

Institution: University of Exeter
Unit of Assessment: 07 Earth Sciences
1. Unit context and structure, research and impact strategy OVERVIEW Unit of Assessment (UoA) 7 staff at the University of Exeter (UoE) conduct world-leading research across a broad spectrum of Earth and Environmental Sciences and in doing so deliver major societal impact by providing solutions to the challenges posed by global environmental change. Evidence of the breadth and depth of our research and impact include: - Launch of the transdisciplinary Global Systems Institute. - Over 1750 published outputs and 55,000 citations across the unit. - Major contributions to the Intergovernmental Panel on Climate Change and government advisory panels on hazardous substances, antimicrobial resistance and ocean acidification. - Development of strategic partnerships with Met Office and Plymouth Marine Laboratory. - #1 in Europe (11th in the world) for scientific impact in the Leiden Ranking (based on outputs in the top 10% of the field). - 128 ISI Highly Cited papers, and 12 Highly Cited authors. - Over £60m research funding awarded during the assessment period. The size of the UoA has more than doubled since REF2014 (35 FTE in REF2014 to 78 FTE in REF2021), illustrating the University's strong commitment to this crucial area of research. Research and impact quality have notably increased even faster than our research productivity. Research income per FTE has risen year-on-year and our published outputs are having far-reaching impact. The average number of citations per year has risen from under 3000 in the REF2014 cycle to over 8000 in 2020; and the number of Highly Cited outputs has more than doubled. To facilitate this success, during the period since REF2014, the University of Exeter has pursued a vigorous growth strategy in Earth and Environmental Sciences with major investment in staff, infrastructure and facilities. This strategic investment has been, and continues to be, a top priority for the UoE. A key part of this strategy is the newly launched Global System Institute, with the ambition to increase the quantity and quality of world-leading research and societal impact that can help steer our stewardship of the Earth system in an era of unprecedented environmental and societal change. The research presented here is connected to a broader activity of Environmental and Sustainability Research, which connects three of the campuses of the UoE (Streatham, Penryn, Truro), and its six colleges (Life and Environmental Sciences; Engineering, Mathematics and Physical Sciences; Medicine and Health; Business School; Social Sciences and International Studies; Humanities). This submission highlights the individuals and research groupings that are most closely focussed on the science agenda set out in the UoA7 descriptor, but the research presented is necessarily tightly connected to research which is also being submitted to other REF UoAs (see Fig. 1). RESEARCH STRUCTURE & ORGANISATION The structure of the UoA7 submission is presented schematically in Figure 1. The UoA7 research activity is divided between Earth System science (46.3 FTE) and Environmental sciences (32 FTE). Earth System science has an explicit focus on understanding the planet as a system and tackling global-scale challenges such as climate change. Environmental science focuses across scales organisms to ecosystems, including humans, and understanding their responses to, and effects on, environmental drivers, including global change.

Earth System science research divides into **Weather and Climate** (20.7 FTE) – with an emphasis on the physical aspects of the Earth's atmosphere and ocean; **Biogeochemical Cycles** (10.4 FTE) – emphasising the biological and chemical components of the Earth system; and **Earth Resources & Global Change** (15 FTE) – focusing on the challenges that society face in response to climate change and the transition to a more circular economy.

Environmental sciences research divides into **Ecosystems** (17 FTE) – focusing on ecosystems and the goods and services they provide; **Environmental Biology** (8 FTE) – focusing on the effects of environmental pollutants on organisms and the ecosystems they inhabit; and **Environment and Human Health** (7 FTE) – focusing on the interconnections between the health of both the environment and humans.

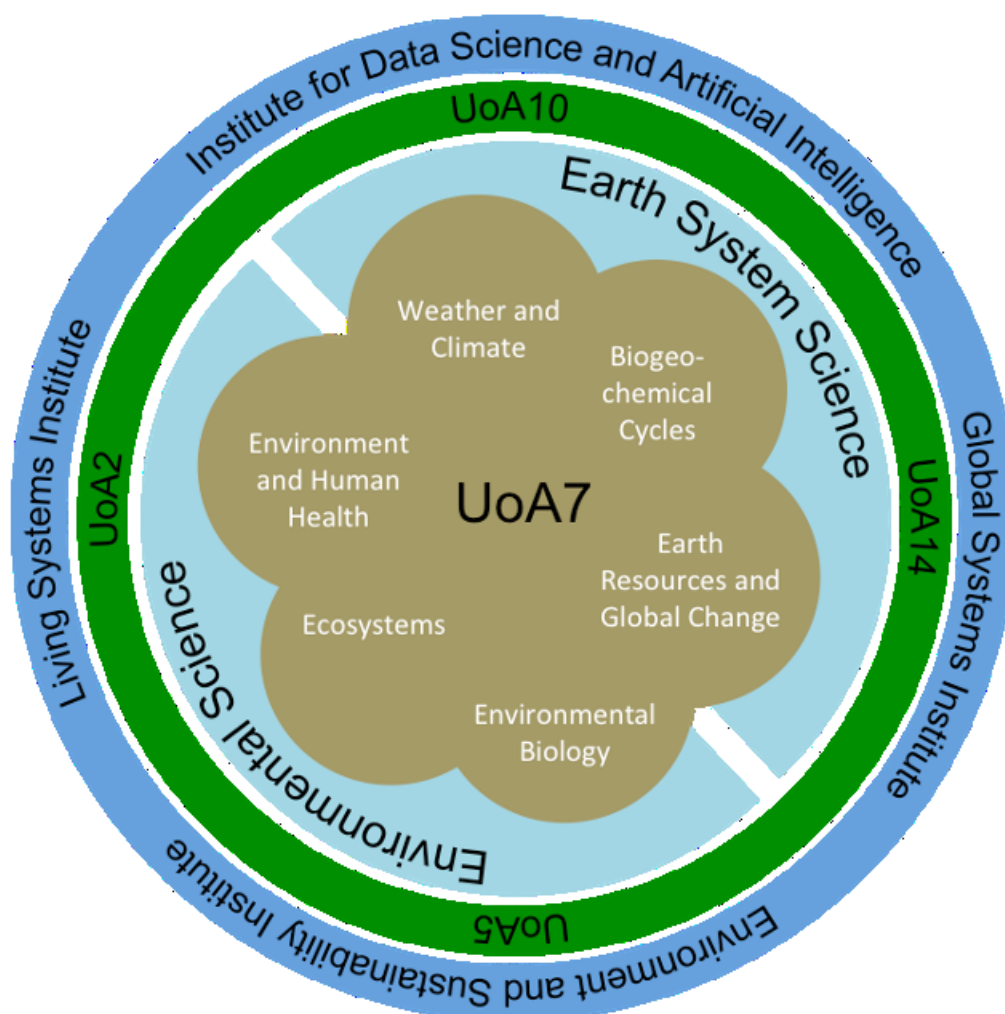


Figure 1: The six research themes of UoA7 (centre) are embedded within University-wide Institutes (blue outer ring), which submit to various UoAs (green ring).

Earth System science research

Weather and Climate (Baldwin, Beare, Betts, Boers, Bradshaw, Browse, Catto, Chadburn, Chadwick, Collins, Cox, Friedlingstein, Harper, Haywood, Jupp, Lambert, Manners, McNeal, Partridge, Robinson, Scaife, Screen, Seviour, Sheen, Stott, Thomson, Unger, Webster, Williams, Williamson, Wiltshire) – centres on modelling of the climate system, and quantifying and reducing uncertainties in climate projections. This group is based within Mathematics in order to maximise the pull-through of mathematics and statistics into the improvement of climate models. Expertise in this group spans the understanding and modelling of most of the major uncertainties in the response of the climate system to anthropogenic forcing: clouds and water vapour, carbon cycle, aerosols, sea ice, land surface, stratosphere. In addition, this group is committed to quantifying the

overall uncertainties in climate projections through probabilistic climate projections and reducing these uncertainties through the application of statistical emulation methods and data-assimilation. This group is primarily based within the college of Engineering, Maths and Physical Sciences at the Streatham campus, many of whom are founding members of the Global Systems Institute.

Biogeochemical Cycles (Belcher, Brewin, Dyke, Halloran, Lenton, Mercure, Messias, Rowland, Schuster, Shutler, Watson) – focuses on the understanding, measurement and modelling of interactions between biogeochemical cycles and climate, across a broad range of timescales and epochs. Particular areas of expertise include the ocean carbon and nutrient cycles, marine ecology, forest fires, and the co-evolution of life and environment. This group is primarily based within the college of Life and Environmental Science at the Streatham campus, and has strong links to the Weather and Climate group through common interests in climate-carbon feedbacks and climate tipping points.

Earth Resources and Global Change (Andersen, Bailey, Broom-Fendley, Hesselbo, Hickey, Hudson-Edwards, Hughes, Kender, Littler, Moore, Newsome, Shail, Ullmann, Wall, Williamson) – focuses on the challenges that society face in response to climate change and the transition to a more circular economy. Major areas of research include the security of supply of critical raw materials (such as the rare-earth elements, platinum, indium, lithium and cobalt) needed for the transformation of our energy infrastructure away from fossil fuels, how deep geothermal heat can be harvested, how the Earth's environments respond to climate change, and how society will need to respond to natural hazards caused by increased weathering, erosion and environmental degradation, and from volcanic eruptions. The group is based on the Penryn Campus with members residing within the Camborne School of Mines and the Environment and Sustainability Institute.

Environmental sciences research

Ecosystems (Bearhop, Chapman, Cresswell, Early, Gaston, Godley, Hawkes, Hodgson, Kaiser-Bunbury, Maclean, Osbourne, Razgour, Thurston, Van Groenigan, Van Veen, Witt, Yvon-Durocher) – focuses on understanding the impacts of environmental change and land management on the goods and services provided by the Earth's ecosystems. The group uses a multifaceted approach, combining field, laboratory, and modelling studies, which integrate with the work of engineers, mathematicians and social scientists. Studies are carried out in many ecosystem types from the ocean, to farmland and industrial mining sites, and for a range of taxa and systems including microbes, plants and biogeochemical cycles, insects, agri-environment and pollination services, marine vertebrates, fisheries, birds, and climate change. This group is based both on the Penryn and Streatham campuses, with a large proportion of staff co-located in the Environment and Sustainability Institute.

Environmental Biology (Galloway, Hawkins, Lewis, Roberts, Santos, Simpson, Stevens, Tyler) – studies the interactive effects of aquatic organisms and ecosystems with environmental contaminants and other anthropogenic stressors. Key areas of research focus on understanding the mechanisms of action and physiological adaptations of aquatic organisms to pollutants (including endocrine disrupting chemicals, pharmaceuticals, microplastics and nanomaterials) and other environmental stressors and the broader implications for ecosystem functions. Methodologies include in vitro and in vivo experimentation (including genome wide sequencing and transgenic fish models) and field studies of unique habitats and degraded environments across the globe. Research into the basic biology of test and sentinel organisms underpins all of the ecotoxicology work and is enhanced by complementary bioimaging techniques within the Living Systems Institute. This group is based within Biosciences on the Streatham campus.

Environment and Human Health (Fleming, Gaze, Leonard, Morrissey, Murray, Taylor, Vos) – carries-out transdisciplinary research into the interconnections between environmental change, human health and wellbeing. Particular areas of expertise include the benefits to human health and wellbeing from interacting with the natural environment, and the evolution and ecology of antibiotic resistance in natural and farmed environments and subsequent transmission to humans. The influences and interconnections of climate and other environmental change and demographic change are key features of this research. The group is based within a larger interdisciplinary

research community at the European Centre for Environment and Human Health and is part of the College of Medicine and Health.

Institutional Structure and Integration

Interdisciplinary Institutes – UoA7 staff sit within several interdisciplinary institutes and research centres across the UoE's three campuses, including the newly launched Global Systems Institute, the Environment and Sustainability Institute, Living Systems Institute and the Institute for Data Science and Artificial Intelligence. The Global Systems Institute is a trans-disciplinary institute with a focus on modelling of complex human-environment systems, based on the Streatham campus in Exeter. The Environment and Sustainability Institute is an interdisciplinary centre leading cutting-edge research into solutions to problems of environmental change, based on the Penryn Campus in Cornwall. The Living Systems Institute, on the Streatham campus, merges research in biology and medicine with ground-breaking physical sciences technologies and powerful mathematical modelling capabilities to pioneer transformative science to engineer control of complex biological systems. The Institute for Data Science and Artificial Intelligence provides a hub for data-intensive science and artificial intelligence activity within the UoE and the wider region.

Since REF2014, the UoE has made major investment in strengthening its existing interdisciplinary research institutes (namely, the Environment and Sustainability Institute) and adding new ones in key areas for strategic growth (namely, the Living Systems Institute, Global Systems Institute and the Institute for Data Science and Artificial Intelligence). These institutes provide flexible co-location for staff from diverse disciplinary backgrounds across our six traditional colleges, to tackle major global challenges from antimicrobial resistance to poverty alleviation and sustainability. Co-locating staff from diverse disciplinary backgrounds has been a huge driver of the vigour and vitality in the research culture of UoA7 and represents a major commitment from the UoE to facilitate ground-breaking interdisciplinary research. Indeed, this institute model has facilitated a sense of trust and shared purpose among staff to enable them to embark on deeper, more fundamental, more risky activities, through working together. Whilst many of the institutes are still very young and it is still too early to assess the impact of this unconventional model, the Environment and Sustainability Institute is the longest running of the institutes, established in 2012 and had its first external review in 2016 carried out by the late Dame Prof. Georgina Mace, who stated the *“already there seems to be evidence of innovative products and projects emerging from this approach”*.

Cross-campus integration – To ensure integration of Earth and Environmental science research across our campuses and institutes several university-wide activities have been created to foster collaboration and a collective community ethos. For example, the Centre for Resilience in Environment, Water and Waste brings together academics from Geography, Biosciences, Engineering, Economics, Medicine/Health, and Psychology, who work with partners in industry, government and NGOs, to develop a shared understanding of the issue related to sustainable water services and water security. Exeter Marine brings together world-leading researchers committed to understanding all aspects of the marine environment, and through partnerships with industry, policymakers and conservation agencies, delivers innovative solutions to real world problems. We also have annual (or biannual) research strategy retreats, which are attended by the majority of UoA7 staff. Faculty from the different campuses also contribute to one another's local seminar series, and these are invariably associated with research discussion and associated social events. Cross campus interactions are also leveraged for fellowship and grant preparation, encouraging embedded internal review and playing an important role in interview preparation, a factor reflected both in our ERC and fellowship application success (see Section 3).

Strategic partnerships – Integration of UoA7 activity also benefits from strategic partnerships with leading UK research institutes and international Universities. The UoE is part of the Met Office Academic Partnership and UoA7 researchers are engaged in around 80 joint projects, with an estimated total value of £18m, including studentships and research projects. Collaboration between UoE and Met Office has been strengthened since 2014 through the creation of 10 new joint Global Systems Institute-Met Office positions, and in 2020 has been further strengthened with the formation of the Joint Centre for Excellence in Environmental Intelligence, which is part of the Institute for Data Science and Artificial Intelligence. The Joint Centre will provide a hub for cutting-

edge research and training that builds on the existing strengths of both centres and is intended to spearhead the development of Environmental Intelligence and promote the UK as a global trailblazer in this new field.

Strategic collaboration between UoE and Plymouth Marine Laboratory has resulted in research funding of nearly £3m and led to flagship research and impact on marine microplastic pollution (see Section 4). The UoE has worked with the Centre for Environment, Fisheries and Aquaculture Science on a number of environmental research projects, including on pollutants and pathogens relevant to environmental and human health, and climate change (see Section 4). The organisations have formed a strategic alliance to support joint research projects and studentships as part of the Great Western Four+ Doctoral Training Partnership. Significant collaboration also occurs with the UK Centre for Ecology and Hydrology with > £2m in recent funding, and multiple joint PhD projects, on the environmental dimension of anti-microbial resistance. The UoE and University of Queensland have partnered to establish the QUEx Institute, a new multi-million-pound partnership designed to bolster their joint global research impact, with Environmental Sustainability being a crucial theme. ENSURE is a £1.9m joint research centre established by Chinese University of Hong Kong and the UoE in 2018, with a mission to embark on large-scale inter-disciplinary collaboration designed to provide sustainable solutions to today's most important environmental threats including climate change, air and water pollution, the environmental dimension of anti-microbial resistance and biodiversity loss.

RESEARCH STRATEGY

Summary

The UoA7 research strategy described here forms part of broader strategy for investment by the UoE in 'Environmental and Sustainability' research. Our working definition of environmental and sustainability research is that it is truly transdisciplinary, spanning the natural and social sciences, medicine, humanities and arts, with a shared focus on the core challenge of achieving a sustainable future for humanity on Earth. Such diverse research activity is built on a solid scientific core of understanding environmental systems. This UoA7 submission covers the scientific core of environmental and sustainability research at the UoE.

Achieving our 2014 Strategy

The key strategic aims during the assessment period were to strengthen the core UoA7 scientific component of Earth and Environmental science research at UoE, and to increase our standing among UK Universities delivering world-leading research in Earth and Environmental science. More specifically, we aimed to increase our critical mass in alignment with our existing research strengths, and to build on our strategic partnerships with the Met Office and Plymouth Marine Laboratory, amongst others.

Our rate of growth over the current REF cycle has far surpassed expectations, with a more than doubling of size of the UoA (35 FTE in REF2014 to 78 FTE in REF2021). This growth has occurred across all research areas. Increases in markers of research quality have notably increased even faster than our research power. For example, income per FTE has increased from £97K in 2014/15 to £133K in 2018/19 (up 17%); citations per year per FTE have increased from 82 to 110 (up 34%); and PGR completions per FTE have increased from 0.17 to 0.35 over the same time periods (up 106%). Notably, Life and Environmental Science at the UoE was ranked #1 in Europe, and #11 in the world in the Leiden Rankings based on the proportion of outputs that are top 10% in the field, underscoring the world leading nature of our research in Earth and Environmental Sciences.

In July 2019, the Global Systems Institute was launched. The Global Systems Institute is a trans-disciplinary institute with a focus on modelling of complex human-environment systems to better predict global changes through understanding the interactions between the climate, natural ecosystems, social and economic systems, and the built environment. The Global Systems Institute aims to become a 'go to' place for global change researchers from around the world, bringing them together with industry, policymakers, students and other stakeholders to tackle shared problems, and acting as a catalyst that enables translation of this research into applications

that deliver tangible and sustainable social and ecological benefit. The institute currently includes 44 staff from across the Weather & Climate and Biogeochemical Cycles groups along with physicists, social scientists and biologists from across the UoE. The UoE has invested in recruiting 10 FTE new academic staff to join the Global Systems Institute and form an integral part of the UoA7 submission.

Collaboration between UoE and Met Office has been strengthened since 2014 through the creation of 10 new joint UoE-Met Office positions at Lecturer and Senior Lecturer level, in addition to the existing 5 joint positions at Professorial level. Eight Met Office scientists have completed PhDs or Masters degrees at Exeter. UoE-Met Office collaboration is also central to the 3rd UK Climate Change Risk Assessment, a major collaborative project led by Prof. Richard Betts (joint UoE-Met Office chair), which will directly inform UK government policy under the Climate Change Act. Strategic collaboration between UoE and Plymouth Marine Laboratory, part of the new Exeter Marine initiative, has resulted in research funding of over £3m and contributed to significant research and impact on marine microplastic pollution. The UoE has worked with the Centre for Environment, Fisheries and Aquaculture Science on a number of environmental research projects, including on pathogens relevant to environmental human health and climate change, and renewal of a collaboration agreement which will help support a further 8 jointly funded PhDs.

Impact Strategy

Our strategic approach to impact is to engage strongly with the communities we serve locally, nationally, across the world, and in the digital realm, to enable our research to fully benefit society. We have embedded an entrepreneurial and enterprising culture in our transdisciplinary institutes and initiatives and aim to foster close collaboration and partnership with industry, policy makers, practitioner networks, grass roots groups, and citizens to co-create evidence-based solutions to global problems. Researchers are supported by a dedicated impact, innovation and business team who help foster these links.

Support and training to encourage impactful research includes cross-disciplinary and early-career workshops, policy reading groups and themed away days; for example, around complexity science and systems of decision making. We have successfully established knowledge exchange fellowships in key areas, including our work on antimicrobial resistance (Gaze) and human health and wellbeing (Fleming).

This impact strategy is augmented by key exemplars of impact that provide a template and inspiration for others, such as in the areas of international and national policy on climate change (Lenton), marine plastics (Galloway), design and implementation of marine protected areas (Godley), aerosol detection and aviation policy in the face of major volcanic eruptions (Haywood), policy, regulation and practice in understanding and managing risk associated with the environmental dimension of antimicrobial resistance (Gaze), and the importance for human health and wellbeing of equal access to high quality natural environments (Fleming). UoA7 academics have also generated major societal impact by improving ocean literacy in the classroom (Lewis), through contributions to the Lancet Countdown on health and climate change (Cox), and through early-stage interventions on mining projects to ensure a responsible supply of essential rare earth elements for green technologies (Wall).

Research and Impact Strategy Post 2020

Global Systems Institute – The growth and development of the Global Systems Institute remains a strategic focus for UoA7 and the UoE as a whole. We aspire to recruit a further 27 FTE by 2024, across all career levels, and to rapidly increase post-graduate research student intake to above 15 per annum from 2022. In addition, the expansion strategy includes recruitment of 5 Research Fellows and 8 FTE for Professional Service staff to enable and support the full societal impact of our research.

Exeter Marine (<http://www.exeter.ac.uk/research/marine/>) – Brings together over 130 principal investigators (40 in UoA7) across our 3 campuses that carry out research on the marine environment, including 11 of ISI Highly Cited researchers in UoA7 (Bearhop, Collins, Fleming, Galloway, Gaston, Godley, Lenton, Roberts, Screen, Tyler, Watson). Marine research, drawing

upon the humanities, physical, social and natural sciences, is a key area for future strategic growth at UoE, building on our existing strengths in this area, and recognising the critical importance of marine environments and ecosystems for planetary functioning and human wellbeing. We will appointment at least 3 new faculty before 2022, with the aim of further increasing research integration within this area. Specific areas include: Fisheries management and conservation and mechanisms underpinning climate change. New areas include the Global Challenges Research Fund Blue Communities Project in Southeast Asia (<https://www.blue-communities.org/Home>) and the growing area of ocean(s) and human health (<https://sophie2020.eu>).

Environmental microbiology – Microbiologists based at the Environment and Sustainability Institute form an integrated team of internationally distinguished scientists who deliver some of the UoE's most impactful and high-profile research into solutions to problems of environmental change. This includes research into the evolution and transmission of anti-microbial resistance in the environment, the evolutionary and ecological responses to global warming, the bioremediation of heavy metal contaminated areas in the environment, and the optimization of microbial fermentations for biogas production. Microbiology research is a major driver of research excellence on the Penryn campus, and delivers around 7% of the UoE's research income from just 10 PIs. Expansion of the pan-college Microbiology research group is a key strategic priority for the UoE over the next REF-cycle, turning the UoE into a global centre of excellence in environmental microbiology. We will develop our expertise in innovative applied microbiology by new targeted investment of ca. £10m to the construction of a new, state-of-the-art laboratory to provide laboratory space for an additional 50 microbiologists, including the appointment of two chairs.

Environmental Intelligence – The increasing availability of large and complex data sets from diverse sources, including environmental monitoring, satellite remote sensing, climate modelling, electronic medical records, social media, and contributions from citizen science, presents and exceptional opportunity to transform our understanding of both the effects of environmental change and our planet-transforming power. The application of Data Science and AI to understand the complex interactions between the environment, climate, natural ecosystems, human social and economic systems, and health is a growth area at UoE. The UKRI-funded Centre for Doctoral Training in 'Environmental Intelligence: Data Science & AI for Sustainable Futures', which will fund 50+ PhDs between now and 2025; and the new Institute for Data Science and Artificial Intelligence will be key stimuli for broader activity in this area. The Institute for Data Science and Artificial Intelligence will work closely with the Global Systems Institute.

Open Research and Research Integrity

Our institutional approach to Open Research and Research Integrity is detailed in the Institutional-Level Environment Statement, including the investment in Open Research Exeter, the UoE's online repository for storing and providing access to research outputs. Within UoA7 we ensure there is an understanding of the San Francisco Declaration of Research Assessment (DORA) and open research compliance through our weekly staff announcements and the regular discussion forums, described in Section 2, as well as during Staff and Student Personal Development Reviews. There is mandatory online training in research integrity for all research staff. We have dedicated ethics officers at both the Streatham and Penryn campuses - academics who are well informed of all the UoE ethics policies and who are able to advise on any issue relating to research integrity and ethics of working with animals and humans.

2. People

The UoE is committed to the Researcher Development Concordat to support the career development of researchers and is accredited under the European Human Resources Excellence in Research Award. The concordat sets out a framework of working practices, roles and responsibilities to attract and sustain research careers in the UK, ensuring the continued provision of well-trained, talented and motivated researchers that is essential to the continuation of research excellence. UoA7 brings together a diverse constellation of researchers from multiple departments across our 3 campuses. Our strategy for supporting the career development of our researchers is

guided by the UoE's Concordat, allowing for the organic development of local-scale initiatives tailored to the needs of individual departments.

Staffing overview

To contextualise this section, our current staff profile for permanent Education and Research academic staff, and the gender and career stage distributions of our outputs are as follows.

Grade	Total	Male	Female
Professor	27	20	7
Asc. Professor	14	10	4
Senior Lecturer	28	16	12
Lecturer	14	7	7

Table 1: Staff totals in UoA7 by gender and career stage.

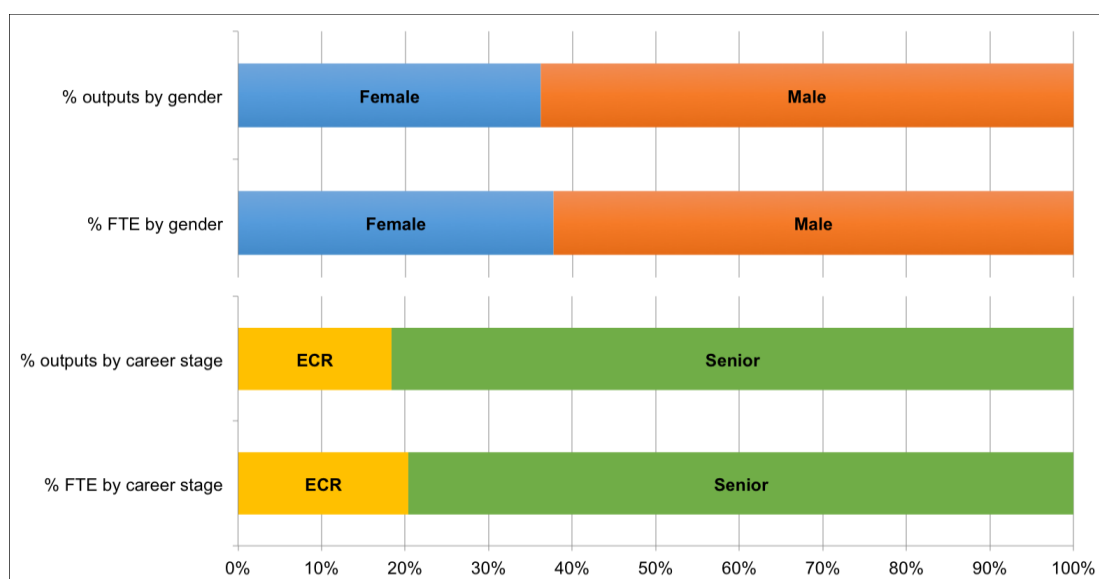


Figure 2: The gender (including nonbinary) and career stage distributions of UoA7 staff and outputs. Figures given as % of all FTEs returned to the unit. Early-career researchers (ECR) are here defined as Lecturers; senior researchers are here defined as Senior Lecturers, Associate Professors and Professors.

Recruitment & retention

Our strategy for staff recruitment and retention has been a major component of our overarching goal to deliver a greater quantity of world leading research outputs in our key priority areas (see Section 1). Since 2014, we have more than doubled in size from 35 to 78 FTE, recruiting and developing a large number of outstanding research-intensive staff at both junior and senior levels, aligned within our areas of strength. The implementation of our staffing strategy has allowed us to radically increase our research outputs both in terms of quantity and quality, to increase our income and our research student base. Nevertheless, our staff and output profile (Fig. 2) highlights a clear gender and career stage imbalance, with a greater proportion of our staff and outputs coming from senior males. Mindful of this imbalance, we have adopted a recruitment and professional development strategy that takes great care to consider gender, career stage, experience and expertise in making new hires and internal promotions (see section below on equality and diversity). Progress to this end has been made and is reflected in the near 50:50 gender balance at Lecturer and Senior Lecturer levels, where we have focused the overwhelming majority of our recruitment; but more work is clearly needed. It is our ongoing aim to ensure that this equitable gender balance is reinforced across all career stages as staff develop their careers at the UoE.

Our PhD students are the drivers of a buoyant research community and thus, recruitment and training of postgraduate research students is of crucial importance for the health and sustainability

of UoA7. We have increased core funding for PhD students in line with the increasing number of active research staff in UoA7. Annual PhD intake into UoA7 has been increasing year-on-year, in line with our increasing FTE and remains stable at around 2 students per FTE on average. We continue to recruit excellent applicants from home and overseas, in particular through our Centres for Doctoral Training and Doctoral Training Partnerships, which are highly competitive and attract the strongest students. In this REF cycle, the UoE was part of consortiums that won the NERC Centre for Doctoral Training in Freshwater Bioscience and Sustainability, and the UKRI Centre for Doctoral Training in Environmental Intelligence: Data Science & AI for Sustainable Futures. Together these Centres for Doctoral Training have funded 36 PhD students up to 2020, many of whom are supervised by UoA7 staff. UoA7 has also been very successful in securing PhD studentships through UoE's Doctoral Training Partnerships (NERC-GW4+, SWBio-BBSRC, MRC-GW4+, EPSRC). A high percentage of UoA7 PhD studentships have industrial or stakeholder partners, with CASE support from Department for Food and Rural Affairs, the Environment Agency, Centre for Environment Fisheries and Aquaculture Sciences, Plymouth Marine Laboratory, Met Office, Syngenta, Natural England and AstraZeneca. International partnerships with the University of Queensland, and with the Chinese Scholarship Council have enabled recruitment of exceptional international students, for whom funding is not typically available under UKRI schemes.

Support & career development

Academic Staff – All academic staff are allocated to an *Academic Lead* who is a senior academic working in a related research area and provides bespoke 1:1 mentorship throughout their career development. Through the system of Academic Leads, each research group has representatives on the College-level Management Group. We aim to provide a stimulating and supportive research environment allowing all colleagues to flourish, supporting international collaboration at every career stage, and encouraging interdisciplinary research. We have an extensive career development support system, which includes an annual review exercise that enables us to be flexible in the allocation of time and resources, and to ensure that our staff are able to maximise the quality and impact of their research outputs. The University operates a 3-year induction and probationary process for academic Lecturer appointments, during which appropriate research goals for each appointee are specified. At the end of a successful probationary period (which may be accelerated by early achievement of goals), the expectation is that staff are promoted to Senior Lecturer grade. New academics are assigned to an Academic Lead who offers guidance and support from the outset. Annual Personal Development Reviews monitor and assist with progress. As part of their induction, new academics are encouraged to gain experience of supervising a PhD student within the first two years of appointment, as first or second supervisor. This aspiration has been achieved through access to a wide range of sources for studentship funding. New academics are encouraged to apply for appropriate EPSRC, NERC, BBSRC and CASE studentship funding as appropriate, and they are supported in this by their Director of Research, Research Administrators, and by their Academic Lead. Expected targets for research income are set. In the grant application process, all applications are first seen at an early stage and then receive close support in their development to full proposals with the required pilot data. A Strategic Research Fund has been established that is used to pump-prime research projects, enabling time allocation to allow completion on key pieces of research/papers, and to support new researchers in obtaining vital 'middle tier' equipment for their research.

The success of the Academic Lead structure to mentorship is evidenced by a large increase in rates of Academic Promotions during this REF Census Period:

- Lecturer to Senior Lecturer: 14 (**Hawkes, Jupp, Taylor, Vos, Moore, Halloran, Littler, Bailey, Early, Sheen, Hickey, Catto, Hughes, Kender**)
- Senior Lecturer to Associate Professor: 11 (**Santos, Witt, Williamson, Beare, Lewis, MacLean, Lambert, Screen, Shutler, Morrissey, Andersen**)
- Associate Professor to Professor: 8 (**Hodgson, Wall, Van Veen, Gaze, Belcher, Yvon-Durocher, Simpson, Unger**)

A further testament to the success of our mentoring is evidenced by the high number of staff members with independent fellowships, the vast majority of which have been won by existing, often ECR staff with the help of our mentoring programme. These include a European Research Council Advanced Grant (Cox) and Starting Grant (Yvon-Durocher); 3 NERC Independent Research Fellowships (Broom-Fendley, Chadburn, Rowland); 2 NERC Industrial Innovation Fellowships (Leonard, Murray) and an EPSRC Living with Environmental Change Fellowship (Harper). In many cases, those who have been awarded long-term fellowships during the census period because of their excellent research performance have also been offered permanent positions at the end of their fellowship (Chadburn, Rowland, Harper).

Our Post-Doctoral Research Fellows (PDRFs) form a large and diverse research community in Earth Sciences. Whilst these staff roles are non-permanent, and reliant on externally funded grants (obtained by permanent staff), we do a lot to support our PDRFs in submitting fellowship applications and grant proposals. As part of this training towards research independence, PDRFs are mentored by a permanent academic staff member. We offer support in the form of reviewing documents, costings and training for interviews (usually using an excellent external consultant). This career support for PDRF's includes a very comprehensive Research Development Manager (RDM) facilitation of fellowship clinics through our ECR network, guidance on eligibility, liaising with directors of research and academic leads. Our support structures for PDRFs provides excellent career trajectory options for these non-permanent ECRs. We find that a significant number of research fellows at the PDRF level develop independence and obtain permanent positions as proleptic lecturers and/or open-ended research contracts (see evidence above).

We have also invested heavily in new and existing buildings to ensure that our working environment facilitates trans-disciplinary collaboration. Our aim has been to develop a friendly, collaborative and supportive environment with fair and transparent governance in which leadership roles (e.g., Heads of Departments, Directors of Research and Education) alternate on a 3-year cycle. The implementation of our staffing strategy has allowed us to radically increase our research outputs both in terms of quantity and quality, to increase our income and our research student base, whilst simultaneously maintaining a happy, healthy and supportive working environment.

Postgraduate Research Students – First year PhD students must undertake a programme of attendance and assessment consisting of at least 100 hours of advanced PhD training modules, associated with taught masters-level programmes (e.g., MSci – climate science). These compulsory modules provide training in world-leading methods including advanced modelling, statistics, computing, sequencing, imaging, and so on. Students are also encouraged to attend relevant external courses and workshops.

Exeter uses the Research Councils and the Quality Assurance Agency interpretation of transferable skills to provide training in research management, personal effectiveness, communication skills, networking, team working, and career management (<http://as.exeter.ac.uk/support/development/researchstudents/>). In addition to formalised Generic Skills training, UoE also provides employability skills training to equip postgraduates with the necessary skills, knowledge and training to enter academic or industrial research careers.

Students develop a learning agreement and plan with their supervisor, and all meetings are documented and signed off through an electronic 'myPGR' system. Students undergo a formal monitoring process, which varies somewhat between departments. For example, students get assessed at 6 months through a written report and viva by two academics independent to the PhD. They then have a full report (part of this can be as a research paper) and a viva at 18 months before they can progress to register for a PhD. All PhDs are now funded for 3.5 years and some (e.g., SwBio BBSRC DTP) are fully funded for 4 years. More generally, first year monitoring includes a report, presentation to a small group of academic staff, a viva, and a review of formal training undertaken - only those students who are making progress and have clear objectives on entering their second year are permitted to continue. PhD students must give at least one research seminar during the first two years of their degree and are actively encouraged and funded to participate in relevant international and national research conferences and workshops. Our students are encouraged to write their thesis chapters wherever possible as research papers,

further developing their skills in scientific writing and helping to ensure they have the currency they need (i.e., papers) when they graduate.

The Colleges have separate Directors of Postgraduate and of Postdoctoral Research, who champion all aspects of infrastructure and career development for postgraduates and research fellows. The UoE's Impact, Innovation and Business, and Research Services departments provide support and guidance to those involved in all forms of research and consultation, from providing contacts, negotiating contracts and intellectual property agreements, to an annual "impact award" that aims to promote excellence in impact and innovation as well as in research.

Diversity & equality

A strong commitment to Equality, Diversity & Inclusivity (EDI) underpins all research and impact activities in Earth Systems and Environmental Science at the UoE. Indeed, EDI training is accessible via the central Researcher Development programme and is part of the mandatory training for new PGRs and research staff. In this REF period, initiatives and policies emerging from our EDI work have shaped many of the staffing strategies, actions and successes discussed in preceding sections. For example, we have provided funding for non-routine care costs, virtual connections to many of our key events, and we ensure that staff and speaker selection is reviewed for diversity amongst protected characteristics via confidential EDI monitoring forms. We take a complementary and well-balanced approach to leadership that is considerate of gender, career stage, experience and expertise. Consistent with the UoE's own REF Code of Practice, all staff in senior management roles, including those involved in REF output selections receive training in Unconscious Bias and how it can influence decision making. Each of our institutes and centres have EDI committees which includes Heads of Department (HoD), Directors of Research, Directors of Education and representatives from post-doctoral, postgraduate and undergraduate communities. The Director of EDI is a senior role, reporting direct to HoD and to College-level EDI committees.

The strength and robustness of our approach to EDI issues is evidenced by our success in Athena SWAN. All the component departments/divisions of UoA7 hold Athena SWAN Bronze Awards, with many achieving Silver Awards (Geography, Mathematics and Computer Science, Bioscience Cornwall, College of Medicine & Health).

Athena SWAN has a primary focus upon gender and career-stage but has also provided an effective springboard for our EDI work more widely (e.g., with respect to race, religion/belief, disability, sexual orientation). EDI considerations are thus systematically embedded within all our recruitment, career-development and promotions processes. All staff involved in academic recruitment (from PGR to Professorial level) are required to have undertaken and passed mandatory EDI training, with training refreshed every two years. All interview and promotion panels in the Colleges are gender balanced. We have recently introduced, sector-leading policies to support Shared Parental Leave. There is no qualifying length of service requirement for Shared Parental Leave or University Shared Parental Pay. We are also fully committed to considering flexibility in working arrangement, and staff with caring responsibilities are entitled to make flexible working requests, to reduce both fractions and available working hours.

Our approach to EDI recognises the need for ongoing critical reflection and continuous improvements to our policies and practices. Our applications for Athena SWAN Silver re-accreditation in 2020 and 2021 will provide one mechanism to achieve this.

Recognition & value

The UoE rewards staff for going "Above and Beyond" in their roles. The Above and Beyond awards range from "thank you" notes, through small financial awards, to Silver (£1k) and Gold (10% of salary) awards. A total of 150 awards have been made since the inception of the scheme in 2015. Heads of Departments hold budgets for small awards. Silver and Gold awards are recommended by Heads of Departments and decided annually at College level.

Associate Deans of Education, Research or International Development, acting for the College, receive bonuses linked to achievement of targets that are reviewed annually. Heads of Department and members of relevant Learned Societies regularly nominate faculty, early career researchers and postgraduate research students for national and international prizes. Important personal achievements are also highlighted at regular staff meetings as well forming the foci of annual performance development reviews between individual staff and their academic lead (see below).

Researchers' responsibilities

The Colleges operate workload systems including a reduced lecturing and administrative load for new academics. The workload system is used to balance the demands of teaching, research and administration for all staff. Academic Leads have flexible funds to support academics via a research travel fund for research conferences, visitors and related expenses. The UoE aims to provide staff of all levels with appropriate training, including an academic leadership programme for senior academics.

3. Income, infrastructure and facilities

Research Income

Our total income during the census period was £62.0m, amounting to £796K per FTE, and up 7-fold from £8.8m during the last REF period. Our annual income per FTE has risen steadily between 2014 and 2019 (£97K and £133K, respectively), which is all the more impressive given the doubling of staff during this period. Research Council income within the UoA comes from a wide range of sources, with funding streams from NERC, EPSRC, BBSRC, MRC, ESRC, GCRF, NIHR, ERC, ERDF, EU H2020 and the World Bank. Other income includes funding from industrial partners such as the Met Office, Cefas, AstraZeneca, Syngenta, the Nanotech Industry Association, BASF, BUPA, and also from Government policy customers and regulators including DEFRA, Natural England, and the UK Environment Agency. Especially important for the UoA has been the membership of the Met Office's Academic Partnership. This partnership has co-funded a number of posts in UoA7 (currently Haywood and Collins). Also important is our strategic partnership with Cefas, which has funded a number of studentships.

Key Funding achievements.

- 7 Early Career Research Fellowships; 4 x NERC Independent Research Fellowships (Broom-Fendly, Chadburn, Rowland, Screen), 1 x Freigeist Fellowship Volkswagen Foundation (Boers), 1 x EPSRC Living with Environmental Change Fellowship (Harper), 2 x NERC Industrial Innovation Fellowships (Leonard, Murray). These fellowships secured highly competitive funding for some of our brightest emerging young talent. It is notable that most of these fellows are 'home grown' and have been nurtured in our mentorship programme to secure their fellowships.
- 3 ERC Grants; 1x Synergy (Roberts), 1 x Advanced (Cox), 1 x Starting (Yvon-Durocher). These represent the most prestigious and highly competitive individual awards for blue skies research.
- 11 NERC Large Grants (Collins x 2, Browse x 2, Friedlingstein, Galloway, Halloran, Hayward, Hesselbo, Lambert, Watson). These awards are for large scale, adventurous, world leading multi-disciplinary projects in Earth and Environmental Science.
- 6 GCRF Grants (Fleming, Galloway, Morrissey, Tyler, Van Veen, Wall). These are large interdisciplinary projects that tackle challenges faced by developing countries.
- Coordination of 2 x EU H2020 Large Grants (Friedlingstein, Betts).
- 5 European Space Agency (ESA) grants (Shutler x 4, Brewin). These include 3 direct negotiations where ESA requested UoE academics to organise European and/or international consortia and lead the research.

Strategies to maximise grant success.

We run biannual grant and fellowship hustings, where staff can pitch initial ideas in a supportive environment, and then receive feedback on the content and the most appropriate funding sources.

We employ extensive mentoring and peer review, through both local Research committees and University-wide Funder Advisory Networks. The model in both cases is akin to journal editorial boards, with members both providing feedback as well as assigning at least two other colleagues to peer review. For interdisciplinary grants, Funder Advisory Network chairs send proposals over to other networks, who undertake the same process. Every grant application is supported by a dedicated, experienced research administrator who helps with finances and personnel details, as well as ensuring compliance.

Research Facilities at the Streatham campus

The Major Research Facilities below have core financial support from the Colleges supplemented by cost recovery through grant-funding (to cover staff and maintenance). Each has an academic director supported by experimental officers.

The **DNA Sequencing Facility** houses Illumina HiSeq 2500, Illumina MiSeq and PacBio Sequel (for long reads). The HiSeq was replaced by a NovaSeq 6000 in 2019 and a 10X Chromium instrument, enabling single cell genomics and transcriptomics (£1m: 50% Wellcome trust; 50% UoE matched funding). The facility supports a wide range of applications for genomics, transcriptomics and epigenetics. Development of single cell approaches is facilitated by a joint clean room at Plymouth Marine Laboratory along with a joint appointment (UoE Environmental Single Cell Genomics Facility), funded by NERC and the Wolfson Foundation. The facility employs a Senior Research Fellow, two bioinformaticians, two wet-lab technicians, and a laboratory apprentice. Academic oversight is provided by a joint Biosciences/Medical School team. The sequencing facility is a major user of the UoE's new high-performance computing facility (Isca).

The **Bioimaging Centre** has a large array of light microscopes to support all key bioimaging techniques (e.g., FRAP, FLIM, FCS, photoactivation). We have confocal laser scanning microscopes (Leica TCS SP8, Leica TCS SP8, Zeiss LSM 880 with Airyscan FAST); Leica SP8X HyVolution II system for super-resolution live cell imaging and cross correlation studies; Olympus IX81 spinning disc system for fast life cell imaging; and Olympus IX81wide-field system with TIRF module. It was several electron microscopes: JEOL 1400 JEM transmission electron microscope; JEOL JSM 6390 LV scanning electron microscope; Zeiss GeminiSEM 500 scanning electron microscope. Facilities for sample preparation include a Baltec HPM010 High pressure freezer and RMC Boekeler freeze substitution unit. Data analysis is supported by a large software suite. The Centre is supported by an Experimental Officer, two technicians and a finance administrator. Additional bioimaging capability is provided via Physics and LSI, and includes super-resolution microscopy, multiphoton imaging, and label-free techniques to probe physical and chemical structure (second harmonic generation and coherent anti-Stokes Raman scattering microscopy).

Aquatic Resources Centre. Over £12m has been invested to provide a world-class teaching and research facility. It includes 14 aquaria rooms, including marine and freshwater, facilities for small and large scale mesocosms and the recent addition of a 3000-tank zebrafish unit, which houses a wide range of freshwater and marine species. The facility is supported by a Wolfson Imaging Unit with specialist microscopes, video and imaging equipment, together with several preparation and laboratory rooms that contain automated respirometry, dosing and gas control systems that allow for sophisticated developmental, physiological and behavioural research. A computer-controlled water treatment plant with 12 recirculating and 7 flow-to-waste systems allows us to provide high quality water of the desired salinity and temperature. Each room also has its own dedicated building management system for air temperature control and independent day-night light cycles.

The **Mass Spectrometry (MS) Facility**, operated by an Experimental Officer, houses two LC-MS systems (LC-triple quadrupole MS/MS and LC-QTOF MS/MS) along with a GC-QTOF MS/MS and HPLC with diode array, fluorescence and refractive index detectors. The facility supports custom targeted small molecule analysis and untargeted metabolite profiling plus data analysis pipelines. Chemical analysis by MS is complemented by a 400 MHz NMR spectrometer (Bruker) and IR spectroscopy. An additional MS outside the facility is equipped with hydrogen-deuterium exchange for protein structure studies.

Plant growth facilities. Plant and plant-pathogen interaction research is supported by controlled environment growth rooms, standalone cabinets, and a climate-controlled seed store. Due to refurbishment, four existing growth rooms are currently being replaced by a ~£400K investment in ten controlled environment chambers with LED lighting and CO₂ control. Our glasshouse has a footprint of 375m² divided into three compartments, with independent climate control, supplemental lighting and 57 m² of bench space with automatic watering. One of the compartments is built to GM containment specifications. The facilities are supported by two full time plant growth technicians.

Isca is the University's high-performance computing (HPC) environment. It represents a £3m investment by the UoE, designed to serve the advanced computing requirements of all research disciplines, including researchers in UoA7. The first of its kind in a UK University, Isca combines a traditional HPC cluster with a virtualised cluster environment, providing a range of node types in a single machine. Isca is available free of charge to all research groups on all campuses. The UoE is also a full partner in the GW4 Centre for Advanced Architectures, allowing access for research staff and PhD students to the Isambard supercomputer.

The **wildFIRE lab** is a specifically designed experimental laboratory to test the flammability of natural fuels. The wildFIRE lab comprises equipment that is more typically used in fire safety engineering, such as a calorimeter and microcalorimeter. The facility is used to understand as much about the flammability of natural plant-based materials in order that we can understand the flammability of our planet both in the present and the past. The wildFIRE lab also hosts a range of standard laboratory equipment necessary for the preparation of modern and fossil samples, and an adjoining microscopy room for sample preparations and microscopic analysis of charcoals complete with digital image capture and analysis facility.

Our **carbon cycle and environmental chemistry laboratories** were heavily refurbished in the current REF cycle. They provide state-of-the-art facilities for the measurement of marine carbon, chlorofluorocarbons, and atmospheric greenhouse gases. Investment in fixed laboratory space has been supplemented by the provision of a well-equipped container laboratory for use on research ships, which has supported participation by the group in six major research cruises, as well as regular observations on commercial shipping routes and at atmospheric stations in the UK, Cape Verde Islands and Northern Norway.

Research Facilities at the Penryn campus

Drone lab. We have a dedicated drone laboratory and a range of systems, including a heavy lifting delta wing aircraft, heavy-lifting octocopter, lightweight powered gliders, and lightweight multi-rotor aircraft. We combine drone survey flights with expert ground-support using field validation methodologies, which we have developed and refined. We have a high accuracy differential GPS to support registration of data and access to a high-performance computing cluster with bespoke software for rapid data processing.

Controlled Environment Rooms. With the addition of a further 6 controlled environment rooms associated with our recently completed Wolfson Evolutionary Entomology suite, we now have 17 large programmable environment rooms with variable temperature and light regimes, and shelving for insect rearing and plant growth applications, arranged across 3 suites. Each suite is managed by the technical manager of each building.

Greenhouses. Two large (69m² & 46m²) fully programmable greenhouses with automated blinds and lighting systems and full racking for plant and insect rearing.

Radars. Our Vertical-Looking Radar is used to investigate the abundance and behaviour of insects flying at high altitudes (150 m to 1200 m). Our harmonic radar enables individual tagged low-flying insects to be tracked continuously as they fly over several 100 metres to ~ 1 km. There are only two institutions in the UK and three in the world that currently possess such technology, facilitating research into animal navigation and animal cognition in a field setting.

Chemical analysis. Complementing our Streatham Mass Spectrometry Facility, we have a fully equipped laboratory for oxidative stress research, run by a core funded technician, including a gas chromatography-single quadrupole MS and a high-performance liquid chromatograph with diode-array detector and fluorescence detectors.

Aquarium. We are currently expanding our existing 100 tank freshwater aquarium facility to include 50 marine tanks to facilitate our expanding aquatic research in Penryn. The outdoor facilities provide aviaries ranging in area from 7-30 cubic metres. The indoor facility has full temperature and light control including simulated dusk and dawn cycles to provide state-of-the-art housing.

Camborne School of Mines facilities. Recent investment at Camborne School of Mines includes a FEI Field Emission Scanning Electron Microscope, a laser ablation system for our Inductively Coupled Plasma-Mass Spectrometer, an Inductively Coupled Plasma-Optical Emission Spectrometer, and a Scanning Electron Microscope. A stable isotope facility was developed in 2015 along with a preparation and microscopy facility for sedimentology and micropalaeontology in 2018. In total, this is an investment of £700K in new research facilities since the last REF.

Research Field. The University owns 5 hectares of agricultural land close to the Penryn campus. This includes two large (50m x 50m) secure fenced compounds with mains power and water, along with laboratory, workshop and poly tunnel facilities and hard standing for vehicles and heavy equipment. The facility provides access to space for a variety of large-scale experiments in the general fields of ecology and environmental science.

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

The diverse, interdisciplinary expertise of academic staff in Earth Systems & Environmental Science at UoE, has ensured that we are exceptionally placed to participate in major research collaborations, and deliver outstanding contributions to economy and society both nationally and internationally. The work of academic staff at UoE is also integral to the vitality and sustainability of Earth and Environmental Science both in the UK and internationally. This section outlines our key roles in major research networks and scientific organisations, our engagement with research users and audiences, and our contributions to the research base.

Research networks and collaborations

The researchers involved in this UoA7 submission are very actively engaged in a wide range of national and international collaborations. The breadth of our international research collaborations is global, and researchers in Earth Systems & Environmental Science are actively involved in >100 networks and collaborations with researchers worldwide. Here, we focus upon some highlight activities from this REF period that are indicative of breadth and scope of our international collaborations.

Prof Betts, joint UoE–Met Office Chair in Climate Impacts, led the EU-funded **HELIX project**, which ran 2013-2017 and saw a consortium of 16 partner organisations, including the Met Office, assess the future impact of global warming at different levels. Over one hundred papers have been published from the consortium which has provided input to the Intergovernmental Panel on Climate Change special report on the impacts of climate change at 1.5 degrees and above, and what we can do to reduce greenhouse gases to maintain that level. The report has fed into the UN negotiations process and is widely credited as kick-starting recent public concern on climate change, triggering the wave of school strikes and Extinction Rebellion protests that have swept across the country this year. The HELIX project has raised public awareness of climate science through interviews with mainstream media and a popular [@helixclimate](#) Twitter feed.

Prof Lenton is a member of **Earth League**, which is an international alliance of prominent scientists from world-class research institutions, who look to work together to respond to some of the most pressing issues faced by humankind, as a consequence of climate change, depletion of natural resources, land degradation and water scarcity. The alliance focus includes how we can manage anthropogenic global change according to the principles of sustainable development. The Earth League aims to provide decision makers with multiple options for addressing pressing sustainability issues, by delivering robust background information and enhancing transparency of the choices available.

Members of the Ecosystems and Environment and Human Health groups (Bearhop, Godley, Fleming) have played an integral role in establishing a £1.9m joint research centre with the Chinese University of Hong Kong, “Environmental Sustainability and Resilience” (**ENSURE**). The first of its kind in Hong Kong, this joint endeavour is embarking on large, impactful interdisciplinary collaborations to tackle emerging issues related to a changing environment and human health and wellbeing. ENSURE serves as a platform for international academic exchange, promoting policy related works, and nurturing the next generation of young researchers to address sustainable development challenges.

Members of the Ecosystems (Bearhop) and Climate Dynamics (Cox) groups have helped develop the **QUEX** partnership between the UoE and the University of Queensland. A multi-million pound partnership that strengthens a joint commitment to co-produce research of the highest quality, boost industry and business collaboration, and publish high-level policy reports, designed to inform and shape key government initiatives across the globe. The two Universities are working together under the overarching banner of ‘Global Sustainability and Wellbeing’. The high-level collaboration brings together the UoE’s global-leading expertise in pioneering environmental research with the University of Queensland’s world-leading reputation in genetic and environmental research.

Members of the Environmental Biology group (Galloway, Lewis, Godley) have developed an international consortium to tackle ocean plastic waste, through circular economy approaches in the eastern Pacific and iconic Galapagos islands. Multi-million funding from GCRF, government, research councils and benefactors supports a network of scientists, practitioners and industries across Ecuador, Chile and Peru. This ground-breaking research has led to a new fundamental understanding of ocean contamination dynamics and impacts in the region and generated award-winning research on remediation of outstanding societal benefit and contributed towards policy documents for countries across the Eastern Pacific rim for controlling plastic waste.

Contributions to the discipline and research base

Researchers in Earth Systems & Environmental Science at the UoE have a distinguished record of providing external disciplinary leadership. This section outlines our contributions to international scientific committees and organisations over the REF period, and our work to sustain the research base across the subject area.

Intergovernmental Panel on Climate Change (IPCC). Earth System Science researchers have a high-profile role in the IPCC process. Four academics from this UoA (Betts, Collins, Cox, Unger) are currently lead authors for the 6th Assessment Report or Special Report on the Ocean and Cryosphere (SROCC).

Third UK Climate Change Risk Assessment (CCRA3). The UoE also leads the scientific analysis for CCRA3 directed by joint UoE–Met Office chair Prof Betts. This government report, which is provided to parliament every five years, evaluates the risks climate change poses to the country and how our health policies, utilities and infrastructure can best protect us under the National Adaptation programme. The final report will go to parliament in January 2022 and will inform the National Adaptation Programme and other government policies on climate change.

Conference of the Parties (COP). The UoE has had a strong presence for many years at the annual Conference of the Parties (COP) to United Nations Framework Convention on Climate Change, presenting research on a global level. Results from the HELIX project were presented at

COP21 in 2015 where the historical Paris Agreement was signed. COP25 in Madrid in 2019 saw the UoE deliver a number of talks including on climate risks, tipping points, increasing climate resilience in vulnerable regions, and progress on the Climate Change Risk Assessment 3 report. UoE will have strong presence again at COP26 which will take place in Glasgow, providing the opportunity to work alongside other UK universities in bringing the latest climate science research to governments, policy makers, scientists and the general public.

Anti-Microbial Resistance (Gaze, Leonard, Murray, Vos). The group, led by Prof Gaze, has contributed to United Nations, World Health Organisation, European Food Safety Authority and EU Water Framework Directive policy. Prof Gaze co-authored a UNEP report on anti-microbial resistance and the environment, which he presented at UNEA3 (2017) in Nairobi. Countries around the world, including the UK, pledged to tackle marine litter and combat anti-microbial resistance for the first time at this meeting. The report was one of only two publications on the environment cited by the UN Interagency Coordination Group on anti-microbial resistance final report to the UN Secretary General. The group has also informed UK government policy on anti-microbial resistance contributing vital parts of the evidence base, which underpins the UK government 5-year anti-microbial resistance strategy. Strong links with the Department for Food and Rural Affairs and the Environment Agency in England have been facilitated by a NERC funded Knowledge Exchange Fellowship awarded to Prof Gaze and supervision of a PhD student, by Dr Leonard, based within the Environment Agency's national laboratory service delivering microbial testing of bathing waters. Key exemplars of research that have informed policy include the work by Dr Leonard and research fellow Dr Zhang on environmental surveillance and anti-microbial resistance transmission in bathing waters. Leonard et al. 2018 was the only paper on anti-microbial resistance and water (of 1000 publications in the last 5 years) to be cited in the UK anti-microbial resistance strategy. Research by Dr Murray and PhD student Isobel Stanton, in collaboration with AstraZeneca, has informed inclusion of two additional antibiotics on the EU Water Framework Directive hazardous substance watch list of environmental contaminants.

Plastic pollution (Galloway, Tyler Lewis, Godley). Environmental biology researchers play a key role in advising governments worldwide on pollution-related issues, including chemical and hazardous substances risk, impacts on natural populations and conservation actions, and future strategies for remediation. This includes expert membership of the UK government Hazardous Substances Advisory Committee and the UKRI Innovate UK Smart Sustainable Plastic Packaging Steering Committee (Galloway); OECD Working Group on Manufactured nanomaterials (Galloway, Tyler) and Sustainable Plastics (Galloway); expert advisory roles to both the UN General Assembly and UN Environment Programme on global impacts of marine plastics and microplastics; and informing EU policy making on microplastics through the Group of Chief Scientific Advisors Science Advice Mechanism.

Health and Wellbeing in Natural Environment (Fleming). Prof Fleming leads research that has provided evidence that equal access to high quality natural environments can improve human physical health and mental wellbeing. This research has been recognised by World Health Organisation Collaborating Centre for Natural Environments and Human Health, with incorporation of this evidence in the Department for Food and Rural Affairs 25 Year Plan for the Environment, Public Health England Healthy Places, Natural England MENE Survey, and World Health Organisation policy recommendations. In particular, evidence around the importance of Blue environments has led to the development of a Strategic Research Agenda in Oceans and Human Health for Europe and Beyond under Horizon 2020 (<https://sophie2020.eu/strategic-research-agenda/>).

Editorial roles. Academics in this UoA7 submission contribute to the discipline and wider knowledge base through editorial roles.

- *Baldwin* – editor of the Quarterly Journal of the Royal Meteorological Society.
- *Collins, Friedlingstein, Screen* – editors of Journal of Climate.
- *Galloway* – editor in Chief Chemosphere.
- *Early, Hodgson* – editors of Ecology Letters.
- *Gaston* – editor of People and Nature.

Advisory roles. Academics in UoA7 also make major contributions through engagement on government advisory groups.

- NERC science and innovation strategy board (Cox).
- Defra Science Advisory Council (Cox).
- UK government Hazardous Substances Advisory Board (Galloway).
- Advisor to Department for Food and Rural Affairs Chemicals and Nanomaterials Division and OECD test guideline panel, Chief Scientific Advisor for the UK-Japan partnership on Endocrine Disrupting Chemicals (Tyler).
- NERC peer review College (Collins [chair panel B], Friedlingstein, Tyler, Simpson, Wilson, Yvon-Durocher).
- Assessments of other research centres (e.g., Cox – review group of MPI-Meteorology, Lenton – review group of MPI-Biogeochemistry, Friedlingstein – member of the Met Office Hadley Centre Science Review Group).
- Involvement in international programmes (e.g., Baldwin – member of the SPARC scientific steering committee; Cox & Lenton – co-chair and member of IGBP-AIMES; Friedlingstein, member of ESSP-GCP).
- International review of grants and through involvement in international scientific assessments (such as the IPCC).

Contributions to economy and society

Research, development and innovation. Since 2014, Earth System & Environment Science scholars have led and partnered a number of regional and national research, development and innovation projects supporting economic and social transformation. Much of this work has been catalysed through European Regional Structural Investment Fund Programmes and UKRI Industrial and Impact focused programmes, such as BBSRC Industrial Partnership Awards and NERC Regional Impact from Science of the Environment.

The UoE is engaged in over £120m of European Regional Structural Investment Fund projects, with a total value to the University of £25m (2020). Throughout this European Regional Structural Investment Fund portfolio, over 700 regional Small and Medium Enterprises (SMEs) have been engaged. Many of the ESIF projects have a strong Earth Systems & Environmental Science component including:

Agri-tech Cornwall and Isles of Scilly, a £11.8m project to increase regional and national research, development and innovation in the Agri-tech sector across Cornwall and the Isles of Scilly, started in 2016 and will run to June 2021. The programme is led by Duchy College (The Cornwall College Group) and partnered by Rothamsted Research, Cornwall Development Company and the University of Plymouth. The Agri-tech Cornwall programme has engaged over 100 SMEs and supported the new-to-market development of over 15 new products and services. Exeter led RD&I projects have focused around: microclimatic modelling for novel crops (Maclean, Early), edible insects, COVID-19 Impacts on the regional food and drink sector, Starling management for farms (Bearhop), fungal pathogen management for viticulture (Yvon-Durocher), and lobster genetics (Stevens). European Regional Structural Investment Fund plays an important role in catalysing industrial partnership and applied research; for example, the biogas optimisation from anaerobic digestion project (Yvon-Durocher) initially supported by the Agri-tech Cornwall Programme led to a successful BBSRC Industrial Partnership Award with Associated British Agriculture (AB Agri) in 2019.

The Tevi Programme (Gaston) www.tevi.co.uk, led by the UoE and delivered in partnership with the Cornwall Wildlife Trust, Cornwall Council and Cornwall development, started in 2018 (£3.08m), and has worked with 258 SMEs and delivered 46 regional events with over 2,283 participants. Tevi is a key regional resource supporting businesses to improve their resource efficiency, transition to increasingly circular economy business models, and contribute to the region's environment growth, net-gain and low-carbon targets. Tevi has developed a state-of-the-art regional environmental intelligence platform (www.lagas.co.uk), now adopted by Cornwall Council to support their spatial planning and deployed a network of 130+ environmental sensors to support

real-time environmental monitoring and engagement with the Tevi-Community. The Tevi programme is to be extended for a further 2 years from 2021 (£1.2m).

In addition to business benefit, environmental science scholars have engaged in regional projects aimed at directly enhancing the quality of the region's natural environment, its biodiversity and accessibility. Green Infrastructure for Growth 1 & 2, £3.47m (Osborne, Gaston, Maclean) is a programme led by Cornwall Council and partnered by UoE. These programmes have collectively delivered over 100 hectares of habitat improvement and improved access to urban green infrastructure in deprived towns. St Austell Bay Resilient Regeneration (StaRR – Gaston) is one of the largest fluvial and coastal flood defence projects in South West England (£11.1m ESIF and £22m Environment Agency). This programme is led by Cornwall Council and the Environment Agency. The UoE and Westcountry Rivers Trust are partners within the project supporting the modelling of natural flood management measures, habitat creation and improvement. Over 36ha and 7km of river corridor are to be improved, in terms of habitat quality and access, as a direct consequence of the project, in addition to over 600 homes and 275 business experiencing decreased risk of flooding.

The South West Partnership for Environment & Economic Prosperity (SWEEP) is a £5m NERC RISE/EPIB funded programme with the express aim of delivering, through 5 themes, increased resilience and business benefit through natural capital. The programme is led by the UoE in partnership with the University of Plymouth and Plymouth Marine Laboratory. SWEEP has funded a number of impact case studies including: Mainstreaming Environmental Growth (MEG – Gaston, Maclean); Policy for Pollinators: impact on the development of New Environment Land Management Scheme Policy (Osborne); Managing Green Space; Quantitative Habitat Mapping; leak detection in the water industry; and One Coast: to establish the foundations of a South West coastal corridor for nature and people (Gaston). SWEEP's mid-term evaluation report (April 2020) reported that the programme had engaged 165 new partner organisations, delivered 45 new impact projects, supported the development of 38 newly created tools, services, products and protocols, generated £6.8m in direct stakeholder match funding, and levered an additional £47.5m investment into the South West region.

Engaging Expert and Public Audiences. Researchers in Earth Systems & Environmental Science at the UoE have a distinguished record of encouraging wider participation and increasing public awareness of key issues in climate and environmental science. Key examples include:

Science in the Square is an annual outreach event for families, which regularly has over 3000 attendees each year. The event involves approximately 70 volunteers at all levels (undergraduate to senior academics) and includes interactive talks and displays, held in Falmouth town centre.

Science of the Sea is an annual event held at the National Maritime Museum and includes approximately 20 volunteers to deliver interactive talks and displays for children and families.

Science of Christmas is a collaboration with local schools to enable every child in every year-3 class in surrounding schools (7 primary schools) to attend. As a result, approximately 90 children attended to listen to interactive talks linking science to Christmas.

How Science Works is a collaboration with a local secondary school to work with all feeder Primary schools (7 in total). Our undergraduate students visit the primary schools and the secondary school over four weeks to help the year-5 children design and carry out a science investigation and then produce a poster of their results. All the primary schools then meet on campus for a conference, which includes oral and poster presentations. This programme occurs twice a year in the autumn and spring terms.

Student-led activities. Our students lead an annual Bioblitz for local families to visit campus. Generation Wild is a student society to get children engaged and inspired about nature and the environment through providing environmental education sessions. In addition to these large

projects, we also have multiple ad-hoc visits throughout the year. We visit between 9 and 10 schools per year and have a similar number of visits from schools on campus.

The Creative Exchange Programme brings together creative practitioners and researchers on our Cornwall Campuses. The programme offers the opportunity to create a unique exhibition to explore environmental and sustainability issues (be it through the medium of photography, narrative, pottery or artwork), and this is then displayed in the Environment and Sustainability Institute's Creative Space next to the cafe. Through this programme we seek to develop the region's creative industries, inspire research and stimulate opportunities for public engagement and collaborative learning. It has been hugely successful and has become a focal point for UoE's Arts and Culture Strategy. Since COVID19 has meant that in house exhibitions are not feasible, the Environment and Sustainability Institute team have supported moving the exhibitions online and support it via social media to publicise the work. In the past year, we have supported projects covering topics as varied as wave energy, material relationships, seashells and climate change, solar panels as art, and microbial underworlds.

The Health and Environment Public Engagement (HEPE) Group (<https://www.ecehh.org/about-us/engagement/>) was established to improve public engagement and involvement with scientific research about health and the environment. In addition to interacting with researchers and students, before and during research projects to provide feedback and citizen involvement, HEPE has taken on its own citizen science projects including My Blue Health.

Eden Project. Several staff (Lenton, Gaze, Hudson-Edwards) from across the unit have been extensively involved in establishing and contributing to the Eden Project's Wellcome Trust funded long term exhibition "Hidden Worlds".

Awards & Recognition

Galloway was appointed OBE for services to Environmental Sciences in 2019, led the team (with **Lewis** and **Godley**) that was awarded the Queen's Anniversary Prize for Academic Excellence in 2020 and received a NERC Outstanding Societal Impact Award for research to prevent microplastic pollution of the world's oceans in 2018. **Friedlingstein** received a Royal Society Wolfson Research Merit Award in 2014, the Vladimir Ivanovic Vernadsky Medal from the European Geophysical Union in 2020, and an Alexander von Humboldt Award in 2019. **Scaife** received the Copernicus Medal in 2018, an Atmospheric Sciences Ascent Award from the American Geophysical Union in 2016, the Met Office CEO Award for Excellence in Science & Technology in 2016 and the Adrain Gill Prize of the Royal Meteorological Society in 2014. **Simpson** received the Zoological Society of London Medal in 2019 and the Fisheries Society of the British Isles Medal in 2016. **Cox** received a Royal Society Wolfson Research Merit Award in 2017. **Yvon-Durocher** received the Founders Award from the British Ecological Society in 2019.

REF2020 SUMMARY

Earth System & Environment Science research at the UoE has seen major advances in critical mass and performance since REF2014. The size of unit has more than doubled since 2014 from 35 to 78 FTE. We have recruited outstanding research-intensive staff and supported the development of our existing staff to achieving our aim (set out in 2014) to increase the critical mass of UoA7 facing research at the UoE. We have seen substantial increases in total income and income per FTE, as well as the strength and quality of our research and scientific impact as indicated by the position of the UoE as #1 in Europe in Leiden rankings for Life and Environmental Science. Our researchers are in high demand for advising governments and NGOs in areas as diverse as climate change, plastic pollution and anti-microbial resistance. UoA7 staff have also been instrumental in driving the UoE's interdisciplinary research agenda, which has featured the establishment of new research institutes that facilitate the co-location of staff from diverse disciplinary backgrounds to tackle global challenges in Earth System & Environment Science. Our broad research portfolio is helping to address many of the most important contemporary scientific challenges faced by society and continues to deliver agenda-setting research.