

Institution: University of Stirling
Unit of Assessment: C14 Geography and Environmental Studies
<p>1. Unit context and structure, research and impact strategy</p> <p>Biological and Environmental Sciences (BES) at the University of Stirling addresses the major interconnecting challenges in water, carbon and biodiversity across scales in space and time. Our mission is to embed the environment and whole systems understanding into decision-making, promoting resilience and prosperity in a changing world. We deliver this mission through the co-development of research-based solutions with policymakers, environmental agencies, non-governmental organisations, industrial partners and local communities.</p> <p>Our strategic objectives are to:</p> <ul style="list-style-type: none"> • deliver <i>novel mission oriented research</i>, catalysed by technological and inter-disciplinary research collaborations; • deliver <i>creative research impact</i> emphasising evidence-based environmental policy impact, stakeholder conflict management, citizen science participation, and integration with industry research initiatives; • address <i>major global challenges</i> by leading and working with <i>global partner networks</i>; • <i>develop next generation research leaders</i> through our commitments to postgraduate researchers (PGRs), post-doctoral training and early career leadership programmes. <p>Building on positive REF2014 submission outcomes and set within the University Research Strategy priority themes of <i>Cultures, Communities and Societies, Global Security and Resilience and Living Well</i>, we have strategically grown our research endeavours during the assessment period.</p> <ul style="list-style-type: none"> • Our REF2021 research staff cohort is 46.3FTE. This includes 20.0FTE new colleagues appointed since 2014 and 4.4FTE Research Fellows; 5.4FTE of our colleagues are early career. Our staff retention over the review period is exceptionally high with only four colleagues on open-ended contracts leaving during the census period; • Annual research income has increased by 289%, from £864k (2013-14) to £2,502k (2019-20); new awards for 2020-21 are already over £8m. NERC success rate is currently 40% and we hold a portfolio of grants across a spectrum of funders including EU-H2020, ERC, UKRI, international research councils including US National Science Foundation, Australian Research Council, and from research charities including Leverhulme Trust; • We lead Climate Emergencies and Biodiversity Crisis research and address directly the UN <i>Sustainable Development Goals</i> of Zero Hunger, Clean Water and Sanitation, Sustainable Cities and Communities, Climate Action, Life Below Water and Life on Land; • Our most recent innovation is the foundation and leadership of Scotland's International Environment Centre with £22m of investment from the UK and Scottish Governments through the Stirling and Clackmannanshire Growth Deal. This is delivering a new living laboratory approach to lead the post-Covid19 green recovery that is co-developed and co-delivered with business, industry and policymakers with a focus on building transitions to a net zero carbon economy. <p>We are structured across six inter-connected Research Groups:</p> <ul style="list-style-type: none"> • <i>Earth and Planetary Observation</i> • <i>Ecosystem Change</i> • <i>Environmental Biogeochemistry</i> • <i>Evolving Organisms</i> • <i>Healthy Environments - Sustainable Societies</i> • <i>Quaternary Science and Palaeoenvironments</i>

These groups define our identity and expertise, promoting multi-disciplinary research across BES, the University and internationally. Eight specialist laboratory and field facilities integrate our Research Groups and underpin shared cross-divisional and University capability, all with high quality technical support (Figure 1).

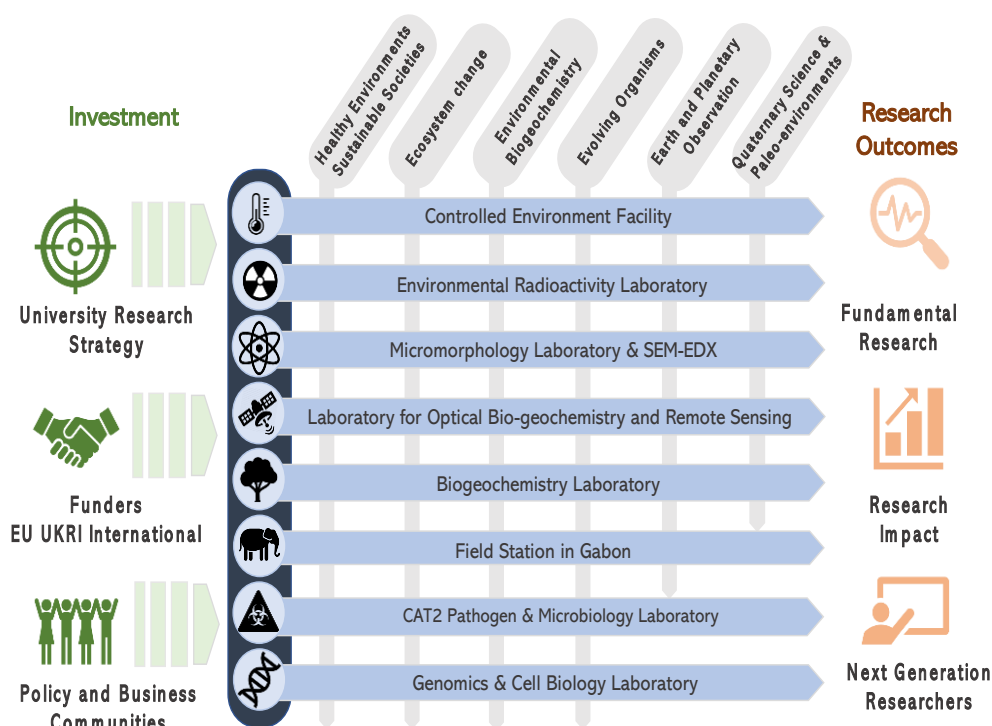


Figure 1: Inter-relationships and interactions between Research Groups, key facilities and stakeholders

Each with Professorial leadership, our Research Groups integrate all academic, post-doctoral and PGR researchers. Boundaries between groups are porous as evidenced in output authorship, holding joint grants and shared PGR supervision. Research Groups are where we embed, enable and mentor new colleagues, where collaborations form and international networks are shared. Critically, Research Groups are a space to formulate ideas, develop grant applications and publications, and cultivate leadership. The groups are sustainable in that they each host grants and have recruited new colleagues over the REF2021 period. Our Research Groups drive growth as evidenced in outputs (improving publication quality and visibility), income (increasing grant-winning applications), impact (delivering agreed impact agendas), successful PGRs (sharing high quality supervisory practice) and mentoring of post-doctoral researchers (supporting career development). Groups are overseen strategically by BES Research Committee and Faculty of Natural Sciences Research Committee. Evidence for the success of our Research Groups and their synergies is summarised below.

1. Earth and Planetary Observation is pioneering in Earth Observation of inland and coastal waters to enable better management of these vulnerable environments impacted by climate and society at global and local scales. We have secured funding through FP7, H2020, UKRI and more recently European Space Agency (ESA) programmes and have made four new appointments since 2014. Our research exploits ESA's Copernicus missions for inland water quality monitoring using an innovative processing chain that intelligently selects the most appropriate algorithm on a per pixel basis. This significantly reduces the uncertainty of water quality estimations on a global scale (NERC GloboLakes). In leading the GloboLakes consortium, and coupling outputs with numerical models, new understanding of the sensitivity of lakes to environmental change is being

revealed. Our research on novel data processing techniques initiated by GloboLakes has been continuously funded through FP7 and then through FP7, H2020 and ESA. These developments are driving new paradigms of monitoring inland waters in the UK and internationally (Impact Case Study) and now form the foundation of the observation node for a new pan-European infrastructure to deliver functioning and climate resilient river-sea systems (DANUBIUS-RI, ESFRI roadmap). Research impact is supported through commercial and user-based service platform developments for inland and coastal water monitoring, driving the GEO AquaWatch Initiative and new H2020, EPSRC-GCRF and ESA programmes. Vital new perspectives and synthetic aperture radar (SAR) expertise has been introduced to this research group through new appointments with a focus on the observation of 'sea-clutter', platforms and shipping. This helps build new portfolios of research, complementing inland, coastal and sea observation analyses. Within the review period the group has extended its remit to include planetary observation. Looking beyond Earth, we identify hazards (asteroids) and explain the environment of our own planet by investigating other planets (Mars) as analogues. On this theme, we have investigated geochemical cycling, the role of Fe and other elemental cycles in terrestrial and extra-terrestrial environments together with the thermal histories of solar system ices. Stirling's planetary researchers are supported by STFC and the UK Space Agency and through participation in major international space missions (NASA MER, NASA InSight, JAXA Hayabusa2, ESA ExoMars Rover).

2. Ecosystem Change focuses on ecosystem function and the UN Sustainable Development Goals by identifying linkages between biodiversity, land use changes, carbon reserves and food security. At the heart of this group's work is the understanding, prediction and monitoring of the impacts of change and working from individual to policy levels to improve environmental management and sustainability. This group develops early warning systems for detecting changes in ecosystem composition and function, supporting policy makers and managers in protecting and restoring resilient ecosystems and communities (UKRI-FLF, NERC ForeSight and SPECTRAL). We co-lead research on the long-term impacts of land-use change on woodland biodiversity to identify policy and management interventions that improve ecosystem services and halt biodiversity loss, funded through Government agencies, industry and conservation charities. The inter-disciplinary H2020-ERC ConFooBio programme addresses conflicts between food security and biodiversity conservation, integrating socio-ecological systems to understand the interaction between human decision-making and dynamics of ecological processes. It offers solutions to mitigate impacts of these conflicts on biodiversity and human livelihoods. Application of computational modelling, interactive computer simulations, and "serious games" further enhances consideration of socio-ecological systems, assessing public engagement with plant biosecurity (DEFRA and Forestry Commission) and strategic management of invasive weed incursions in South-East Asia (GCRF). Our field station in Gabon (Lopé National Park), established 40 years ago, and our permanent office in the Gabon National Science Centre (since 2008), provide vital insights on tropical forest resilience and climate change, biodiversity loss and exploitation (hunting and deforestation; Impact Case Study) through a long-term partnership with the Gabon Government (GCRF TRADE Hub, US Fish and Wildlife Service, Gabon National Parks). New capabilities in remote sensing and environmental informatics applied to ecosystem change have been co-developed with the *Earth and Planetary Observation* group. Together, our researchers are transforming our understanding of large-scale forest habitat processes and related human impacts.

3. Environmental Biogeochemistry conducts research on biogeochemical processes with a focus on C and N cycling and dynamics, making explicit links between terrestrial, freshwater and marine realms. This group attracts major funding from NERC, including Discovery Science and NSFDEB-NERC. Research on terrestrial C and N dynamics has spanned arctic to temperate ecosystems and now extends to tropical grasslands. Work is focused on responses to, and feedbacks between, terrestrial ecosystems and global change drivers including climate change and land management regimes. Work in the Arctic integrating land-atmosphere and land-freshwater fluxes of C has applied cutting-edge isotopic techniques, including stable isotope pulse-chase experiments and natural abundance ^{14}C sampling and analysis, to understand C and N dynamics of 'permafrost-carbon feedback' and the delivery of C from the terrestrial to the freshwater realm. Long-term engagement with, and leadership of, the International Tundra

Experiment (ITEX) has underpinned leading global meta-analyses of Arctic ecosystem responses to global change drivers. In temperate regions we focus on upland and peatland ecosystems, plant-soil interactions, and land-use (including tree planting) implications for C management. In the marine realm, we investigate the molecular and population biology of microbes driving major biogeochemical cycles in the oceans, with a particular focus on picoplankton and cyanobacteria. Using state-of-the-art proteomics approaches, important changes have been revealed in gene expression and light–dark cycles of marine microbes in response to changes in ocean acidification and radiation balances. Related techniques are now being applied within the NERC-NRF-BEIS South-East Asia Plastics (SEAP) programme to investigate biodegradation of microplastics, and their potential role as vectors of pollutants and pathogens. Work on the global C cycle and ocean acidification also includes a multidisciplinary focus on biominerals, creating new ways of extracting environmental data from marine calcifiers and determining how such organisms will be affected by continuing acidification. This has transcended our understanding of the shell-bone divide, determining how stem cells respond to topography of molluscan nacre to produce bone.

4. Evolving Organisms addresses fundamental and applied aspects of the ecology and evolution of biological systems. This group offers urgently needed eco-evolutionary approaches to understand how species adapt to rapidly changing environments. These include responses to climate change, environmental contamination, antimicrobial and pesticide resistance, and biological invasions. The group has designed strategies to reduce evolution of resistance by insect herbivores to agricultural pesticides and make bio-pesticides more effective at pest suppression, improving crop yields in developing countries (BBSRC in collaboration with FAPESP-Brazil). Artificial intelligence and mathematical modelling are optimising antibiotic dosage regimes for treating bacterial infections and combating emerging resistance in agriculture and aquaculture (CEFAS, NERC). Researchers in this group investigate the ecological and co-evolutionary response to different pathogens in natural host-parasite systems, using the crustacean *Daphnia* and its bacterial and fungal parasites as model systems. The group also investigates how plants, including crop species, rely on specialised bee pollination systems (buzz pollination) in light of recent and rapid declines of bee populations around the world (Leverhulme Trust). A key focus is on understanding how ecological systems adapt to environmental stresses caused by exposure to ionising radiation and on how cellular and molecular mechanisms may be impacted (NERC, Environment Agency and Radioactive Waste Management Ltd). This work uses field cases, including the Chernobyl Exclusion Zone, and parallel controlled laboratory exposure studies that are unique in the UK and provide evidence to underpin international recommendations for radiological protection of the environment. Investigations incorporating population-level data into understanding species responses to global change using genomic, macro-ecological and macro-evolutionary approaches also yield significant insights (Impact Case Study). These also include how maternal effect and early-life adversity influence offspring phenotypes, and how species invasions may affect food security (BBSRC, Carnegie, CEFAS).

5. Healthy Environments, Sustainable Societies is delivering solutions to ecosystem and resource degradation that promote societal resilience. Our leadership in freshwater science provides the evidence behind impact assessment and restoration of freshwater ecosystems, and support for implementation of international water policy (Impact Case Study). This work is exemplified by leadership of the NERC-funded Hydroscape project on interactions between stressors and connectivity within freshwater ecosystems. Complementing this are strengths in catchment management, sustainable soil and water use, environmental microbiology and public health. Studies of contaminant behaviours in soil-water systems have advanced process understanding in environmental and agricultural systems and served to mediate changes in farming practice (NERC). Our work brings a multi-disciplinary approach to provide both transformative and sustainable solutions to food and water security challenges. It is driving new major programmes on the impact of marine plastics, including their role as host vectors for microbial pathogens (NERC-GCRF, SPACES, SEPA). Through research on sand beach ecosystems we have explored the use of algal saprophytes as alternative sustainable sources of protein and health-promoting fatty acids in food and aquaculture feed. Use of interdisciplinary and participatory approaches has exposed the risks from air pollution to public health for residents of low-income urban areas within developing countries together with the complex socio-

environmental interactions within the energy landscape. This research integrates public understanding and reaction to energy transitions, energy justice and the social challenges associated with the shale gas industry and other sub-surface energy technologies across national and international contexts (NERC, ESRC-GCRF, EPSRC, UKRI, BGS).

6. Quaternary Science and Palaeo-environments creates new evidence of long-term environmental change and human adaptations, giving deeper temporal perspectives to environmental issues. Late Pleistocene and Holocene environment reconstructions in glaciated terrain and based on submarine glacial landforms, modern-day analogues and numerical modelling offers new interpretations and predictions of ice-sheet processes (NERC). Integration of process-based numerical modelling and geophysical data underpin new insights on patterns of storminess and geomorphological responses to past and contemporary extreme coastal events in the NE Atlantic and SW Indian oceans (ERC). We have identified common critical factors contributing long-term sustainability, resilience and adaptation in historic sub-Arctic, semi-arid and tropical regions (US-NSF). Our work on site and landscape histories in UNESCO World Heritage Sites includes the Lumbini site where we are defining new timescales and sacred space interpretations for the emergence of Buddhism and which contributes to heritage tourism initiatives in some of the poorest areas of South Asia (UNESCO). Post-earthquake (Gorkha 2015) research in the Kathmandu Valley World Heritage Site has guided restoration planning and given new insight to the emergence of urbanisation and monumentality (AHRC-GCRF, BA-GCRF). In the Middle East, using Bayesian statistical approaches to geo-chronologies we have enhanced understanding of Neolithic origins of urbanisation and associated art forms at the iconic site of Catalhoyuk (AHRC-NSF). Further methodological developments integrating our Micromorphology and Environmental Radioactivity Laboratories have given new understanding of archaeological human burials, maximising data recovery and interpretations where visual remains are no longer present (ERC), and revealing the contamination legacies of historic metal lead mining (Carnegie).

We exploit research synergies across Research Groups when targeting those challenges that require multiple and diverse approaches. Highlight exemplars include:

- Water quality modelling capabilities in *Earth and Planetary Observation* that enhance freshwater habitats programmes and use remote sensing to refine models of primary productivity in inland and coastal waters, and which interface with *Environmental Biogeochemistry* group. They also refine recognition of marine plastics, contributing to work on plastics as vectors for bacteria and viruses within the *Healthy Environments, Sustainable Societies* Group;
- *Earth and Planetary Observation, Ecosystem Change* and *Environmental Biogeochemistry* interface to deliver large-scale observations of forest change over extended time periods, underpinned by mechanistic understanding of rhizosphere processes, forest structures and whole-ecosystem C dynamics;
- Integration of physical and biological drivers of biogeochemical cycling brings together *Environmental Biogeochemistry, Earth and Planetary Observation* and *Quaternary Science and Palaeo-environments* together, providing integrated analyses of C dynamics and long temporal reach of historical environmental contamination;
- *Quaternary Science and Palaeo-environments* interfaces with *Ecosystem Change* and *Environmental Biogeochemistry* giving chronological control and long-term perspectives on the dynamics and responses of ecosystems to perturbations;
- Bringing *Evolving Organisms* and *Ecosystem Change* colleagues together to understand habitat change as drivers of disease and epidemiology, together with assessments of natural pathogens of crop pests to provide sustainable alternatives to synthetic pesticides;
- The common theme of ice legacies draws together *Quaternary Science and Palaeo-environments* and *Planetary Observation*, giving new understanding of landscape morphologies ranging from asteroids to sea-beds.

Our research programmes are inherently applied as they are co-produced with partners and agencies in direct response to need, external policy drivers and horizon scanning priorities. Our

approach to research impact, developed through the Faculty Impact Strategy, emphasises impact literacy, support structures and impact tracking. It is implemented through our divisional Impact Champion with support from the University Research Impact Officer. We have integrated four key strands that enable impact:

1) The active inclusion of stakeholders through regular business engagement events highlighting research opportunities and stakeholder needs. These lead to co-produced research programmes, including PGR studentships, with formal PGR supervision from stakeholders and embedded impact training as necessitated by the applied nature and mission oriented focus of the research. This approach gives direct access to business organisational structures and contributes changing cultures, practices and evidence-based influences on public policy with specific foci on issues of long-term sustainability. Examples include new PGR driven research programmes on modelling climate change impacts on heritage sites (Historic Environment Scotland) and on woodland ecological networks (WrEN; Forest Research, DEFRA, Woodland Trust).

2) Our laboratories (with ISO 17025 accreditation, as required) regularly work with external partners on a range of research services and in so doing deliver state-of-the-art analyses *in situ* and mobile instrumentation and data processing that further enhances our awareness of commercial opportunities. For example, the Environmental Radioactivity Laboratory delivers key evidence and technologies to support SEPA's regulatory activities.

3) We have developed knowledge exchange beyond NERC funded programmes with the appointment of a NERC-KE Fellow. This enables communication of scientific outputs from the Radioactivity in the Environment (RATE) programme to relevant stakeholders by fostering and developing strategic partnerships with industry, regulators and other interested parties, addressing the challenges of radiation protection and radioactive waste management. A second NERC-KE Fellow appointment in earth observation has now transferred to lead SEPA's earth observation and digital landscape initiative.

4) Citizen science approaches, in collaboration with Social Science and Education colleagues, include shared ESRC studentships and allied user engagement workshops in both national (Living Landscape Programmes) and international contexts (air pollution impacts) focussed on delivering enhanced research capacity, public knowledge of science and influencing national environmental policies.

Our research activities are inherently interdisciplinary, embedded in University research themes as our organising framework and emphasising synergistic approaches; The University Research and Innovation Service provides dedicated and efficient administration of inter-disciplinary programmes. Institutional support for researchers includes developing workshops as catalysts for integrating disciplines and the inclusion of international collaborators. Recent workshops in cross-disciplinary arenas have included the 'reach of drought', 'local supersite approaches to infrastructure development', 'vacant and derelict land', 'global challenges in heritage', 'Earth Observation for water quality and capacity building in ODA countries'. Programmes are supported with funding enabling participation of international colleagues in Stirling-based workshops. This support also enables Stirling colleagues to travel internationally for the purpose of initiating and fostering international and interdisciplinary research collaborations. Our weekly internal seminars give opportunities for all Research Groups, including PhD students, to present recent ideas and research findings, and in doing so test and stimulate new collaborative research. These activities enhance our interconnectedness, contributing to international authorship of research outputs and opportunities for early career researchers.

Open access is a priority for all research outputs from BES via green and gold routes in a manner compliant with funder, publisher, ethical and legal requirements. Research data associated with research projects is stored in DataStorre (Stirling Online Repository for Research Data), publicly accessible at <https://datastorre.stir.ac.uk>. DataStorre enables safekeeping, with a unique and persistent identifier and fully searchable metadata.

Based on *The Concordat to Support Research Integrity* the University implements a Code of Good Research Practice that all staff and PGRs follow. This sets out standards and responsibilities for staff involved in research – from project initiation through to publication and data curation - and serves to encourage and maintain a culture of respect and practice for the highest standards of integrity and honesty. All research projects from concept through to field, laboratory and data analyses are subject to ethical scrutiny through *General University Ethics Panel* or the *Animal Welfare and Ethical Review Body*. We reinforce this through Research Groups sharing exemplary practice and giving guided support to all colleagues. Concentrated support is given to PGRs in developing exemplary ethical practice, particularly where there may be different cultural norms. Where we work internationally our norm is to develop and work within the boundaries of an agreed Memorandum of Understanding and we draw on and respect the three domains of COHREDS Research Fairness Initiative.

2. People

Staffing Strategy and Staff Development

Our staffing strategy of attracting and retaining high quality staff is based on the research portfolio of applicants, potential for development and in response to external environments and opportunities. Each of the six Research Groups have been strengthened during the REF2021 review period with recruitment at all grades to give early career opportunity, mid-career establishment and research leadership.

Our REF2021 cohort is 46.3FTE comprising 11.0FTE Professor (two of our Professors hold senior Faculty positions as Dean and Associate Dean - Research), 11.8FTE Associate Professor / Senior Lecturer, 19.1FTE Lecturer and 4.4FTE Research Fellow; 5.4FTE are ECRs. During the assessment period we have recruited 3.9FTE Research Fellows 12FTE Lecturers, 2FTE Associate Professors, and 2FTE Professors. We also support 20.2FTE Research Assistants.

We have a balanced demographic range from early career to senior colleagues and our succession approach has focussed on strategic development of opportunities for successful transitions between academic grades. There have been 17 promotions during the review period, primarily based on external review of research performance indicators (five to professor, six to associate professor / reader and six to senior lecturer). We have created a research culture of enthusiasm, dynamism and opportunity, stimulating increases in research awards and impact by all Research Groups.

The University was one of the first signatories in the UK of the RCUK Researchers Concordat 2009 and we are signatories to the revised Concordat 2019. Its implementation earned Stirling the EU HR Excellence in Research Award in 2011 continuing to our most recent 2020 award. Evidence of the Concordat's continuing positive influence within BES are research induction programmes upon employment, peer to peer mentoring arrangements for all staff, and mentoring of early career staff by senior colleagues. Dedicated funds are available for RFs and RAs to attend specialist training events and conferences. Limited bridging funding from one grant to another is also available for RFs and RAs although the emphasis is on creating open-ended posts for these colleagues where possible.

The Stirling Researcher Development Programme, mapped to the Vitae Researcher Development Framework and managed by the University's Institute for Advanced Studies, is available for all staff. To support and develop the potential of individual researchers an annual performance review scheme, 'Achieving Success', is undertaken by all staff. This framework provides the opportunity to reflect on achievements and plan short- and long- term goals guided by workload modelling. This review is also used to provide information on staff activities, aspirations and resource requirements, in turn facilitating development of Faculty planning and promotions processes. Our environment is highly supportive for early career colleagues and includes start-up and recurrent financial support, mentoring, reduced teaching load (typically a maximum 25% of workload time in the first year) together with training opportunities to expand potential.

Post-doctoral and post-graduate forums contribute directly to BES strategy and management through research and staff committees. Introduction to inter-disciplinary research is made through the Stirling Crucible programme, working with colleagues from across the University. This offers models and practical experience for interdisciplinary working and pump-priming opportunities. Direct research support for all research grant applications is given by a dedicated Research Development Officer. This, together with the Research Groups, supports colleagues in the research grant application process, including grant craft workshops, review and mock interviews.

Non-probationary academic staff are eligible for one six-month period of research leave after six full semesters of completed service. Appropriate activities include development of new ambitious research proposals, extended field and laboratory research and leading on major team-based research paper writing and impact development. Between 2014-20 nine colleagues have undertaken thirty-nine months of research leave.

Our Honorary staff are drawn from statutory environmental agencies, NGOs and businesses to develop partnerships and provide guidance on matters ranging from research innovation to maximising research impact. Our consultations and workshops with industry and involving national and international organisations stimulate ongoing engagement with industry representatives ensuring that our research is co-designed and of maximum relevance to the user community. These partnerships are increasingly embedded within research programmes and enhance our research environment through funding and co-supervision of PGRs, providing placement facilities and career expertise for PGRs, and input into project advisory boards. The effectiveness of this approach is now exemplified by the creation of Scotland's International Environment Centre.

Success in research, innovation and impact endeavours is rewarded financially with uplift in personal research accounts based on an internally agreed weighting of income, studentships and publications, and is invested to enhance networking, support new staff, research studentships and facilities. Reward is also through a promotions system that explicitly includes research performance indicators.

We support colleagues in the delivery of impact through the work of a designated impact 'champion' with close links to industry and through Faculty initiatives that include a series of impact workshops and fora with case study discussions, toolkits developed to highlight routes to impact, recording and curation of impact and impact related to public engagement.

Equality and Diversity

Equality and Diversity is integral to the BES research environment and is embedded in our committee structures, recruitment processes and staff training. The Equality and Diversity Committee within BES was instigated in 2013, and we received Bronze Athena SWAN awards in 2015 and 2019. BES colleagues are active participants in the Aurora programme - designed to encourage and develop research leadership in women through mentoring and role models and which has enhanced research participation. All colleagues at grades 7 and above have participated. We ensure equality within our committee structure and recruitment panels, actively encourage female speakers in seminar programmes and as alumni speakers at our PGR symposium.

In 2014, we pioneered a 6-month 'return to research sabbatical' to support lecturing staff returning from parental/adoption leave enabling them to focus entirely on research. Three sabbaticals to date have been awarded (2017, 2019, 2020) leading to outputs that include high profile papers (*Science; Science Advances*). This policy covers teaching and administrative duties of academic staff returning from parental leave through short-term teaching appointments. This exemplary practice has now been adopted across the University.

We have introduced commitments to flexible working and support for staff and research students returning from periods of leave by giving particular attention to research application processes and implementation that recognises commitments to caring responsibilities. In doing so we have enhanced support for all colleagues across all areas of activity. The University's technical infrastructure enables home access to shared drives and a wide range of licensed online applications so academic staff can work flexibly and remotely, with the supportive atmosphere of a scholarly community maintained. Most flexible working is implemented informally, and staff adjust working hours to cater for family commitments and travel needs. Staff surveys indicate that informal flexible working is appreciated and used regularly to enable care for families during pressured times, for example school holidays, when children or family members are ill or for care of elderly relatives. There has been one application for formal flexible working within the past three years as part of new arrangements for parental leave, and this was successful. Following periods of leave (for parental leave, illness, or carer responsibilities), staff can apply to work flexibly or part-time upon their return. If they wish, they can request a move to part-time work for a defined period and return to full-time work (two requests between 2015 and 2017 were granted).

Research Students

Current PGR cohort is 65 (head count; years 1-4) and our recruitment strategy has delivered a critical mass of PGRs that consistently delivers research outputs of significant impact to both academic and industrial partners. Recruitment success draws from four strands: integration within leading UKRI Doctoral Training Partnerships supported by additional university investment and industrial partners; strong ability to secure end-user/industry funding, often co-funded with University investment; our capability to recruit overseas students on prestigious home-country funding bursaries; and attracting self-funded PGRs, including those on part-time programmes.

Since 2013 BES has been a core member of the NERC IAPETUS DTP through which we have achieved significant recruitment success. NERC IAPETUS2 is now one of the largest DTPs in the UK placing us in an expanded collaborative PGR training consortium (alongside Durham, Newcastle, Glasgow, Heriot-Watt, St Andrews, Centre for Ecology and Hydrology, British Geological Survey and British Antarctic Survey). The University supports a minimum of two studentships a year as part of the NERC-DTP. From 2013-14, 40% of our DTP PGRs have been CASE with fourteen different organisations providing CASE support. We are also a member of NERC-SUPER, ESRC-funded Scottish Graduate School of Social Sciences and BBSRC-EastBio. We are strategically placed to exploit national funding sources with Historic Environment Scotland, NatureScot and Scottish Government's HydroNation Scholars scheme all supporting our PGRs. Just under a third of our PhD projects receive some form of co-funding from end-users or industry; these close industry ties help maximise the impact of our research, strengthen PGR training opportunities and enhance PGR career prospects in government, industry and environmental charities. Our PGR community benefits from an extensive support network and rigorous, constructive progress monitoring. This is independent from supervisors and includes regular meeting with the PGR Tutor and Associate Faculty Dean-Research. The student-led BES PGR Forum meets regularly to discuss PGR issues and support needs. It also interfaces with the Postdoctoral Forum, giving a clear understanding of career progression within academia, and is represented on Faculty and Divisional Research Committees, Equality and Diversity Committee and in the divisional Staff Committee.

New PhD students are assigned a peer mentor (an established PhD student) and attend a programme of internal induction events to assist integration and facilitate cohort building. We have three dedicated PGR Tutors - members of academic staff who offer independent academic guidance, pastoral support and implement training activities. PhD progress is monitored by PGR Progress Committee at four checkpoints: 10 weeks, 9 months, 22 months and 36 months. For each checkpoint, students submit a structured document on which feedback is provided by supervisors and the PhD Progress Committee. The latter three checkpoints involve a formal independent progress viva that includes student presentation, assessment of research progress, and mentorship of completion plans. This close monitoring of progress has supported

achievement of an on-time completion rate exceeding 85%. Our overall supervision attracts 91% approval in the most recent PRES2019 survey, comparing favourably to the sector average (85%).

Our weekly internal seminars (online throughout the COVID-19 pandemic), at which the majority of presenters are PhD students, provide speaker training and feedback experience. Our annual 2 day 'winter symposium' gives all PGR students further experience of oral (2nd and 3rd years) or poster (1st year) presentations. Here we celebrate the research successes of our community, including prizes for presentation quality, publication output and outreach activities. At this event we provide inspiring role models by featuring plenary addresses from recent alumni, professorial staff, Honorary staff and external collaborators. Our approach to skills development is exemplified by our PGR student-led (and staff mentored) bi-weekly statistical support group Semin-R, our community's extensive outreach activities via social media and in person (Science Fair, Festival of Research, I'm a scientist get me out of here, Pint of Science), and mentorship through Research Groups. In parallel, our PGR students gain formal training through frequent DTP training events (often with access granted to non-DTP students), Strategic Alliance for Geosciences, Environment and Society research pooling graduate schools, NERC advanced training short courses. The Stirling Institute of Advanced Studies also operates a programme of generic researcher development courses in which BES students meet and share experience with those from other disciplines.

Approach to supporting the wellbeing of staff and research students.

We work hard to develop a cohesive, open and collegiate division for the benefit of both staff and students through our common mission. Our success is exemplified in recent surveys (2019, as part of our Athena Swan action plan) indicating 100% of academic/research staff feel that "work related social activities are welcoming to all genders" and that 94% of academic/research staff feel that BES is a 'great place to work for any gender'. During COVID-19 lockdowns we have ensured that 'Lab-groups' meet regularly online and involve all research staff and PGRs together with informal weekly individual catchups for PGRs. Individual staff also have a 'critical friend' for support through regular discussions. As part of the University Mental Wellbeing Campaign, two champions have been appointed in BES to raise awareness of mental health issues and signpost available support and the University's Employee Assistance programme offers counsellor support and information.

An agreed workload model is used by the HoD in discussion with colleagues and, after annual appraisal, ensures responsibilities are allocated transparently and fairly. The model accounts for: (i) research activity (outputs, grant applications, impact, PGR supervision) (ii) teaching provision; (iii) internal administrative and leadership roles within BES, FNS, University as well as externally. This typically approximates 40% research, 40% teaching and 20% administration, varying with research grant commitments, management and leadership responsibilities. Our yearly analysis of commitments suggests no systematic bias towards either gender; where potential for imbalance is noted we address this through reallocation of duties. There are frequent, regular events that help foster research communication amongst all staff and PGRs, including scheduled coffee times and the weekly internal seminar to which both academic staff and students contribute. PDRAs and PGRs also meet individually with supervisors at least once a week.

3. Income, infrastructure and facilities

Research Funding and strategies for generating research income.

Annual research income has increased from £864k to £2.50m p.a. during the period 2013-14 to 2019-20, evidencing the success of University target-setting and Research Group responsibilities for research income generation (Figure 2). As further evidence of our funding success over the REF2021 review period, total research awards between 2013-14 and 2019-20 are £14.40m compared to £4.56m for REF2014. Our positive awards trajectory continues with awards in 2020-21 currently over £8m.

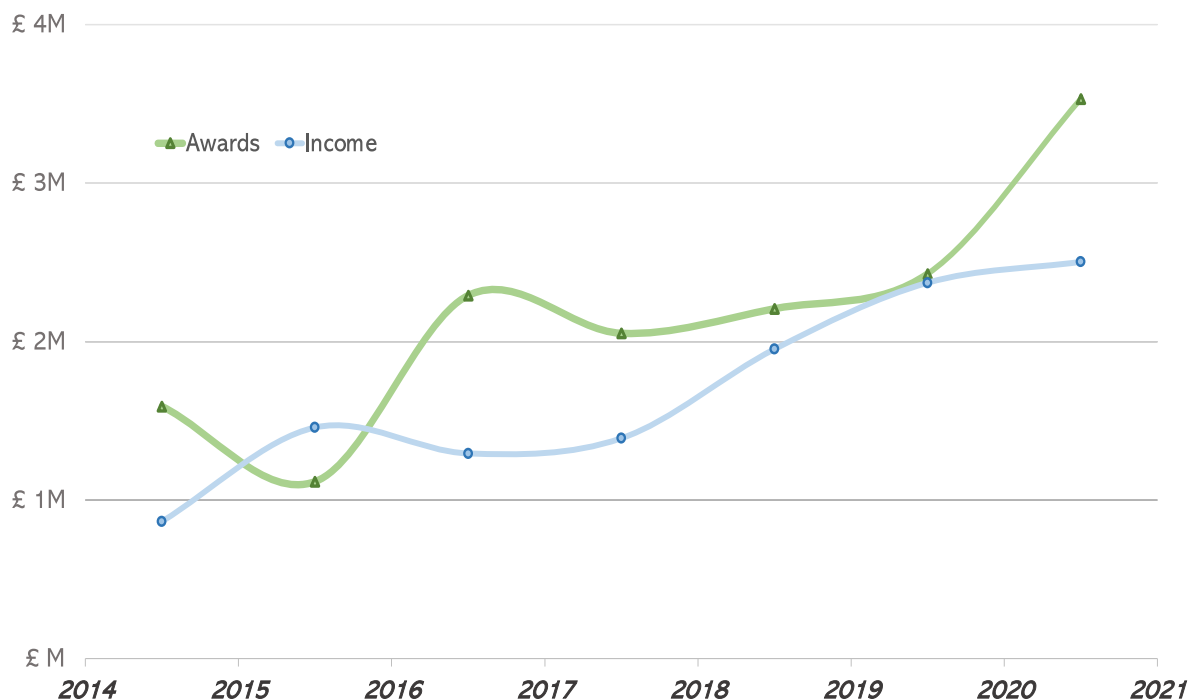


Figure 2: UoA Research awards and income over the REF2021 review period

As part of our post-REF2014 review and to enhance award success rates we assessed research income potential against EU, UKRI and research charity funder demand. We agreed to the principle that all research active staff should hold a research grant, and implemented an internal application process that includes concept assessment, peer support and review of draft applications, and appropriate workload management during large grant applications. From these foundations we have implemented four strategic approaches to generate income, evidenced as awards in Figure 2:

- 1) Work with and mentor early career colleagues to build portfolios of research funding, including seeking success in internal pump-priming initiatives and smaller research grant applications (<£50k) as stepping-stones to major grant applications;
- 2) Encourage collaboration of early career researchers as Co-PIs and PI researchers in their own right, building experience in major grant applications;
- 3) Widen our funding network by explicitly encouraging international funding collaborations, examples of which are with National Science Foundation, Australian Research Council, the Global Challenges Research Fund programme (with AHRC, British Academy, EPSRC, Royal Academy of Engineering and GCRF Hub Grant funding), Newton Stage 1 and 2 awards, six H2020 programmes and ESA CCI awards;
- 4) For more experienced colleagues we encourage peer mentored major grant applications above a £500k threshold. To drive excellence in application for NERC standard grants, at least six months ahead of each deadline, internal competitions are held to select the best applications to put forward to ensure high quality applications. Implementing this approach has significantly lifted our research grant successes >£500k. Leading major and prestigious awards during the review period include ERC ConFooBio (£1.2m), NERC Hydroscape (£2.9M, £663k to Stirling), NERC PrimeTime (£771k), TransferExposureEffects (TREE) (£455k), NERC GloboLakes (£2.6M; £632k to Stirling), NERC ForeSight (£800k; £526 to Stirling), BBSRC-FAPESP (£628k), NERC 'Plastisphere' (£1.85m, £550k to Stirling).

As further evidence of our performance in major research awards our most recent (2020) successes include Future Leaders Fellowship Beacon Project (£1.19m) – evidencing our commitment to early career colleagues – NERC-GCRF SPACE (£3.415m, £2.811m to Stirling), NERC-GCRF SEAP (£1.5m, £364k to Stirling), NERC SPECTRAL, (£798k), NERC RestREco (£2.5m, £715k to Stirling), H2020 WaterFoCE (€3.0m, €314k to Stirling) and H2020 DOORS (€9.0m, €408k to Stirling).

Organisational infrastructure

The organisational infrastructure underpinning our Research Groups includes our close working with the University Research and Innovation Services Office on intelligence gathering related to the recognition of distinctive and niche attribute in our research portfolio and which integrate with University research themes. This approach has stimulated investment in new posts across all Research Groups and in response to emerging themes, challenges and opportunities.

Evidence of our effectiveness in bringing the organisational infrastructure together for major strategic developments is in leadership of the innovation workstream of the Stirling and Clackmannanshire City Region deal (February 2020). Scotland's International Environment Centre (SIEC), supported through £22m of government funding, will lead regional scale environmental change assessments to tackle the climate emergency. This investment transforms relationships between BES and environmental management in policy making and business so that the protection and enhancement of our natural resources becomes a driver of clean, inclusive growth.

SIEC is committed to delivering Scotland's first net zero carbon region, achievable by breaking down traditional disciplinary and institutional silos, and working in partnership with a regional innovation community across the whole of the Forth Valley. This includes education, private, public, third, fourth sector partners and local communities. With water being the primary medium through which we will sense the effects of climate change, the initial phase of the SIEC project involves the establishment of The Forth Valley Environmental Resilience Array (*Forth-ERA*), driven by partnership between University of Stirling and BT Group.

A demonstrator project is in place (Spring 2021), working with the Scottish Environment Protection Agency, Scottish Water, Diageo, NatureScot, Forth Estuary Forum, the Forth Valley Chamber of Commerce and UK Centre for Ecology and Hydrology. *Forth-ERA* harnesses our EO capability and sensor networks coupled with artificial intelligence-based models to deliver a digital twin of the Firth of Forth Catchment. BT's 5G capability is being utilised to demonstrate how the ERA platform provides: (i) innovative ways to monitor water quality in drinking water reservoirs; (ii) near real-time forecasts of bathing water quality; (iii) early warning and monitoring of floods; and (iv) real time data on water temperature to help inform the brewing and distilling sector. The co-development of the platform with our partners builds valued outputs that will help transform traditional methods of working, business sectors and export capability to the global green marketplace.

Recognising our innovation in coupling the Digital Revolution with the Green Recovery, the SIEC initiative has levered additional Scottish Government investment through the siting of Scotland's first flagship 5G Innovation Hub with SIEC (announced by Paul Wheelhouse MSP, Minister for Energy, Connectivity and the Islands, September 2020). Further evidence of SIEC's ability to leverage funding is the £3.5m Hydronation Chair award secured by the University (Scottish Water, December 2020), to lead research and innovation across the Scottish water sector and designed to be self-sustaining beyond the first six years of funding. Internationally, the establishment of SIEC has enabled us to secure a new £1.2m investment in ecology research to establish the forestLAB in Gabon, expanding our long-established work there, through a collaboration with the African Conservation Development Group and LSE.

Operational, specialist and scholarly infrastructure

Infrastructure funding is optimised within the framework of our Campus Masterplan and through integrated Faculty and capital planning processes and there has been continuous upgrading of facilities throughout the review period. Infrastructure supporting our research and impact is shared across all Research Groups and provides collaborative research opportunities:

- *Controlled Environment Facility* (state-of-the-art >£1 million facility), supports research funded by NERC, EU Marie Curie, Royal Society, Carnegie Trust, Scottish Environment Protection Agency, Historic Environment Scotland, BBSRC-FAPESP, Newton Fund and commercial activity. This facility delivers bespoke experimental capabilities examining impacts of modelled future environmental changes on biological and environmental systems. It comprises walk-in and reach-in chambers where temperature, humidity, light and CO₂ can be regulated for long- and short- term experiments. The facility enables programming of environmental change scenarios in experimentally replicated designs and controlled remotely. Managed by a joint academic and Technical Facilities Group this facility is fundamental to understanding climate changed futures;
- *Environmental Radioactivity Laboratory (ERL)* is an ISO 17025:2017 accredited laboratory supporting research funded by Scottish Environment Protection Agency (SEPA), Environment Agency and NERC. Specialising in laboratory, *in situ* and mobile gamma ray detection capabilities and dose assessment, the ERL works with national environmental regulators and international partners on some of the most problematic legacy and decommissioning radiation pollution issues in the UK and Europe, whilst also delivering evidence to support regulatory action. The laboratory now includes a radiation exposure facility allowing exposure experiments at dose rates from background to those seen in the most contaminated sites as well as simulation of environmental radiation environments on Mars and on comets. The ERL is supported by two dedicated technicians, one RA and a PDRA;
- *Micromorphology, Microscopy and SEM-EDX Facility*, supporting research funded by ERC, AHRC-GCRF, UNESCO, US-NSF and commercial activity. Managed by a Facilities Group and with dedicated technical and academic support this facility is internationally unique in its bespoke thin section manufacture of complex samples and in its analytical capabilities that attract researchers and associated samples from across the world. Analytical facilities include advanced light microscopy with image analyses, and SEM imaging with associated EDX element-based capability. This facility works in close collaboration with the Instrument Laboratory, the Controlled Environment Facility, and external facilities including Scottish Universities Environment Research Centre and NERC Life Sciences Mass Spectrometry Facility. It currently supports the work of eight PGRs;
- *The Laboratory for Optical Biogeochemistry and Remote Sensing (LOCHS)* (new investment within review period) specialises in the development, validation and application of remote sensing for studying responses of terrestrial and aquatic ecosystems to natural and anthropogenic environmental change. The laboratory has delivered the capability to monitor more than half of the earth's surface freshwater through the Copernicus Land Service and now provides operational monitoring for almost 1000 UK lakes. The laboratory, with associated research boat, houses state-of-the-art equipment for laboratory- and field- based optical and radar measurements. This underpins our work on the acquisition, processing and analysis of data from sensors mounted on near-ground platforms, UAVs, aircraft and satellites. This facility supports research and knowledge exchange activities funded by UKRI, European Commission, European Space Agency, Environment Agency, Scottish Environment Protection Agency and industry. The laboratory hosts four RFs, one RA-technician and PGRs;
- Our field station in Gabon (Station d'Études des Gorilles et Chimanzés in Lopé National Park) has been established for over 40 years and is managed in partnership with the government of Gabon. The facility focusses on tropical forest evolution and ecology and holds unique long-term datasets on equatorial African ecosystem function unparalleled anywhere on the continent. Current research focusses on forecasting of ecosystem

change under climate change and realistic scenarios of future human impacts. The station has accommodation, field laboratory and transport capabilities attracting a vibrant international research community. Our Gabon programme staff currently collaborate on 10 international research consortia using the Lopé facility and it provides an excellent environment for research innovation across our Research Groups;

- *Ecological, Greenhouse and Experimental Garden facilities*: Includes 1) an extensive range of field equipment facilitating research on animal and plant populations (including UAVs, environmental datalogging, e-fishing kit, automated samplers), bioacoustics arrays for recording animal vocalisations, plus a 12 m high Rothamsted-style suction trap providing data on aerial insect densities since the 1970s; 2) 200m² of glasshouse space, and 3) a well replicated system of pond mesocosms. These resources support NERC, BBSRC-FAPESP, Newton Fund, Leverhulme Trust and industry funded research;
- *CAT2 microbial laboratory*: supporting research on establishing faecal indicators and pathogen risk in agricultural catchments and bathing waters. Funded by NERC this facility is now developing critical work on quantifying and understanding the pathways that support persistence and dispersal of potentially pathogenic microorganisms on marine plastic debris;
- *Genomics and Cell Biology*: fully equipped recently refurbished suite of three molecular ecology laboratories, with fragment analysis and sequencing being provided through commercial agreements with external partners. These facilities currently support work funded by NERC, Leverhulme Trust, BBSRC-FAPESP, Newton Fund and a range of conservation charities;
- *Biogeochemistry Laboratories*: Supports NERC-funded work on global change, ecosystem dynamics and C cycling with field and laboratory equipment including respirometers for CO₂ emissions from soils and sediments, field portable infra-red gas analysers for ecosystem carbon flux measurement, gas chromatography, DPIR for methane flux measurement and temperature-cycling cooled incubators. Well established links to NERC facilities (Radiocarbon Facility and Life Sciences Mass Spectrometry Facility) augment our in-house provision;
- *Mössbauer spectroscopy facility*: allowing investigation of iron-bearing materials, ranging from rocks, soils and sediments and nanoparticles. The facility supports research funded by the Carnegie Trust, STFC, the UK Space Agency, and the Commonwealth Scholarship Commission;
- *Planetary Ices Laboratory*: simulates environmental conditions on Earth, Mars, comets and asteroids. The facility supports STFC, UK Space Agency and H2020 funded projects, and is part of a successful H2020 EuroPlanet Research Infrastructure award. It is recognised by the European Space Agency amongst European key facilities in experimental planetary science;
- *Instrument Laboratory* including ICP-OES, Coulter Counter – Particle size distribution and cation and anion chromatography, AAS, CHN and TOC, microwave digestion. We undertake development of wet and analytical chemistry techniques; all standards and results are NIST traceable. Supports a range of UKRI funded programmes and consultancy-based research.

We also provide:

- Mechanical workshops;
- A divisional full-time IT technician and a University science-dedicated computing liaison colleague providing IT hardware and software support to researchers. Key roles are software support for remotely sensed image analysis, GIS based analyses and Big Data capabilities. All researchers, PGRs and laboratories are provided with their own networked computer;
- *Library support* include a dedicated Science librarian and web site with supporting documentation on information tools and resources. This enables effective early career researcher participation in the research process and includes electronic Document Delivery Service and membership of SCONUL Research Extra. We are an active

participant in the University Open Access Digital Research Repository, holding all research theses and research output from 2006.

Our facilities are developed, maintained and managed by 11FTE Technical Staff who provide vital support in research delivery. Through University level commitment to the Technician Charter, we ensure their training is complete and up to date in the facilities they are responsible for. Technical support staff make vital contributions to the skills training of PGRs and PDRAs in the use of specialist analytical capabilities.

All academic staff receive an annual discretionary fund calculated using a performance-based algorithm based on research output, grant income, PGR numbers to cover basic laboratory expenses, pump-prime small research projects and attendance at meetings and conferences. PGR consumable monies are given directly to principal supervisors for allocation to individual research students. Funds for equipment purchases (typically £75k-£150k pa) are allocated to groups of academic colleagues on the basis of competitive bids for small equipment purchase, often match-funded by external sources, moderated for early career researchers, and with an emphasis on collaborative research and shared use. The Universities Infrastructure Fund and allocated through the planning process is available for more expensive equipment and regularly supports the division.

Infrastructure and expertise in relation to impact

Organisational, scholarly and facilities infrastructure and expertise contributes directly to impact, highlighted in our four Impact Case Studies and in our broader impact activities. Our high-quality IT, Big Data processing and optical biogeochemistry capabilities enable our work on global lake water quality and the design of mitigating measures. The Environmental Radioactivity Laboratory enables and calibrates our work on protecting wildlife and society from ionising radiation. Dedicated field support enables our research on protecting and restoring freshwater systems and the Water Framework Directive implementation impacts that emerge from this work. The Gabon Field Station is the foundation for our tropical conservation research programme contributing directly to the science that supports sustainable natural resource conservation policies and practices in these environments.

More widely, our CAT2 microbial laboratory now directly contributes to quantifying pathogen and environmental risk in a range of socio-environmental contexts. Our micromorphology and instrument laboratories, together with cross-HEI shared laboratories, contribute the science that shapes sustainable futures related to UNESCO World Heritage Site designations in ODA countries; these laboratories also have a 'travelling lab' capability for work with schools and local communities. Our Controlled Environment Facility is shaping biological and heritage conservation organisation (charity and statutory agency) responses to the growing Climate Emergency.

Cross-HEI sharing of research infrastructure

There is substantial cross-sharing of research infrastructure and the building of strong collaborative networks as a result. As part of the Scottish Alliance for Geosciences, Environment and Society we share facilities with the Optically Stimulated Luminescence Laboratory at the Scottish Universities Environmental Research Centre (SUERC). This contributes to a range of palaeo-environmental and geochronological dating programmes. We are a key collaborator with SUERC stable isotope laboratories contributing to contemporary global change and C cycle research. This work has also made extensive use of the Abisko Scientific Research Station in Sweden for Arctic C dynamics research programmes since 1991.

We work with the James Hutton Institute through CREW and Hydro Nation initiatives and their confocal microscopy facility in the visualising of organic decay features as well as their 'MOORCO' experimental tree plantings. Our Gabon field station is working with the ESA-NASA AfriSAR programme calibrating sensors for the BIOMASS satellite (2021 launch). Planetary observation,

by its nature, demands high-level facility sharing. We participate in the NASA Mars Exploration Rover and Mars InSight lander missions as well as the Japanese Hayabusa 2 sample return mission to asteroid Ryugu.

Collaboration with the NERC Plymouth Marine Laboratory has contributed to the development of NEODAAS and COPERNICUS initiatives. We work with the NERC Life Sciences Mass Spectrometry Facility on environmentally indicative biomarkers and ecosystem processes, the NERC ship RSS James Cook for the recovery of ocean and seafloor cores, and NERC-CEH Loch Leven Observatory and CEH data centres. NERC facility payments 'in kind' totalled £452k between 2013/14 and 2019/20.

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

Arrangements for effective research collaboration

Our framework for research collaboration is founded on leadership of national and international networks and partnerships. Locally, ideas are initiated and tested through our cross-Faculty University Research Programmes that include *Environmental Change, Extremes in Science and Society, Global Food Security, and Cultural Heritage*. Initiatives from University Research Programmes are supported by a Research and Innovation Service programme manager. These programmes have been successful in establishing wider partnership links in Scotland, through the Scottish Universities Insight Institute, the National Centre for Resilience, the Scottish Alliance for Geosciences pooling initiative, James Hutton Institute and NERC research centres (UK Centre for Ecology and Hydrology; British Geological Survey and Plymouth Marine Laboratory). Collaborations and leadership across Europe are also stimulated by these programmes and integrate with research infrastructure and research-synergy based developments. This includes Stirling's role as the UK lead alongside BEIS and UKRI NERC in the development of the DANUBIUS-RI pan-European Research Infrastructure (consortium status pending) on river-sea systems roadmap, delivering a new paradigm in understanding and managing the catchment to sea water continuum.

We have a dynamic internationalisation agenda that brings broader and cross-cultural interdisciplinary frameworks and has enabled long-standing collaborations with over 30 countries. Our collaborations with US colleagues are driven by NSF support for programmes on Mycorrhizal drivers of soil organic matter formation and decomposition (NSFDEB-NERC), the Comparative Island Ecodynamics (NSF) and Threatened Science & Heritage in Greenland: Response and Capacity (NSF). More widely, our UKRI Future Leaders Fellow gives leadership in complex human-environment interactions in Kazakhstan, India and Brazil. We currently contribute to and lead working groups on international advisory boards of major research programmes driving the linkages between research and impact for intergovernmental agencies and stimulating new collaborative programmes. These include the *International Ocean Colour Coordinating Group (IOCCG)*; the *Group on Earth Observation (GEO) AquaWatch Initiative*; *International Atomic Energy Agency, International Electrotechnical Commission, International Committee for Radiological Units; Scientific Committee of the North Atlantic Microplastics Centre - Bergen*.

During the review period we have hosted self-funded research collaborators (>1 month) from 14 countries, bringing new research ideas and vitality to our laboratories. Increasingly we develop Memoranda of Understanding as foundations for our research activities and as exemplars of best working practice, supported through the University's International Office. Our adoption of this approach includes cross-disciplinary collaboration with Stirling Faculty of Arts and Humanities and Historic Environment Scotland delivering environmental change research within two UNESCO World Heritage Sites partners in China; The Emperor Qinshihuang's Mausoleum Site Museum, Xian and The Palace Museum, Beijing.

Interaction and engagement with key research users

Pathways to impact are developed through partnership training and mentorship activities stimulated by Faculty and Honorary staff and connecting academic and research 'user' partners. We stimulate interaction with the 'research-user' community' through well-attended research beneficiaries' workshops where our latest research agendas and outcomes are set out and discussed. As a matter of principle, our academic researchers work with end users to 'translate' findings into workable outcomes, exemplified in our impact case studies. We are enhancing existing and growing new partnerships that will co-deliver research and user activity as the new SIEC emerges.

Informal and regular group meetings and sharing of opportunities, experiences and best practice are also part of this ecosystem of academic and user interactions. We have close working relationships with a wide range of international and national organisations, for example UNESCO – World Heritage Sites, UNESCO – Geoparks, UN Environment GEMS/Water; Central African Forest Initiative, UNEP African-Eurasian Water-bird Agreement, IUCN Species Survival Commission, CAB-International, EU Joint Research Centre; UK and Scottish regulatory bodies (Scottish Environment Protection Agency, NatureScot, Historic Environment Scotland, Forestry & Land Scotland, Environment Agency); conservation charities (Royal Society for the Protection of Birds, Woodland Trust, Bat Conservation Trust, Wildlife Conservation Society, National Trust for Scotland) and environmental industries (Nuclear Decommissioning Authority). These partnerships lead to roles for researchers as members of advisory panels, commissions, or on peer review groups developing guidance on research impact, legal frameworks and environmental standards.

Wider contributions to the economy and society

Our wider contributions are focussed on public engagement activities, policy development, environmental management toolkits and work with schools. *Public engagement* activities include science fairs on campus including science and arts interactions showcasing the aesthetic and practical properties of bio-minerals, the 'Pint of Science' initiative explaining big science issues to local pub regulars, performance at the Beltane Network's 'Cabaret of Dangerous Ideas' at the Edinburgh Festival Fringe and online events at the Edinburgh Science Festival - A Decade to Decide and Saving our Seas. Especially notable is our Buzz Pollination contribution to the 'Brilliant Bugs' Royal Mail stamp series which featured one of our research paper and figure on the sleeve of the Presentation Pack.

Our research is underpinning *science-based policy* on peatland restoration for the Scottish Government's National Greenhouse Gas Strategy in collaboration with the RSPB, and forest management for soil carbon sequestration with the Forestry Commission. Carbon cycling research in the Arctic, including the Permafrost Carbon Feedback is directly contributing to UK and international policy (All Party Parliamentary Group for Polar Regions; and the 2nd Arctic Ministerial process). In the tropics we are directly contributing scientific data to the Central African Forests Initiative, the International Consortium on Combating Wildlife Crime, the IUCN Red List of Threatened Species and the Congo Basin Forest Partnership.

We are trialling *environmental management* tools such as quantitative PCR detection of *Escherichia coli* in contaminated farmland soils in work supported by NERC. Related, decision-support tools for catchment management have been developed and are being trialled to visualise pathogens and environmental risk in China and the UK. We are working with SEPA, Scottish Water and Anglian Water to exploit satellite remote sensing for monitoring and managing water quality of inland water bodies including drinking water reservoirs.

In collaboration with Stirling colleagues in History and Education and supported by the Strathmartine Trust, ESRC, Royal Society and Scottish Wildlife Trust, we *work with schools* in remote areas and attainment- challenged locations. Here we translate and integrate Citizen Science and Travelling Labs approaches to learning into the school curriculum. Workbooks

developed for these projects are now being evaluated for wider school use. An unsolicited written quote from one of our partner teachers highlights our impact: *...the kids did really well in their [Higher] exams – “the soil assignments that they wrote up based on the fieldwork really helped some of the kids pass when they might not otherwise have done so... “*.

Contributions to disciplinary and inter-disciplinary sustainability; national and international initiatives

We explicitly apply our research to sustain disciplines across the environmental geo- and bio-sciences. Sustainability in a social sense is evidenced through research-based participation in our respective learned societies (research committees and boards of governance), our active involvement in school curriculums, research pooling initiative (SAGES) and the success we have had in making new academic appointments. We contribute in an economic sense to discipline sustainability through our anticipatory, horizon scanning and research lead in our successful research funding programmes, enabling collaborators in other universities, and ourselves, to thrive. In an environmental sense the continual upgrading of our laboratory facilities, made available to others, contributes discipline sustainability and we lead new sustainability initiatives on waste, travel and energy use in the University.

We have excellent inter-disciplinary research collaborations in which we explicitly integrate our biological and environmental sciences with social and economic sciences approaches, humanities and engineering contexts. Exemplars include work in East Africa considering the spatial aspects of particulate pollutant impacts on urban social groups (MRC, social sciences), development of citizen science programmes in developed and developing nation contexts (ESRC PGRs, social sciences, education), energy policy related to fracking and community responses (NERC, social sciences), post-disaster management of World Heritage Sites (GCRF, arts and humanities, engineering) and integration of human decision-making processes with ecological processes in biodiversity and livelihood conflicts (ERC, social and economic sciences). During the review period we have focussed on environment and development issues through international development GCRF imperatives, inter-disciplinary research demands made possible through UK Industrial Strategy and local 'levelling up' opportunities through 'place-based' research.

Indicators of wider influence

Senior colleagues contribute to the leadership of learned societies. This includes the Royal Society of Edinburgh Vice President (Physical Sciences, 2017-2020), chairing the Learned Societies Group and Scottish Government STEM Strategy Advisory Group, and in these roles advising on COVID impacts on STEM Education (Cusack).

Recent prizes highlighting transformational leadership include the 2017 Schlumberger Medal from the Mineralogical Society (Cusack), the 2018 Sistema Nacional de Investigadores Nivel II, CONACyT, Mexico (Vallejo-Marin), the prestigious Romanian *Order of Cultural Merit* for leadership in developing the pan-European infrastructure DANUBIUS-RI 2019 (Tyler), the 2014 IEC 1906 Award for Excellent Leadership of Working Group International Electrotechnical Commission (Tyler).

We currently contribute as members and Chairs to a range of national and international environmental committees. Highlights include:

- Environmental Radioactivity: Convenorship of the Instrumentation Subcommittee 45B-Environmental Radiation Protection; Membership of the Particle Recovery Advisory Group (Dounreay); Dalgety Bay Particle Advisory Group; Member of Committee 4 (Applications of the Recommendations of the ICRP), International Commission on Radiological Protection; Chair of the ICRP Task Group 105 on considering the environment when applying systems of radiological protection; Chair of the Society for Radiological

Protection's Non-Nuclear Industry Committee and Treasurer to the UK's Co-ordinating Group on Environmental Radioactivity;

- Earth observation and Water: International Ocean-Colour Coordinating Group (IOCCG) expanding the remit to inland waters; GEO AquaWatch initiative leading the global capacity building working group in Earth observation; recent appointment to the leadership council of the UK Water Partnership and member of the United Nations World Water Quality Alliance;
- Environment and Heritage: Contributions to the UNESCO Chairs panel, as an expert member of the UK National Commission for UNESCO and membership of the peer review committee for Historic Environment Scotland;
- Arctic Science: Chaired the International Arctic Science Committee's (IASC) Terrestrial Working Group (2017-2019), currently co-Chair the Action Group on Carbon Footprint, Steering Committee member of the International Tundra Experiment (ITEX), and Steering Committee membership of the EU 'INTERACT' Transnational Access Board (since 2011);
- Biological Conservation: Colleagues are members of the IUCN Species Survival Commission, The UK DEFRA Darwin Expert Committee and Chair of the UK Bat Conservation Trust;
- Within and through the National Academies there is lead of the review of research funding within RSE; membership of the Royal Society Partnership Grants Panel for school STEM projects (2019-), membership of the Scottish Government STEM Advisory Group and the Sustainable Stirling Partnership. In these roles we provide academic research policy expertise that guides development of disciplinary areas.

In media contributions we give informed opinion on matters ranging from biological conservation to planetary exploration across national and international printed and web media, television and radio, including primetime current affairs programmes. Furthermore, we train Thomson Reuters editors and journalists globally in science foundations for media reporting in relation to environmental radioactivity and nuclear safety.

Our future

Biological and Environmental research at Stirling draws tremendous energy, commitment and excitement from our mission oriented research leading to the successes evidenced in our research environment. We have strong trajectories in staff FTE growth, accelerating research grant income together with quality and volume of research outputs, strong commitment to the development of early career researchers and PGRs, significant impact in our research outcomes, and leadership in local, national and international collaborative and partnership networks.

Our research environment is now the platform for the partnership-based Scottish International Environment Centre that will deliver the next step-changes in our journey. This includes the drive towards achieving net zero carbon at local, regional and global scales, water management in multi-purpose landscapes through the new Scotland Hydro Nation Chair, addressing the challenges of biodiversity loss, conservation and restoration, and the new insights needed to explain and mitigate the consequences of plastic wastes and related environmental contaminants.

The environmental systems of our planet are facing unprecedented pressures. Biological and Environmental Sciences at the University of Stirling has the agenda, insight, skills, passion and resources to make positive differences to our shared home. Leading by example, the University has signed the Global Climate Letter for Universities and Colleges, committing us to becoming a net zero organisation.