

Institution: University of Aberdeen

Unit of Assessment: 7 (Earth Systems and Environmental Sciences)

Section 1. Unit context and structure, research and impact strategy

1A. UNIT CONTEXT AND STRUCTURE

Research in the *Earth Systems and Environmental Sciences* has been a traditional strength at the University of Aberdeen with a **long and sustained reputation for research excellence** that is pivotal to the research strategy of the Institution moving forward.

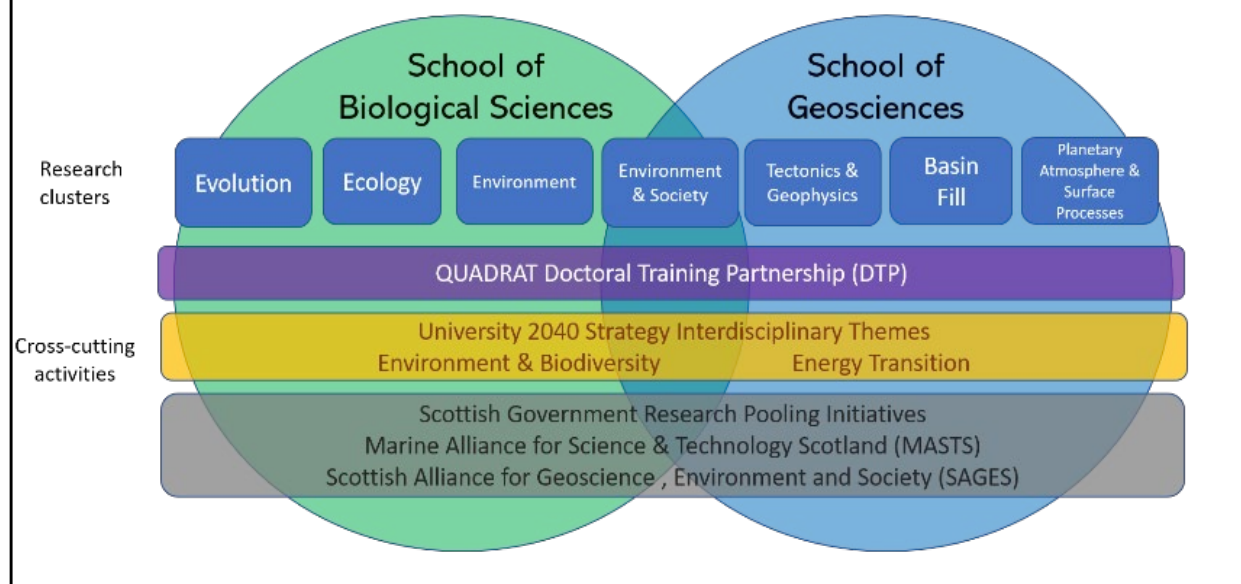
Our reputation for research excellence in this area is facilitated by our co-location in Europe's energy capital and in the immediate vicinity to major offshore fishing hubs, the aquaculture industry, world-famous water courses, intensive agriculture and the UK's largest National Park. This places the University on the very "front line" of environmental research and **a collaborating partner of choice for government, NGOs and industry to co-design and deliver leading edge research that translates into impact**. This activity is now being shaped around new and emerging national and global environmental challenges including oil and gas decommissioning, development and deployment to renewable energy infrastructure, post-Brexit management of natural capital and resources and increasing protected marine habitat.

Recognising our research strength, and the global importance of our endeavour, **the University has placed environmental science at the core of its newly 20-year strategic plan – "Aberdeen2040"** (www.abdn.ac.uk/2040/), around which **major research investment and teaching activity will be structured**. "*Environment & Biodiversity*" and "*Energy Transition*" are two of the five interdisciplinary themes core to this strategic plan, and these are being supported by major investment such the newly opened GBP38M National Decommissioning Centre (www.uknrc.com) that partners industry with academia to transform all aspects of the decommissioning process.

Earth Systems and Environmental Sciences research at the University is primarily channelled through two Schools –Biological Sciences (SBS) and Geosciences (SG), with extensive collaborations with the other ten Schools (but notably Engineering, Law and Social Science) to deliver **truly transdisciplinary research** that is effectively translated to impact (Figure 1). This submission includes 87 (83.2 full-time equivalent (FTE)) academic staff from across SBS and SG who, together, **have published more than 3500 peer reviewed publications** during the REF period, have had **their work highlighted in over 8000 policy papers, patents, news items and blogs** (source: Altmetrics), **secured more than GBP59M of competitively acquired funding** from UKRI, charity and industrial sources, **supported 287 PhD students** and **published with collaborators from more than 80 countries**.

In REF2014, the University's submission to UoA7 was from SG alone and purely centred on Earth systems research. This REF2021 submission reflects a wider integration of Earth and environmental science research, emphasising **research coherence** and a **fundamental commitment to promote interdisciplinary collaboration** across multiple Schools.

Figure 1: UoA 7 – School Research Clusters and cross-cutting, interdisciplinary activity



The **School of Biological Sciences (SBS)** has a research portfolio that covers pure and applied research, with a cross-cutting theme of **understanding the biological consequences of environmental change**. Our research incorporates theoretical, empirical and experimental studies on plants, animals and microorganisms that spans from gene to global scales, from the deep ocean to high altitude and from poles to tropics. Research activity is organised through four research clusters where we have **an international reputation for cutting edge research**. 1) *Ecology*; 2) *Environment*; 3) *Evolution*; and 4) *Integrative Environmental Physiology* (returned to UoA5). These clusters affiliate staff and students with shared research interests, facilitate interdisciplinary ways of working and incorporate seminar programmes, symposia and workshops to foster collaboration and interaction.

The *Ecology* cluster focuses on understanding the **impact of natural and anthropogenic processes on the abundance, dynamics and distribution of individuals, populations and species**. This encompasses population, behavioural and community ecology with an emphasis on long-term, large-scale field studies to provide an empirical understanding of how ecological processes affect natural populations and time-series data to identify population responses to environmental change. This is supported by strong theoretical research and novel statistical modelling and laboratory-based tools. Recurrent research themes within the Ecology cluster where we have provided major new insights include understanding the causes and consequences of range-shifts and demographic change in natural populations (Bodie, Burslem, Cornulier, Gubry-Rangin, Lambin, Lancaster, Payo-Payo, Ponchon, Prosser, Reid, Woodin), the factors affecting the emergence and spread of zoonotic diseases (Moseley, Telfer, Strachan), management of invasive non-native species (Bodie, Burslem, Douglas, Lambin, Woodward), effective management of sustainable fish resources (Fernandes, Marshall, Scott), functional linkages between oceanographic processes and the life history traits and population dynamics of top marine predators (Reid, Scott, Thompson) and mitigating the impacts of human activity on conservation and management (Lusseau, Ponchon, Redpath, Thompson, Van der Wal). Research highlights include Lancaster's work on thermal tolerance and range shifts in plants (DOI: 10.1073/pnas.1918162117) and insects (DOI: 10.1038/s41559-020-1199-1), Lambin's work on trophic transfer of pesticides (DOI: 10.1111/1365-2664.13578), Cornulier and Lambin's work on large-scale invasive species control (DOI: 10.1111/1365-2664.13115), Prosser's work on bacterial and fungal network stability (DOI: 10.1038/nature13604) and Fernandes' work on applied fisheries management (DOI: 10.1038/s41559-017-0170).

The *Environment* cluster integrates complementary expertise in biogeochemistry, ecosystem modelling, environmental restoration and global environmental change to deliver **insight on the impact of climate change, land management practice, environmental sustainability and pollution**. We have generated major insights into effects of climate change on soil carbon stocks (Smith-P, Smith-J), evidenced by Smith-P's inclusion in the annual world's highly cited list, - and developed decision support tools, which have been adopted in over 100 countries, that model the impacts of land use and soil management on greenhouse gas emissions (Smith-P, Smith-J, Hastings). We have examined the ecological impacts of climate change and land management on plant communities (Burslem, Cameron, Taylor, Woodin, Woodward), the biogeochemical processes and ecosystem function in deep sea and arctic ecosystems (Witte, Kuepper), the interplay between soil physical properties and biological processes under environmental change (Hallett, Malik, Norton) and the development of microbial bioassays to monitor environmental perturbations (Paton). Research highlights include Burslem's work on how active restoration of logged forests generates higher rates of carbon accumulation than naturally regenerating forest (DOI: 10.1126/science.aay4490), Smith-P's work on farming, habitat and management practices that co-deliver food security and climate change mitigation (DOI: 10.1073/pnas.1710465114//10.5281/zenodo.883444, 10.1111/gcb.14878,10.1073/pnas.1611576114).

The *Evolution* cluster **examines the adaptive processes and genetic mechanisms that shape the patterns of biodiversity and the genetic basis of key phenotypic traits**. This research spans molecular and quantitative genetic approaches to understand eco-evolutionary dynamics in natural populations (Bocedi, Douglas, Fisher, Lancaster, Layton, Piertney, Reid, Travis), interactions between behaviour and evolutionary responses to environmental change (Lancaster, Pilakouta), microbial diversity and function in relation to ecosystem service and biogeochemical cycling (Gubry-Rangin, Malik, Prosser) and functional genomics and transcriptomics to understand the genetic basis of commercially/agriculturally important and functionally relevant traits (Jones, Norton, Piertney, Price, Sleight, Vogwill). Research highlights include Rangin's work on diversification and pH adaption in archaea (DOI: 10.1038/s41467-020-19132-x, 10.1073/pnas.1419329112 // 10.5061/dryad.0nv00), Reid's work on quantitative genetic analysis of mating systems and fitness in birds (DOI: 10.1086/686198, 10.1111/evo.13575), Vogwill's work on evolution of antibiotic resistance (DOI: 10.1093/molbev/msu262) and Price's work on the genetic basis of functional traits in rice that influence human health and food security (DOI: 10.1073/pnas.1317360111)

The **School of Geosciences (SG)** covers **pure and applied research in Earth, planetary and environmental sciences, including work on societal interactions and sustainability**. Research addresses a full spectrum of scales, from molecular geochemistry to planetary geosystems and temporal scales from instantaneous mass movement events to deep geological time. A consistent theme throughout is **the use of state-of-the-art earth and planetary observation methods with advanced modelling tools**. Our research clusters staff and research students around four main themes with porous boundaries and natural interactions. This has built an interactive community for sharing research ideas through seminar series and more focused workshops. Increasingly, the **synergies with the three SBS clusters are further developed and reinforced**.

The *Basin Fill* cluster provides a **“source to sink” framework of how energy, fluids and material fluxes shape process-morphology interactions of the Earth system**. Within this over-arching framework, sub-groups focus on specific topics over distinct space-time scales. One sub-group focuses on modern and ancient sedimentary systems to understand basin fill through deep time, how processes are preserved and identified in the stratigraphic record and how this informs the identification of hydrocarbon reservoirs (Brackenridge, Hartley, Hole, Howell, Hurst, Jolley, North, Schofield-N). A cognate sub-group of researchers have a strong geochemistry focus (Bowden, Brasier, Muirhead, Neilson, Parnell) with emphasis in using organic and trace-metal geochemistry to investigate carbonate systems, the deep biosphere and planetary atmospheres. An understanding of water resource systems is the focus of the hydrology sub-group (Comte, Geris, Green, Haro, Soulsby); research integrates empirical and

modelling approaches, with emphasis on understanding multiscale hydrological systems using stable isotopes, land use change effects on water quantity and quality and characterisation of coastal and hard-rock groundwater systems. The cryosphere sub-group (Rea, Spagnolo) research ice-climate interactions, ice sheet mass balance, glacial landform genesis and palaeoglaciology. Finally, a palynology sub-group (Mauquoy, Mighall, Schofield-E) focuses on reconstruction of Holocene environmental change, with links to human activity during prehistory and early history using pollen analysis, macrofossil analysis, non-pollen microfossils, peat geochemistry and isotopic dating. Highlights include Schofield-N, Alsop and Jolley's explorations into the influence of igneous intrusions on basins and reservoirs (DOI: 10.1130/G35406.1, 10.1306/05091918193); Bowden's interdisciplinary work on the deep ocean biosphere (DOI: 10.1126/science.aaa6882, 10.1126/science.abd7934); Soulsby's research on isotope-based modelling of water sources and biogeochemistry (e.g. DOI: 10.1038/s41561-018-0218-1, 10.5194/gmd-11-3045-2018); and Rea, Spagnolo and Howell's work on marine terminating ice sheets (DOI: 10.1126/sciadv.aar8327).

The *Tectonics and Geophysics* cluster **focuses on tectonic influences on sedimentation systems and the dynamics of lithosphere deformation**. One sub-group is centred on tectonics and structural geology (Alsop, Bond, Butler, Gan, Healy). Here the focus is on investigation of deformation across scales; integrating diverse data and observations, including seismological studies of regions of active tectonics to developing understanding of rock fracture in the geological record through laboratory experimentation and numerical modelling. This includes industry-supported investigations of thrust systems, changing perceptions of interpretation uncertainty in forecasting subsurface structure. The geophysics sub-group (Cornwell, Giannakis, Gilligan, Loer, Stephenson) is active across the spectrum of solid Earth sciences from upper mantle and crust/lithosphere characterisation ($>10^6\text{m}$) through imaging of sedimentary strata. Theoretical and practical development of a wide range of geophysical methodologies are employed across this spectrum. Recent highlights include Healy's quantification and modelling of fractures and anisotropy (DOI: 10.1016/j.jsg.2014.02.008, 10.1016/j.jsg.2016.12.003); Bond's work on geological controls on carbon capture storage (DOI: 10.1038/s41467-018-04423-1); Butler's work on structural geometry in fold-thrust belts (DOI: 10.1016/j.jsg.2018.06.019); and Cornwell's extensive international collaboration on quantifying background seismic noise (DOI: 10.1126/science.abd2438).

The newly established *Planetary Atmospheres and Surface Processes* cluster (Martin-Torres, Zorzano, Bhardwaj, Sam, Singh) builds upon our previous planetary science work (e.g., Parnell, Bowden). Research **focuses on planetary atmosphere-surface interactions, particularly radiative transfer and innovations in instrument design for space exploration, integrating remote sensing, field studies and laboratory simulations**. Cross cutting themes include atmosphere and climate interactions, field and laboratory analogue studies, *in-situ* resource utilisation and astrobiology and habitability. The group have been active investigators on the NASA Mars Curiosity Rover and the European Space Agency (ESA) Trace Gas Orbiter. Highlights include: the work of Martin-Torres and Zorzano group on the detection of methane (DOI: 10.1126/science.1261713) and liquid water (DOI: 10.1038/ngeo2412) on Mars; the possible role of aqueous processes on Martian hillslopes (DOI: 10.1029/2018RG000617); and Parnell's work on methane in Martian meteorites (DOI: 10.1038/ncomms8399).

The *Environment and Society* cluster explores **the complex, evolving relationships between social and ecological systems in the context of rapid environmental change** (Duffy, Phillip, Pierce, Potts, Prager, Wartmann). Foci include the governance of natural capital, resources and human systems (coastal, marine, rural agricultural), rural and coastal populations, landscape perception, demography and change and urban geography. Research utilises a variety of mixed methods integrating spatial sciences, longitudinal surveys, innovative qualitative and contextual analysis and direct participatory research with stakeholders and communities. Publication highlights include Pott's work on coastline ecosystem services and management (DOI: 10.1016/j.ecoser.2019.101009; 10.1016/j.marpol.2016.06.012); Philip's work on remote rural

areas (DOI: 10.1016/j.jrurstud.2016.12.002); and Haro's work on water and food security (DOI: 10.1016/j.gloenvcha.2016.05.003).

Although SBS and SG have independent research agendas and objectives, activity is increasingly aligned, leveraging gains through multiple cross-School synergies. These are demonstrated by joint funded research projects, co-supervision of PhD students and shared use of analytical facilities, equipment and infrastructure. Examples of interdisciplinary collaboration include successive NERC-funded projects between Geris, Hallett and Soulsby that combine expertise in Critical Zone Science to sustain soil and water-related ecosystem services in sensitive agri-ecosystems in China. Similarly, Scott and Potts integrate ecological and social science perspectives to the assessment of ecosystem services for planning Marine Protected Areas (see impact case study). Both Schools partner through Scottish Government Research Pooling initiatives including the Scottish Alliance for Geoscience, Environment and Society (SAGES), Scottish Universities Life Sciences Alliance (SULSA) and Marine Alliance for Science and Technology for Scotland (MASTS).

SBS and SG collaboration gained a major further impetus through the award in 2018 of two NERC Doctoral Training Partnerships (DTP): QUADRAT-DTP (www.quadrat.ac.uk) is a partnership between the University of Aberdeen and Queen's University Belfast to provide a transformative platform for PhD research and training in biodiversity, earth systems and environmental management. QUADRAT-DTP will support 100 students (60 NERC funded, 40 matched funded by Schools), half of whom will be within SBS and SG, and involves joint supervision and explore multidisciplinary topics. SUPER-DTP (www.superdtp.st-andrews.ac.uk) involves eight Scottish University partners, with a focus on the broad themes of environmental dynamics, biodiversity and challenged ecosystems.

1B. RESEARCH STRATEGY

Environmental science is at the core of the *Aberdeen2040* strategic plan around which major research investment and teaching activity is structured. **Ensuring research excellence with impact** is a key tenet within that strategy and is reflected in our research strategy for *Earth Systems and Environmental Sciences*.

Research activity and strategy within SBS and SG is overseen by research committees comprising a Director of Research, the Head of School and research active staff at different stages of career including Early Career Researchers (ECRs). These research committees meet regularly for information exchange, horizon scanning, peer review of grant applications and papers, distribution of discretionary research funds to pump-prime new research and identification of funding and collaboration opportunities. Both School Directors of Research sit on the University Research Policy Committee chaired by the University Vice Principal for Research, which is a conduit for inputting into the institutional research vision, overseeing research governance and ethics procedures and target setting for individual Institutes/research programmes. Unit staff (Brasier, Johnson, Piertney, Rea) also play pivotal roles in institutional strategy around, and **support for, interdisciplinary research**, sitting on working and oversight groups to enhance interdisciplinary ways of working, developing core facilities and directing investment. Unit staff also lead the University's Interdisciplinary themes around Environment and Biodiversity (Burslem) and Energy Transition (Potts) which are core to the *Aberdeen2040* strategy.

SBS and SG research strategies feed into their broader School plans to deliver the University strategic goals. The strategy is centred on enhancing external research grant income, research student numbers, high-quality outputs, partnerships with end-users and stakeholders, research impact, outreach activity and institutional profile.

The associated operating plans identify areas for staff recruitment and infrastructure investment, capacity building development and maintenance of facilities, peer-review of grant and manuscripts, disseminating information on research opportunity (collaborations, funding etc),

pump-priming innovative research, foster interactions with external collaborators and support impact and outreach activities.

The effectiveness of interaction around peer review is exemplified by a combined NERC Discovery mode application support and review panel established in response to the NERC demand management cap in application numbers. This panel provides a thorough review pipeline for applicants from consideration of initial idea through to final submission, and this process in part resulted in the successful removal of the institute from a capped quota in 2018. This model for applicant support and bid development has been extended to include all grant applications from across all funding bodies.

SBS Research Strategy REF2014 – REF2021

For REF2014, most (29.2FTE) SBS staff were submitted to Unit of Assessment 5 (*Biological Sciences*) and fewer (20.4FTE) to UoA6 (*Agriculture, Veterinary and Food Science*). For these areas 83% and 92% of our overall research activity was considered to be world-leading or internationally excellent (4*/3*), respectively. The UoA6 submission was ranked number one in the UK for *Agriculture, Veterinary and Food Science*. Overall, 100% of the School's impact was judged as 4*/3*, as was the research environment.

After REF2014, research direction has undergone a concerted and engineered shift towards greater interdisciplinarity and increased collaboration with SG and also to consolidate emphasis around the three stated objectives from REF2014.

Integration of 'omics technologies: The School has traditional strength in using genomic and transcriptomic data to identify the genetic basis of adaptive and functionally important traits (Price, Norton, Douglas, Lancaster), link microbial community dynamics to fundamental biogeochemical processes (Rangin, Prosser) and resolve patterns of population genetic structure and gene flow (Piertney, Jones). This expertise has been extended and expanded by the **targeted recruitment of six early career staff** with direct expertise in the use of multi 'omics approaches and analyses across a range of ecological, environmental and evolutionary contexts (Malik, Moseley, Layton, Pilakouta, Sleight, Vogwill). Our capacity for developing and exploiting 'omics approaches is enabled by **sustained investment in the University's Centre for Genome Enabled Biology and Medicine (CGEBM)** (www.abdn.ac.uk/genomics). CGEBM offers both the research infrastructure and bioinformatics support to facilitate leading edge research across a broad taxonomic range of model and non-model animal, plant and microbe systems. There has been targeted investment and training in Oxford Nanopore 3rd generation DNA sequencing technologies to enable field-based assessment of biodiversity in real time and/or from eDNA samples. This ensures that emerging 'omics techniques dovetail with our traditional expertise in field ecology and environmental monitoring to provide new insight into aspects such as causes and consequences of variation in the microbiome and rhizosphere, detection of emerging zoonotic diseases and detection of invasive non-native species.

Translational ecology delivers impact through recursive interaction between researchers and end-users to develop management actions and conservation tools for the effective stewardship of the environment and natural resources. This has been delivered across multiple contexts including the control of invasive species (Burslem, Douglas, Lambin, Travis), development of tools that minimise fisheries by-catch (Fernandes, Marshall) and the deployment of renewable energy devices (Scott, Thompson), the control of emerging zoonotic diseases (Telfer), ecological and evolutionary constraints on population viability and ecosystem services (Burslem, Reid) and the resolution of conflict between biodiversity conservation and human livelihood (Redpath, Van der Wal). We have recruited four new staff to consolidate expertise in this area (Bodie, Morimoto, Moseley, Payo-Payo) with increasing emphasis on dovetailing activity with socio-economic outcomes and the integration of new remote sensing and *in situ* autonomous field-based monitoring technology.

Quantitative and modelling capacity is a traditional strength within SBS, with the application of complex quantitative approaches and predictive models across a range of ecological and

evolutionary contexts involving quantitative genetics (Reid), oceanographic processes (Scott, Witte), dispersal (Cornulier, Lambin, Ponchon, Piertney, Telfer), epidemiology (Moseley, Telfer) and multi-trophic interactions (Burslem, Lambin, Van der Wal, Woodin). The School has also **developed several high-profile modelling platforms** that have found broad application within the community. These include: (i) decision support models such as the **“Cool Farm Tool” to enable real world reduction in greenhouse gas emissions** which has been adopted by 82 of the World’s largest agri-food businesses (Smith-P, Smith-J, Hastings – see impact case study); and (ii) the “Rangeshifter” platform (Bocedi, Travis), a **state-of-the-art individual based simulation software for predicting eco-evolutionary dynamics in complex landscapes** that is being used in multiple projects and across several countries in the context of rewilding, ecological forecasting, epidemiology and response to environmental change.

Recruitment of new staff over the assessment period has been made with explicit recourse to increasing our bioinformatics, biostatistics and modelling skills base (Bodie, Fisher, Layton, Malik, Morimoto, Payo-Payo, Pilakouta, Sleight, Vogwill). Moreover, there has been considerable investment in high performance computing capacity and staff training opportunities to underpin the move towards big data analytics.

SG Research Strategy REF2014 – REF2021

In REF2014, the UoA7 submission was solely focused on SG staff, with research centred on geology, geophysics and physical geography to emphasise a strategic re-focussing of our research across the Earth and environmental sciences and diversification from our traditional interests centred on hydrocarbons. In total, 28.4FTE were submitted with 89% of our overall research activity ranked as 3* or 4* quality. Restructuring within the University and School since 2014 has continued this diversification with the integration of six social scientists and three palynologists. Within this context, our research strategy in the REF period has had three core elements:

1. Integration through advancing Earth observation. Since REF2014 we have advanced and diversified our capability to generate extensive and intensive data streams across our main areas of research strength, through strategic appointments and investment in novel, advanced field equipment. This has driven greater integration and interdisciplinary collaboration between our clusters. New appointments have extended our capacity in geophysics, for example, in passive seismology (Gilligan, Loer), machine learning (Giannakis) and characterisation of shallow depths, which have environmental and socio-economic implications (Comte). This has received sustained investment by the University in developing the Aberdeen University Geophysical Equipment Repository (AUGER), which provides a wide spectrum of techniques for subsurface characterisation. Likewise, in tectonics, a new rock physics and geomechanics laboratory supports by new staff (Gan) and fosters collaboration with other sub-groups on issues as diverse as the role of fractures as hydrogeological controls and structural influences on ice sheet movement. New appointments have also enhanced geochemistry capability, notably through use of Raman spectroscopy (Muirhead), which has helped provide a basis for integrating the new palynology sub-group (Mauquoy, Mighall, Schofield-E) within the Basin Fill cluster. The appointments of Geris and Haro ensure new capability in hydrology and enabled the establishment of a new experimental catchment to assess land use change effects on water resources. Meanwhile, strengths in the sediment system sub-group have been consolidated by new capacity in deep water sediment systems as resources and geohazards (Brackenridge).

2. Establishing the Planetary Atmospheres and Surface Process Cluster is a focused strategic investment by the University that builds capacity in Earth and planetary observation. It provides a hub for integration across the Unit, but also externally with the UK Space Agency, British Antarctic Survey (BAS) and industry. Staff bring world-leading expertise in space exploration and environment sensor design (Martin-Torres, Zorzano), as well as new capabilities in remote sensing and GIS applications (Bhardwaj, Sam, Singh). The group diversifies existing capacity in the use of unmanned aerial vehicles (UAV) in advanced earth surface characterisation (Howell). New initiatives include development and deployment of environmental

sensors and remote sensing applications in glaciology (with Rea, Spagnolo) and research on planetary analogue environments with BAS.

3. Interfacing with the social sciences: the newly established Environment and Society group provides a platform for expanding our research more explicitly in a range of societal global challenges beyond those related to energy. New appointments build capacity in coastal zone and marine resource management (Potts), agri-food policy (Prager), cultural ecosystem services (Wartmann), urban geography (Pierce) and the demographics of coastal communities (Duffy). Increased interdisciplinary work with traditional areas of Earth science are being developed (e.g., Haro in water security) and is further facilitated by collaboration with ecological and climate modellers in SBS.

UoA7 Research Strategy REF2021 – ONWARDS

Within **SBS**, new investment in facilities (section 3C) and the appointment of new staff over the previous REF period (section 2A) provide further capacity to leverage research achievement and impact around the cross-cutting theme of understanding the **fundamental biological consequences of environmental change**. Our research focus will further emphasise multidisciplinary approaches to understand, measure and manage ecological, environmental and evolutionary resilience across different scales of organisation (populations, species, communities, landscapes) to different drivers of natural and anthropogenic environmental change. Our research activity will continue to be both challenge-led and curiosity-driven and translated to deliver impact and influence wherever possible. There are several emerging sectoral and technological opportunities that the School will exploit. These include issues such as **decarbonisation**, especially around carbon capture and storage, the deployment of renewable energy devices, the decommissioning of oil and gas infrastructure and biodiversity offsetting; **rewilding and the effective management of natural capital** especially in the context of **new socio-political landscapes** for the management of natural resources, such as fisheries management in a post-Brexit UK and changing land-use; and **new 'omics, experimental evolution and gene editing technologies** allowing more mechanistic understanding of the genetic basis of ecologically relevant traits in non-model systems and novel interventions in the management and conservation of natural resources and eradication of invasive species.

For **SG**, we are widening our focus on fundamental research into the Earth and other planetary systems and deepening our work in partnership with various end-user communities to ensure our research has impact and serves key societal and commercial ends. Three priority cross-cutting themes emerge going forward. Firstly, the diversification of our Earth Systems Science **research continues to evolve and align with the energy transition**. This cements our strategy within the University's core Energy Transition theme and adapts our traditional research strengths developed from collaboration with the hydrocarbons industry but now evolving to support the energy transition. Examples include research to characterise fracture patterns, processes and fluid pathways in geothermal fields and potential subsurface CO₂ storage sites, and in reducing uncertainty in forecasting fault distributions that can compromise the integrity of nuclear waste repositories. The SG remains an international magnet for applied research associated with the energy sector, as evidenced by a large international PhD community in this area. Our involvement in the GeoNetZero Centre for Doctoral Training (<https://geo-net-zero.hw.ac.uk/>) will diversify graduate research in this field. Secondly, **leveraging investment in the Planetary Atmospheres and Surface Process cluster to provide a hub for synergies** across other research groups and between SG and SBS. Integrating themes include the development of new environmental sensors, particularly for extreme environments, and remote sensing applications with momentum building through involvement in the ESA/IKI ExoMars 2022 mission. Finally, we will prioritise **strengthening the social dimensions of our Earth and environmental research** through internal and external collaborations on national and international challenge-based research.

There are several cross cutting strategic objectives that underpin all activity across the Unit:

(i) **Interdisciplinarity** - the *Aberdeen2040* strategy identifies challenge-led, interdisciplinary research in the service of others as central to our ambition. Fundamental discovery research and pathways to impact frequently demand interdisciplinary solutions that emerge from inter-School collaborations, increasingly with the dovetailing of social science aspects. This activity gain added impetus through the University-prioritised *Environment & Biodiversity* and *Energy Transition* interdisciplinary themes, which provide a springboard through which different disciplines can integrate to magnify their impact, providing added value, capacity building and generating new synergies. SBS and SG staff have been instrumental in developing and applying this theme-based approach to facilitate broad and previously refractory collaborations.

(ii) **Translational research and pathways to impact** – we are developing and expanding our links with key end-users across government, industry and other stake-holder groups. Working through the University interdisciplinary themes, we engage in dialogue between science and end-users to identify and address relevant questions and translate science into integrated evidence to help inform policy decisions to deliver real economic and societal impact. We will also form closer links through our existing DTP collaborations and interactions using student training and placement as a conduit to closer research links.

(iii) **Capacity building** – people are at the heart of our strategy, and, going forwards, we ensure that our recently appointed researchers have the support to build collaborative networks, focus on leading edge research questions linked to societally relevant issues, secure research funding and effectively translate research to impact. We will build on our existing DTP and seek new collaborations to provide more critical mass around key environmental challenges. We will also attract and support further independent research fellows who align with existing research strengths and where we can develop their careers. This is facilitated by our Grants Academy fellowship mentoring programme, designed out of the *Vitae Researcher Concordat* to support high quality ECRs at all stages of the fellowship application process.

(iv) **Robust, reproducible and open research** - The Unit's research and impact strategies are directed to all aspects of research integrity and governance, transparent, robust and reproducible research practice, open data and publication. This enables the delivery of the highest quality research, maximises dissemination of research findings to facilitate both academic and non-academic impact and leverages future collaboration and interaction. We will continue to ensure that all our research practice complies with the University's *Research Governance Framework*, *Universities UK Concordat to Support Research Integrity* and the UK Research Integrity Office *Code of Practice* to deliver the highest standards of excellence, honesty, integrity, rigour, transparency, accountability, care and respect and foster both disciplinary and interdisciplinary approaches (see section 3D). We will i) ensure training around all aspects of research ethics and integrity, effective research governance and open access for researchers at all levels; and (ii) echoing the UKRI open data mandate, as described in the *Concordat for Open Data*, we will ensure all data and metadata are deposited into EIDC, BODC and online repositories such as Genbank, PANGAEA metadata repository for Earth and environmental sciences, the D4Science virtual research environment and DataCite open. The Unit continues to support and encourage pre-print submission onto BioRxiv and EarthArXiv, with open publication of R Markdown, PERL and Python scripts via DRYAD, *figshare*, GitHub and equivalent open repositories.

1C. IMPACT STRATEGY

Translating research excellence into non-academic impact is central to our research ethos and embedded within our strategy. Our case studies showcase the global reach of our translational research activity, highlight the spectrum of end-users, stakeholders and policy makers that benefit, and illustrate the UoA impact strategy in practice. For example, they highlight global and transformational influences on greenhouse gas reductions (Smith-P), direct and substantial influence on industry and the economy (Bond, Schofield-N) and major influences on national and international construction practices and decision-making (Thompson). These are

only a proportion of our activity that is benefitting the awareness, attitude, behaviour, capacity, performance, policy, process and understanding of various end-user groups, from local community to government and industry. Other examples of our research programmes with a positive impact locally, nationally and internationally, across a range of REF-defined areas of impact, include:

- 1) Telfer's research on ecological, environmental and socio-economic drivers influencing the spread of plague, leptospirosis and hantavirus in Madagascar that impacts on the health and wellbeing of people and animal welfare and control of diseases in developing countries.
- 2) Paton's research developing technologies for the sustainable remediation of contaminated land and water that levered Scottish Government and Scottish Enterprise investment funds and contributed to innovation through the delivery of new products that led to spin out companies generating economic benefits and jobs (Esh Remedios and Epona Technologies).
- 3) Norton and Price's work around sustainable rice production that has provided gains in productivity realised as a result of research led changes in practice around the water saving capabilities of alternate wetting and drying regimes for rice paddy cultivation and the identification of rice varieties carrying genomic loci for traits relevant to sustainable production.
- 4) Lambin, Burslem and Travis's Newton-funded multidisciplinary research on alien invasive species management in South America that will protect biodiversity, conserve natural resources and preserve rural livelihoods.
- 5) Reid's work building on a REF2014 impact case study that has put in place a range of conservation measures including habitat management, parasite treatment and supplementary feeding to help prevent the extinction of threatened red-billed choughs in their remaining Scottish populations.
- 6) Hurst's long-standing research into the identification, assessment and management of petroleum reservoirs in sand injectites is in its 4th cycle of funding by industrial consortia, contributing to economic development and wealth creation.
- 7) Howell's SAFARI (Sedimentary Architecture of Field Analogues for Reservoir Information) research consortium is also in its 4th cycle of funding and provides an on-line resource of virtual outcrops to aid reservoir assessment for a wide range of industrial partners and sponsors.
- 8) Phillip's work on the long-term impacts of flooding on rural communities has informed government on the health and well-being consequences of extreme floods on economically fragile communities.

Our strategy to **maximise impact** from our research is structured around the following routes:

- 1) Development of a high-quality research portfolio addressing key societal issues - **the foundation of our approach to the generation of impact from research is to develop and direct a portfolio of internationally excellent research activity addressing end-user demand and grand societal challenges**. A major University-wide research mapping exercise by Lusseau used machine learning techniques to align all the University research outputs within the REF period to UN Sustainable Development Goals to identify novel areas of inter-, multi- and transdisciplinary collaboration that were previously refractory. This is used to coordinate researchers across disciplines and provide horizon-scanning capability for emerging research opportunities that ensures that research emphasis is underpinned by societal need.
- 2) Researcher training - **Impact training is embedded in staff development programmes for researchers at all levels**. The University Researcher Development Unit, with School-based dedicated Research Development Advisors, deliver tailored training on how to consider and deliver impact from development through execution of a project. We provide workshops, good-

practice case studies and networking opportunities which focus on knowledge exchange, development of pathways to impact plans, communicating research to the public, interacting with end-users, entrepreneurship and research commercialisation (see section 2A).

3) Engagement with stakeholder and decision-making groups (see section 4A) – **We recognise that impact is maximised through effective and recursive engagement with key end-user groups.** This ensures that our research is both relevant and developed in partnership, and that Unit staff are positioned to influence research priorities and future research agendas to place us at the forefront for new and emerging areas. Our relationships with end-users are based upon successful, long-term interactions (e.g., NatureScot, Royal Society for the Protection of Birds, James Hutton Institute, Centre for Ecology & Hydrology, Beckley Foundation). Likewise, in the geosciences, we have long-standing collaborations with a wide range of strategic partners in the energy industry, with Joint Industry Projects involving both major corporations and smaller companies. Relationships are maintained by inclusion of end-users in student supervision and as collaborators on research grants, by researcher and student placement in end-user organisations and by funding research showcasing events, colloquia, meet-and-greet and catch-up sessions and workshops relevant to industry, policy makers and practitioners. We support and encourage staff to participate on Boards, Committee and Advisory Groups where there are clear opportunities for end-user engagement and to leverage impact and influence (see section 4). We have high-level engagement at national and international policy levels (e.g., Science Advisory Board to UK Global Food Security programme (Smith-P), ESA/NASA working group on Mars/Exo Rover (Martin-Torres)), which allow us to inform practice at the highest levels of decision-making.

4) Public engagement and knowledge exchange – (i) The Unit has embedded researcher-led public engagement, supported by a dedicated Public Engagement with Research Unit (PERU) to assist in the implementation and promotion of the strategy. Unit staff exploit events such as Café Scientifique, Café Med, Café Controversial and Café Light; *Techfest*, Aberdeen’s annual science festival; and Word, Aberdeen’s annual literary festival, to maximise dissemination of results and impact; (ii) **We provide dedicated internal funds to promote impact and Knowledge Exchange (KE).** These include a central Knowledge Exchange and Transfer Fund to pump-prime projects that enhance relationships with industry, public or third sector partners; discretionary funds held by Institute research directors to invest in KE activity; and (iii) maintain close links with our dedicated Communications Team (CT), which forms the critical link between researchers and public through local, national, specialist and international media. The CT issues around 400 press releases a year in addition to regularly placing stories with key media and identifying researchers for expert comment (see section 3B).

5) **Exploitation of commercialisation potential** – The Unit is supported by the central Research and Innovation (R&I) team (see REF5a) of business development and commercialisation professionals to embed intellectual property (IP) agreements in all research awards, translate research excellence into commercial application and develop and direct knowledge transfer activities. There are dedicated R&I staff in SBS and SG to ensure the most appropriate routes to impact are identified and exploited. They help develop a researcher’s impact plans and provide administrative and logistical support to ensure its implementation, including protection of IP, patent application and spin-out companies (see section 3B).

Section 2. People

2A. STAFFING STRATEGY AND STAFF DEVELOPMENT

Our staffing policy is centred on: (i) the **appointment of scientists who are world-leading in their fields** or are early career scientists on an upward trajectory towards becoming future research group leaders; (ii) a **strong commitment to the development, training and mentoring of researchers** at every stage of their career, from doctoral training, through ECR and to the professional development of established academic staff; and (iii) **nurturing an environment that promotes opportunity, equality and inclusion.** This, in turn, has also

sought to build capacity in key areas, further interdisciplinarity, facilitate succession planning and has resulted in a more diverse researcher community.

The REF period has seen considerable turnover of staff in both SBS and SG, which has allowed for pro-active aligning of appointments with research priorities and strategy. Since 2014, we have appointed 32 new staff across SG and SBS, providing a balanced complement of career stages within the submission (33 Professors, 9 Readers, 21 Senior Lecturers, 15 Lecturers and 11 ECR fellows). These new appointments exemplify our dual strategy for recruiting both established group leaders who already have international reputations and supporting ECRs with exceptional promise. Two Chair level appointments (Martin and Zorzano) have established the *Planetary Atmosphere and Surface Process* research cluster extending and expanding research capacity within SG, plus facilitating interactions with SBS through common interests in remote sensing and extreme environments. SBS has also recently completed a major initiative to recruit early career postdoctoral researchers (Bodie, Fisher, Morimoto, Payo-Payo, Vogwill) into academic fellowship positions aligned with current research strengths. These positions mirror research fellowship schemes offered by UKRI and equivalent funders and provide the support and academic freedom for fellows to undertake independent research and develop their own research groups, with proleptic appointment onto academic staff.

Working with an assigned mentor, all new academic staff prepare a three-year plan of objectives which is reviewed annually and forms part of a 36-month probation. New staff have lighter teaching and administration loads to allow them to establish their research groups. They are also provided with dedicated research laboratory space and are prioritised in resource allocations and PhD studentships. Each new start member of staff identifies training needs from the outset, and these are met through the course of probation. New staff are provided with mentoring and support around grant applications and provided with an allocation of School discretionary funds to kick-start research activity and generate preliminary data.

All staff have a designated Academic Line Manager (ALM) who coordinates an annual review. This exercise provides opportunities for staff to reflect on research activity over the previous 12 months, identify impediments to progress and consider target setting for the coming year. It also strategically informs research teaching and administration loads and identifies opportunities for staff development for which there is a dedicated budget. A *Framework for Academic Expectation* is provided to enable staff to benchmark their research activity and performance with colleagues and achieve equity in teaching and administrative loads for different stages of career.

Recruitment, training and support of independent research fellows (IRF) is a key part of our research strategy. There is an established framework for mentoring postdoctoral staff and an application development and mentoring programme for potential applicants that involves a “traffic light” system to identify appropriate funding opportunities and provide bespoke support for application and career development. Over the REF period we have **hosted a number of highly prestigious independent fellows**, including Aden (Marie Skłodowska-Curie Actions - MSCA), Bocedi (Royal Society University Research Fellowship), Cochard (MSCA), Feliciano (NERC Knowledge Exchange Fellowship), Gilligan (Royal Astronomical Society Fellowship), Gubry-Rangin (Royal Society URF), Gormley (NERC KE), Kumari (MSCA), Lee (MSCA), Losdat (MSCA), Martin (MSCA), Moseley (Wellcome Trust Clinical Research Fellowship), Mustin (MSCA), Ponchon (MSCA), Sheehy (MSCA), Telfer (Wellcome Trust Senior Research Fellow), Twedde (NERC KE), Zabala (MSCA). All IRFs who have been awarded a five-year fellowship have secured pro-leptic lectureship positions within the University with fast-tracked probation (since REF2014: Gubry-Rangin, Telfer, Moseley).

The University is a signatory, and active implementor, of the *Vitae Concordat to Support the Career Development of Researchers* and has successfully gained the HR Excellence in Research Award in 2014, 2016 and 2018/19, demonstrating alignment with the European Charter for Researchers. Our delivery of the *Vitae Concordat* principles is led by the University's Postdoctoral Researcher Committee, with an action plan to address the principles and obligations around research environment and culture, employment practices and professional and career development policy and practice for research staff. Our approach for the transparent and robust assessment of research quality for any and all purposes is compliant with the

principles and practices in the San Francisco Declaration on Research Assessment (DORA) and the Leiden Manifesto, with the University being a signatory of the former. As such, no reference to citation metrics (e.g., h-index) are included in job application review, promotion documentation or annual review and appraisal.

We retain a number of Teaching and Scholarship lectureships to support strategic areas. These teaching-only positions enhance our research activity by freeing up time to enable researchers to maximise research application, output and impact. The success of this strategy is evidenced by **three members of SBS academic staff with long-term reduced teaching loads being elected as Fellows of the Royal Society of London** (Prosser and Smith-P to UoA7, and Speakman to UoA5) during the REF period.

We have in place pro-active succession planning with targeted recruitment to ensure there is no loss in critical mass or in strategic priorities or research quality as well as an appropriate transition period.

All research staff are supported through the central *Grants Academy* (see REF5a) during all stages of the research grant application - from identifying funding opportunities, stimulating new ideas for grant applications through *Grant Foundry* events and supporting their development, to facilitating the effective translation of research excellence into non-academic impact, patent applications and spin-out companies (see section 3B).

2B. SUPPORT TRAINING AND SUPERVISION OF PhD STUDENTS

The **training and development of PhD students is a fundamental component of our research strategy**. The UoA is has trained and supported a total of 287 students since 2014. The Unit is a partner in three UKRI doctoral training partnerships (DTP) and two Centres for Doctoral Training (CDT): QUADRAT-DTP (NERC funded), SUPER-DTP (NERC funded), EastBio-DTP (BBSRC funded) and NERC funded CDTs in Oil and Gas and GeoNetZero. The QUADRAT-DTP is a new partnership between SBS and SG with equivalent Schools at Queen's University Belfast supporting 20 students per year for five years. This provides a major impetus for collaboration and a cross-School cohort of students providing critical mass in interdisciplinary research. The EastBio DTP is now in its third cycle of funding, having been renewed in 2015 and 2019, a testament to the high quality of training delivered. This is now the 3rd largest BBSRC DTP in the UK, with matched funding from the partnership and industry creating 60 full studentships per annum.

We also **recruit students through joint funded strategic partnerships** such as with Marine Scotland Science, the James Hutton Institute, National Decommissioning Centre, Scottish Aquaculture Innovation Centre, the Scottish Government's HydroNation scheme, and through research pooling initiatives including SAGES and MASTS. The University has improved the international reach of its PGR programme with its *Elphinstone Scholarship* initiative, which provides a full international tuition fee waiver scheme that allows the best students from across the world access to our doctoral training. Since 2014, 12 *Elphinstone* students from across five LMI countries have graduated from the Unit.

Combined, the Unit welcomes a new cohort of, on average, 21 new PhD students each academic year over the REF period, which guarantees a vibrant research community for postgraduate research and training. Over the REF period 21 PhD projects have been CASE partnered, highlighting our involvement with a range of end-users and stakeholders to support translational research and promote applied impact.

The University Postgraduate Research School (REF5a) oversees all aspects of PhD student appointments, training and monitoring of progress. Candidates are selected based on criteria that include academic achievement, motivation and potential ability to complete a PhD programme and engage as part of a broader postgraduate cohort. Each research student has a

minimum of two Aberdeen-based supervisors and an advisor to whom they can turn for independent advice. Supervisors undertake mandatory training on effective supervision and pastoral care for students and hold at least monthly formal recorded meetings with students. Student progress is monitored through six-monthly reviews, providing an opportunity for students to reflect on achievement and map out objectives. These are reviewed by the School Postgraduate Officer and the Graduate School. A formal 9-month review of progress is made by written report, oral presentation and a viva with two members of staff. Students may be confirmed for entry into year two, recommended for a remedial programme of work or have progress halted. In year 2, students submit a draft manuscript and present a poster at an internal "Research Day". In year 3, students deliver an oral presentation at a postgraduate symposium run within each School. At 27 months, students submit a thesis plan and progress is reviewed until completion. The success of our training environment is evidenced in our thesis submission rate of over 90% for the REF period.

All PhD students follow a "**T-shaped**" training model whereby they develop disciplinary excellence around a specific research project but also gain a breadth of knowledge and a diverse, transferable core and generic skills base to ensure that upon graduation they are competitive for a range of different career paths. Development of research skills, transferable generic skills and discipline-specific techniques are defined in an individual student's Personal Development Plan. Mandatory training courses include an induction workshop on scientific conduct, research ethics and governance, health and safety, project design, scientific writing, data handling, statistics, presentation skills, entrepreneurship and knowledge exchange. Central to training is the provision of non-academic placement experience for students. This is a formal part of training across the DTPs involving a 3-month secondment with a research partner not directly associated with the student's immediate project. This provides students with broad experience and outlook and an opportunity to develop skills and experience away from an academic environment and helps with employability through development of contact networks. We also provide fully funded **Research Experience Placements** for undergraduate students from STEM subjects outside environmental science as part of our QUADRAT DTP to facilitate multidisciplinary interaction and widen participation.

An integral part of our PhD student DTP training is around professional development, which is formalised through **students attaining a CMI level 7 Certificate in Strategic Management and Leadership (QUADRAT-DTP) and a PG Certificate in Researcher Professional Development (SUPER-DTP)**. We encourage all students to gain professional accreditation where appropriate (e.g., Royal Society of Biology, Geological Society of London, associate fellowship status with AdvanceHE); present their research at international conferences and early career workshops; participate in internal and external seminar series; and lead journal clubs and research discussion groups. This is exemplified by the *Aberdeen Study Group*, a student-led network that interacts to share and develop coding skills (R, Python, Perl) and tools and facilitates co-working around coding and open access issues.

2C. HOW THE UNIT SUPPORTS AND PROMOTES EQUALITY, DIVERSITY AND INCLUSION

Inclusivity is a pillar of the *Aberdeen2040* strategy, and the promotion of equality, diversity and inclusion is central to the activity and strategy of SBS and SG. The University has a suite of key performance indicators around EDI issues and an EDI advisor and EDI oversight group to monitor progress, activity and compliance. All new University and School policies are subject to a full EDI audit. The University is a signatory of the Advance HE's Race Equality Charter, aiming to improve the representation, progression and success of minority ethnic staff and students. Both SG and SBS have a specific Equality and Diversity committee, and separate Athena Swan committees leading the Schools' next stage of accreditation from their current bronze status. All staff and students undertake mandatory equality and diversity training with refresher exercises to maintain awareness. We blend formal accreditation and procedure with informal approaches to raising awareness and providing support around EDI issues. This has been informed by a series of University or School led staff surveys that consider how policy and practice could be improved. Input has led to an action plan and brought about changes in ways of working that include: gender-balanced interview panels for all appointments at any level; inclusion of EDI

questions as part of the interview process; including a male and female point of contact for any job adverts; policy that administrative meetings, seminars and events occur within core working hours of 10-00 to 16-00; gender-balanced seminar speaker programmes; monitoring and adjustment of all electronic and printed material for gender balance and ethnic diversity; family-friendly social events; encouraging ECRs to join and lead administration and strategic committees; and increased awareness of bullying and harassment procedures.

Staff returning from periods of leave, including parental leave, other caring responsibilities, or after long-term ill health attend a “return meeting” with their line manager to aid the return-to-work process. Long-term ill health effects are managed with the professional help of occupational health, with reasonable adjustments to working practice, for example, phased return, altered start and/or finish times or a period of homeworking.

The University has a range of policies and practices in place to support the wellbeing of staff including: a commitment to consider proposals for flexible working and job sharing from staff; an annual leave purchase scheme; wellbeing coordinators and mental health champions within Schools; mental health first aid and mental health awareness training for staff; and mental health support services. The University runs a Workplace Dignity Network to provide support to staff in cases of bullying/harassment, stress, work relationships, work/life balance or mental health issues.

Section 3. Income, infrastructure and facilities

3A. INCOME

Staff submitted to this UoA have achieved around GBP59M of research income since 2014. This has been awarded from a diverse range of funding agencies reflecting ability to attract funds that cut across conventional discipline boundaries, with around GBP22.6M (38.3%) coming from RCUK/UKRI, GBP15M (26%) from industry and GBP4.2M (7.2%) from charitable bodies. Selected examples of major research grants from across funding sources that highlight the global scope of activity and impact include: GBP1M to Telfer from Wellcome to determine effects of rodents on plague epidemiology in rural Madagascar; GBP1.1M to Lambin, Burslem, Cornulier and Travis from NERC for adaptive management of invasive species in South America; GBP1.1M to Geris, Hallet and Soulsby through linked grants from NERC on sustainable soil and water management in China; GBP2.6M to Thompson from Beatrice Offshore Windfarm Ltd and Moray Offshore Renewables Ltd to monitor effects of deployment of renewable energy devices on marine mammal populations; GBP2M to Hurst from a consortium of energy companies to improve assessment of sand injectites as petroleum reservoirs; GBP1.3M to Smith-P from BBSRC to provide solutions for intensified crop productivity supported by closed-loop N cycling in Chinese agriculture; and GBP1.1M to Howell from a consortium of energy companies for virtual outcrop tools for reservoir assessment.

3B. INSTITUTIONAL INFRASTRUCTURE

The University provides support for researchers at all stages of the research process:

The *Grants Academy* provides support developing research ideas and identifying funding opportunities. This is facilitated through the *Grants Foundry* programmes within Schools where staff are invited to present nascent research ideas to help hone experimental design, identify collaboration and recognise appropriate sources of funding. The Grants Academy also supports internal funding opportunities to catalyse research and enable knowledge exchange and impact success. These include the Global Challenges Research Fund (GCRF) Internal Pump-Priming Scheme, the Wellcome Trust Institutional Strategic Support Fund (ISSF), the Core Facilities Voucher Scheme and the Research Enhancement Scheme. The enhanced support afforded is evidenced by Telfer and Moseley, who used Wellcome Trust ISSF support to help underpin subsequent successful independent fellowship applications to the Wellcome Trust.

The *Research Financial Services* (RFS) team undertakes project finance planning, with *R&I*, supporting grant review and submission, formation of collaboration agreements, development of

pathways to impact plans, creation and protection of IP and patent applications. This commercialisation support is exemplified by Paton's spin out company Epona Technologies, which was developed through a NERC CASE studentship and evaluated the use of a whisky by-product for the remediation of contaminated waters. The technology secured Scottish Enterprise Proof of Concept Funding (PoCF) which secured a patent and took the product to market. R&I underpinned the cost of a team member to lead Epona Technologies through company start-up, director training, IP management and all the other key skills to transform scientists into credible entrepreneurs. R&I worked closely with Scottish Enterprise on the post PoCF stage to enable Epona Technologies to trade and cooperated with SBS and other parties to host and service the company. Once established and trading R&I were essential in the sale of the company to a third party, confirming their ability to transition credible IP into genuine value. In the case of Remedios/ Esh Remedios (spin out by Paton), R&I were able to work with a fifteen-year-old spin-out company in diversifying and updating its offering through Scottish Enterprise funding and SBS laboratory support to enable a trade sale to a GBP250K turnover company based in the north of England. This redirecting of science and technology deliverables was only made possible through innovative collaboration between all of the partners and a recalibration of the IP position.

The *Public Engagement with Research Unit* (PERU) coordinates downstream knowledge exchange, public engagement and research dissemination activity. This includes the University *Communications Team* (CT) which forms the critical link between researchers and public through local, national, specialist and international print, broadcast and social media. CT issues around 400 press releases a year in addition to regularly placing stories with key media and identifying researchers for expert comment.

IT services provides support on all aspects of research data management and archiving, with 2TB provided for all staff and individual projects. The *Library, Special Collections and Museums* directorate coordinates aspects of Open Research, running the Aberdeen University Research Archive (*AURA*), our open access repository for data and also coordinating green or gold route open access for publications (section 3D).

3C. FACILITIES

The University offers a suite of Technology Hubs that are state-of-the-art analytical core facilities and provide research advice, training and support around genomics, cytometry, chromatography/spectrometry, microscopy/histology, proteomics, qPCR and antibody/peptide library screening. Each is managed by dedicated and experienced staff responsible for support and training.

Overall investment in analytical infrastructure and facilities regularly used by Unit staff and students since 2014 totals over GBP7M. Key components that underpin research outputs through the current REF period include: 1) increased investment in the Centre for Genome Enabled Biology and Medicine (CGEBM; www.abdn.ac.uk/genomics) to support increased bioinformatics expertise and capacity and updated/expanded multi-'omics hardware. This now includes Illumina MiSeq, NextSeq500, Ion Torrent proton and Oxford Nanopore GridION sequencers and a 10x Genomics Chromium system for single cell sequencing applications; 2) upgrade of the Maxwell high-performance computing cluster to 1240 CPU cores, 12TB of RAM and 1PB of storage; 3) Aberdeen Centre for Electron Microscopy, Analysis and Characterisation (ACEMAC), which provides a state-of-the-art nano scale electron microscope facility; 4) flow cytometry and cell sorting facility that includes Becton Dickinson and Attune NxT instruments, a BioPlex 200 for multiplex bead analysis, an Image Stream for single cell image cytometry and a BD Influx cytometric cell sorter; 5) climate controlled experimental evolution facility; 6) greenhouse refurbishment with GM growth facilities; 7) Refurbishment of freshwater and saltwater aquaria with high biosecurity freshwater pathogen challenge, and associated zebrafish breeding facility designed for use of GM models; 8) Skyscan 1072 and Nikon XT225ST MicroCT facility; 9) upgraded environmental analytical suite including ICP-MS, LC-ICP-MS, FAAS, HG-AAS, FIA, Los Gatos laser spectroscope for liquid/gas stable isotope analysis, field deployable

Picarro, GC-FID/ECD and TOC; 10) a new rock physics and geomechanics laboratory with high pressure/temperature triaxial rock deformation apparatus for strength and permeability testing (along with permeameters, porosimeters and acoustic velocity apparatus), funded through NERC, Industry and the Oil and Gas Technology Centre (OGTC); 11) development of a Raman spectroscopy facility for analysis of sedimentary of organic matter, along with a general upgrade of the organic geochemistry suite with GC – MS for C stable isotopes; and 12) Mars environment simulator established with ESA funding.

This analytical investment adds to the world-class array field data acquisition systems and interpretation facilities in the following areas, which have been developed or enhanced from externally won and internal investment funds. New platforms for earth and planetary observation systems include: (1) A new terrestrial LiDAR system. (2) An upgraded and extended fleet of UAVs (drones) and associated remote sensing platforms. (3) Two fully instrumented hydrological observatories and research catchments (one newly established in the REF period) variously funded by ERC, NERC, Royal Society, Carnegie Trust and the Scottish Government. (4) The University also invested in the Aberdeen University Geophysics Equipment Repository (AUGER) (managed by Cornwell) with new, in-house capability for seismics, magnetometry, ground penetrating radar and electrical resistivity tomography for subsurface characterisation. We have continued to maintain and enhance the SeisLab computer suite for seismic interpretation funded through industrial partnership.

We have also secured more than GBP600K in **major NERC capital equipment grants** to expand the research infrastructure and facilities available for staff: PolyExESS - PolyEXtremophile Environment Simulation System (Piertney), a mobile isotope and GHG laboratory (Johnson); and a multi-vis X-Ray CT Scanner (Hallett).

The University, alongside the Oil and Gas Technology Centre (OGTC; www.ogtc.com) and as part of the Aberdeen City Region Deal, has invested GBP38M in the UK National Decommissioning Centre (UKNDC.com). This state-of-the-art research and development hub was opened in 2019 to partner industry R&D demand with academic capability and skills to transform all aspects of the decommissioning process, including extending field and asset life and environmental impacts. The NDC funds knowledge exchange postdoctoral fellows and PhD students within the Unit (Fernandes, Kuepper, Paton, Piertney) and brokered new industrial collaborations (e.g., with Chevron).

The University has invested GBP39M in a state-of-the-art *Science Teaching Hub* facility (opening 2022) that will consolidate all science laboratory classes. While this is mainly for teaching and learning, the building will include dedicated space for public and stakeholder engagement, science outreach and conference hosting. It will also provide a unique space for research skills training for both staff and PGR students. This facility will also enable focussed investment to transform previous teaching and learning laboratory spaces dispersed across Schools into multiple group occupancy laboratory space designed and fitted for specific research sub-disciplines. This will future-proof research needs aligned with current strategic research priorities, enhance capacity, widen applications, upskill the technical and research teams and activate new multidisciplinary collaborations.

3D. RESEARCH INTEGRITY AND GOVERNANCE, UNDERPINNING ROBUST, REPRODUCIBLE AND OPEN SCIENCE

The University's *Research Governance Framework* provides the bedrock for all aspects of transparent research integrity and governance, robust and reproducible research practice and open data and publication. This framework complies with the Universities UK *Concordat to Support Research Integrity* and the UK Research Integrity Office *Code of Practice for Research* to deliver the highest standards of excellence, honesty, integrity, rigour, transparency, accountability, care and respect and foster both disciplinary and interdisciplinary approaches.

The University's Research Policy Committee has overarching responsibility for ensuring rigour and consistency in our research ethics and governance arrangements, which then reports upwards to Senate and Court. There are clear mechanisms in place to monitor research governance practice, involving independent scrutiny and assessment by the University Deans and Vice-Principal for Research. An annual exercise is also undertaken whereby the data provenance of a random selection of publications is verified by research Directors and Deans.

Research involving animals is governed institutionally by the Advisory Group to the Establishment Licence Holder and the Animal Welfare and Ethical Review Body, which carries out robust ethical reviews on all research proposals submitted to the Home Office as part of personal and project licence application. There is a Biological Safety Committee that oversees research using genetic modification and wild-type organisms, a separate ethics committee for research involving interaction with the public and external bodies through questionnaires and a Nagoya Protocol oversight group to ensure compliance around any biodiscovery activity.

The University and Unit recognise the importance of open research, incorporating the FAIR principles (Findability, Accessibility, Interoperability and Reusability) which are being applied to *Open Access, Data and Platforms/Tools*. The University has a policy for Research Data Management and all PIs now include a data management plan in research proposals. We comply with the UKRI open data mandate as described in the *Concordat for Open Data*, and the University is a member of the *Research Reproducibility Network*. All data and metadata are deposited into EIDC, BODC and online repositories such as Genbank, PANGAEA, D4Science virtual research environment and DataCite open. The Unit supports and encourages publication of R Markdown, PERL and Python scripts via DRYAD, *figshare*, GitHub and equivalent open repositories. These open data resources are all mirrored on the Aberdeen University Research Archive (AURA), our Institutional open access repository managed by the *Library, Special Collections and Museums* directorate. Unit staff have **published 115 datasets** on AURA since 2014.

The strategic use of the RCUK/Wellcome block grant enables gold-route publication of high-impact publications with green-route publication for all other manuscripts. The Unit supports and encourages pre-print submission onto BioRxiv and EarthArXiv. The University advocates ORCID registration for unique researcher identification through its research governance website.

Online training resources are available for all aspects of research ethics, open research and research integrity and governance. This is mandatory for tenured staff and part of the induction activity for new start researchers. This training is also embedded within the core and generic training modules for PhD students within the Quadrat DTP.

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

4A. RESEARCH COLLABORATIONS, NETWORKS AND PARTNERSHIPS

We have an **outstanding track-record of international and national collaboration**. Since 2014, successful collaboration (defined as joint peer-reviewed scientific papers, joint doctoral student supervision and joint active grants) by the 87 staff has involved over 900 unique Institutions (comprising businesses, universities and government organisations) located in over 80 countries.

We recognise that **benefits to the wider economy and society from our research are maximised through close partnerships with key stakeholders**. This ensures that research being undertaken is relevant to stakeholder needs, and that staff are positioned to influence research priorities and future research agendas. Many relationships with end-users are based upon successful, long-term interactions (e.g., Royal Society for the Protection of Birds, Centre for Ecology & Hydrology, Marine Scotland Science, Beckley Foundation, NatureScot). Our sustained links to the energy industry and contribution to economic activity are well-exemplified in the two Impact Case studies of Schofield-N and Bond. These show how **industry directly**

benefits from our work and respectively show how understanding volcanic intrusions and reduced uncertainty in subsurface interpretation aid reservoir management. Thompson's research on the responses of key marine mammal populations to different stages of wind farm construction (which led to the development of novel approaches to mitigating the effects of piling noise) also yielded **significant improvements in the economic viability of offshore renewable energy schemes** (see Impact case study). Our relationships with end users are maintained by staff involvement in science advisory boards (section 4C); inclusion of end-users in student supervision and as collaborators on research grants where appropriate; by researcher placement in end-user organisations; and by funding research showcasing events, colloquia and workshops relevant to industry, policy makers and practitioners.

The Unit has had a formal alliance with the James Hutton Institute (JHI) since it was founded as the Macaulay Institute for Soil Research in 1930. We share joint appointments (Taylor), field sites, co-supervision of PGR students, joint grant applications and joint infrastructure research bids. Multiple JHI staff have honorary appointments, and this allows for multiple collaborations and shared capacity. The Macaulay Development Trust facilitates partnership through the funding of blue-sky research projects and innovative infrastructure purchases.

Collaborator networks and multidisciplinary research activity are enhanced through Scottish Research Pooling initiatives including the Scottish Alliance for Geoscience, Environment and Society (SAGES), Scottish Universities Life Sciences Alliance (SULSA) and Marine Alliance for Science & Technology for Scotland (MASTS) and doctoral training partnerships (SUPER, QUADRAT). These involve nine HEI and 27 non-HEI partners from across sectors.

Our profile and reputation for multidisciplinary research and impact delivery ensures Unit staff are invited onto new and emerging research networks and partnerships. This is exemplified by Scott being invited to become co-director of the GBP9M EPSRC Supergen ORE Hub (www.supergen-ore.net), a multidisciplinary consortium that was established in 2018 to provide research leadership to connect stakeholders, inspire innovation and maximise societal and economic value in the development and deployment of offshore wind, wave and tidal renewable energy.

4B. AWARDS

Since REF2014 **multiple staff have received prestigious awards or research fellowships**. Highest profile among these are Smith-P and Prosser being elected Fellows of the Royal Society of London (FRS) and Lambin, Redpath, Reid, Soulsby and Thompson as Fellows of the Royal Society of Edinburgh (FRSE). Other notable awards include the Dewey Medal of the Geological Society (Butler), Marsh Award for Marine and Freshwater Conservation (Thompson), RSPB Nature of Scotland Awards (Lambin, Reid, Thompson), Fellowship of the German Academic Merit Foundation (Studienstiftung des Deutschen Volkes) (Kuepper), Norwegian Academy of Science and Letters (Reid), Einstein Fellowship (Einstein Stiftung Berlin) (Soulsby), Fellowship of the Royal Statistical Society (Douglas) and Fellowship of the Institute of Soil Science (Hallett, Paton). Smith-P is also named in the **world's highly cited researchers list**.

4C. SCIENTIFIC ADVISORY ROLES

A key indicator of the wider influence of our research is the range of key science advisory roles for industry, government and academia held by staff. Examples include:

Government/NGO: CEFAS (Marshall), Foods Advisory Committee (Strachan), Food Standards Scotland (FSS) (Strachan – Chief Scientific Advisor), French High Council for Evaluation of Research and Higher Education' (HCERES) (Lambin and Rangin), Gesellschaft für Tropenökologie (Burslem), International Council for the Exploration of the Sea (ICES) (Fernandes, Layton, Scott), IUCN Species Survival Commission (Burslem), Marine Science Coordination Committee (UK Government) (Potts), Marine Scotland Science, Science Advisory

Board (Thompson), Rural Affairs Food and the Environment Strategic Research Board (Strachan), Rwanda Mines and Energy Board (Hurst), Scottish Government's Rural Communities Liaison Group (Phillip), Scottish Marine Energy Research (ScotMER) (Scott), Scottish Natural Heritage (now NatureScot) (Lambin, Reid, Scott, Woodin - Scientific Advisors).

Industry: Fisheries Innovation Scotland (Fernandes), Moray Offshore Renewables Ltd (Thompson), Glensol Enviroklien-ZA Technical Advisor (Bowden), RAB-UK Technical Advisor (Bowden), STW (Inch Cape) Offshore Windfarms (Thompson).

Science/Academia: American Geophysical Union Fellows Selection Committee (Soulsby), Big Van Science (Payo Payo), British Ecological Society (Lancaster), British Ornithological Union (Payo Payo), European Geoscience Union (EGU) Geomorphology Committee (Spagnolo), EGU Ecohydrology Committee (Geris), ESA/NASA working groups on Mars/Exo Rover (Martin-Torres), Geological Society Geo-conservation Committee (Bond), ICS Committee on Space Research (COSPAR) Planetary Protection Commission (Zorzano), LifeScanner (Layton), Marine Synopsis for Conservation Evidence Initiative (Marshall), Orkney Native Wildlife Project Heritage Lottery Fund (Lambin), Royal Society of Edinburgh (Lambin and Lancaster), Royal Society Southeast Asia Rain Forest Research Committee (Burslem), South Atlantic Environment Research Institute (Piertney – Trustee), Scottish Association of Geosciences, Environment and Society (Rea and Spagnolo), Scottish Invasive Species Initiative (Lambin), Spanish Ornithological Society (Payo Payo).

Unit staff are also frequently asked to provide written evidence to both the Scottish (e.g., Fernandes - Culture, Tourism, Europe And External Affairs Committee www.parliament.scot/S5_European/Inquiries/CTEEA_S5_20_FR_012_HeathCookFernandes.pdf) and UK governments (e.g., Scott - Foresight Future of the Sea: A Report from the Government Chief Scientific Adviser https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/706956/foresight-future-of-the-sea-report.pdf)

4D. PEER REVIEW

Participation in the scientific peer review process is an expectation of all staff, with involvement reflecting experience. **Several staff have chaired or participated on national and international grant award committees**, including BBSRC (Douglas), British Ecological Society (Fisher, Wenzel), Carnegie Trust (Douglas, Piertney), DFG (Hallett, Rangin), ERC (Martin-Torres), FCT Portugal (Travis), Academy of Finland (Paton, Piertney, Reid), EPSRC (Scott), UKRI Future Leaders Fellowship (Marshall, Piertney, Travis), Zoological Society of London (Reid), NE Fisheries Science Center (Fernandes), Newton Fund (Burslem), NOAA Alaska Fisheries Science Centre Recruitment Processes Programme (Fernandes), Norwegian Research Council (Fernandes, Paton), NSF (Scott), NSF- Ecology and Evolution of Infectious Diseases Panel member (Strachan), NSERC (Soulsby), Norwegian Research Council (Rea), Royal Society Hooke Committee (Rangin), Royal Society Newton International Fellowship Committee (Reid).

The Unit is particularly active and prominent in NERC, with 12 staff involved with the NERC Peer Review College (Geris, Hallett, Healy, Kuepper, Lancaster, MacDonald, Mauquoy, Mighall, Rea, Redpath, Teh and Travis) and Lambin being Chair of PRC Panel D then E (2014-2016) and Piertney being Chair of Panel C (2018-present). Lambin has also been Chair of the NERC Global Partnerships Fund (2019 – present). Piertney and Thompson have sat on the NERC Special Committee on Seals (2012-2015 and 2015 – present, respectively), and since 2018, Piertney has been Chair of the NERC Biomolecular Analysis Facility (NBAF) now NERC Environmental Omics Facility (NEOF) Steering Group.

4E. EDITORIAL ROLES

Multiple staff have been journal editors over the REF period, including for *Agronomy* (Norton), *Algae* (Kuepper), *Aquatic Conservation* (Thompson), *Biological Nitrification Inhibition* (Rangin), *Biomass & Bioenergy* (Smith-J), *Botanica Marina* (Kuepper), *Current Zoology* (Fisher, Pilakouta), *EGU SOIL* (Malik), *European journal of Agronomy* (Hastings), *Exposure & Health* (Norton), *Fisheries Oceanography* (Scott), *Frontiers in Marine Science* (Payo Payo), *Frontiers in Plant Science* (Norton), *Global Change Biology* (Smith-P), *Global Change Biology Bioenergy* (Smith-P), *Global Ecology and Biogeography* (Lancaster), *Journal of Animal Ecology* (Lancaster), *Journal of Hydrology and Hydromechanics* (Hallett), *Marine Biotechnology* (Kuepper), *Nutritional Ecology* (Wenzel), *Progress in Oceanography* (Scott), *Royal Society Open Science* (Smith-P), *Scottish Geographical Journal* (Mighall, Phillip).

Staff have also been active on broader editorial review boards of international journals. These include: *Agriculture, Ecosystems & Environment* (Smith-P), *Andean Geology* (Hartley), *Annals of Applied Biology* (Price), *Arktos* (Rea), *Biological Invasions* (Bodeh), *Canadian Journal of Fisheries and Aquatic Sciences* (Marshall), *Conservation Genetics* (Piertney), *Current Opinion in Environmental Sustainability* (Smith-P), *Current Research in Environmental Sustainability* (Smith-P), *Earth & Environmental Sciences: Transactions of the Royal Society of Edinburgh*, (Alsop, Soulsby) *Ecological Reviews* (Burslem), *Environmental Microbiome* (Rangin), *Environmental Archaeology* (Mighall), *Environmental Science* (Paton), *European Journal of Soil Science* (Hallett), *Fish and Fisheries* (Marshall), *Experimental Results* (Bowden), *Food & Energy Security* (Price), *Functional Ecology* (Pilakouta), *Geomorphology* (Spagnolo), *Geografia Fisica e Dinamica Quaternaria* (Rea), *Geosciences* (Alsop), *Global Change Biology* (Hastings), *Greenhouse Gas Management & Measurement* (Smith-P), *Geosphere* (Bond), *Hydrogeology Journal* (Comte), *Hydrological Processes* (Soulsby), *Hydrology and Earth System Science* (Geris), *International Journal of Agricultural Sustainability* (Smith-P), *Journal of Animal Ecology* (Piertney), *Journal of Evolutionary Biology* (Lancaster, Piertney), *Journal of Geodynamics* (Stephenson), *Journal of the Geological Society* (Alsop, Gilligan, Hartley, Stephenson), *Journal of the North Atlantic* (Schofield-E), *Journal of Structural Geology* (Alsop, Butler), *Land Degradation and Development* (Smith-P), *Marine and Petroleum Geology* (Bowden) *Microbiome* (Rangin), *Molluscan Research* (Layton), *Oikos* (Travis), *Pedosphere* (Hallett, Smith-P), *Plant Ecology and Diversity* (Burslem), *Sedimentology* (Brasier), *Soil* (Hallett), *Solid Earth* (Gan), *Soil Biology & Biochemistry* (Paton), *Special Publications of Geological Society of London* (Butler), *SPE Formation* (Hastings), *Vadose Zone Journal* (Hallett), *Water, Air & Soil Pollution* (Paton).

4F. CONFERENCE ORGANISATION

Staff have been actively involved in the organisation of conferences including the International Conference on Environmental Impacts of Marine Renewable Energy Technologies (EIMR) (Scott), 14th Symposium on Bacterial Genetics and Ecology (Rangin), 16th Archaea Network (Rangin), 20th European Nitrogen Cycle Conference (Rangin, Prosser), 21st European Meeting in Evolutionary Biology (Pilakouta), Sea Scotland (Payo-Payo), as well as many sessions at the annual European Geoscience Union and American Geophysical Union meetings. Additionally, Smith-P is contributing to the COP26 Universities Network published briefs (particularly the brief on nature-based solutions) being prepared for the upcoming COP26 conference and is also on the organising group for the forthcoming "ClimateExp0" conference.