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| Institution: University of Plymouth (UoP) |
| Unit of Assessment: UoA7 (Earth Systems and Environmental Sciences) |
| <p>1. Unit context and structure, research and impact strategy</p> <p>a) Unit context and structure</p> <p>The University of Plymouth (UoP) has a long-established, integrated and dynamic group of research staff with common interests in Earth and Ocean observation, detection and quantification of environmental processes. This is underpinned by experimental approaches to understanding global change drivers and subsequent elucidation of underlying mechanisms, leading to novel theories on how Earth and Ocean systems function and integrate. The continuity and enhancement of our research has been achieved by a long-term, coherent policy supporting research groups within the following:</p> <ul style="list-style-type: none"> • Biogeochemistry Research Centre (BGC) exploring the environmental behaviour, fate and impact of nutrients, metals and pharmaceuticals; • Centre for Research in Earth Sciences (CRES) investigating geological processes, from plate tectonics to modern surface processes to the evolution of life on Earth; • Coastal and Ocean Science and Engineering Research Centre (COSE) understanding and predicting the functioning of coastal and ocean systems; • Marine Biology and Ecology Research Centre (MBERC) investigating marine biology, conservation, ecophysiology and ecology. <p>These research centres represent the chemical, geological, physical and biological components of the UoA7 subject area respectively. They are four key themes in the University's Marine Institute (led by MBERC's Professor Richard Thompson FRS, <i>OBE for Services to Marine Science</i>), and Sustainable Earth Institute (led by CRES's Professor Iain Stewart, <i>MBE for Services to Geology and Science Communication</i>). These multidisciplinary institutes bring together diverse research interests from across the University including science, engineering, arts, humanities, health and business. This interdisciplinarity is of key importance to ensuring the impact and broad reach of Plymouth's UoA7 research in delivering cutting-edge science to address global challenges. The University's Marine Institute is the first and largest such institute in the UK, representing 3000 staff, researchers and students (180 staff, 250+ PhD/PDRA researchers and around 2600 students).</p> <p>Each of the four research centres has a lead academic who liaises with the constituent research group leaders and represents their research centre at School Research Committee (SRC). SRC is attended by the Head of School, chaired by the Associate Head (Research) and includes Early Career Researcher (ECR), Post-Graduate Researcher (PGR) and Post-Doctoral Research Associate (PDRA) representation. SRC feeds into Faculty Research Committee chaired by the Associate Dean (Research) which in turn feeds into the University's Research and Innovation Committee chaired by the DVC(R), with the Institute leads being on both the Faculty and University level committees.</p> <p>UoA7's unifying philosophy maintains that like-minded staff within research groups are the engines of innovative research within their specialist fields, and that strategic planning and investment in the four research centres maximises opportunities for developing world-leading research. The constituent research groups, comprising academic and technical staff, PDRAs and PhD students, typically meet weekly through scheduled meetings to share research ideas, results and plans, so creating a strong and supportive research community.</p> <p>UoA7 is traditionally UoP's largest and strongest research area, ranking 10th in the UK for research power in REF2014. To provide continuity and build on this strong REF2014 outcome, the structure and philosophy of the unit has been maintained with expansion to 61.5 FTE staff (an increase of 37%) mainly due to the recruitment of talented new staff at Lecturer grade. There</p> |

are 65 cat A staff (and 5 cat B staff) included, currently working with 25 PDRAs, 72 PhD students and 20 technicians, plus 212 Masters students across our seven Environmental Masters degrees, giving a research team of 400 staff and postgraduates across UoA7.

Over the REF2021 period, Plymouth UoA7 staff published 1410 peer-reviewed papers with 28,800 citations and a field weighted citation index (FWCI) of two, i.e., twice the number of citations expected according to the global average. Almost a quarter (24%) of these papers are among the top 10% most cited worldwide and 56% are in the top 10% journals. The most prominent topics are: microplastics (96 papers, FWCI = 6.20); beach processes (94 papers, FWCI = 2.45) and ocean acidification (73 papers, FWCI = 2.12), (Elsevier SciVal, 27/01/2021).

Research income has increased 66% over the REF period from £1.76 M/year in 2013/14 to £2.92 M/year in 2019/20, with almost half (45%) coming from BEIS Research Councils, mainly NERC. Continuing this upward trajectory, over £6.3M of research income was awarded to Plymouth UoA7 on new large grants from August 2020 to March 2021 (see Section 3).

b) Research and impact strategy

The REF2014 UoA7 submission outlined six key priorities. Addressing these in the current REF period, we have successfully:

1. Supported the research objectives of the four constituent research centres through focused resource maintenance and acquisition. The four UoA7 research centre leaders are now members of the Marine Institute Strategy Team, thus ensuring seamless support throughout the School/Faculty/Institute research structure.
2. Maintained and enhanced the excellent infrastructure and instrumentation base for obtaining high quality environmental measurements. The University invested £4.65M in its waterfront Marine Station, which opened in 2014, providing a base for several new research vessels, laboratories and ocean-view teaching rooms.
3. Further enhanced our supportive environment for ECRs, for example by ensuring their integration and representation throughout the research structure at research group, centre and institute level. Internally school-funded studentships and seedcorn funds are often targeted specifically to ECRs.
4. Targeted funding from a diversity of sources, including the EU, UKRI and industry (see Section 3).
5. Re-certified our four ISO 9001 laboratories to the ISO 9001:2015 standard (from ISO 9001:2008).
6. Expanded existing strengths by encouraging more staff to actively engage in external professional activities, including serving on national and international committees, professional bodies and editorial boards of high impact journals (see Section 4).

The city of Plymouth has an internationally leading and innovative marine science community comprising the *University of Plymouth*, *Marine Biological Association (MBA)* and *Plymouth Marine Laboratory (PML)*. These organisations provide an exceptional critical mass of marine expertise, together with high quality education and training, and specialist facilities for marine science and technology. Collectively they have published more marine research outputs than any other UK city in the last 10 years, with over half of these papers coming from Plymouth UoA7 staff.

Across Plymouth UoA7, in the current REF period, there were 92 co-authored papers with the MBA, involving 55 co-authors, with 2300 citations and a FWCI of 2.62. Plymouth UoA7 staff have a similarly strong collaboration with researchers at PML: 96 co-authored papers, involving 81 co-authors, with 3000 citations and a FWCI of 3.19, (SciVal, 27/01/2021). To capitalise on this, NERC has pump-primed a 3-year project to establish **Marine Research Plymouth** which aims to '*further strengthen the partnership between UoP, MBA and PML to grow marine science and technology in Plymouth through the sharing of resources, the coordination of marketing and knowledge exchange and the exploitation of complementary research skills and facilities*'.

Looking forward, the post-2021 5-year strategic vision for the University's UoA7 research is to:

1. Invest in our established internationally-leading research areas, whilst also developing, via the University Institutes, new multi-disciplinary research areas to tackle national and global challenges.
2. Further strengthen collaboration between UoP, MBA and PML, using *Marine Research Plymouth* as a springboard, to produce more world-leading and impactful research.
3. Maintain and develop our collaborations and contribution to the research base, economy and society, and continue to increase the impact of our research in terms of the breadth and significance of its reach.
4. Maintain our 'one team' philosophy whereby all academic and technical staff, PDRA's and PhD students work together and support each other in developing the highest quality research and impact.
5. Grow PhD numbers by capitalising on our new status as a full partner of the NERC ARIES ('Advanced Research and Innovation in the Environmental Sciences') DTP and developing a new DTC across the *Marine Research Plymouth* partners.
6. Continue to seek new sources for funding high-quality research, as exemplified by recent large grants from UKRI GCRF and the Garfield Weston Foundation, a grant-making trust, part of the Bertarelli Programme in Marine Science (see Section 3).

UoA7 research areas are prominent in UoP's new strategy '**The University 2030 – A Future of Excellence**' (<https://www.plymouth.ac.uk/about-us/strategy>), which aims to build on: (i) 'established areas of excellence; notably earth and environmental science, particularly marine, and health'; (ii) 'the culture and heritage of its outstanding coastal location'; and, (iii) 'the collegial nature of its workforce'. The broader context is a focus on 'marine and maritime environments and societies' as Plymouth's internationally-understood areas of excellence. This ties in with: (a) the vision, initiated by UoA7's Attrill, for *Plymouth to be the UK's first National Marine Park*, (<https://plymouthsoundnationalmarinepark.com/>), an initiative supported by UK Government and an initial grant from the Marine Management Organisation, (*Marine Policy*, 103,160-171); (b) the *UK Government's Maritime 2050 strategy* (<https://www.gov.uk/government/publications/maritime-2050-navigating-the-future>) to establish a 'maritime innovation hub' at a UK port by 2030 to accelerate the pace of innovation in Britain's maritime sector; and, (c) the *United Nations Decade of Ocean Science for Sustainable Development (2021-2030)* (<https://www.oceandecade.org/>) that aims to ensure ocean science underpins the future sustainable development of the world's oceans, e.g. via our new UKRI GCRF '*One Ocean Hub*' project (Howell).

The four UoA7 research centres (BGC, CRES, CCOSE and MBERC) were formed following RAE2008, so enabling them to develop long-term plans and flourish. Each research centre houses an integrated team of researchers, demonstrated by 50% of the REF2021 selected outputs having more than one author from a given research centre. These research centres contribute to the overall UoA7 strategy and vision as outlined below:

Biogeochemistry Research Centre (BGC)

<https://www.plymouth.ac.uk/research/biogeochemistry>

Current staff in UoA7: *Centre Lead* (Fitzsimons); *Marine Biogeochemistry* (Belt, Fitzsimons, Lengger, Manners, Milne, Ussher); *Chemicals in the Environment* (Tappin, Turner A); *Environmental and Fluid Modelling* (Laudone); with 7 PDRAs, 16 PhD students, 6 technicians and 2 cat B staff (Emeritus Professors Worsfold and Rowland).

BGC's environmental research is focussed in UoA7, mainly in the *Marine Biogeochemistry* area, exploring nutrient cycles in contemporary ecosystems, and the development and application of molecular biomarkers to identify past and present environmental processes. BGC has upgraded its extensive analytical portfolio of instruments, for example, applying state-of-the-art pre-concentration and separation methods to advance understanding of phytoplankton-produced volatile gases and their contribution to climate regulation, especially in the climate-sensitive Southern Ocean. BGC's work on the reactivity of micro-nutrients has revealed key controls on concentrations of dissolved iron in the ocean, directly impacting primary production. Work on

carbon fixation has identified the hitherto unknown contribution made by ammonium-oxidising bacteria to the carbon budget in hypoxic areas of the deep ocean, influencing the expansion of nutrient-fuelled 'dead zones' in the global ocean. BGC continues to be a world leader in the use of source-specific biomarkers as tracers of past climate events, most notably changes in sea ice extent and open ocean primary productivity in both the Arctic and Antarctic.

Environmental and Fluid Modelling is a sustained area of expertise for Plymouth, including the study of pollutants (e.g. cable oil) and nutrients in soil. Similarly, BGC has a strong track record researching *Chemicals in the Environment*, particularly the environmental occurrence of metal and organic contaminants, now expanded to include microplastics, and their chemical composition and environmental fate. Our Consolidated Radio-Isotope Facility (CORIF) has supported world-leading research on micro- and nano-plastics through organism exposure experiments in collaboration with MBERC.

Post REF2021 BGC will: (i) advance understanding of climate effects on marine ecosystems by expanding its dataset on volatile amines and integrating into regional sea models; (ii) demonstrate how engineered soils can provide a sustainable and climate-resilient substrate for food security; (iii) continue to contribute to core UK and international biogeochemical oceanographic programmes, expanding capabilities to determine trace-level iron and conducting sensitive multi-elemental analyses on marine samples; (iv) expand the use of source-specific biomarkers to identify marine food web responses to climate change in both polar regions; (v) develop its expertise to measure and track indicators of plastic pollution in the environment, through addition of a pyrolysis facility to its analytical infrastructure.

Centre for Research in Earth Sciences (CRES)

<https://www.plymouth.ac.uk/research/earth-sciences>

Current staff in UoA7: *Centre Lead* (Harris); *Formation and Deformation of Earth Materials* (Anderson, Gebelin, Harris, Morris, Stephen); *Active Tectonics and Geohazards* (Cole, Manzella, Mildon, Stewart); *Earth History and Palaeoclimates* (Balthasar, Grimes, Price, Watkinson); *Modern Landscapes and Climate Change* (Boulton, Smart, Stokes M); with 6 PDRAs, 12 PhD students, 4 technicians and 2 cat B staff (Dijkstra and Menegon).

CRES seeks to understand the drivers of change in the Earth system, from plate tectonic processes to past climates and the response of modern environments to climate change. Since REF2014, CRES has grown stronger and more diverse with six new ECR appointments (Balthasar, Gebelin, Harris, Manzella, Mildon, Stephen).

Advances in the *Formation and Deformation of Earth Materials* area benefit from strong engagement with the *International Ocean Discovery Program* (IODP), and the *International Continental Scientific Drilling Program* (ICDP). CRES palaeomagnetism research has revealed hitherto unrecognised first order structures in the Troodos ophiolite, provided new perspectives on magmatic processes in the Oman ophiolite, and demonstrated how oceanic detachment faults can be inverted to initiate new subduction zones (Morris, Anderson). Geochemical tracers of fluid flow at mid-ocean ridges have revealed the controls on fluid pathways and fluxes and identified the necessity of deep hydrothermal circulation in the lower crust (Harris).

In *Active Tectonics and Geohazards*, numerical modelling of earthquake hazards has quantified the role of Coulomb pre-stress as a factor in earthquake triggering, improving our ability to reproduce historical earthquake locations (Mildon). In *Earth History and Palaeoclimates*, research in high latitudes during the Mesozoic greenhouse world demonstrated that current climate models underestimate past marine temperatures, questioning their ability to predict future warming (Price, Watkinson). In *Modern Landscapes and Climate Change*, research identified structural controls on rapid river gorge formation during unexceptional floods, challenging established models of gorge formation and landscape evolution (Stokes M).

Post REF2021 CRES will: (i) quantify fluid/rock reactions in the lower oceanic crust and develop understanding of the role of fluids during magnetisation of the crust via a new NERC project 'The

3D anatomy of magma transport at fast-spreading ocean ridges'; (ii) develop multi-scale integrative modelling of a range of geohazards to meet the needs of society via two newly-funded projects, UKRI Future Leaders Fellowship 'Quake 4D' and NERC 'SENSUM'; (iii) adopt inter-disciplinary approaches to study active tectonic processes, including developing expertise in cosmogenic isotope research; (iv) pursue quantitative understanding of how future warming will be distributed between the oceans and atmosphere and explore new approaches to studying past climate; (v) explore the interplay between climate and tectonics on landscape development using an integrated remote, field and geochemical approach.

Coastal and Ocean Science and Engineering Research Centre (COSE)

<https://www.plymouth.ac.uk/research/centre-for-coastal-and-ocean-science-and-engineering>

Current staff in UoA7: *Centre Lead* (Russell); *Coastal Processes Research Group* (Conley, Davidson, Masselink, O'Hare, Poate, Russell, Scott, Shapiro, Stokes C); *Marine Physics Research Group* (Bass, Gales, Hosegood, Manning, Nimmo-Smith, Schwarz, Vlasenko); with 6 PDRAs, 9 PhD students and 5 technicians.

COSE integrates the University's long-established research strengths in physical oceanography (*Coastal Processes Research Group* and *Marine Physics Research Group* in UoA7) and coastal engineering (Coastal Engineering Research Group 'COAST' in UoA12), making one of the largest coastal science and engineering groupings in Europe. COSE's mission is to measure, understand and predict the functioning of coastal and ocean systems in support of appropriate management of resources and activities.

COSE has an international reputation in recording and predicting coastal behaviour through pioneering fieldwork and developing ground-breaking numerical models, for example inputting into the EA's *National Flood and Coastal Erosion Risk Management Strategy* with its operational real-time storm impact model for regional coastal flooding. Multiple scientific breakthroughs have enabled COSE's coastal research to have direct practical application leading to the creation of a research-informed consultancy *Coastal Marine Applied Research (CMAR)* in 2015. COSE hosts the UK's only operating two station HF wave radar and utilises the University's *Coastal Ocean and Sediment Transport (COaST)* wave tank laboratories for physical model tests and marine renewable energy research.

In marine physics, COSE specialises in dynamical physical oceanography, flocculation dynamics, particle imaging, turbulence microstructure and non-linear internal waves. Work on bio-physical interactions brings together COSE's physical oceanographers and MBERC's marine biologists, showing how currents, frontal dynamics, turbulence and numerical modelling can be used to enrich biological knowledge of species ranges and food web interactions. In collaboration with MBERC, COSE is looking at a vast array of these interactions, working with species from microscopic plankton to the ocean's top predators, in environments ranging from coastal surface waters to the deep sea floor. COSE also hosts the *Plymouth Ocean Forecasting Centre* that creates cutting-edge regional ocean models for a range of end-users.

Post REF-2021 COSE will: (i) apply its internationally-leading research on predicting shoreline change (e.g. Davidson *Nature Sci Rep* **10**, 2137, 2020) to facilitate coastal management as sea-levels rise in a changing climate; (ii) develop satellite-calibrated models for the prediction of coastal evolution world-wide; (iii) examine how coral islands respond to sea-level rise using planned new field measurements on islands in the Indian Ocean (e.g. Masselink *Science Advances* **6**, 24, eaay3656, 2020); and, (iv) capitalise on combined COSE/MBERC expertise to provide further breakthroughs in the understanding of bio-physical interactions and contribute to ensuring sustainable use of the oceans.

Marine Biology and Ecology Research Centre (MBERC)

<https://www.plymouth.ac.uk/research/marine-biology-and-ecology-research-centre>

Current staff in UoA7: *Centre Lead* (Rundle); *Marine Ecophysiology Research Group* (Bilton, Ciotti, Cunliffe, Rundle, Spicer, Tills, Truebano, Turner L); *Marine Conservation Research Group* (Attrill, Davies, Edwards, Embling, Firth, Foggo, Hall-Spencer, Howell, Ingram, Knights,

McQuatters-Gollop, Reid, Sheehan, Wilson A, Wilson W); *International Marine Litter Unit* (Thompson); with 6 PDRAs, 35 PhD students, 5 technicians and one cat B staff (Parmesan).

MBERC encompasses three research groups: *Marine Ecophysiology*, *Marine Conservation* and the *International Marine Litter Unit (IMLU)*. Since REF2014, MBERC has expanded, with the formation of the *IMLU* and 12 staff appointments across *Marine Ecophysiology* (Ciotti, Cunliffe, Tills, Truebano, Turner L) and *Marine Conservation* (Davies, Firth, Knights, McQuatters-Gollop, Sheehan, Wilson A, Wilson W). In recognition of the pioneering work on microplastics and their environmental impacts, led by Thompson's *IMLU* team, the University received its third *Queen's Anniversary Prize* in 2019.

MBERC research has focused on the following areas:

- 1) *The influences of environmental change, fisheries and pollution on marine biodiversity*, including: (i) the impact of fishing and other physical disturbance on the seabed; (ii) sources, fates and biological effects of microplastics in marine habitats; (iii) the effects of ocean acidification, ocean warming and hypoxia on species' eco-physiology, calcification, community composition and ecosystem level effects; and, (iv) the effects of other forms of pollution (light and noise).
- 2) *The use of large-scale temporal and spatial data for the understanding and management of marine biodiversity*, including: (i) habitat mapping for assessing the effectiveness of Marine Protected Areas (MPAs) and impact of marine renewable energy; (ii) the use of long-term plankton data for identifying regime shifts; (iii) the importance of changes in range size and phenology; and, (iv) the influence of fronts and small scale hydrodynamics in influencing the distribution of marine vertebrates.
- 3) *The development of new approaches for biological assessment*, including the use of: (i) novel phenomics technology for the automated measurement of stress responses in marine embryos; (ii) underwater video methodology designed at UoP for habitat mapping and surveys, including using artificial intelligence for processing video; (iii) '–omics' approaches for measuring biodiversity; and, (iv) acoustic telemetry for monitoring mobile species.

MBERC research has contributed substantially to the understanding of how marine biodiversity is responding to environmental change and has informed management decisions at regional, national and international levels. MBERC's marine conservation research has influenced government policy through the *25-year Environment Plan* and helped change the way seas are managed through marine protected areas and marine conservation zones.

Post REF2021: Within the context of the pressing need to understand, mitigate and manage the effects of climate change, fisheries and pollution in the marine environment, it is envisaged that MBERC's work in the three key areas listed above will continue to grow. For example, the new 'Embryo Phenomics' laboratory is building novel approaches for more rapid and thorough assessment of environmental impacts on biodiversity in the field, facilitated by the award of a new, 7-year, UKRI Future Leaders Fellowship to Tills.

Interdisciplinary research

Interdisciplinary research is encouraged across the four UoA7 research centres, and at a broader scale across the University's three strategic research institutes (Marine, Sustainable Earth and Health; <https://www.plymouth.ac.uk/research/institutes>). For example, COSE coastal scientists, with their expertise on waves, currents and sediment transport, routinely work with engineers in marine renewable energy research. MBERC marine biologists work with engineers developing sustainable construction practices for sea defences, with medical scientists to develop new antibiotics from deep-sea sponges and with psychologists to study human behaviours relating to plastics pollution. CRES geologists work with social scientists to understand the communication of risk. The broad mix of subject areas contributing to our

research outputs is illustrated in Figure 1, with 24% of the subject matter from Earth and Planetary Sciences, 23% from Agricultural and Biological Sciences (mainly reflecting our Marine Biology research), 23% from Environmental Sciences and various smaller contributions from Engineering, Chemistry etc.

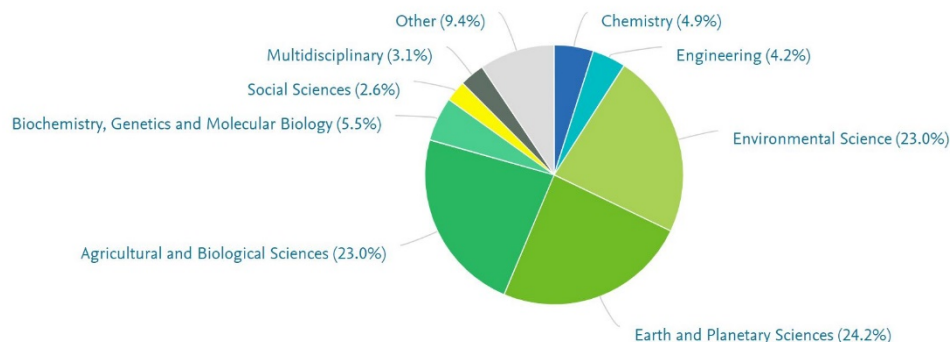


Figure 1: Subject areas contributing to Plymouth's REF2021 UoA7 outputs (Elsevier SciVal, 27/01/2021)

Open research environment

The *University Research Data Policy*, in accord with the *Concordat on Open Research Data*, provides thorough guidelines for good practice in research data management and open access to research data as an integral part of high-quality research. Implementing this policy, all the published UoA7 papers, not just those submitted for REF, are available (or will be available, when embargo is complete) through the University's open access research repository, PEARL. PEARL is also used as an open access repository for research datasets, both 'stand-alone' and connected to published papers. For example, our EPSRC '*Waves Across Shore Platforms (WASP)*' dataset in PEARL has a CC-BY licence and a standard and quality of metadata that allows for ease of discovery and reuse <https://pearl.plymouth.ac.uk/handle/10026.1/9105>. Repositories such as the British Oceanographic Data Centre (BODC) are used to provide open access to datasets from other research council-funded projects. Our internal process of *peer grant development and review* specifically ensures all research proposals conform to the University's Data Management Policy.

Research at UoP is conducted according to the principles of integrity, academic excellence, accountability, inclusiveness and professionalism. All research must follow appropriate ethical, legal and professional frameworks, obligations and standards. The University's *Research Ethics Policy* and the *Code of Good Research Practice* conform to the principles laid out in other relevant policies, guidelines and codes of conduct, including those of the research councils and Universities UK's *Concordat for Research Integrity*. All UoA7 research activities are subject to the approval of the Ethics Committee (where appropriate) and our internal process of *peer grant development and review* ensures all research is supported by, and contributes to, a culture of research integrity.

Impact strategy

Impact and innovation are at the heart of Plymouth's research culture and the impact strategy outlined in REF5a applies across UoA7. The development of impact is supported by an impact-training programme that delivers events, workshops and 1-2-1 sessions on planning research impact, developing pathways, impact generation, writing & corroborating impact, impact software usage and showcasing research impact. This is supplemented with a range of online impact development tools and resources, such as the cloud-based software '*VV-Impact Tracker*' that helps researchers plan for and evidence social, economic and environmental impact. The University's *Research Impact and Quality Officer* supports staff in engaging with the impact-training programme to develop and maximise the impact of their research.

All Uo7 academics are fully engaged in the impact agenda and routinely consider how to maximise the impact of their research. Academics produce *Personal Research Plans* that include impact as part of their annual Performance Development Review (PDR). Impact is further developed as an integral part of external and internal research proposals. All funding proposals go through a formal *peer grant development and review* procedure that requires reviewers to evaluate the potential impact from the research and the actions to deliver that impact. With nearly half of Plymouth UoA7's grant funding coming from the research councils, impact is fully embedded as a requirement of those proposals. As a result of the embedded impact culture, there were many more than the five required impact case studies potentially available across this UoA.

The UoA7 experience is that particularly significant and far-reaching impact is often achieved in research areas supported by a series of related research council grants over a long period. This ensures the impact is built on internationally-leading science and it applies to all five of UoA7's selected impact case studies. For example, the selected impact case studies on coastal resilience and beach hazards were developed in collaboration with the '*South-West Partnership for Environment & Economic Prosperity (SWEEP)*' project (total £4M over 5 years), funded under NERC's *Environmental Science Impact Programme* that specifically aims 'to translate excellent NERC-funded research into actions or policies that improve performance, resilience and sustainability, and support local growth.' This is facilitated by two staff (Poate and Stokes C) who have 0.5 PDRA posts on SWEEP and with COSE's *Coastal Applied Marine Research (CMAR)* research-informed consultancy.

On a broader scale, EDRF *Marine Business Technology Centre (MBTC)* (2018-21) (<https://www.plymouth.ac.uk/research/esif-funded-projects/marine-business-tech>) and *Marine-i* (2017-22) (<https://www.plymouth.ac.uk/research/institutes/marine-institute/marine-i>) projects link businesses with academics to support the development of new products, provide access to model testing facilities and support business growth through direct access to UoP's marine research. So far, *MBTC* and *Marine-i* projects have worked directly with 45 separate companies securing over £3.1M in new marine research, development and innovation project value to UoP. Example projects include developing *Reef Cubes* that also provide marine habitats with *ARC Marine* (Firth) and developing the *Tidal Revival App* to document plastic pollution in the marine environment world-wide with *Evidence Plastic CIC* (Thompson). Four new research fellows on 2-year (2020-22) posts have been funded through *Marine-i* to work with academics and businesses in UoA7 research areas such as coastal processes, remote sensing and marine plastics, utilising the COaST wave tanks and HF wave radar facilities.

UoA7's research impact has been recognised by *two NERC impact awards* ('Societal Impact Award' and 'Overall Winner') for microplastics research (Thompson) and an *EU Horizon Impact Award* for societal impact world-wide of the 'Innovative technologies for safer European coasts in a changing climate (THESEUS)' project, a collaboration between Plymouth UoA7 ecologists (Firth) and UoA12 coastal engineers.

2. People, including:

a) Staffing strategy and staff development

The UoA7 bid has expanded significantly with 65 academic staff (headcount), 61.5 FTE, (compared to 44.9 FTE in REF2014). Our staffing strategy is to maintain a good balance between experienced Professors, mid-career staff and lecturer-grade staff, whilst simultaneously supporting progression through this structure, and enhancing vitality with new appointments mostly at Lecturer grade. Our philosophy is that all staff contribute to both research and teaching through a 'one team' approach. A key characteristic of our research environment is that the academic staff are integrated with the PDRAs, PhD students and technicians in research groups to create a vibrant research community.

The UoA7 staff profile (Figure 2) is characterised by staff being mainly on permanent full-time academic contracts, with a normal distribution across the age ranges, equally distributed between Professors, Associate Professors and Lecturers. This profile provides long-term stability, balance and sustainability to the unit.

| Grade | % | Age group | % | Contract | % |
|---------------------|----|-----------|----|------------|----|
| Professor | 31 | 25-34 | 7 | Permanent | 98 |
| Associate Professor | 29 | 35-44 | 30 | Fixed-term | 2 |
| Lecturer | 34 | 45-54 | 37 | | % |
| Research Fellow | 6 | 55-64 | 24 | Full-time | 94 |
| | | 65+ | 2 | Part-time | 6 |

Figure 2: Staff profile across Plymouth UoA7, based on grade, age-profile and contract

Staff retention is high, with only five staff from REF2014 having left for other Universities and research laboratories: Bennett, Calosi, Kirby, Lohan and Pagli. In addition one retired (Munn) and five became Emeritus Professors (Burkhill, Griffiths, Hart, Rowland and Worsfold).

In keeping with the principles of REF2021 and inclusivity, 89% of academic staff across the two constituent Schools (*School of Geography Earth and Environmental Sciences* and *School of Biological and Marine Sciences*) are on AEF3 (teaching and research) contracts and are therefore REF2021-returned, with only 8% of academic staff in these Schools being on AEF1 (teaching only) contracts, and the remaining 3% being on AEF2 (research only).

Staff development

Plymouth UoA7 research relies on the quality of the staff and the stimulation brought about by the recruitment of new staff, PDRAs and PhD students. A vibrant research culture is promoted by creating an environment in which new ideas can flourish with interaction across the unit. We continue to focus on the recruitment, mentoring and development of ECRs. New academic staff are rapidly embedded within an active research group, assigned a more experienced colleague as a mentor and give a research seminar at the earliest opportunity. They are initially given light teaching loads and start-up funds are provided to help them establish their research careers. New staff attend lecturing and staff development courses run by the University. ECRs are also prioritised for funding internally, with PhD studentships and seedcorn funds.

The commitment to succession planning, supporting and developing new talent and equal opportunity is illustrated by the appointment of 24 new academic (AEF3) staff during the REF period, mostly at Lecturer level, of which 13 are female and 11 male, distributed across the four research centres as follows:

- BGC: Laudone, Lengger, Manners, Milne;
- COSE: Gales, Poate, Scott, Stokes C;
- CRES: Balthasar, Gebelin, Harris, Manzella, Mildon, Stephen;
- MBERC: Ciotti, Davies, Firth, Knights, McQuatters-Gollop, Sheehan, Tills, Truebano, Turner L, Wilson A.

The progression of staff in this REF period is shown by six staff being promoted to Professor (Anderson, Conley, Fitzsimons, Howell, Price, Rundle) and eight staff being promoted to Associate Professor (Boulton, Cole, Cunliffe, Ingram, Knights, McQuatters-Gollop, Menegon, Ussher).

Plymouth holds the *European Commission HR Excellence in Research Award* presented to universities that uphold the principles of the *Concordat to Support the Career Development of Researchers*. Annual Performance Development Review (PDR) procedures for the career development for all staff are underpinned by *Personal Research Plans* nested within broader individual and group strategic five-year research planning. Staff in the UoA also benefit from

researcher development programmes delivered by the University's *Research Support Programme* and from a *Research Leadership Programme* provided by the consultancy firm Barefoot Training that is specifically targeted at mid-career staff and researchers.

High priority is given to supporting and integrating individuals into the research culture of the unit. This is evidenced by one-third of the REF-submitted papers including authorship by a Plymouth PDRA. Many of our previous Masters and PhD students have gone on to become excellent PDRAs, and many of those have gone on to successful academic positions. Examples of such staff in the current bid are: Manners, McQuatters-Gollop, Poate, Scott, Sheehan, Stokes C and Tills.

McQuatters-Gollop's 2-year secondment to Defra is an example of exchange between academia and outside organisations, which is encouraged and facilitated, usually by adjusting workload at the University. Other examples of this exchange are the close ties between MBERC and the MBA, which include joint appointments (Cunliffe, Edwards, Reid, Wilson W) and a joint MRes in Marine Biology (led by Cunliffe) that has run since 2003. This both reinforces existing research collaborations (e.g. McQuatters-Gollop with Reid, McQuatters-Gollop with Edwards and Cunliffe with Hall-Spencer, all of which are evidenced by joint publications) and stimulates new research through joint supervision of MRes projects. The annual *Plymouth Marine Science and Education Foundation (PlyMSEF)* conference brings together PhD students from across UoP, MBA and PML and acts as a showcase for Plymouth's marine expertise.

Plymouth UoA7 recognises and rewards staff for carrying out research and achieving impact with: (i) development funds available from the School strategic research account that all staff can apply for (based on their research record and justification); (ii) an annual allowance to spend, without needing to apply for further justification, for staff who have directly-allocated time on grants of 5-10% for 3 years; (iii) access to a competitive 6-month sabbatical leave process to supplement research time and further develop impact; (iv) workload planning that explicitly includes research workload, so other teaching and management commitments are balanced accordingly; (v) all staff on teaching and research contracts having 40% of their time allocated to research; and, (vi) successful research areas targeted for investment in infrastructure and facilities, e.g. New 'International Marine Litter Unit' and 'Embryo Phenomics' laboratories.

b) Research students

Postgraduate research students (PGRs) are central to our research environment and are fully integrated into it, as evidenced by one-third of UoA7 REF-submitted papers including authorship by a Plymouth PhD student. We have an excellent record of attracting high-quality PGRs to Plymouth, and of recruiting excellent PGRs from our seven Masters courses in *Applied Marine Science, Environmental Consultancy, Environmental Geochemistry, Hydrography, Marine Biology, Marine Conservation* and *Marine Renewable Energy*.

Across Plymouth UoA7 there were 94 PhD completions in the present REF period compared to 70 completions in REF2014. The potential for future increases in completions is illustrated by the 72 students currently undertaking PhDs across the UoA and our plans to develop a new DTC with the *Marine Research Plymouth* partners post REF2021.

PhD Training Partnerships

Plymouth is a full member of the NERC ARIES (*Advanced Research and Innovation in the Environmental Sciences*) DTP, launched in 2018. ARIES draws together expertise from five universities, nine research labs and over forty other research-users. The partnership has a mission to equip PGR students with the skills to become 21st Century Scientists: leaders in the science and sustainable business of the natural environment. ARIES is supporting a minimum of 75 fully funded PhD studentships over five student cohorts, the first of which started in October 2019. A total of six ARIES PhD students registered at UoP in 2019, two of these being based at

the MBA, and one at the British Geological Survey, further cementing our collaborations with these institutions. The remaining three students are registered and based at UoP.

From January 2020 UoP became a partner of the GeoNetZero CDT (*Centre for Doctoral Training in Geoscience and the Low Carbon Energy Transition*) that aims to train the next generation of geoscientists needed to meet the UK Government target of net zero carbon emissions by 2050. Through this CDT, UoP is recruiting one PhD student/year.

In terms of international PhD collaborations, UoP was a full partner in the *EU MARES Doctoral Programme on Marine Ecosystem Health and Conservation*, funded by Erasmus Mundus, where PhD students studied at two partner institutes across Europe, USA and Australia. Three UoA7 PhD students graduated from this scheme during the REF period.

Recruitment, monitoring and support of PhD students

The success of our PGR training is attributed to supportive and rigorous selection, training and monitoring procedures. All PhD positions are widely advertised and short-listed by a mixed-gender panel on the basis of excellence of their academic qualifications, relevant experience and quality of the planned research. Short-listed candidates are then interviewed by the same panel, following the University's normal interview procedures.

UoP has a policy of support, training and supervision for PGR students that is well-respected across the sector. Each student has a Director of Studies and a team of 2-3 supervisors who oversee the direction of research and offer welfare support. All PGR students are carefully supervised and supported from their first day until graduation, and thereafter into employment. This is achieved by integrating PhD students into our active research groups, providing peer academic and social support, and by regular meetings with supervisory teams.

PGR activities are managed by the University's *Doctoral College* to ensure PhD students have an experience that is both successful and enjoyable. In each school a senior member of staff pays special attention to the administrative needs of its PGR students and liaises directly with the Doctoral College on their behalf. PGR students record notes on supervisory meetings and submit 'milestone forms' using software called *GradBook* that supervisors also use to check deadlines, set up formal meetings and approve milestone forms, providing a formal way to monitor progress.

The Doctoral College has a *Research Development Programme* supported by UKRI, Vitae and employers of researchers. All our PGR students regularly attend these courses, which are divided into four domains:

- *Knowledge and Intellectual Abilities*, e.g. Advanced R, LaTeX, Matlab, Python, thesis production;
- *Personal Effectiveness*, e.g. Working with feedback and setbacks, Transfer process, Preparing for the viva, Careers;
- *Research Governance and Organisation*, e.g. Research integrity, Applying for ethical approval, Intellectual property, Funding opportunities, Project management, GradBook;
- *Engagement, Influence and Impact*, e.g. Using the media to publicise research, Introduction to podcasting and panopto, Designing an effective research poster, Getting published, Impact, Leadership, Three Minute Thesis competition.

In addition, advanced training is provided within the research community, and through the NERC ARIES DTP. The ARIES training focusses on *five skill areas* linked to the vision of the 21st century scientist, and, space-permitting, these courses are available to UoP PGR students outside of ARIES, as well as those doing ARIES PhDs:

- (i) *Developing understanding and skills in the management and use of big data;*
- (ii) *Impact, innovation and engagement in commercial and non-commercial environments;*
- (iii) *Development of multi-disciplinarity;*
- (iv) *Transferrable skills training;*

(v) *Completion, careers and employability.*

New PGR students in Plymouth UoA7 can also take taught Masters modules to provide specific training. In order to gain presentation skills and obtain feedback from peers, they present their work regularly, internally to their research group, and externally at conferences such as the *Young Coastal Scientists and Engineers Conference (YCSEC)* and the *Plymouth Marine Science Education Foundation (PLYMSEF)* annual conference.

In addition to the *Researcher Development Programme*, the Doctoral College runs University-level inductions for new PGR students, providing cohort development, networking opportunities and mentoring, as well as training sessions for supervisors and examiners. PGR students are represented on School Research Committees and on Research Institute Strategy Teams. PGR students have dedicated desk space with ICT provision and generous access to appropriate laboratory facilities and technical support.

From **PhD destinations** data, 51% of our PhD graduates continued in careers in higher education, mainly as lecturers and postdocs. Many PhD graduates from the geological and chemical sciences obtained *employment in industry* (e.g. AECOM Engineering). Other PhD graduates went into *commercial consultancy* (e.g. Met Office), *work for charities* (e.g. RNLI) or hold *government-related posts* (e.g. Geological Survey). Examples of **prizes** awarded to our PhD students include: the *Crown Estate Seabed Innovation Award* (to O'Shaughnessy, 2017), the *Marine Conservation Society Wakefield Memorial Award* (to Napper, 2017), the *EGU Outstanding Student Poster and PICO (OSPP) Award* (to Vickers 2016) and the *British Science Association Charles Lyell Award* (to Gibson, 2015).

c) Equality and Diversity

Equality and diversity are embedded in our approach, both formally, via a mandatory staff training course, and as an integral component of day-to-day research activities in accord with the University's equality, diversity and inclusion policy, <https://www.plymouth.ac.uk/about-us/university-structure/service-areas/equality-diversity-and-inclusion>

Our commitment to equality and diversity is recognised through Bronze Athena SWAN awards to the two contributing Schools: *School of Geography Earth and Environmental Sciences* (housing BGC and CRES) in 2017 and 2020; and, *School of Biological and Marine Sciences* (housing COSE and MBERC) in 2020. 31% of Plymouth UoA7 staff are female, 50% of the 154 REF-submitted papers have UoP female co-authors and 2/5 (40%) of the impact case studies are female led. Our PhD completions are 48% female and 69% white. The low % BME of the Plymouth UoA7 staff (96% white) reflects both the subject area and that of the South-West region as a whole (95% white at the last census), and is a metric we seek to improve, supported by the University submitting to Advance HE's Race Equality Charter by 2022.

All staff across the University undertake regular training courses in equality and diversity, unconscious bias, mental health awareness, health and safety and general data protection regulation (GDPR). There is additional training for interview panel members and panel chairs. All appointment panels, promotion panels and internal funding panels are gender balanced and adhere to the University's equality and diversity policy, as testified by our Athena SWAN awards.

Complementing the priority for its employees to have a good work-life balance, the University offers various staff support, <https://www.plymouth.ac.uk/about-us/university-structure/service-areas/equality-diversity-and-inclusion/staff-support>. Full support is available to staff, PGRs, and their family members during periods of pregnancy. The University has a range of supportive policies including ones on maternity, paternity, and parental leave, which often go beyond the statutory requirements. A comfortable and private room is provided for nursing mothers. The Freshlings' Nursery offers childcare, and childcare vouchers are available. There is a flexible working policy aimed at supporting those caring for children or others. Staff can request reduced

hours, varying working patterns, timetable constraints or to work from home. Staff submitted in UoA7 have taken up these options with great success.

Staff suffering illness are given support either to recover fully or to properly manage their condition. Arrangements are made to facilitate return to work following illness with the option of a phased return. The collegial 'one team' philosophy across the UoA means colleagues are ready to cover for each other. Beyond this altruism between colleagues, the University has specific structures and resources in place to support staff health and well-being. These include the University Medical Centre, which provides access to doctors and nurses, and the staff counselling service. There is also an established system of staff networks funded by the University, where staff meet to support each other. These include the LGBT+ Staff Forum, the Women's network and a network for staff with disabilities. The Sports Centre possesses a well-equipped gym and offers a range of classes, such as yoga, aimed at improving staff well-being.

3. Income, infrastructure and facilities

a) Income

Grant income spent across the UoA over the REF period was £13.3M (Figure 3), up from £12.1M in the last REF. This represents 'pure research income' only, so excludes income for assets (such as a building, or large equipment, like boats) and also excludes income from consultancy, knowledge transfer and commercially funded research of public benefit.

The largest funding source was the Research Councils (predominantly NERC) with 45% of total funding, followed by EU Government bodies (18%), UK Charities and UK Government bodies (both 11%) and UK Industry and non-EU Charities (both 5%).

| | 2013/14 | 2014/15 | 2015/16 | 2016/17 | 2017/18 | 2018/19 | 2019/20 | Total Income £ | Total % |
|--|-----------|-----------|-----------|-----------|-----------|-----------|-----------|----------------|---------|
| Source | Income £ | Income £ | Income £ | Income £ | Income £ | Income £ | Income £ | | |
| BEIS Research Councils | 959,384 | 688,596 | 547,556 | 1,028,764 | 1,011,087 | 816,215 | 913,930 | 5,965,533 | 44.8% |
| UK-Based Charities (Open Competitive Process) | 33,685 | 100,511 | 183,998 | 221,527 | 100,968 | 392,778 | 499,120 | 1,532,585 | 11.5% |
| UK-Based Charities (Other) | 10,058 | 16,108 | 8,590 | 15,585 | 0 | 1,918 | 1,172 | 53,430 | 0.4% |
| UK Central Gov. Bodies/Local Auth, Health & Hosp Auth. | 242,260 | 47,090 | 11,522 | 369,371 | 224,943 | 204,749 | 331,479 | 1,431,413 | 10.7% |
| UK Industry, Commerce & Public Corporations | 41,026 | 75,651 | 57,335 | 117,418 | 86,211 | 187,868 | 91,779 | 657,290 | 4.9% |
| UK Other Sources | 0 | -124 | 0 | 126 | 103 | 415 | 0 | 520 | 0.0% |
| EU Government Bodies | 328,272 | 439,825 | 213,224 | 436,743 | 288,295 | 412,915 | 325,919 | 2,445,192 | 18.4% |
| EU-Based Charities (Open Competitive Process) | 49,904 | 17,213 | 1,801 | 3,093 | 5,258 | 6,969 | 1,064 | 85,301 | 0.6% |
| EU Industry, Commerce & Public Corporations | 0 | 0 | 0 | 0 | 0 | 944 | 186 | 1,130 | 0.0% |
| EU Other | 90,518 | 66,806 | 5,630 | -5,518 | 3,644 | 1,549 | 516 | 163,144 | 1.2% |
| Non-EU-Based Charities (Open Competitive Process) | 0 | 0 | 0 | 10,094 | 167 | 36,045 | 654,684 | 700,990 | 5.3% |
| Non-EU Industry, Commerce & Public Corporations | 131 | 10,984 | 22,811 | 493 | 8,196 | 3,685 | 0 | 46,299 | 0.3% |
| Non-EU Other | 1,077 | 4,796 | 24,370 | 20,872 | 50,818 | 41,204 | 96,901 | 240,039 | 1.8% |
| TOTAL | 1,756,315 | 1,467,455 | 1,076,835 | 2,218,569 | 1,779,690 | 2,107,254 | 2,916,751 | 13,322,868 | 100.0% |

Figure 3: Breakdown of Plymouth UoA7 pure research income by funding source and University finance year (1 August – 31 July)

Examples of our NERC grants include: (i) 'South West Partnership for Environment and Economic Prosperity (SWEEP)' (2017-22, £776k to UoP) that is facilitating the two selected impact cases studies on coastal resilience and beach hazards; (ii) 'Biological and Lithological Underpinning of Evolution of Coasts (BLUE-coast)' (2016-21, £753k to UoP); and, (iii) 'Artificial Light Impacts on Coastal Ecosystems (ALICE)' (2019-23; £712k to UoP).

European funding was from: European Maritime and Fisheries Fund (6 projects, collectively £1M to UoP); FP7 (e.g. *SEA-on-a-CHIP*, £224k to UoP); H2020 (e.g. *Clean Energy From Ocean Waves*, £180k to UoP); and, Interreg (e.g. *Preventing Plastic Pollution*, £331k to UoP).

UK Government funding was from Natural England, DEFRA and the Environment Agency. The Leverhulme Trust funded three projects and smaller amounts of research funding were received from industry, charities and professional societies, including Blue Marine Foundation, EDF Energy, European Association of National Meteorological Institutes, Offshore Shellfish Ltd, PDF Ltd, Prince Albert II of Monaco Foundation, RNLI and the Total Foundation.

The IMLU's microplastics research was supported by a diverse array of funders including UNEP, EU, NERC, Defra, National Geographic and Exxpedition (all-women voyages), facilitating the production of both high quality research outputs (e.g. three papers with > 500 citations in *Marine Pollution Bulletin*, *Water Research* and *Royal Society Open Science*) and impact (microplastics impact case study).

The annual income totals from Figure 3 show an upward trend over the REF period (Figure 4). The most recent year, 2019/20, shows the highest income as spend began on new large grants such as: (i) UKRI GCRF 'One Ocean Hub', (2019-24; started Feb 19; UoP £949k) and (ii) Garfield Weston Foundation (Bertarelli Programme in Marine Science) 'Oceanographic drivers of ecosystem variability in the Chagos archipelago (British Indian Ocean Territory, BIOT)', (2018-22; started Sept 18; UoP £922k).

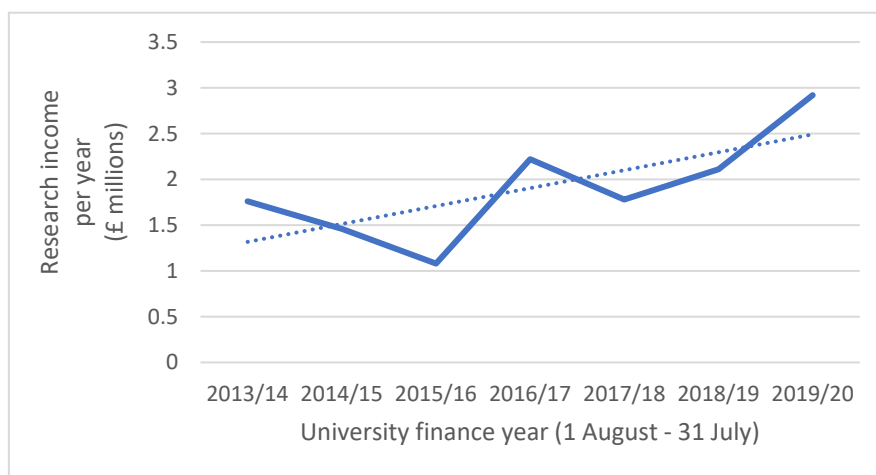


Figure 4: Plymouth UoA7 pure research income over the REF2021 period

Continuing this recent success in securing funding, **from August 2020 to March 2021 over £6.3M in other substantial grants** have been awarded to Plymouth UoA7, including:

- NERC Highlight Topic, 'Biodegradable plastics as emerging environmental pollutants', 4-year project, £1.4M to UoP (Thompson);
- UKRI Future Leaders Fellowship Award, 'Quake 4D', 4-year project to generate a new multi-disciplinary way of calculating earthquake hazard, £1.1M to UoP (Mildon);
- GCRF 'A systems analysis approach to reduce plastic waste in Indonesian societies' with Brunel and other UK HEIs, £1M to UoP (Thompson co-lead with Austen in UoA14);
- EU Interreg, 'Investigating the movements of key fish species and their preferred habitats (FISH INTEL)', €4M international project led by UoP, £881k to UoP (Sheehan);
- NERC 'The 3D anatomy of magma transport at fast-spreading ocean ridges', £790k to UoP (Morris);
- Garfield Weston Foundation, for a further 2-year project investigating the oceanographic drivers of ecosystem variability in the BIOT, £500k to UoP (Hosegood);
- NERC Constructing a Digital Environment Programme, 'Smart SENSing of landscapes Undergoing hazardous hydrogeological Movement (SENSUN)', £400k to UoP (Manzella);
- NERC 'Lost at Sea - where are all the tyre particles?' £328k to UoP (Thompson).

Our approach to **research grant capture** is managed through robust grant preparation and support processes. Research ideas and grants are developed through strategic 5-year research planning, supported by annual *Personal Research Plans*. We support the development of cross-

research centre special interest groups, where research plans, ideas and grants can be openly formulated, discussed and developed. All external grant applications undergo rigorous internal peer review by nominated research specialists that includes financial scrutiny to ensure appropriateness of resources requested. Development of applications is supported by UoP's dedicated research advisors, with specialists across different funding sources who provide further peer-review and advice on financial and legal aspects of research.

b) Infrastructure and Facilities

Since REF2014, the use of new University facilities at the £4.65M waterfront *Marine Station* and £19M *Marine Building* have significantly enhanced research capabilities.

The *Marine Station* provides enhanced facilities for teaching and research, with ocean-view teaching rooms, a sector-leading diving facility, wet laboratory, aquaria, berths for vessels and equipment storage facilities to support boat-based activities. The range of vessels now includes a 14m catamaran '*RV Falcon Spirit*', a 13m sailing yacht '*Take the Helm*' (useful for marine mammal and other noise surveys), an 11m catamaran '*Wavedancer*', a 10m dive support vessel '*JoJo*' and three 6m powerboats. In addition, there is a growing fleet of Uncrewed Surface Vessels (USVs), including a new £250k C-worker 4m CETUS and in-house developed catamarans, configured for a variety of survey tasks.

The three-storey *Marine Building* houses the Marine Institute, *Plymouth Coastal Observatory (PCO)* and state-of-the-art *Coastal Ocean and Sediment Transport (COaST) wave tank facilities*, consisting of a 35m x 15.5m x 3m Ocean Wave Basin and a 15.5m x 10m x 0.5m Coastal Basin. The Ocean Basin builds on a growing research base in marine renewable energy, designing and testing wave and tidal energy devices. The Coastal Basin provides a physical model capability complementing Plymouth's internationally-recognised strengths in coastal field measurements. These facilities are heavily used, through the £1M ERDF *Marine-i* initiative, designed to help the local marine technology sector grow through research, development and innovation, and through the EU H2020 *Marinet2* project, whereby free access is provided to the COaST lab for researchers from across Europe through a series of competitive calls. A £605k wind generator is presently being added to facilitate applications such as the testing of offshore wind farm models.

Coastal and Ocean Science and Engineering Research Centre (COSE) research is underpinned by the development of new sensing systems (e.g. bed-level sensing, particle imaging) and sampling methodologies (e.g. fully-integrated coastal survey from aerial drones and USVs), supported by a team of internationally-leading technicians. This includes a '*Rapid Coastal Response Unit*' that is unique in the UK for measuring coastal impact during extreme storms. COSE has over £1M of coastal measurement equipment, including manned and unmanned aerial, terrestrial and marine survey platforms and a comprehensive pool of high-grade *in-situ* oceanographic instrumentation. COSE also hosts the UK's only operating two station HF radar installation for remote sensing of the coastal ocean. This is, globally, the only installation designed for collection of spatial information on directional wave statistics and provides hourly output (waves and surface currents) for a 40 x 40 km region at 1 km resolution, with data available on a public web site (<https://www.plymouth.ac.uk/research/hf-radar>). Complimenting COSE research, the *Plymouth Coastal Observatory (PCO)* routinely monitors waves, beach levels and coastal dynamics across the south-west region, providing a long-term data resource that is publicly-available via the National Coastal Monitoring Network's website.

In **Biogeochemistry Research Centre (BGC)**, the University has continued its strong track record of investment in analytical chemistry facilities through: (i) developing novel methods for industrial and environmental applications, and (ii) providing internationally-recognised, high quality trace analysis in ISO-certified research laboratories. Examples include new cutting-edge purchases (2014-2021) of inductively coupled plasma mass spectrometers, isotope mass spectrometers, liquid and gas chromatograph-mass spectrometers, and a dual-channel ion chromatograph. Investment in the ISO 9001:2015 certified *Consolidated Radio-Isotope Facility (CORiF)* since the last REF includes a wavelength dispersive x-ray fluorescence spectrometer

(WD XRF) used for geochemical analyses of materials such as soils, sediments and rock powders. This is used by a variety of internal (CRES, MBERC, BGC) and external users. The CORiF instrument suite also includes three state-of-the-art gamma spectrometers, two liquid scintillation counters and a laser granulometer. Purchase of a cutting-edge GC system for the measurement of volatile and greenhouse gases is planned for 2021, investing in an area (marine amine cycling) where Plymouth UoA7 is world-leading.

In **Marine Biology and Ecology Research Centre (MBERC)**, the Embryo Phenomics laboratory has been formed from a strategic internal investment (including HEIF funding) in hardware for the high-resolution bio-imaging of marine embryos. This led to a successful NERC bid to develop software for the automated extraction of data from video images and analysis of the phenome. The recent award of a UKRI Future Leaders Fellowship to MBERC's Tills is supporting the extension of this technology into various different industrial, biomedical and environmental applications, including via transfer of these technologies into the field for remote sensing of biological stress in the natural environment. HEIF POC funding supports the R&D of these technologies in collaboration with *Plymouth Science Park*, which is co-owned by the University and Plymouth City Council. Investment has also been made in MBERC via the International Marine Litter Unit's new laboratory (£160k for new Fourier transform infrared microscope and clean room).

In **Centre for Research in Earth Sciences (CRES)**, several successful NERC grants have demonstrated strength in palaeoclimate research and have facilitated University investment into the stable isotope mass spectrometry facilities, with the purchase of a new Thermo Scientific delta advantage IRMS instrument. This instrument set-up has greater capabilities, extending our capacity to measure sulphur isotopes in addition to oxygen, carbon and nitrogen isotopes and will enable a broader range of users to capitalise on this investment. In particular, stronger links with researchers in BGC working on organic compounds will be possible and post REF2021 this is an area of expected growth. CRES researchers regularly make use of School and Faculty level analytical facilities and have received in-kind funding for a range of NERC facilities (ion microprobe, stable isotopes, radiocarbon and cosmogenic isotopes).

CRES's Stewart is Director of the *Sustainable Earth Institute (SEI)* and leads the new 'Sustainability Hub and Impact Lab' facility. Supported by a £2.6M ERDF investment, this facility houses the SEI in a refurbished building that provides a physical space where businesses, social enterprises and community groups can mix with researchers and students around the issue of sustainability.

CRES's Stephen is Director of The *Plymouth Electron Microscopy Centre (PEMC)* which has continued to expand within this REF period, adding a Zeiss FIB-SEM via the £1M ERDF *Plymouth Materials Characterisation Project* in 2017. The instrument suite now comprises the FIB-SEM, two JEOL SEMs with EBSD, elemental analysis and cryo-capabilities and a JEOL TEM. Within CRES, the NERC research grant to Menegon has benefitted from these facilities. In March 2021 a further £1M ERDF investment was secured in PEMC allowing it to move to new facilities on the Plymouth campus, increasing both its size and capacity.

Specialist technical teams are an integral part of the Plymouth UoA7 research environment, looking after and operating the PEMC, COaST wave tank laboratories and Marine Station laboratories and vessels.

4. Collaboration and contribution to the research base, economy and society

International Collaboration

Our extensive international collaboration is evidenced by 65% of the papers published in the REF period having international co-authors, and these papers having over 18,000 citations and a field weighted citation score (FWCI) of 2.01, (SciVal, 27/01/2021). Examples of international collaborations in the four research centres are:

Biogeochemistry Research Centre (BGC)

BGC are leading a major international project that uses organic geochemical tracers to quantify the contribution of food sources to Arctic food webs and biogeochemical fluxes, collaborating with University of East Anglia, Alfred Wegener Institute, Russian Arctic & Antarctic Research Institute and University of Colorado in the €60M 'Multidisciplinary Drifting Observatory for the Study of Arctic Climate' (MOSAIC) project; this is the largest polar scientific expedition in history involving >500 scientists from >20 countries.

BGC are also leading the use of organic geochemical proxies for reconstruction of the sea ice history of the Antarctic spanning the entire quaternary period as part of International Ocean Drilling Program Expedition 382 (Iceberg Alley). BGC's ability to measure volatile amines at trace levels are at the core of international efforts to understand the ocean-air flux of biogenic trace gases and their role in climate regulation. This has comprised three research campaigns since 2015, including the first Antarctic Circumpolar Expedition completed in 2017.

Centre for Research in Earth Sciences (CRES)

CRES researchers are engaged in international collaboration and leadership at all levels within the International Ocean Discovery Program (IODP) and the International Continental Scientific Drilling Program (ICDP). Morris is working with IODP colleagues to develop the next IODP Science Plan 'Exploring Earth by Scientific Ocean Drilling' that will last until 2050. Since REF2014, CRES staff have participated in seven IODP expeditions and are actively involved with several ICDP projects, at proponent level (Anderson, COSC-2), with leadership roles within projects (Harris, OmanDP) and as members of these international science teams.

Coastal and Ocean Science and Engineering Research Centre (COSE)

COSE's research benefits from long-term international collaborations, particularly with colleagues in Australia, France, The Netherlands and New Zealand. A 20-year coastal research collaboration with University of New South Wales (UNSW, Australia) has produced 25 co-authored, high-impact, journal articles, supported by grants from NERC, EPSRC and the Australian Research Council. The Director of UNSW's Water Research Laboratory (Turner) holds a Visiting Professorship at UoP and there have been many reciprocal sabbatical visits between the groups.

COSE have a 15-year collaboration with University of Bordeaux studying rip currents and coastal change. Presently, that collaboration is leading a European hub of expertise in continental-scale coastal impact of extreme storms and coastal hazards (13 co-authored journal articles since 2016). In collaboration with scientists from University of Auckland (NZ), Simon Fraser University (Canada), US Geological Survey (USA) and Deltares (Netherlands), COSE are leading the 'Understanding Flooding On Reef-lined Island Coasts (UFORIC)' working group looking at the impacts of sea-level rise on low-lying coral reef environments, work that will have major impact for the future of island communities across the Pacific and Indian Oceans.

Marine Biology and Ecology Research Centre (MBERC)

MBERC's Howell is Co-Director of 'One Ocean Hub', a £20M project funded by UKRI GCRF (2019-2024), involving 22 research organisations from the UK, South Africa, Ghana, Namibia, Kenya, the South Pacific and the Caribbean. Howell is also Co-I on 'Mission Atlantic', a €10M EU H2020 project on the sustainable management of the Atlantic ecosystem (2020-2024), involving 34 partners from 15 countries, with UoP leading in the areas of deep-sea habitat mapping, artificial intelligence and autonomy.

In marine renewable energy, MBERC researchers are co-leading environmental monitoring with colleagues from Exeter and University of Uppsala (Sweden) to understand the ecological effects

of wave energy devices deployed by the Finnish developer Wello (EU H2020, *Clean Energy From Ocean Waves* project).

MBERC researchers are leading and co-leading many other projects with international colleagues, including:

- in South Africa, on the biodiversity and conservation of inland waters (Systematics Association and Newton Fund grants with Albany Museum/Rhodes University and University of Johannesburg);
- in Brazil, on the integrated internationalisation of knowledge production and training of human resources in marine and coastal biodiversity (Brazilian CAPES grant with Federal University of Santa Catarina);
- in China, on phytoplankton-zooplankton dynamics on warming acidified nutrient rich coasts (Chinese NSF grant with Xiamen University);
- in Sweden, on rhodochronology using coralline algae (Swedish FORMAS mobility grant with Gothenburg University) and,
- in Cyprus, to stem a lionfish invasion in the Mediterranean (EU LIFE Programme project, RELIONMED, with University of Cyprus).

Interdisciplinary research

Interdisciplinary research is extensive across the four UoA7 research centres, and with other disciplines (UoAs), some examples of which are:

- UoA7 physical oceanographers (e.g. Conley), with their expertise on waves and tides, routinely work with offshore engineers (e.g. Greaves, UoA12) in the design and testing of offshore renewable energy devices. Joint Conley/Greaves grants include EU-Interreg, '*Marine Energy in Far Peripheral and Island Communities (MERIFIC)*' and EU-FP7 '*Marine Renewables Infrastructure Network for Emerging Energy Technologies (MARINET)*.'
- In the H2020 €4.1M 4-year *LimnoPlast* project, UoA7 natural scientists (Thompson) and social scientists (Pahl, UoA4) are working with 13 academic and industry (Evonik and BASF) partners to take a holistic view of litter in freshwater systems, exploring the acceptability of potential solutions as well as the suitability of behaviour change options to reduce the flow of microplastics.
- Addressing society's need to discover new antibiotics, UoA7 ecologist (Howell) is leading the '*Deep-sea discovery - mining marine environments for novel biologics*' project, funded by the Society for Applied Microbiology, working with medical microbiologists (Upton, UoA3) to identify and develop potential new antimicrobials produced by deep sea sponges.

Collaboration with end users

Over the REF period 94 papers were co-authored with end users, representing 6.7% of our paper output, with a relatively high FWCI of 2.38, (SciVal, 27/01/2021).

For example, there are prominent industry collaborations between:

- BGC and *EDF Energy* on the characterisation of the porous space of Gilsocarbon graphite;
- CRES and *Lockheed-Martin/UK Seabed Resources* on critical material potential of deep sea polymetallic nodules, currently funding one PhD project in CRES;
- CRES and *Posiva OY* (the Finnish expert organisation in nuclear waste management) including Posiva currently funding one PhD project in CRES.

COSE's '*Coastal Marine Applied Research (CMAR)*' research-informed consultancy has a client base that is both international (Netherlands, France, New Zealand) and national (EA, National Trust, local councils, Natural England, CEFAS). COSE's '*Plymouth Ocean Forecasting Centre*' (Shapiro) led the £4M '*UAE Ocean*' project (2014-2020) using state-of-the-art modelling to deliver ocean forecasting capability for the United Arab Emirates.

Around half of our ~200 Masters research projects each year are carried out with external organisations (government bodies, NGOs and commercial companies), acting as a catalyst for developing joint research projects, strengthening existing links (e.g. with MBA and PML) and making new links (e.g. a wider research programme on lionfish under development with the Joint Nature Conservation Committee, JNCC).

Wider research environment

Plymouth UoA7 staff have made substantial contributions to the wider research environment and demonstrated leadership in the academic community. For example:

- Morris is: Chair of the European Consortium for Ocean Research Drilling Science Support and Advisory Committee (ESSAC) (IODP Program Member Office for Europe and Canada) (2018-2021); Chair of NERC UK-IODP Site Survey Initiative Panel (2015-Present); a member of the UK IODP Program Advisory Group (2015-Present); and member of the 'Instituting Scientific Drilling Beyond 2023' Science Plan Working Group.
- Hall-Spencer is Chair of the NERC National Facility for Scientific Diving Steering Committee and was elected as President of the British Phycological Society in 2018.
- Howell is a member of the NERC Marine Facilities Advisory Board (2018) and co-chair of the Deep Ocean Stewardship Initiative's working group on the Decade of Ocean Science (2018). Attrill is on the International Advisory Panel for the Institute of Oceanology Qingdao (China) and the Finland Academy Ecology grant panel.
- McQuatters-Gollop chairs the OSPAR group leading Europe's implementation of the Marine Strategy Framework Directive for pelagic habitats.
- Manzella Chairs the SW Regional Group of the Geological Society of London.

As well as contributing to the academic community through committees and working groups, Plymouth UoA7 staff engage with wider society through public lectures and outreach. COSE staff delivered over 50 outreach talks to schools, providing young people with an insight into how their coastlines are changing and how coastal communities may need to adapt in the future. CRES's Stephen recently launched *Lockdown Learn* to assist school teachers with remote learning, and its new website has already been accessed from over 23 countries, <https://sites.google.com/view/lockdown-learn/home>

Advice to Governments

Plymouth UoA7 staff have provided advice to Governments, including:

- Advice to House of Commons, DEFRA, Parliamentary and Scientific Committee and UK House of Commons Environmental Audit Committee on protecting oceans and plastic pollution (Thompson); Presentation of 'Science Advice for Policy by European Academies (SAPEA)' report on Microplastics (Washington DC, 2019) (Thompson);
- Advice to UK Government on ocean acidification, fisheries management and sustainable seas and submitting evidence to the Scottish Parliament on salmon farming (Hall-Spencer);
- Appointed as Scientific Advisor, Defra, Tranche 3 Marine Conservation Zones Evidence Panel, 2018, (Hall-Spencer);
- Plenary talks at the House of Commons on the "Blue Belt" plan for Plymouth Sound National Marine Park, 2018, (Attrill);
- Evidence to the government review on highly protected marine areas (Sheehan);
- Appointed to UN World Ocean Assessment team and as a Scientific Advisor on the UN IAEA Ocean Acidification working group (Hall-Spencer).

Awards

Some examples of personal awards to UoA7 staff are shown in Figure 5:

| Year Awarded | Award | Staff | Details |
|--------------|---|--|--|
| 2020 | Royal Society Fellow | Richard Thompson | Thompson also named as one of the world's Highly Cited Researchers for 2020 based on Clarivate list of publications that rank in the top 1% by citations. |
| 2020 | Jordan-UK Research Chair in Sustainability | Iain Stewart | Awarded by the British Academy and the Royal Scientific Society of Jordan. 4-yr 0.75 FTE secondment supported by the Newton Fund, started 1/1/2021. |
| 2020 | UKRI Future Leaders Fellowship Award | Zoe Mildon | £1.1M to UoP for a 4-year project combining geology, physics and computer science to generate a new multi-disciplinary way of calculating earthquake hazard. |
| 2020 | Geologists Association Halstead Award | Zoe Mildon | Awarded to ECRs, recognising Mildon 'as one of the rising stars of UK structural geology and earthquake hazard analysis'. |
| 2020 | UKRI Future Leaders Fellowship Award | Oliver Tills | £440k to UoP for a 7-year project developing an integrative approach to phenomics. Collaboration with British Antarctic Survey, Scymaris ecotoxicology consultancy, University of Leiden and Italian Institute of Marine Science. |
| 2019 | Queen's Anniversary Prize for Higher and Further | UoP | Awarded for the University's research and policy impact on microplastics pollution in the oceans. This follows on from the Queen's Anniversary Prize UoP received in 2012 for the breadth and excellence of its marine and maritime research and teaching. |
| 2019 | EU Horizon Impact Award | Louise Firth, Simon Rundle, Richard Thompson | Recognising 'the societal impact across Europe and beyond' of Plymouth's EU project ' <i>Innovative technologies for safer European coasts in a changing climate (THESEUS)</i> ', a collaboration between UoP ecologists and coastal engineers. |
| 2019 | Tech South-West Research Award | Mark Fitzsimons | Awarded to FABSOIL project, a collaboration between UoP and The Eden Project, showing how fabricated soils could help ensure future global food security. |
| 2018 | Two NERC impact awards , 'Societal Impact Award' and 'Overall Winner' | Richard Thompson | Awarded for the University's microplastics research, also named as one of the UK's 100 best university breakthroughs in a list compiled by Universities UK. |
| 2018 | The Geological Society of London RH Worth Award | Sarah Boulton | For the initiative "Girls into Geosciences" https://www.plymouth.ac.uk/news/girls-into-geoscience-wins-national-award-for-inspiring-female-scientists |
| 2018 | Officer of the Order of the British Empire (OBE) | Richard Thompson | For 'Services to Marine Science' |
| 2017 | The Zoological Society of London Marsh Award | Richard Thompson | For Marine and Freshwater Conservation. |
| 2014-2018 | Holds the UNESCO Chair in Geoscience and Society (from 2018 onwards) | Iain Stewart | Stewart was also elected Fellow of the Royal Society of Edinburgh (2017) and received the European Federation of Geoscientists Medal of Merit (2016) , the Royal Society of Edinburgh Senior Public Engagement Award (2015) , the American Association of Petroleum Geologists 'Geoscientists in the Media' Award (2014) and the ' Scientia Medal ' from UNSW Australia (2014). |

Figure 5: Examples of Personal Research Awards to Plymouth UoA7 staff during the REF2021 period.

Summary of other contributions

Plymouth UoA7 staff hold a number of **Visiting Professorships and Fellowships**. For example, Hall-Spencer is Adjunct Professor at Xiamen University and Research Professor at

Tsukuba University. Menegon was awarded a Guest Professorship at University of Vienna in 2015. McQuatters-Gollop is a Defra Senior Policy Fellow, a NERC Knowledge Exchange Fellow and holds a Japan Society for the Promotion of Science Invited Fellowship. Lenger is a Rubicon Fellow at University of Bristol, fully funded by the Netherlands Organisation for Scientific Research.

Over the current REF period, Plymouth UoA7 staff have delivered > 100 invited **keynote lectures** across the UK, Europe, North and South America, Pakistan, India and China including to the American Geophysical Union (San Francisco), British Antarctic Survey (Cambridge), Dorothy Hill Women in Earth Sciences Symposium (Brisbane), European Geophysical Union (Vienna), International Arctic Science Committee (Davos), Royal Society (London) and United Nations (Ecuador).

Plymouth UoA7 staff are journal **editors-in-chief** for *Geomorphology* (Stokes M), *Organic Geochemistry* (Rowland) and *Regional Studies in Marine Science* (Hall-Spencer), **associate editors** for *Marine Biodiversity Records* (Ciotti, McQuatters-Gollop), *Environmental Chemistry Letters* (Fitzsimons), *Marine Chemistry* (Turner) and *Continental Shelf Research* (Ussher) as well as contributing to numerous journal editorial boards. Ussher received a Certificate of Outstanding Contribution to Reviewing from *Continental Shelf Research*.

Plymouth UoA7 staff are NERC **peer review** college members (e.g. Fitzsimons, Grimes, Hall-Spencer, Howell, Stokes M) and contribute to NERC panels (e.g. Discovery Science Large Grant and Standard Grant, Industrial Case Award, Global Partnerships Seedcorn Fund, National Capability Services and Facilities Isotope and Radiocarbon Assessment). Hall-Spencer was an expert reviewer for the IPCC and the Arctic Monitoring and Assessment Programme (AMAP) assessment of ocean acidification in the Arctic. Spicer was an expert reviewer for the First Order Draft IPCC Special Report on the Ocean and Cryosphere in a changing climate (SROCC). Staff also carried out reviewing for the EU (e.g. FP7 SEAS-ERA, Marie Curie International Fellowships, Innovative Training Networks), Portuguese Science and Technology Foundation, Austrian Science Foundation, French National Research Agency, German-Israeli Foundation, Italian Ministry of University Education, Norwegian Research Council, the National funding councils in Australia (e.g. CSIRO), and in the USA (e.g. National Science Foundation, NOAA Sea Grants, National Undersea Research Centre).

Plymouth UoA 7 staff have been **external examiner for PhDs** at *UK Universities* (e.g. Aberdeen, Bangor, Bristol, Durham, Exeter, Heriot-Watt, Imperial College London, Leeds, Manchester, Queen Mary College, Royal Holloway, Sheffield, Southampton, St Andrews, York), *European Universities* (e.g. Brest, Cagliari, TU Denmark, Leuven, Lyon, Paris, Porto, Stockholm, Utrecht, ETH Zurich) and *Overseas Universities* (e.g. Adelaide Australia, Alberta USA, Andhra India, Hong Kong, Marrakech Morocco, Sydney Australia).