could upset the ecological balance along rocky coasts. The experiments acclimated one group of dog whelks to an artificially-lit night sky, while a second group acted as a control under a more natural night/day cycle. The dog whelks that experienced the night-time lighting sought out refuges far less than those under 'normal' conditions; were exposed to predators for longer; spent longer seeking food, and so were energetically stressed and potentially at risk from predation. Light pollution is yet another challenge for rocky shore organisms, already exposed to a range of stressors including rising temperatures and sea levels, changing ocean chemistry, noise pollution and a tide of plastic debris.

## LARVAL FISH INGEST MICROPLASTICS

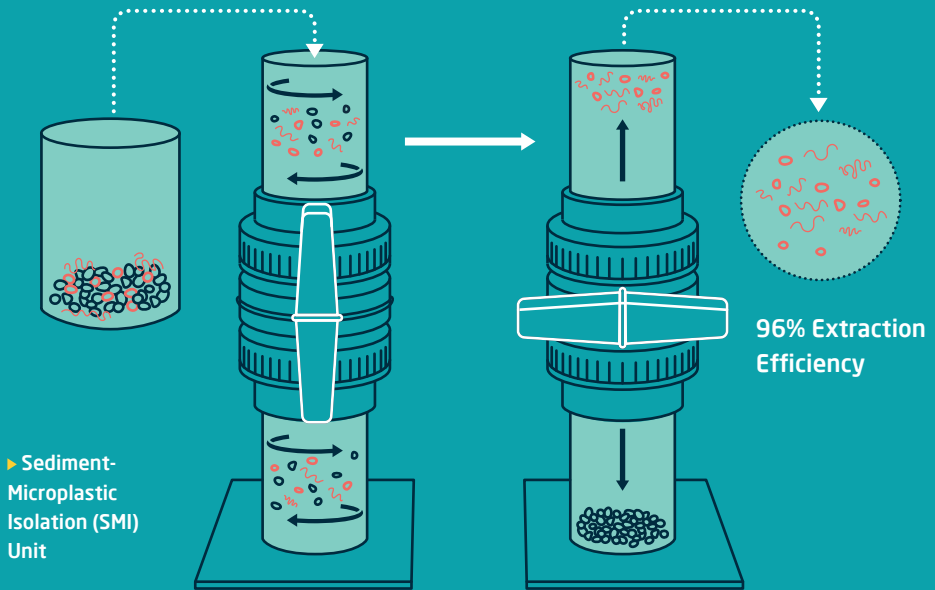
► Microplastics, tiny particles (0.1 µm-5mm) which may result from the breakdown of larger plastic items, or may originate from cosmetic products as exfoliating microbeads, are thought to be widespread globally through the ocean, where they can be a risk to marine life. PML is at the forefront of microplastics and, in laboratory studies, has been investigating how organisms, lower down in food chains, interact with these tiny fragments. In the coastal zone, where fish are important both ecologically and economically, there are high levels of plastic pollution. Fish larvae are known to be especially vulnerable to many forms of pollution, as well as other environmental stressors and predation. Working with colleagues at the Universities of Exeter and Plymouth, PML researchers have been assessing the occurrence of microplastic

ingestion in wild fish larvae. They took samples of water and fish larvae from three sites within the western English Channel over a three month period. They found that 2.9% of fish larvae, including: whiting, thickback sole, poor cod, common dragonet and European eel, had ingested microplastics, and in 66% of these the plastics were in the form of blue fibres. The percentage may appear low but the researchers point out that the larvae would only have been part of the plankton for a few weeks. Existing evidence suggests the microplastic is likely to be harmful to individual organisms, but it remains unclear whether populations would be negatively impacted, and more research is required to understand the mechanisms behind larval fish behaviour and microplastic ingestion. What is clear is that zooplankton, including fish larvae, are ingesting microplastics and ingestion is likely to be highest in productive habitats where plastic concentrations are higher.



► **66% OF  
INGESTED  
PLASTICS WERE  
BLUE FIBRES**





## EXTRACTING MICROPLASTICS FROM MARINE SEDIMENTS

► Tiny plastic particles, microplastics, are now well-recognised and widespread marine pollutants. PML scientists have been at the forefront of bringing the issue of microplastics to a wide stakeholder community including the general public, policy makers, and the press and media. Following the ban by the government on microbeads in cosmetic and personal care products, further increased media interest has galvanised a broad section of society to the point where there are moves to minimise single-use plastics in our everyday lives. However, microplastics abound in the ocean where they impact on marine organisms and interfere with habitats and the functions, goods and services they may provide. PML researchers

have continued their investigations to gain a better understanding of how the plastic legacy will impact marine life. To do this it is essential to obtain accurate measurements of microplastic abundance and composition in marine sediments. Existing methods are expensive, complex, have low extraction efficiencies and don't always work with fine sediments. PML researchers have overcome this challenge by developing a Sediment-Microplastics Isolation unit using the principle of density floatation. Not only is it cheap, reproducible and easily portable, allowing it to be used in the laboratory and in the field, it also demonstrated a mean efficiency of 98.5%, so enabling accurate estimates of microplastic type, distribution and abundance in sediment.



## REGIME SHIFTS AND MEDITERRANEAN FISHERIES

► Climate change is known to affect the global biosphere by causing large-scale reorganisations in populations, communities and ecosystems. In order to ensure environmental integrity, food security, and sustainable economic growth an advanced understanding of how natural systems reorganize themselves in the face of such change, is required. Complex systems respond to changing stressors in either a continuous or discontinuous way. Where the change in structure and function of social-ecological systems is both large and abrupt and remains persistent this is known as a regime shift. Regime shifts can have major impacts on the ecosystems and the services they provide, with knock-on effects for human economies, societies and health and well-being.

Using an Integrated Resilience Assessment Framework, a complex statistical method originally developed by neuroscientists, PML and colleagues in Greece implemented this approach to investigate the temporal development of the Mediterranean marine communities in response to sea warming during 1985-2013. Analysis of fisheries landings data showed that step changes favouring warmer water species took place - in effect the Mediterranean has been 'tropicalised' in a series of abrupt regime shifts in parallel to sea surface temperature rising. Knowing these abrupt regime shifts have taken place and are likely to occur in the future as global temperatures continue to increase is an important contribution to fisheries' management formulation. Such management might include restrictions on fishing effort, for example.





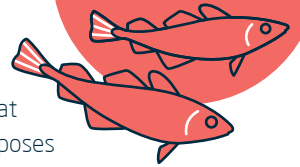


## CLIMATE SCIENTISTS SHOULD THINK MORE ABOUT SEX

► Very little research into how males and females respond differently to climate change has been carried out: less than 4% of climate change studies have tested the impact of ocean acidification on males and females separately. The impact on different sexes should be properly assessed in all aquatic animals to accurately predict how populations will respond to climate change. Any effect on spawning, settlement or survival could have a major impact on sustainable supplies of fish and shellfish. Over the past decade, research into the impacts of rising CO<sub>2</sub> on fish and shellfish species has increased dramatically, helping

scientists accurately predict the threat climate change poses to ecosystems worldwide.

Worrying changes in behaviour, survival, growth, reproduction and health have been found in many species, but ignoring potential differences in how males and females respond could have implications for managing the future ocean. CO<sub>2</sub> levels are projected to be 2.5 times higher in the ocean by the end of this century, which is causing the ocean to acidify at a rate unprecedented for 300 million years. By taking into account the differences in response to stressors by males and females, scientists can avoid underestimating the impact of climate change on wildlife and vital sectors of the ocean-based economy.

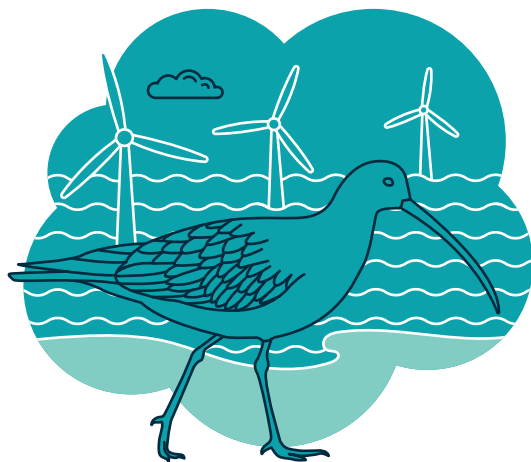


# 3 NATURAL CAPITAL

► The marine environment underpins all life on Earth; it not only gives us food, drives our climate and weather, and provides jobs and wealth, it is essential to cultures around the world and underpins our health and well-being. Understanding the complex interactions between physics, chemistry and biology, alongside human needs and benefits is the crucial first step in ensuring we all have a sustainable future. PML research is clarifying the true value of this natural capital.



## WIND FARMS AND WETLAND BIRDS



► As new wind farms appear in the midst of the estuarine habitat, how will wetland bird populations be affected? By simulating the conditions of the Solway Firth, one of the largest intertidal zones of the UK coastline, scientists have been able to examine the predicted effects of tidal development on a protected estuary. They discovered that any habitat loss is likely to be minor, suggesting no major impact on wildlife. The change in intertidal areas is also expected to be smaller than the change if tidal barrages were used instead of wind farms, a finding that suggests turbines could be a less harmful, better energy solution in protected areas. The method used here will be essential in predicting the potential impact of tidal energy on intertidal habitats and their wetland wildlife. However, the researchers suggest that all wind farm impacts should be studied in detail prior to development, with each specific site and turbine layout assessed independently.

## GOOD ENVIRONMENTAL STATUS (GES) AND ECOSYSTEM SERVICES

► The EU Marine Strategy Framework Directive (MSFD) requires member states to attain GES for their seas; GES is measured against a set of 11 descriptors and their associated indicators, but are they relevant to the ecosystem services approach advocated as ensuring sustainable use of the environment? PML socio-economists working on the Marine Ecosystems Research Programme considered whether a selection of GES indicators could be used to provide information relevant to ecosystem services, so allowing collected environmental data to be used for more than a single purpose. Indicators for seven selected marine ecosystem services were compared to 296 biodiversity-related indicators used for MSFD. They found that 64 of the biodiversity indicators were indeed directly comparable to the ecosystem indicators being considered; 247 of the biodiversity indicators were identified as potentially useful ecosystem service indicators. The researchers hope that future monitoring can be used for both ensuring GES is being attained, and ecosystem service provision is maximised.



## GENETICALLY MODIFIED MICROALGAE AND ENVIRONMENTAL RISK

► Genetically modifying microalgal strains for enhanced or modified activity has shown great promise as sources of bioproducts. However, as large scale cultivation of modified strains gathers momentum there are real concerns for the environmental safety and potential human health impacts of these genetically altered organisms. A PML-led project investigated the current status of genetic modification techniques, large-scale cultivation implications, existing legislation and monitoring strategies, in the light of developing a safe, effective assessment system, for both contained and open production systems. The researchers concluded that, while the existing procedures still lack the ability for accurate and exhaustive risk assessment, there is a substantial knowledge base and expertise within the biotechnology, fermentation and aquaculture industries, which could be combined to ensure safe use in the future. More information is needed on how genetically modified material 'escaping' to natural environments might impact the wild biota. The scientists suggest that it is common sense to recommend the precautionary use of closed systems, such as photobioreactors, in preference to open ponds and, where this is not possible, any ponds should be enclosed in glass or polythene tunnels.

## ECOSYSTEM SERVICES AND ENERGY IMPLICATIONS

► Understanding how the growth of offshore wind farms (OWFs) may impact upon ecosystem services is vital in future marine planning. The ecosystem services approach (ESA) aims to provide a more complete picture than what environmental assessments alone can provide, by including the socio-economic perspective. By employing the ESA onto a common framework, PML scientists have been able to show that the

## COASTAL BENEFITS HAVE POSITIVE BENEFITS

► The positive benefits of interaction with nature are well documented, with numerous studies reporting a reduction of stress levels in participants and an increase in overall well-being in those spending time in nature. Now, by examining the experiences of over 4,500 people, scientists have investigated for the first time how different natural environments and their quality impacted on psychological

► **30 MINUTE VISITS GIVE GREATER BENEFITS**



impacts of OWFs vary across ecosystem services – it highlights, for example, that wind turbines are beneficial in many ways; including the support of fisheries by providing nursery habitat for the juveniles of key species, and the formation of artificial reefs at the turbine foundations, populated by mussels whose filter-feeding contributes to water quality. There are negative outcomes too, with OWFs implicated in the spread of invasive species, and dissatisfaction with the aesthetics of a location – a characteristic that could impact on recreational ecosystem services in

the area as people deem the offshore developments unsightly. The ESA can be a useful tool when applied in this way, and one that could, and perhaps should, be employed in the evaluation process of any coastal energy developments.



well-being. Asking participants to describe their visit and to evaluate their overall encounter, researchers discovered that those who visited rural and coastal locations reported greater psychological contentment than those who spent time in urban green spaces, such as city gardens and parks. PML and other researchers found these visits to nature (especially those to protected sites and to coastal and rural green settings) were associated not only with both greater feelings of relaxation and refreshment, but also stronger emotional connections to the natural world. Interestingly, it was revealed that visits longer than 30 minutes were associated with a better connection and subsequently had greater psychological benefits. Socio-economic status was also found not to be a factor in enjoyment of nature, demonstrating the importance of providing free or affordable entrance to sites to help prevent socio-economic inequality in accessing nature.

The findings not only help understand what is behind these psychological benefits, but they can also help to prioritise the protection of these important environments.

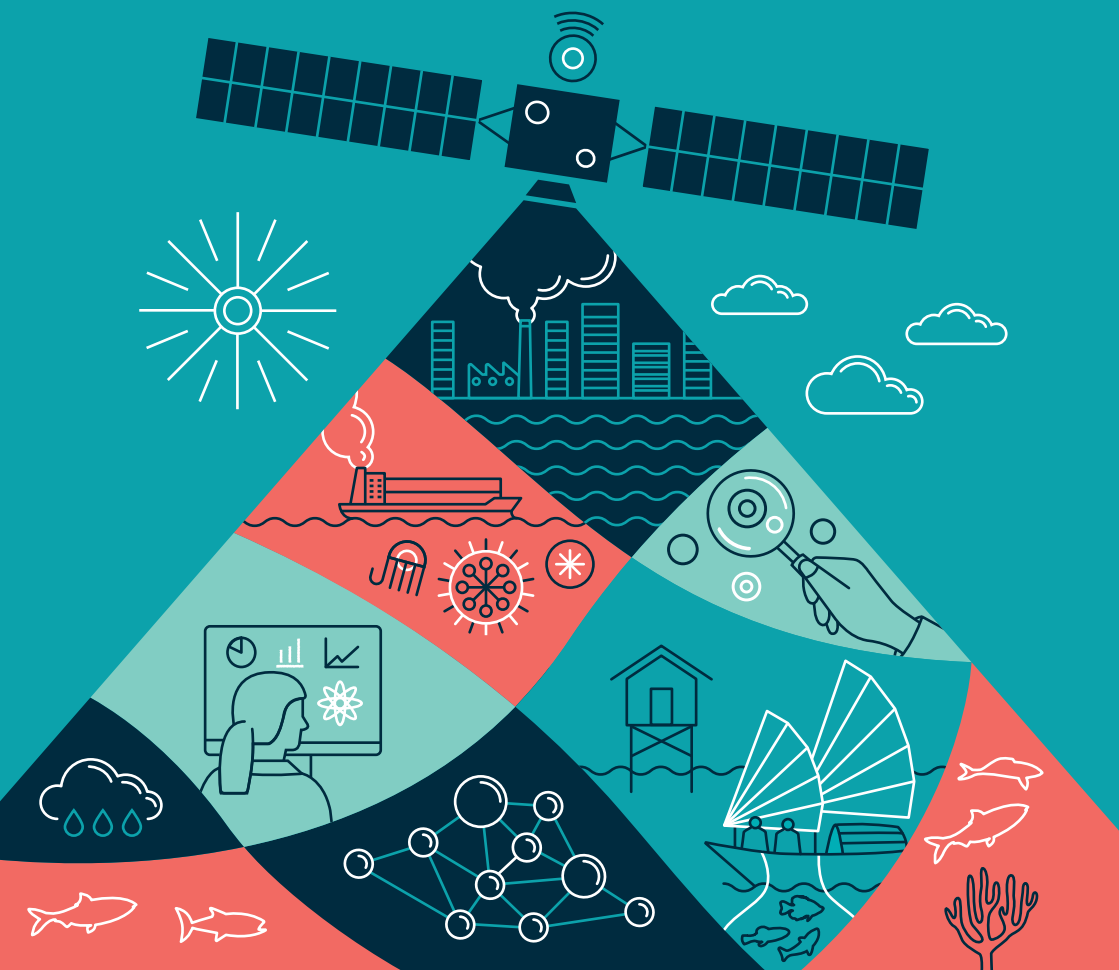


### SEA AND SOCIETY GROUP

- The PML Sea and Society group is at the forefront of developing techniques to quantify the value of benefits and services provided by the marine environment and to understand the risks and trade-offs of developing the blue economy.

# 4 REMOTE VIEW, CLOSER UNDERSTANDING

► Earth observation (EO), of the environment, has become a keystone in understanding how the ocean functions. PML's internationally renowned Earth observation group is involved in many societally relevant research programmes, from climate change and primary production to smaller scale, illegal fishing and harmful algal blooms.





## USING OCEAN COLOUR TO ESTIMATE CHLOROPHYLL IN PHYTOPLANKTON

► As a result of the continuing improvements in satellite sensor technology and techniques for interpreting ocean-colour data over recent years, our ability to gain more detail about the actual community structure of phytoplankton communities over large areas (synoptic scales) has been greatly enhanced. Garnering this level of detail goes a long way to meet the growing need from ecosystem modellers requiring better representation of these communities to populate their models. To be useful for modelling such products need to match what modellers need, along with knowledge of how close they correspond to reality. PML Earth observation scientists set out to 're-tune' a method of estimating chlorophyll concentration of three phytoplankton size groups: pico- ( $< 2\mu\text{m}$ ), nano- ( $2\text{--}20\mu\text{m}$ ) and micro-phytoplankton ( $> 20\mu\text{m}$ ). The modifications took account of sea surface temperature (SST) influences and



the partitioning of micro-phytoplankton into diatoms and dinoflagellates to match groups in the state-of-the-art European Regional Seas Ecosystem Model (ERSEM). The chosen study area was the North Atlantic, a region that has been extensively sampled over the last decade, providing a large number of *in situ* observations, and has also been the subject of many marine ecosystem modelling studies. It is also the location of one of the largest spring phytoplankton blooms on the planet and is a major area of biological drawdown of seawater and primary production. They found that in the North Atlantic the relationship between the total chlorophyll and the size-fractionated chlorophyll changes with SST; and the ratio of dinoflagellate chlorophyll to micro-phytoplankton chlorophyll increases with SST. They validated the model using another dataset of 800 satellite and *in situ* match-ups. These improved satellite products will be useful in evaluating ERSEM performance by assimilating the chlorophyll for each plankton group into the model and, they hope, will have applications in other ecosystem models that simulate phytoplankton functional groups.



## UNSTEADY EDDIES: SMOKE RINGS OF THE OCEAN

► They may be the ocean's equivalent of smoke rings: pairs of eddies, called 'modons', joined together in a way that sees them travel vast distances at greater speeds and in different directions from other, singular eddies. The majority of eddies are thought to drift west at a speed that depends largely on latitude. They are faster near the equator, slower near the poles, and can travel 1-2 km per day at mid-latitudes. However, it has long been thought that eddies can sometimes pair up, become travel companions, and, like smoke rings, this allows them to move faster, often in unusual directions. For the first time, using satellite measurements of sea level, modons have been spotted and tracked travelling great distances. In total PML Earth observation and University of Liverpool sea level scientists have spotted eight pairs around Australia and one in the South Atlantic. With their mutual motion, modons can travel at speeds far greater

than a lone eddy, lasting up to 6 months as a productive pair and covering distances of over 1000 km. As they travel, modons play an important, wider role in ocean dynamics, stirring up sea surface temperatures. In the Tasman Sea in particular, between New Zealand and Australia, they are likely a significant and unusual pathway for the spread of waters into the open ocean.

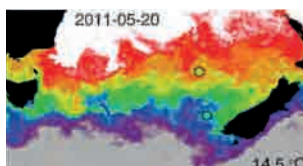
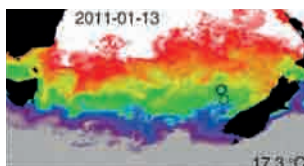
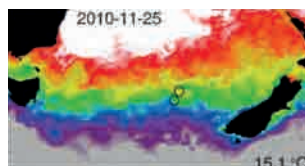
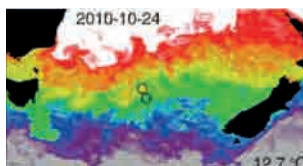
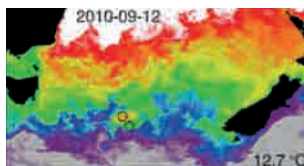
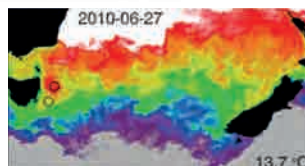
The properties of the Bass Strait's waters – located between Tasmania and Australia – are different in temperature, oxygen and salinity levels to the Tasman Sea and the oceans beyond. Transported rapidly across the Tasman Sea by the eddy pairs, these water features will have vastly different properties to the surrounding

conditions, and could have important ecological consequences and an influence on the pelagic food web far beyond the usual range.

► **EDDIES  
CAN TRAVEL  
AT 1-2KM PER  
DAY AT MID-  
LATITUDES**



► This scientific paper is in the top 5% of all research outputs scored by Altmetric.



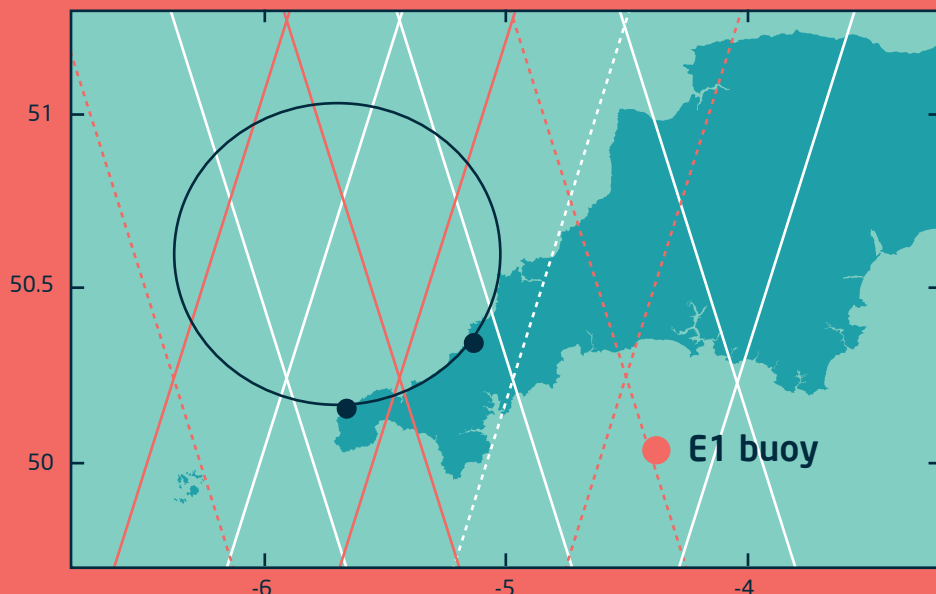


## NEW LEVEL FOR SEA CHANGE SCIENCE

► A Europe-wide effort has improved the accuracy of a dataset that provides vital information on global sea level changes. As sea levels rise, more coastal communities come under threat of flooding, ranging from popular tourist destinations, such as the islands of the Maldives, to large areas of coastal European countries, such as the Netherlands and Belgium. Sea level change is one of the many variables tracked by the European Space Agency's Climate Change Initiative since its establishment in 2010. It is a key indicator of climate change, as sea level rise is widely acknowledged as an effect of warmer oceans and an increase in melting of glaciers and sea ice. Sea surface elevation is measured by altimeters, scanning from around 1000 km above the planet to determine sea level to within just a few centimetres. The task

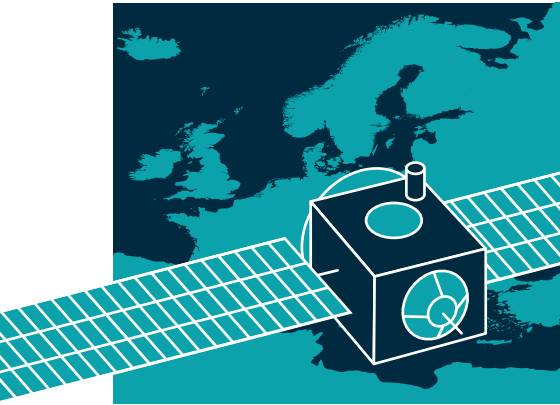
of monitoring sea level change, however, is challenging. The past two decades have seen many different instruments contributing data, each with its own uncertainties and caveats. PML and a large number of research labs across Europe have co-ordinated their efforts to improve the atmospheric, oceanographic and instrumental corrections to produce a consistent dataset of sea level spanning 23 years. Preliminary observations suggest that although major climate phenomena, such as El Niño, can unsettle the global mean sea level, there is still a clear rise of 3.2 mm per year since recording began. The six years spent on the project have allowed a thorough reappraisal of everything from orbits to tide models, and these data are being combined with temperature and salinity measurements to investigate long-term changes in the ocean.

## MEASURING THE SEA



► Measurements of sea surface elevation, wave height and wind speed, obtained through the technique of radar altimetry are used by many agencies, businesses and scientific researchers for understanding changes in the ocean-atmosphere interface. In order that these data can be used with confidence they have to be assessed for consistency and any biases that may creep in from the datasets used to validate them. The open ocean can be assumed to be homogenous, while coastal waters often produce signals which are influenced by changing wind, wave conditions and proximity to land. This results in inaccurate readings from the coastal zone, where societal impact can be greatest through storm surges or enhanced wave activity. Sentinel-3A,

a satellite launched in early 2016, is carrying new technology which will be able to retrieve useful measurements in the coastal zone. PML scientists are working on how this instrument can be assessed in the near shore environment where variability in wave height and range are the norm. Two existing validation opportunities were utilised: The Western Channel Observatory E1 meteorological buoy and the Cornish High Frequency Radar System. Early indications are that Sentinel-3A and the *in situ* measurements are in good agreement. The scientists point out that to ensure assessments are robust there should be consistency in how satellite data is processed; in anticipation of subsequent processing, validation methods are being further refined.



## SEASONAL SEA WATER COLOUR IN THE BALTIC

► The Baltic Sea shows strong seasonality in the composition of its phytoplankton community and wide gradients of chromophoric dissolved organic matter (CDOM). CDOM relates to dissolved organic carbon and can, like phytoplankton, be detected through remote sensing techniques. However, existing remote sensing techniques struggle to handle the strong presence of CDOM among highly seasonal phytoplankton dynamics in the Baltic Sea. A group of remote sensing scientists, including PML and colleagues from Finland and Estonia, investigated natural variability in the optical properties of the Baltic Sea to advise on appropriate remote sensing techniques. The seasonality of the Baltic Sea, with intense but short-lived algal blooms in spring followed by cyanobacteria blooms in summer, was shown from *in situ* samples collected and analysed from eight research cruises. The particle composition in summer was most complex and variable, owing to particles lingering in thermally stratified waters.

From a remote sensing perspective the light absorption by CDOM masks phytoplankton absorption signatures, so that algorithms developed to retrieve chlorophyll-*a* are not always as sensitive as in other coastal seas. There is thus a clear requirement for both models and remote sensing methods to adopt optical seasonality to capture this seasonal variation.

PML scientists have also contributed to ship-based monitoring of water colour in the Baltic Sea using merchant vessels. Following strict quality control of the ship-based observations, such measurements help decide which algorithms are best able to separate water colour from atmospheric interference in the signals recorded by satellites. These methods are now more routinely applied to validate the ocean and land colour sensors on the Sentinel satellites.



## EARTH OBSERVATION SCIENCE AND APPLICATIONS GROUP

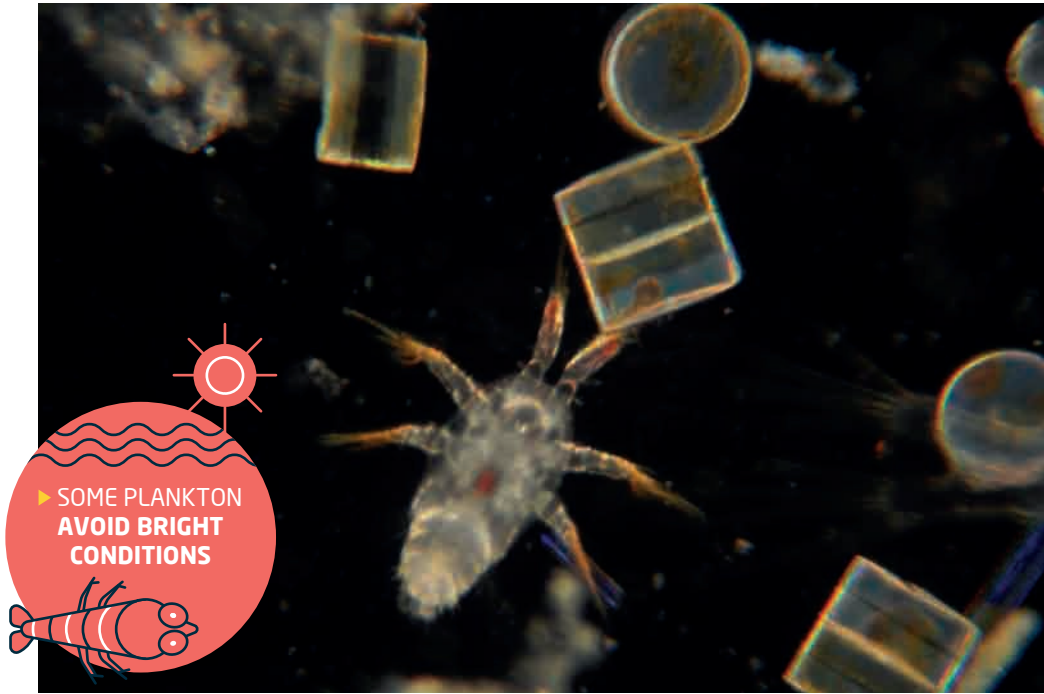
► The Earth Observation Science and Applications group's activities are centred on the remote sensing of the Earth's ocean and atmosphere, whilst not ignoring the intimate connections between the ocean, the atmosphere and terrestrial, estuarine and lacustrine environments.

# 5 BUILDING SCIENCE FOR BETTER UNDERSTANDING

► Good science builds upon what has gone before and provides foundations for further research in the future. PML research, such as the Atlantic Meridional Transect and the Western Channel Observatory, continues to contribute large amounts of data that help to explain how the ocean functions and may be changing.







## STRESS AT THE SURFACE

► Life at the ocean's surface can be stressful for the plankton that dwell there. The near-surface ocean layer is subjected to a range of challenges that differ from those in the deep. For the zooplankton in this habitat, the stresses include high turbulence, a brightly-lit environment – increasing the risk of being seen by predators – and exposure to ultra violet (UV) radiation. To investigate stress levels caused by harmful UV, PML researchers involved in the Atlantic Meridional Transect cruise programme examined the presence of protective compounds in zooplankton. These compounds, mycosporine-like amino acids (MAAs), act as a natural sunscreen, and higher quantities suggest a stress response to UV radiation. MAAs were found in a third

of the zooplankton tested from different regions, although were most prevalent in copepods in temperate waters than in low latitude warmer more brightly lit seas. Juvenile copepods were found not to contain any MAAs and indeed were far less abundant in surface layers than in the underlying water column. It may be that zooplankton with a low UV-tolerance resort to daily vertical migrations to escape the harmful UV; temperatures and food supply might also limit the opportunity to live at the surface, but a stress response to UV is at least a contributory factor. This suggests that the warmer, brighter regions, as are found closer to the Equator, are more of a challenge for the diverse zooplankton swimming just beneath the surface; something to be considered when investigating future ocean health and productivity.

## PUTTING 'JELLIES' INTO MODELS

► Gelatinous zooplankton, such as the familiar jellyfish, display a stunning variety of forms from giant barrel jellyfish to minute species only seen through microscopes. They range throughout the world's ocean and exhibit diverse life history strategies, body compositions and prey preference from bacteria to fish. There is now a growing appreciation that gelatinous zooplankton can have significant impacts on ocean ecosystems and human activities. Amongst the more dramatic impacts are those recorded in the media when blooms of jellies 'invade' bathing beaches, block power station inlets or, as found in the Black Sea, have a massive impact on fisheries. Alongside the recognition of this previously unacknowledged importance is the need to incorporate gelatinous zooplankton into ecosystem models exploring future



scenarios for marine ecosystems. For modellers however, capturing the vast variety of form and function in a more limited set of equations has been challenging. Often organisms are included in models based upon their body size, which is known as the 'master trait'. But what exactly do we mean by size? For example jellies can vary enormously in volume, but their watery bodies contain variable but often very low amounts of carbon tissue. PML scientists and colleagues working on the Marine Ecosystems Research Programme have now developed an approach that allows this spectrum of variability in water content of zooplankton to be incorporated into models. Using existing literature sources and the Western Channel Observatory L4 time series, they found first that the percentage of carbon in zooplankton bodies varied enormously, and along a near-continuous spectrum. Second, incorporating this variability in carbon percentage into models of zooplankton growth greatly increased their explanatory power. This approach allows the diversity of jellyfish to become better incorporated as a variable trait within our models.



### MARINE ECOSYSTEMS MODELS AND PREDICTIONS GROUP

► PML's Marine Ecosystems Models and Predictions group applies and develops modelling techniques to a range of topics of societal interest.

## JELLIES ARE MORE THAN A TRIFLE IN MARINE FOOD CHAINS

► As jellyfish numbers around the UK and elsewhere appear to be on the increase, it is becoming more important to understand the part they play in food webs. Typical food chains do not consider the parts played by jellyfish, but there is a growing understanding that they have important roles in marine food webs. Research undertaken by PML scientists and their colleagues, as part of the Marine Ecosystems Research Programme (MERP), has provided some of the answers by using molecular techniques to determine the relationships between jellies and fish. Seven sampling cruises were carried out around dusk when jellyfish are most active, over an entire annual cycle. A combination of horizontal jelly-

net tows, with a 0.5 millimetre mesh to capture the jellyfish, and vertical plankton net hauls to determine the available prey field was used. 59 DNA samples were sent for high throughput sequencing, a fast cheap way to sequence, which generated 23 million sequences representing 900 operational taxonomic units (OTU = proxy for 'species'). A bonus of the research resulted in 24 species of adult fish also being sequenced with results being added to the GenBank database. Preliminary results show that fish larvae eat jellyfish as well as other fish larvae, while jellyfish eat other jellyfish in addition to fish larvae; both groups were also shown to eat copepods. This shows, for the first time, interactions between fish larvae and jellyfish, as predator, prey and competition. The understanding gained from this research will contribute into other parts of MERP and add an additional, previously neglected, layer into ecosystem models.



## INVASIVE SPECIES AND BALLAST WATER



► The spread of non-native species and their ecological impacts on native species, often from ships' ballast water and biofouling, have been a cause of concern for decades. As world trade continues to increase with a parallel increase in shipping to carry it, the issue has gained more attention with calls for a response to the threat of non-native species of marine life. PML scientists and colleagues carried out a study which scoured existing literature and databases on shipping and invasive species in the NE and SW Atlantic Ocean to assess the risk from shipping between the two regions. 44 high impact species have been reported for the NE Atlantic with 15 for the SW Atlantic, although this is thought to be an underestimate. As suspected biofouling and ballast water are the main vectors for invasive species, although aquaculture was also identified as a 'very significant pathway'. Despite there being significant shipping traffic between the two regions, there was no clear evidence of direct

## REGIONS OF THE ATLANTIC

► Over the course of twenty years, the Atlantic Meridional Transect (AMT) cruises have produced a rich data-set. It has become a valuable, significant resource, containing a wealth of information on the Atlantic Ocean's temperature, salinity, and nutrients, among other aspects. Often these variables have been used to provide context for other studies. Now, for the first time, some of the core variables in the data have been combined with Earth observation and modelling to provide an extensive insight into the unseen differences between six regions of the Atlantic. Analysis has revealed key environmental variation in each region, such

as currents and net heat transfer at the ocean surface and how these affect large scale biological processes, especially within the composition and functioning of the plankton. The data resource also enables the further study of differences between regions in the way nutrients interact. By establishing such a comprehensive resource from the AMT, PML scientists continue to play their part in advancing interdisciplinary science to further understand important, unwitnessed ocean dynamics.



exchange of species between them. However, the scientists stress, ballast water exchange between the two regions should be brought under control, via the recent IMO ballast water convention.



► **NATURAL  
PROCESSES**  
UNDERPIN  
BENEFITS

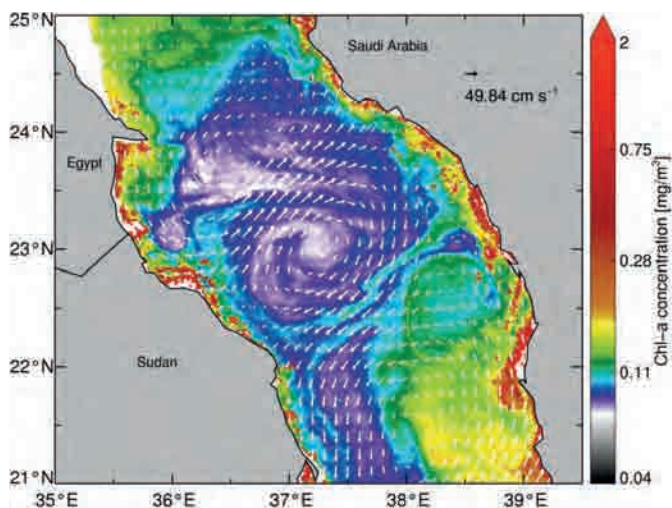
## HOW HUMAN ACTIVITIES AFFECT THE SEABED

► Extensive research into how industry and environmental change are affecting our seafloors suggests more work is needed to help safeguard these complex ecosystems and the benefits they provide to people in the future. Researchers from eight organisations have worked together to examine areas of sea located on the UK continental shelf to understand the sensitivity of these systems to human activities. The societal importance of these ecosystems extends beyond food production to include biodiversity, carbon cycling and storage, waste disposal, nutrient cycling, recreation and renewable energy. The research team analysed the biodiversity, nutrient, metal and carbon cycling in areas of the seafloor

around the UK subject to different environmental conditions and human use. PML investigated how nitrogen changes across the seafloor of the Celtic Sea. The researchers found that a combination of seasonality, plankton productivity in the water column, and sediment type, (e.g. mud, sand, sandy mud etc) influences how nitrogen is cycled across the seafloor. Across this study, the scientists showed that 6-9% of the nitrogen is being lost from this system annually. Importantly, this level of nitrogen loss needs to be replaced to maintain a healthy system. The project has provided a wealth of insights into the natural processes at the very base of marine ecosystems that underpin many benefits we obtain from the sea.



## CORAL CONNECTIONS



Dynamic circulation features in the Red Sea, such as eddies and currents, form pathways along which marine life can flow. At the source of these pathways are 'mother reefs', invaluable for spreading life to other Red Sea reefs. These 'mother reefs' are perhaps the most important reefs of all when considering management and conservation strategies.

► Coral reefs, hundreds of miles apart, are connected by ocean currents. Observing these networks from space may prove vital for their conservation.

Coral reefs are among the most biodiverse ecosystems on the planet. They occupy less than 0.2% of the world's ocean, but support a treasure trove of life – around 35% of all known marine species are found on and around reefs. They are, however, under threat; climate change, ocean acidification and a range of human activities are all affecting these fragile ecosystems. Resilience to these threats is stronger when the reefs are better connected, sharing a flow of life and genes between them that helps to maintain healthier populations, but such connections are not easy to identify. By bringing together satellite observations, genetic population data and model simulations, a team led by PML scientists has now traced this connectivity.

Initial conclusions had been based on the connectivity between reefs observed from satellites in space. To establish if these findings had any real ecological substance, the team tested the results against the genetics of the Red Sea's anemonefish (*Amphiprion bicinctus*) population. The predictions of connectivity were remarkably consistent with the population data, demonstrating how currents and circulation form pathways for larval stages of marine life around the Red Sea.

Connectivity models often require costly approaches and data that are difficult to collect. This research instead showcases a cost-effective tool and method, using freely available satellite data-sets to enable the estimation of connectivity remotely, and guide more effective management of waters where oceanographic information may be in short supply.



## MORE CO<sub>2</sub>, MORE PRIMARY PRODUCTION

© E. DARLINGTON



► As atmospheric CO<sub>2</sub> levels continue to increase, the accompanying phenomenon of ocean acidification and its effects on the functionality and productivity of marine ecosystems are a cause for concern. Understanding how different species, groups and populations might be affected will be crucial to our future expectations of the goods and services the ocean might offer. One aspect of this is the effect of CO<sub>2</sub> enrichment on phytoplankton photosynthesis in a range of organisms and different trophic systems, and how that in turn could affect food webs. PML scientists on board the RSS *James Cook*, during the Atlantic Meridional Transect 20 Cruise in the North Atlantic sub-tropical gyre, carried out a series of shipboard incubations of natural phytoplankton assemblages. The 48 hour-long incubations were conducted at 760ppm CO<sub>2</sub> and control 360ppm CO<sub>2</sub>. Under elevated CO<sub>2</sub> the pH dropped to 7.94 compared to the control at 8.27. In one

► AMT  
REVEALS CO<sub>2</sub> AND  
PRODUCTIVITY LINK

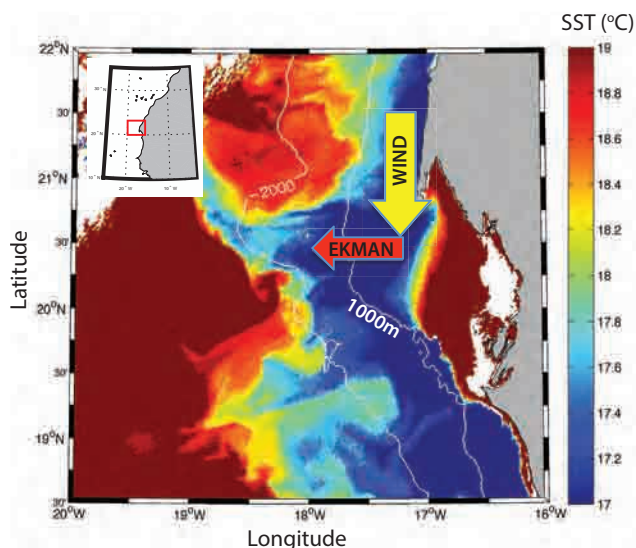


experiment the biomass comprising pico- and nano-eukaryotes (small, 0.2 – 10 µm, planktonic organisms whose cells have a cell nucleus and other organelles) increased under CO<sub>2</sub> enrichment although primary production decreased against the control. Two experiments in which dinoflagellates dominated showed no significant increase in biomass but did show a significant increase in the maximum photosynthetic rate and a 25% increase in primary production, due to changes in light harvesting efficiency and carbon fixation. In conclusion, elevated CO<sub>2</sub> can drive a 25% increase in primary production, depending on the dominant phytoplankton species.



### MARINE BIOGEOCHEMISTRY AND OCEANS OBSERVATION GROUP

► The Marine Biogeochemistry and Ocean Observations group investigates the cycling of the major elements in the surface oceans and coastal seas in order to predict how marine productivity and climate feedbacks between the oceans and atmosphere might alter in a changing world.



► **Sea surface temperature (SST) throughout the Cap Blanc region. The upwelling area is shown at the transition from cold to warm water. The upwelled water is transported offshore as a mesoscale (medium sized) filament at latitude 20.5° N.**

## FILAMENTS FEED REMOTE PRODUCTIVITY

► The upper layer of the ocean, or euphotic zone, is where sunlight penetrates and encourages phytoplankton growth. While light is a key component for photosynthesis to take place, nutrients are equally important in driving this primary productivity. Where dynamic processes, such as eddy pumping, and frontal processes inject nutrients into the euphotic zone, productivity is enhanced. In stratified regions, where vertical exchange is limited, biological productivity is low. Understanding the processes that regulate this vertical exchange is key to understanding both the initial injection of nutrients that stimulates the phytoplankton community, but also the ongoing supply of nutrients

from beneath the euphotic zone that sustains it and the productivity that stems from it. In a reverse process nutrients bound into the organisms are eventually remineralised back into inorganic forms following a return journey to deeper waters. The rate of these vertical exchanges is crucial to carbon export to the deep ocean and is of global importance. As part of the Surface Ocean Lower Atmosphere Study (SOLAS) PML scientists took part in a research cruise on board the RRS *Discovery* to

determine the coastal and shelf influence on microbiological activity and chemical interactions in an eastern boundary current upwelling system, off Mauritania. Observations indicate that nutrients upwelled into the euphotic zone stimulated high levels of primary production. However, the coastal front under observation forms filaments of upwelled water that could extend several hundred kilometres offshore and underpin enhanced productivity well away from the main nutrient supply. Nutrient rich water from below the euphotic zone was carried within these filaments leading to new production which was higher than could be explained by local nutrient availability and the existing vertical flux into the euphotic zone. In fact only about 60% of local productivity could be explained by local conditions, the remainder being supplied by the filaments.

## RIDING A WAVE TO STUDY NEAR-SURFACE SEAWATER

► Stratification is a well-documented phenomenon in which the seawater immediately below the surface of the ocean arranges into layers based on different levels of salinity or water temperature. In sub-optimal conditions these layers near the surface can be difficult to assess, and to fully understand the gradients found – and their influence on the biogeochemistry of the ocean – more effective sampling and measurement systems are needed.

PML scientists working on a new approach have developed a method for studying seawater and stratification just below the surface. The Near-Surface Ocean Profiler (NSOP), is a re-purposed buoy, redeveloped to allow precise measurements of the ocean's top 10 metres. In trials, the new design has proved effective even in turbulent conditions – including wind speeds of up to 10 ms and wave heights of up to 2 m.

With the NSOP in use and effectively riding the ocean swell, future studies will be able to gather data and measurements that are unaffected by a bumpy ocean ride, and develop our knowledge of water profiles close to the sea surface.



# 6 PML PEOPLE & PERFORMANCE

► The success and international reputation of PML is firmly dependent upon the calibre, commitment and enthusiasm of its staff. In many areas of its scientific research PML has become the partner of choice for inclusion in or to lead multi-national research projects. Underpinning the science staff are state-of-the-art facilities and support groups dealing with technical services, finance, communication, marketing, project management and administration.





## PML PEOPLE

► Organizational success is critically dependent upon the performance of staff and, for PML, 2017 has been a standout year for a number of reasons.

Firstly, PML scientists' success in winning new competitive research contracts has been exceptional. Whilst PML's current financial year ends on 31 March 2018, a record level of new contracts has already been secured, which bodes well for the future.

Major projects started during the year covered topics ranging from livelihoods of coastal communities to marine litter, and coral reef connectivity. Also started in 2017 were two Natural Environment Research Council (NERC) funded projects which relate to developing countries and which are being

delivered in partnership with the National Oceanography Centre:

- **Addressing Challenges of Coastal Communities through Ocean Research for Developing economies (ACCORD):** focus on Southeast Asia and the Western Indian Ocean
- **Sustainable Oceans, Livelihoods and food Security Through Increased Capacity in Ecosystem research in the Western Indian Ocean (SOLSTICE-WIO).**

Other new projects for 2017 with a particular societal focus included:

- **Coral Communities:** Building Socio-Ecological Resilience to Coral Reef Degradation in the Islands of the Western Indian Ocean
- **Earth And Sea Observation System (EASOS):** Marine pollution challenge in Malaysia

Many other smaller projects also include aspects of direct relevance to society including those which deal with aquaculture, pollution, health and well-being, fisheries and coastal resilience.





## PUBLICATIONS & IMPACT

► PML scientists were also very active in the year in producing scientific publications, which are the most tangible indicator of the performance of a research organization. A total of **167** peer-reviewed papers were published in 2017, a record in PML's history, with an increase in first authorships of **23%** over the previous year.



Whilst publications are an important output of research, impact from scientific findings is equally crucial to understand. In 2017 there were 62 mentions of PML research papers in policy documents,

including publications by the UK government, such as the "Future of the Sea", and by the United Nations Food & Agriculture Organization. PML's wider influence on policy making matters was also evident in the

year, through contributing written and oral evidence to the House of Commons Science & Technology Committee's inquiry on ocean acidification, as well as through the provision of information into the Parliamentary Office of Science & Technology POSTnote on Environmental Earth Observation.

PML representatives also worked closely with UK government officials at the UN Ocean Conference in June which focused on Sustainable Development Goal 14 (Life Below Water), as well as the UN Framework Convention on Climate Change (UNFCCC) Conference of the Parties meeting – COP23 – in November. PML's role in highlighting ocean and climate issues was publicly acknowledged by the Head of the Intergovernmental Oceanographic Commission of UNESCO, the President of the Global Ocean Forum and Ambassador H.E. Ronald Jumeau, of the Seychelles.



► **167** PEER-REVIEWED PAPERS IN 2017







## STAKEHOLDER ENGAGEMENT & COMMUNICATION

► The UN Ocean Conference and COP23 provided global platforms for engagement with a wide range of stakeholders at country and organizational level. Equally important is regular stakeholder engagement, which forms an intrinsic part of activities for PML researchers, marketing and communications staff, and many others across the organization. Such engagement is necessary to help shape PML's research, to share findings from this research and to raise PML's profile. Through stakeholder and end user workshops on specific research projects, visits to PML and conferences presentations PML has ensured regular dialogue with its stakeholder community. Examples from the last year include:

- The Advances in Marine Ecosystem Modelling Research conference 2017
- The East Asian Seas Partnership Council meeting
- Presentations and discussions with Oil Spill Response Limited's Industry Technical Advisory Committee

## ENGAGING WITH OUR LOCAL AND REGIONAL COMMUNITY

► Whilst PML has a global reputation and operates worldwide, local and regional relationships are equally important. PML has been strongly engaged with a number of south and southwest initiatives, including:

- the Marine Business Technology Centre in Oceansgate Plymouth, where a consortium bid for European Regional Development funding has recently been announced as successful
- early discussions on a National Marine Park plan for Plymouth Sound, and
- the South Coast Marine Cluster which brings together 32 world-renowned universities and research institutions.





## COMMUNICATION

► Communicating PML's research to our many stakeholders is an important aspect of a marine research organization's remit, and can take many forms – from websites and social media, to specific presentations, talks, training courses (in person and on-line). Some of the highlights of the year included:

- Visit of Her Royal Highness, The Princess Royal to PML in July
- A new short animation on PML available at [https://www.youtube.com/watch?v=x9Wiq\\_a\\_Wwuc](https://www.youtube.com/watch?v=x9Wiq_a_Wwuc)

- A joint poetry and marine science event, with pairings of poets and scientists exploring subjects ranging from algal blooms to microplastics
- Painting by Numbers – a TEDx Talk on the colourful world of marine satellite imagery by Dr Hayley Evers-King available at [youtu.be/eEnvTxTVknQ](https://youtu.be/eEnvTxTVknQ)

PML's performance in communications is also measured and over the course of the year our average impressions per tweet increased by 95%, with the Facebook likes increasing by 78% compared to the same 12 month period in 2016.



► **PML's PhD students exchange ideas over a coffee.**

## RECOGNITION

► Recognition of its achievements or its staff by others is appreciated by PML, and at organizational and individual level, 2017 saw PML and its people recognised in a number of ways:

- PML and its trading subsidiary, PML Applications Ltd, successfully achieved certification of their business management systems to the ISO9001:2015 Quality Management Standard.
- Terence Lewis, former Chairman and Trustee, was awarded an MBE for his services to marine science
- Prof. Mel Austen was appointed as an independent member of the Joint Nature Conservation Committee
- Dr Marie-Fanny Racault was awarded a Long-Term Invitational Fellowship by the Japan Society for the Promotion of Science
- Award to PML of 6 PhD studentships through NERC and the Doctoral Training Partnerships scheme
- Receipt by PML of a generous donation of £20,000 from an anonymous benefactor, which is being used to fund a new apprentice.

## PML APPLICATIONS LTD

► PML Applications, PML's wholly owned trading subsidiary, is an important factor in the success of PML. The company facilitates the application and commercialisation of research from PML. The current financial year has seen growth, with turnover forecast to be almost double that of the previous year, as a result primarily of the establishment of the Centre for Geospatial Applications, which focuses on the satellite applications and services market, and also repeat business and new clients for the Centre for Marine Biofouling & Corrosion.

## NEW FACES

► During the year we welcomed a number of new staff to PML Group, some to replace leavers, and some to join Science Areas where success in winning new research projects has necessitated expansion. Two new Trustees joined PML – Baroness Mary Watkins and Nick Buckland OBE.



► **Baroness Watkins and Nick Buckland OBE who both bring with them a wealth of experience at Board level and as Trustees.**

# THE PML YEAR



## JANUARY 2017

- ▶ A major new UK research programme is announced to investigate the impact of climate change on the vulnerable Arctic Ocean.
- ▶ PML heads two projects: ChAOS and DIAPOD.



## FEBRUARY 2017

- ▶ ISO9001:2015 certification of PML & PML Applications Business Management Systems achieved.



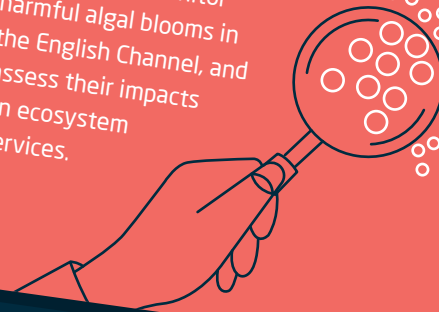
## MARCH 2017

- ▶ PML gives evidence to the Science & Technology Committee on ocean acidification.



## APRIL 2017

- ▶ €2.6M awarded to a PML led project to monitor harmful algal blooms in the English Channel, and assess their impacts on ecosystem services.



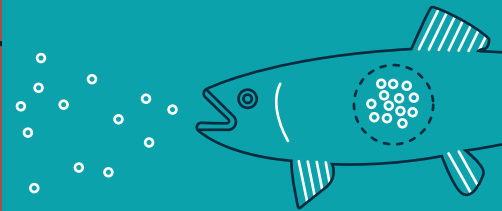
## MAY 2017

- ▶ Coral Communities workshop with local people in Mauritius, engaging with coral reefs and understanding threats to livelihoods.



## JUNE 2017

- ▶ PML marine microplastics research featured in Science in Parliament, adding to policy maker awareness of the threats posed to marine life.



## JULY 2017

- ▶ A Royal Visit: PML welcomes HRH Princess Anne, The Princess Royal, on a guided tour to meet scientists and learn more about PML's ground-breaking marine science.



## SEPTEMBER 2017

- ▶ A generous and anonymous £20,000 donation plots the course for a new apprentice to embark on training and experience for a career in marine science.
- ▶ Building on success: A £5.4m initiative will develop PML's pioneering research with a refurbishment that includes brand new laboratories.

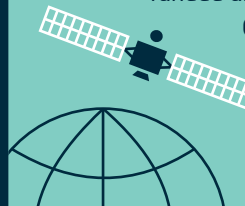
## AUGUST 2017

- ▶ Plymouth's new MP, Luke Pollard, visits PML to discuss the exciting prospect of the designation of National Marine Park centred on Plymouth Sound.



## OCTOBER 2017

- ▶ Two new grants for ground-breaking Earth Observation research: Ocean Colour and Biogeochemistry, funded by the Simon's Foundation; and REVIVAL, funded under the UK-India Water Quality Programme.



## NOVEMBER 2017

- ▶ PML is once again influential at COP23 in Bonn, leading the international partnership, Oceans of Impact, to advise on the multiple stressors the world ocean faces.



## DECEMBER 2017

- ▶ PML Head of Science for Sea and Society, Prof. Mel Austen, appointed as an Independent Board Member to advise the Joint Nature Conservation Committee.
- ▶ MONOCLE announced, a £4.5million project using satellite observations to improve knowledge of coastal and inland waters.





# PML APPLICATIONS

## GEOSPATIAL APPLICATIONS

► PML's Centre for Geospatial Applications (CGA) has had a busy year with two new contracts as part of the Copernicus programme, which is using satellite and other sensors to monitor the Earth, including its oceans. PML is providing expert comment and advice and a marine training programme for using marine satellite data, which helps to build capacity in the use of remote sensing products, across the globe including Ghana, Caribbean, Belgium and Hamburg. The CGA is also part of the UK Space Industrial Partnership Project and leads the oil pollution domain and has a system that takes imagery from the Sentinel 1 Synthetic aperture radar (SAR) satellite sensor, processes it and passes it to a third party who can model the original source of any oil pollution. The profile of the CGA has grown impressively over the last 12 months and continues to be a success.



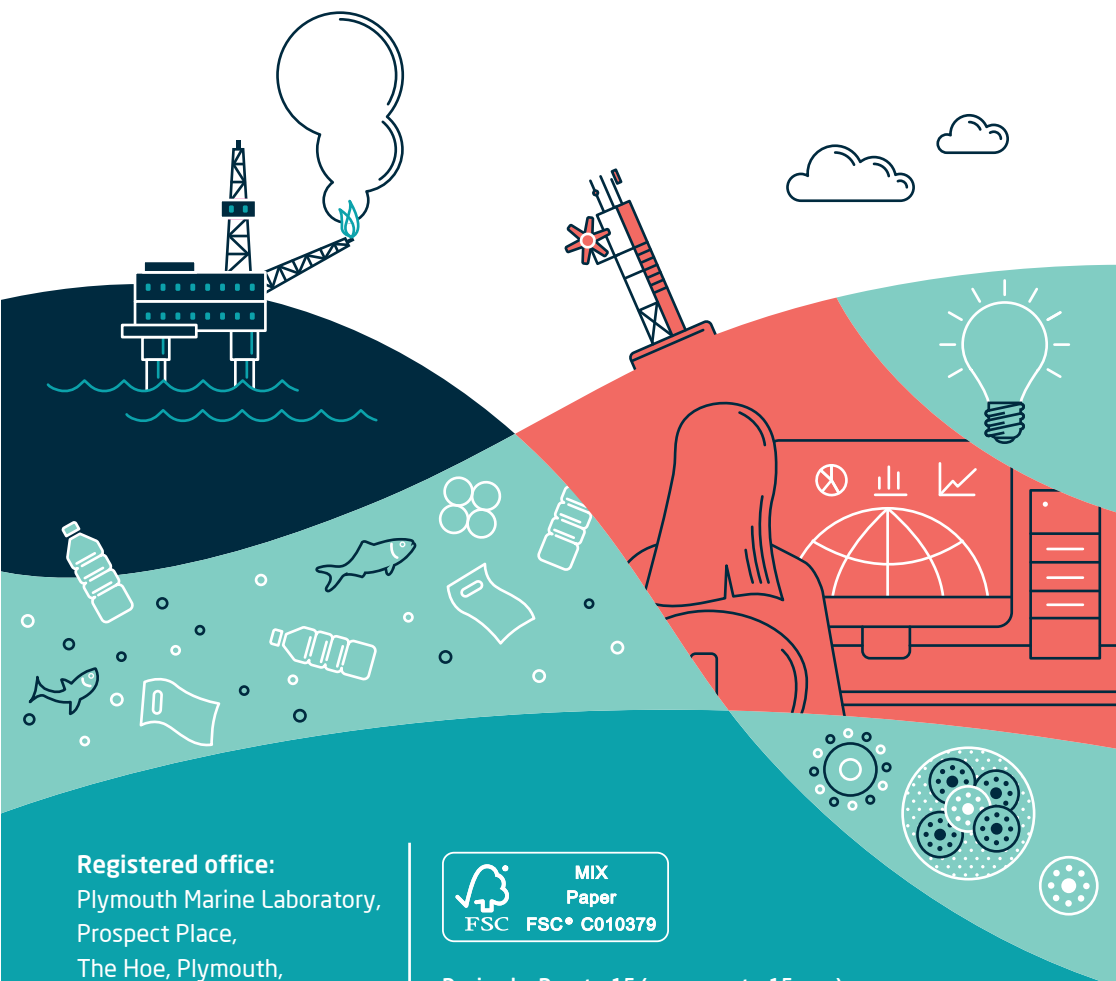
## CENTRE FOR MARINE BIOFOULING AND CORROSION (CMBC)



► Biofouling has become a major concern for all sectors of the shipping industry and beyond. Increased drag, slows vessel speed and journey times, and leads to higher fuel consumption and hence costs, and more emissions to the atmosphere.

The main focus of CMBC activities over the last twelve months has been directed toward developing innovative and biocide-free antifouling solutions for Babcock International, at the Centre's bespoke coating test facility in Millbay Marina. An R&D programme has also been completed with Rolls-Royce, helping to assess a novel coating system for commercial vessels.

The CMBC was also pleased to become a strategic partner in the International Maritime Organization's Glofouling project, as well as a founding partner in the £26 Million National Biofilm Innovation Centre (NBIC) where it can further assist in novel biofilm prevention technology development.

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Registered Charity number 1091222

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