Institution: University of Sheffield

Unit of Assessment: 7 - Earth Systems and Environmental Sciences

a. Overview: The University of Sheffield has established an outstanding international reputation for leadership in environmental and ecological research that addresses some of the key challenges in Earth Systems and Environmental Sciences (ESES) such as climate change impacts on ecosystems and sustaining biodiversity and ecosystem services. The research activity in this UoA is focussed on mechanistic understanding of organism-environment interactions and evolution across the full spectrum of scales from molecules, to whole organisms and ecosystems, through to global biogeochemical cycles and biosphere-geosphere-atmosphere interactions over geological time. This return builds on our RAE2008 ESES submission of 22 staff that was led by Animal & Plant Sciences (APS) and included two members of Molecular Biology and Biotechnology (MBB). In REF2014 we return 26 staff (23.9 fte) including 7 Independent Research Fellows, and 7 Early Career Researchers. These staff benefit from the shared infrastructure, equipment and facilities both of the School of Biology, and the wider university, through inter-departmental collaborations and access to centrally maintained facilities. This interdisciplinarity is reflected in our inclusion of *Casson* from MBB whose interests lie in plant sensing and signalling, and two professors in the School of Mathematics and Statistics (SOMAS), one focussed on applications of Bayesian Analysis to environmental research (*Buck*), and the other (*Quegan*) is the Director of the Sheffield NERC Centre For Terrestrial Carbon Dynamics. Our *Global Change* and *Ecosystem Ecology* research clusters of RAE2008 have now developed into two synergistic and non-exclusive groups:

1. ***Biotic Interactions*** which includes: the mechanistic, functional and evolutionary consequences of interactions between organisms, their environments and ecosystems, and conservation biology. (**19** staff: *Beckerman**, Blanchard**, Cameron, Casson, Childs**, Dugdale, Edwards, Hatchwell**, Holt, Leake**, Leegood, Rolfe, Scholes, Ton, Robinson, Smith, Watt, Warren** Webb).*
2. ***Environmental Change*** which includes: climate change impacts on ecosystems, evolution, functioning and perturbations of biogeochemical cycles, biology of pollution, and urban ecology. (**13** staff: *Beckerman**, Blanchard**, Buck, Callaghan, Childs**, Evans, Hatchwell**, Leake**, Maltby, Phoenix, Quegan, Warren**, Zona*). ***Staff common to both groups (**6**).

b. Our research strategy is to seek to be at the forefront of addressing key challenges facing humankind, including understanding the impacts of environmental change on ecosystems, how to ensure provision of essential ecosystem goods and services (such as sustainable agriculture and marine fisheries), and how to protect biodiversity and ecosystem functioning in the face of global changes. We combine high quality fundamental research that provides a rigorous science evidence-base for environmental policy, underpinned by an extensive network of international collaborations with leading scientists, policymakers and end users.

The overall success of our strategy is reflected in our **key achievements relative to RAE2008**:

- **Increased publication numbers and impact**: A 37% increase in ISI listed publications by members of this submission, to more than 450 articles, cited more than 8100 times.
- **Strengthened publication quality** we have published 28 papers in the highest impact international journals (12 papers in *Nature*, *Science,* or *PNAS*; 7 in Nature Group journals (*Nature Geosciences*, *Nature Climate Change*, *Nature Communications, Nature Genetics*), and 9 papers in *Ecology Letters,* the highest impact journal for ecology).
- **More international collaborations**: Over 54% of our papers in the review period have overseas co-authors (RAE2008: 46%), distributed over a total of 56 countries. Nearly 40% of our papers have a non-university co-author, three quarters of these being overseas, reflecting both the global reach of our research, and our strong commitment to end-user engagement.
- **Doubling and diversification of net income**: Research spend has risen from £4M to £9M, RCUK income capture increased 3-fold to £6M, EU awards have risen 5-fold to over £2.9M, and from charities increased 10-fold to over £2M. Support from industry has more than doubled.
- **Growth to over 200 researchers**: including 54 PDRAs, >130 PhD students (64 individuals completed), 26 Research assistants/ technicians.
- **Rise in research fellowships**: 60% of staff have held a total of 18 research fellowships/ research leadership awards during the review period, with awards totalling over £4M.
- **Greater national and international professional representation**: Membership of 28 Journal Editorial Boards and 32 grant review panels. Organisation of 29 conferences attended by over 10,000 delegates and hosting 30 international visiting scientists for 19 person-years.

Achievement of strategic aims: In RAE2008 our future mission was "*to conduct high quality*

interdisciplinary research that advances understanding of ecosystem functioning and informs the development and implementation of science-based policy for sustainable environments". This was framed in relation to the ongoing critical threats to the integrity of ecosystems and the services ecosystems provide to humanity caused by climate change and urbanisation, and the need for better scientific understanding and predictive capabilities in relation to these threats. Central to this goal was the importance of *"developing techniques for scaling up from short-term, local-scale studies to regional, global and long-term changes*". We identified capacity building opportunities in relation to these goals from: **(i)** building synergies between our *Ecosystem Ecology* and *Global Change* clusters; **(ii)** capitalising on interdisciplinary interactions; and **(iii)** optimising our portfolio of collaborations and end users.

Since 2008 we have developed the *Biotic Interactions* and *Environmental Change* groups out of our previous research clusters. Both new groups have been at the forefront of integration of environmental and evolutionary biology using a systems approach. This has enabled our advances in understanding effects of *Biotic Interactions* on selection and inheritance of adaptive traits, behaviour and functioning of organisms, to provide better predictions of larger-scale and longer-term consequences of/for *Environmental Change* (e.g. urbanisation effects on wildlife, and how plant evolution has affected biogeochemical cycles). Collaboration is strong within and between the two research groups, with 6 staff in common, and our strengthened portfolio of external collaborators has enhanced the reach, significance and impact of our work.

Biotic Interactions*:* Group achievements. *Beckerman, Blanchard, Dugdale, Childs, Hatchwell, Holt, Warren, Watt* and *Webb*, have made important advances in understanding the fundamental environmental, behavioural, demographic, predator-prey and food web controls on population growth and reproductive success. By developing systems-based models that reflect these controls, longer-term and larger scale effects of human activities and climate change on organisms are being determined, strengthening the synergies with the *Environmental Change* group. For example, *Blanchard* established relationships between body size and abundance in marine food webs, to develop a size-based food web model that was then coupled to an earth system model to predict effects of climate change on regional variations in marine fish biomass and production across the globe, in collaboration with oceanographic and fisheries research teams at NOAA. *Robinson* has shown how environmental heterogeneity interacting with parasite loads select particular phenotypes in Soay sheep, whilst *Childs* has combined evolutionary game theory and structured population modelling to understand reproductive allocation in these sheep. Work on plant-environment interactions by *Cameron, Casson, Leake, Leegood, Rolfe, Scholes,* and *Ton* ranges from the evolution and genetic controls on stomatal function and photosynthesis, the origins and functioning of plant-fungal symbioses, biochemical signalling pathways involved in plant-parasite interactions and defence, through to effects on plant communities. This includes the role of plant phylogenetic distance in controlling the regeneration niche in tropical forests through effects mediated by parasites and herbivores. Outstanding achievements include *Ton*'s work revealing systemic acquired resistance to pathogen attack in plants can be inherited epigenetically to prime progeny against local pathogens, and identification of the DNA-methylation mechanism underpinning inter-generational defence priming. *Smith* has pioneered synergistic work on plant epigenetics, and *Scholes* has resolved the genetic basis of rice resistance to parasitism by *Striga*.

Environmental Change*:* Group achievements. Our world-leading studies on Arctic ecosystem responses to climate change include: *Callaghan* discovering that warming in the subarctic increases respiration from subsurface peat to a much greater extent than previously realised, *Zona* revealing the importance of summer-dry lakes in methane fluxes and *Phoenix* showing how extreme winter warming can devastate Arctic ecosystems through loss of snow insulation.

Leake's work on mineral weathering by major phylogenetic groups of plants and fungi at the nanometre-scale in laboratory and field studies, have fed into process-based models developed in collaboration with colleagues in Biology and Engineering, to determine the global-scale effects of plant and mycorrhiza evolution on the geochemical carbon cycle, over tens of millions of years. *Buck* has used Bayesian analysis to improve radiocarbon calibrations and reconstruct sedimentation histories. *Quegan* has used remote sensing to detect regional deforestation in Sumatra and determine forest biomass in Siberia, revealing limitations in current data used in dynamic global vegetation models. This was a prelude to his leading the successful bid for the €470-million European Space Agency's BIOMASS mission that will launch in 2020 to provide the first accurate global maps of forest biomass from space. In our work on environmental pollution, *Phoenix* and

Leake have determined multidecadal effects of nitrogen deposition on terrestrial ecosystem functioning, and *Hatchwell* has studied long-term impacts of oil spills and climate on sea bird populations. *Maltby* has played a pivotal role in developing risk assessment methods for aquatic pollutants and assessing ecological quality within an ecosystem service framework. In urban ecology, *Warren's* paradigm-shifting work has revealed the importance of domestic gardens as contributors to biodiversity, and *Leake* found urban ecosystems store more organic carbon per unit area than the surrounding countryside, overturning previous dogma. *Evans* has found rural and urban blackbird behaviour differences are linked to selection of genes for harm avoidance.

Future strategy, goals and vision:

To provide world class research leadership that advances understanding of the evolution and functioning of organisms and ecosystems and is engaged in informing the development of science-based policy and practice to deliver more sustainable environments and benefits to society.

Our strategy builds on: (**i**) Continued alignment of our research to major international and national research priorities in the areas of living with environmental change, food security, sustainability and protecting biodiversity. **(ii)** Gaining in-depth understanding of fundamental processes which can be scaled up to predict regional and global consequences. **(iii)** Further developing our systems approach to integration of evolutionary and environmental biology using genomic and metabolomic tools, in combination with modelling approaches that enable predictions of longer-term and larger-scale effects of environmental change. **(iv)** Addressing the grand challenges of how to sustainably feed and fuel human populations without destroying the global ecosystem services that support us. **(v)** Conducting this kind of policy-relevant research as leaders or partners in interdisciplinary and international consortia that aim to provide holistic understanding of complex problems, the solutions to which require insight from a range of fields of knowledge. **(vi)** Continuing to foster world-class leadership both in research and in engagement with policymakers, industrial partners and the general public, to ensure that our science informs evidence-based policies and actions for protection of the Earth, the delivery increased sustainability, and their long-term benefits to society.

Ongoing strategic developments: Amongst our most important strategic developments are:

(i) Leadership and involvement in international multidisciplinary consortia to enable holistic understanding and up-scaling from individual experiments to global consequences. *Callaghan* coordinates the INTERACT pan-Arctic network of 40 research stations in which his 3M concept (Monitoring changes, Manipulation experiments and Modelling to predict future effects), is being rolled out to improve large-scale-long-term climate change impact predictions. Both *Phoenix* and *Zona* are also involved in similar consortia focussed on multi-scale studies across the Arctic and sub-Arctic. **(ii)** Strategic new academic appointments (see **c. i.** below). **(iii)** Further engaging and expanding our portfolio of international collaborators and industrial partners (see **e**). **(iv)** Recent major investment in new labs and plant-growth facilities at our £4.5M Environment Centre (see **d.**) and **(v)** new mass-spectrometers and DNA sequencers for state-of-the-art metabolomic and genomic studies especially in relation to interactions between symbionts and pathogens, and environmental stresses (see **d.**). **(vi)** Strengthening of crop and soil science research capabilities through industrial partners (*RAGT Seeds*, *Bayer CropScience* and *Syngenta*), a White Rose University Consortium with Leeds, York and *Fera* based at Spen Farm, and a £2.6M BBSRC LoLa commencing in 2014. (**vii**) PGR developments, including: leading the £5.8M NERC Doctoral Training Programme (2014-19) with York, Liverpool and CEH (£9M total) that will provide 110 studentships; the Faculty's £5M 'Project Sunshine' Doctoral Training Centre (DTC) for food, energy and sustainability; and the Grantham Foundation for the Protection of the Environment's £2M donation for a Faculty DTC on sustainability starting in 2014. **(viii)** Staff in this UoA have already secured well over £3M of new research grant awards post REF2014 (see **d**).

c. People: 1. Staffing strategy and staff development:

Recruiting, mentoring, supporting and developing exceptionally gifted staff is central to achieving our future strategy and goals, and is underpinned by our commitment to provide a thriving, mutually supportive research environment that retains and grows talent. Of the staff returned, 17 (65%) have been here since before 2008, and successful career development has increased the number of staff at senior grades to 9 professors (2 promoted since 2008), 3 Senior Lecturers (1 promoted from lectureship after a RCUK fellowship), and a Senior Research Fellow. Only one established staff member has left (Osborn to a chair at The University of Hull), three have retired, and 4 early career researchers have secured lectureships elsewhere. Our recruitment strategy has therefore focussed on young talent, exemplified by our retaining 3 and attracting 5 independent research fellows, and 5

recent lectureship appointments in fast-moving priority areas. *Ton*- plant defences and signalling**,** *Casson*- evolution and control of stomatal functioning, *Blanchard***-** marine conservation, climate change and fisheries management, *Evans***-** urban ecology and macroecology, *Edwards***-** tropical forest biodiversity and conservation. We have also appointed two University funded fellows: *Zona*- working on Arctic biogeochemistry, and *Smith*, on plant epigenetics. All these new staff strategically combine research excellence in priority areas that complement our existing expertise, with a track record of commitment to collaboration and leadership in end-user engagement. They further strengthen our representation on national and international policy-advisory panels, and potential for impact on agri-food and forestry industries.

Research Fellowships/ Research Leadership Awards: The quality of our staff, commitment to knowledge-exchange for science-based policy, and effective mentoring of early career researchers is reflected in our portfolio of prestigious leadership and fellowship awards totalling over £4M. *Ton,* appointed in 2011, has won both a Leverhulme Trust Research Leadership Award (£0.9M) and an ERC Starting Independent Researcher Grant (£1M). More than half our staff, ranging from senior professors to early career researchers have held research fellowships since 2008, with 15 fellowships being awarded worth a total of over £2M, including a High Level NERC/Defra Policy Placement Fellowship (*Maltby*), Leverhulme Trust Research Fellowships (*Hatchwell, Scholes*), Royal Society University Research Fellowships (URF) (*Webb* - award plus extension; and *Cameron*), NERC Advanced Fellowships (*Childs* and *Cameron* – award declined for URF), NERC Postdoctoral Fellowships (*Childs, Dugdale, Robinson*), NERC Knowledge-Exchange Fellowship (*Holt*), Leverhulme Trust Early Career Fellowship (*Evans*), and a Leverhulme Trust International Academic Fellowship (*Rolfe*). *Blanchard* was awarded an International Visiting Fellowship from the Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER) in France. *Phoenix* was an RCUK fellow until appointed to a lectureship in 2009, Cameron was an NERC Fellow until securing his URF in 2010 and *Childs* has progressed from NERC Fellowship to NERC Advanced Fellowship- reflecting our vibrant research environment support for career development of fellows.

Post-doctoral Researcher Career Development: Our strategy is to train and mentor PDRAs to enable them to undertake research of the highest academic quality and importance and to communicate their findings in high-visibility journals, international conference presentations, and engage in knowledge-exchange with leading academics and end users. This helps them to identify key research priorities, build collaborations and gain increasing recognition of their skills and achievements that facilitate their development of successful independent funding for a future career in research. We are proactive in encouraging participation in *Researcher Professional Development* activities that facilitate networking across disciplines and provide training, career planning (including for non-academic positions), mutual support and mentoring (e.g. *Broadening Horizons, Think Ahead*, *Spring Board for Women*, and *Researcher Mentoring.* The residential *Sheffield Crucible* provides training in media, public and policy engagement, building research networks, and skills for innovation, creativity and enterprise. Our success in receiving the HR Excellence in Research Award from the European Commission in 2012 signifies the internationally recognised high quality environment we provide for early career researchers and acknowledges our commitment to the 7 principles of the UK Concordat for the career development of researchers.

International staff appointments, visits and exchanges: We have recruited two lecturers from overseas- *Edwards* from Australia and *Zona* from Belgium. *Petchey* moved to be Associate Professor, University of Zurich shortly after completing his Royal Society Fellowship. In 2012-13 *Beckerman* was awarded a CONICYT Visiting Professorship to Chile. *Maltby* is a '*High End Expert*' visitor to the Chinese Academy of Sciences, *Quegan* was awarded a Royal Society of Engineering research exchange with China and India, *Buck* a Leverhulme Trust Academic Collaboration International Network and *Hatchwell* a Royal Society International Outgoing visit to ANU, Australia. *Blanchard* has received 4 visiting fellowships/awards to work with collaborators in New Zealand, NOAA, Hawai'i, IFREMER, France and the North Pacific Marine Science Organisation, Japan.

We have hosted over 30 international scientists from Australia, China, Chile, Brazil and Europe (Czech Republic, France, Germany, Spain, Sweden etc.) for more than 19-person years since 2008 to benefit from our expertise and facilities. This includes senior study-visitors and externally funded PDRAs (3 Marie-Curie Fellows and a BBSRC Capacity Building Fellow from Kenya).

Technical staff: To ensure future sustainability and skills-transfer from our experienced senior technical staff that maintain central facilities, equipment and conduct various kinds of analyses, *Maltby* (as head of APS Department) instigated a technician apprenticeship scheme. Apprentices

were trained over 2 years gaining in-depth knowledge of research in all our main research laboratories, and familiarity with all existing staff and their expertise. They were trained to be able to maintain all the research-critical activities of senior technical staff. The apprenticeships have trained highly skilled and versatile new staff, benefitting from the accumulated experience of senior staff, and enabling deployment in any area where there is greatest need. The scheme has been run twice in APS, and its success has led to other University departments following our example.

Equality and Diversity: We are committed to the provision of an excellent, fair environment with equality core to our culture in which all staff are valued and enabled to flourish. Reflecting the ranking of the University of Sheffield as one of the top 50 employers in the UK for women in 2011, we have more than doubled the proportion of female staff in this UoA to 35% of FTEs, including a tripling of women at Professorial level since 2008. Our female staff have taken leading roles locally, nationally and internationally (*Maltby* has served as HoD, *Blanchard* is Council member of The British Ecological Society and is a member of the International Union for Conservation of Nature committee on ecosystem based management, *Scholes* is Vice-President and President-Elect of the International Parasitic Plant Society, and *Buck* was selected as co-chair of the Palaeo50 International Review Group on palaeoecological research). Such activities act as role models in our highly successful Impact Mentoring and Researcher Development Programme. The departments support flexible working practices to facilitate childcare and carer commitments. APS was awarded Athena Swan Silver (2013), with MBB and SOMAS having applications underway. The coordination by a female PDRA of a discussion workshop on women-in-science that engaged most of our PDRA's and identified action points for the Athena Swan group was highlighted as "noteworthy good practice" in our award. Nearly half (46%) of our research students are female, reflecting increasing success in overcoming female-under representation in scientific research.

Fostering Good Research Practices (GRP). Our research environment is founded on a culture of integrity, and collegiality, underpinned by rightful recognition and acknowledgement of each individual's contributions to research activities and outputs. Sheffield is one of the few Russell Group Universities to deliver compulsory GRP training for all research students. We have had exemplary leadership by senior staff who have been totally committed to maintaining high ethical standards both in the conduct of research and in its outcomes, in knowledge exchange, and commercialisation opportunities, and made this integrity central to mentoring of more junior staff.

2. Research students make a major contribution to our research and esteem, for example co-authoring over 86 of the ISI-listed papers published since 2008 by staff returned to this UoA, and winning awards and prizes for presentations at international conferences. Research student completions in REF4a (55.6) are apportioned to supervisors, and our interdisciplinary research means many co-supervisors are returned to other UoAs. Our total research students (132) and PhDs awarded (64 persons) in this UoA increased by over a third compared to RAE2008, even though 30% of our staff have been appointed after 2011, so have not yet had students complete. Training. PhD students are provided with dedicated bench and computer space and participate fully in our research activities. The QAA in its 2012 review was highly satisfied by our research student training and support and praised several aspects as exemplars of good practice including our comprehensive induction programme and records of supervisory meetings. As a result of the highly interdisciplinary nature of much of our research, many of our PhD students have two or more supervisors, often including staff in other departments in Biosciences, and faculties (e.g. Geography, Civil and Structural Engineering (CSE)), and in some cases have co-supervisors from outside Sheffield. All students are assigned a primary supervisor and an independent advisor as an impartial mentor, and are required to pass formal training courses both in generic professional and research topic specific skills provided by the departments and the University's Doctoral Development Programme. A written literature review, research report and oral presentation are compulsory and assessed at staged points, with detailed feedback provided. Students attend research group seminars, departmental seminars and give regular presentations to their research groups. Training is provided to enable them to acquire teaching skills by acting as laboratory demonstrators or small-group tutors. Partners. Our research students benefit from our strong culture of interdisciplinarity and collaboration- gaining access to expertise and facilities shared across the University, and through our networks of external collaborators and CASE partners who provide financial, logistical and scientific support. This includes facilitating access to UK and overseas field sites, long-term data sets, samples, and specialist expertise (e.g. in taxonomy). We have grown the range of industry, government-agency and NGO collaborations in NERC, and BBSRC CASE-Partnerships, and in the

EPSRC E-Futures Doctoral Training Centre. CASE partners include *Heineken*, *TATA Steel*, *Bayer Crop Science, Microsoft Research, Centre for Environment, Fisheries and Aquaculture Science (Cefas), Freshwater Biological Association (FBA), Marine Scotland Science, Environment Agency, British Trust for Ornithology,* and *Moors For The Future*. Several sponsors have 50% funded studentships including *Cefas* and *Syngenta*, and both *Shell International* and *Syngenta* have fully funded PhD studentships, in the latter case with technician support. Students have won competitive RCUK-Funded 12 week internships in the Welsh Assembly Members Research Service and the BES Parliamentary Office of Science & Technology Fellowship and together with early career researchers and technicians are promoting science-policy discussion across all tiers of our departments (http://www.sheffieldscienceinpolicy.com/).

d. Income, infrastructure and facilities:

Our research alignment to UK and international research priorities has enabled our research income to more than double since RAE2008 to £12M of new awards (£9M spent, >£3M carried forward post REF2014), and we have diversified our income sources. The average grant income spend/FTE for this UoA was £0.2M in RAE2008, but has now risen to over £0.39M, despite 30% of our FTEs being staff appointed since 2011, and 30% being Early Career Researchers.

New awards since 2008 comprise £6M from RCUK (£4.5M NERC, £0.8M BBSRC, £0.7M EPSRC), £2.9M from Europe (£1.8M from the EU and £1.1M from the ERC), and £2.5M from charities (including £1.4M from the Leverhulme Trust and £1.0M The Royal Society), together with a total of £0.5M from government, industry and international collaborators. We have continued our success in participation in large multidisciplinary thematic grants funded in RCUK priority areas including the NERC Biodiversity and Ecosystem Service Sustainability programme Urban consortium (*Warren*), Arctic Research Programme (*Phoenix*), and two EPSRC Sustainable Urban Environments consortia (*Leake, Maltby, Warren*). We have not only increased by a factor of three our RCUK funding, but the contribution from European funding agencies has risen by more than 5-fold, and from charities by more than 10-fold, simultaneously strengthening and diversifying our income. We have also substantially increased the number of industrial partners and their financial support in cash and in kind for research including: *Shell, Unilever, Microsoft Research, Syngenta, Bayer CropScience, Heineken, RAGT Seeds, Boningale, Tata Steel, Lindam Turf, Europolymers, Oxford Advanced Surfaces, Biotrack Ltd, and Nebion,* Zurich. Industry-funding of CASE-partnerships in which cash is paid directly to students or to offset bench fees has risen to >£60K. The newly awarded NERC Doctoral Training Partnership *Adapting to the Challenges of a Changing Environment* we lead (with York, Liverpool and CEH) will fund 110 studentships 2014-19.

Infrastructure and facilities. Our high-quality research is facilitated by an extensive array of world-class laboratory facilities and internationally important long-term field experiments in Arctic Sweden (UV-B, warming and snow manipulation), Svalbard (nitrogen deposition on Arctic Heath), Derbyshire Dales (nitrogen deposition on species rich limestone and acid grasslands), and sea bird colony studies on Skomer. These underpin some of our most important work on multi-decadal global-change and pollutant impacts on ecosystems and organisms.

During the previous review period £10M JIF awards were invested in providing refurbished laboratories and the purpose-built, Sir David Read Controlled Environment Facility (DRCEF) that houses 32 Conviron growth chambers. Recent RCUK funded enhancements to the DRCEF allows subambient CO_2 conditions to be maintained in up to 12 chambers. These world leading facilities enable us to conduct replicated studies that can simulate the majority of terrestrial climates from tropical to polar regions, from the Phanerozoic CO_2 minimum of 180 ppm to the 2000 ppm maximum of the past 380 million years. This facility underpins *Leake*'s NERC-funded work investigating the effects of evolution of land plants and mycorrhizal symbioses on mineral weathering, the geochemical carbon cycle and the effect of plant-fungal-coevolution on feedbacks operating between the biosphere, geosphere and atmosphere through the Phanerozoic. The University has invested £4.5M to create a new Environment Centre (AWEC, opened 2009), with 1000m^2 of controlled environment, climate-controlled gro-dome plant growth space and associated laboratories, together with space for external long-term monitoring studies. Together DRCEF and AWEC provide unrivalled infrastructure for environmental, plant, microbial and ecology research enabling world-class science that addresses climate change and food security. Analytical facilities underpinning our biogeochemistry and plant-microbial mineral interactions work include a Veeco Vertical Scanning Interferometer, and Inductively Coupled Plasma Mass Spectrometer at the Kroto Research Institute, and our in-house Sercon IRMS with gas, liquid and solid phase capabilities for

$^{12/13}C$, $^{14/15}N$, and $^{16/18}O$ isotopes facilitated by a new gas cryocentrator. These facilities are complemented by our radioisotope monitoring suite that includes real-time radioisotope imaging used in ^{14}C and ^{33}P tracer studies. We have strengthened our biological mass spectrometry capability with a £0.75M Waters Sinap for metabolomics. This has been integrated into our new (2013) Faculty Mass Spectrometry facility with 300m^2 refurbished lab space providing access to 14 mass spectrometers (value >£5M). Our 200keV cryo-EM and AFM instruments facilitate our studies on nano-scale interactions between microorganisms and their substrates and the physical properties of cell surfaces in response to different environmental conditions. Molecular-genetics and DNA analysis is provided by NERC- Biomolecular Analysis Facility (N-BAF) which has received £2M external funding in the review period and has DNA sequencer/TILLING/SNP facilities which allow high-throughput screening of DNA samples. Bioinformatics and large data analysis is facilitated by Iceberg, a University high-performance computer cluster. Our major facilities, including the DRCEF, AWEC, N-BAF, aquarium, analytical chemistry, stable and radioisotope and mass-spectrometry suites, are each run and managed by dedicated support staff. Sustainability is ensured through raising monies for facility maintenance through research grants. The excellence of infrastructure remains a key element in attracting international collaborators, independent research fellows, PhD students, securing research grants, and producing high quality outputs.

e. Collaboration or contribution to the discipline or research base

International Collaborations. Over 55% of the more than 450 ISI listed papers published since 2008 by the staff in this UoA have overseas co-authors, distributed over a total of 56 countries and 230 universities, together with over 160 research institutes or non-governmental organisations, 10 charities, and industrial partners. Collaborations have involved 99 European universities, 80 Universities in the USA, 13 in Canada, 12 in Australia, together with universities in Asia (China, Nepal, Malaysia, South Korea), South America (Argentina, Brazil, Chile, Ecuador) and Africa (Kenya, Nigeria, South Africa). Of our papers, 38% have one or more co-authors from outside of universities, three quarters of these being overseas (e.g. *World Wildlife Fund for Nature, BirdLife International, The International Institute for Applied Systems Analysis*, Max Planck Institutes, CNRS, INRA, NOAA, NASA, *Sabah Forestry Dept., Nature Seychelles*, etc.), reflecting the global reach of our research, our network of studies overseas and our strong commitment to end-user engagement. For example, *Leegood*, is a PI in the *C4 Rice Consortium*, a $20M project supported by the *International Rice Research Institute* in the Philippines and *Bill and Melinda Gates Foundation* to develop rice with improved photosynthetic and water-use efficiency.

Industry Partners. We have more than doubled the numbers of industrial partners since RAE2008 (see lists under income and research students above and REF3a examples) as well as maintaining longstanding partnerships like *Scholes*'s work on rice and sunflower resistance to *Striga* funded by *Syngenta Foundation For Sustainable Agriculture.* A new partnership with *RAGT Seeds*, a major European cereal breeder with whom *Cameron* and *Leake* have a £476K Technology Strategy Board BBSRC grant, is developing new wheat varieties with broad spectrum disease resistance for use in sustainable agriculture. *Cameron* and *Phoenix* helped industry-partner *Boningale Nurseries* to develop 'GreenSky' – the first green roof substrates optimised for different climate regions.

Inter-departmental Collaborations at Sheffield. *Rolfe, Scholes* and *Leake* work with CSE in the *Kroto Research Institute* and *Cell-Mineral Research Centre* on cell-mineral interactions, microbial degradation of aquifer pollution and mineral weathering. *Warren* and *Maltby*'s work on urban river ecology in the *Catchment Science Centre* with CSE and Geography. *Phoenix* co-led with a Geographer the Marie Curie Training Network (*NSink*) on N deposition on arctic ecosystems, and the NERC Urban BESS project links *Warren* and *Evans* with the Department of Landscape.

Service to Grant Review Panels. Half of our staff served on UK grant colleges/panels during the review period, a factor of 5 increase from 2008. This includes 9 NERC College Members, 2 NERC Fellowship Review panels, and 1 on each of the following: Defra Peer Review College, Royal Society International Exchanges Committee, Nuffield Foundation Grant Adjudication Panel, British Council, BBSRC, and BBSRC-DFID-GATES panels. Staff have served on five international funding panels: the Leverhulme Trust Royal Society Africa Award Grants, and Royal Society Dfid Pan Africa Capacity Building Grants, the Czech Science Foundation, CONICYT Chile and NSF USA.

Service to Policymakers and Regulators: *Maltby* is a member of the Expert Working Group of the European Food Safety Authority, UNEP Scientific Expert Group on Chemicals in the Environment and Scientific Committee European Centre for Ecotoxicology and Toxicology of Chemicals, and served on the UK Advisory Committee on Pesticides. *Cameron* is one of 40 young scientists

appointed to the World Economic Forum in "recognition of their scientific excellence and commitment to science improving society". *Scholes* serves on the Royal Society Capacity Building Policy Network Committee providing advice to the Foreign Secretary on issues such as barriers to postgraduate training in Africa and science needed for development. *Dugdale* contributed to a report for Defra on behavioural, ecological and epidemiological impacts of badger mortality to inform policy on badger culling to reduce bovine TB. *Blanchard* serves on the National Centre for Ecological Analysis & Synthesis working group on effects of climate warming on food webs, IUCN Committee on Ecosystem Based Management, task-group co-chair for Indicators For The Seas working group, International Council for the Exploration of the Seas working group member, and was an invited expert at a Strategic Ocean Funding Initiative workshop. *Blanchard* has provided policy advice on the use of large fish indicators to Defra, informing the UK position on the choice of indicators and targets for Good Environmental Status, as required by the Marine Strategy Framework Directive. *Webb* is a member of UN pool of Experts on Oceans. Quegan has provided briefings to the All-Party Parliamentary Climate change Group in 2008 and 2009, and represented NERC in giving evidence to the Science and Technology Committee enquiry into the European and UK space agencies in 2013. He is a member of the Kyoto and Carbon Advisory Group of the Japanese Space Agency, and Chairman of the ESA BIOMASS Mission Assessment Group. *Phoenix* is a member of The Committee on Air Pollution Effects (on ecosystems).

Service to Education: *Cameron* is a strategic advisory group member for Pearson/Edexel A-Level Biology, *Callaghan* was commissioned to write the A-Level Geography text book, '*The Rapidly Changing Arctic*' (published in 2011). *Watt* is a Trustee of the Field Studies Council, and a member of their Executive and Education committees. *Buck* has been a panel member for International Evaluation of Research and Doctoral Training at the University of Helsinki.

Conference Organisation: Our staff have organised 29 conferences, attended by over 10,000 delegates, together with more than 20 sessions. *Beckerman* organised the British Ecological Society (BES) annual meetings in Sheffield and Birmingham, as well as INTECOL. *Maltby* organised the 5th and 6th SETAC World Congresses in Australia and Germany.

International Speaking Engagements: We have given over 170 presentations at international conferences, workshops, and seminars across 25 countries including in USA, Canada, India, Malaysia, Indonesia, Japan, Australia and New Zealand, and 15 European countries. This includes more than 80 invited international conference lectures, and 45 plenary / keynote addresses.

Journal Editing: Of the submitted staff, 60% since 2008 have served on a total of 28 journal editorial / advisory boards, including an Editor in Chief (*Ecology and Evolution*), 5 subject editors, 3 guest editors, and a Book Series (*Ecological Reviews*). The journals we have served include: *Ecol. Lett.*; *Global Change Biology*; *Global Ecol. & Biogeog.; New Phytol.; Plant, Cell & Environ.; Plant Signalling & Behaviour; Biogeosciences*; *Planta; Func. Ecol.; J. Animal Ecology; J. Applied Ecology; Animal Conservation; Bayesian Analysis; Advances in Space Research*.

Learned Societies and Conservation Agencies: *Callaghan* is the Founder and Chair of the Terrestrial Working Group of the International Arctic Science Committee. *Scholes* is Vice-President and President-Elect of the International Parasitic Plant Society. Five staff serve the BES. *Phoenix* and *Blanchard* are elected Members of Council**,** *Beckerman* is Chair of Meetings, *Blanchard, Webb* and *Warren* serve on various groups (Public and Policy, Macroecology, Digital Steering, Publications and Open Access Strategy). *Hatchwell* served on Council for the Association for the Study of Animal Behaviour. *Evans* is British Ornithologists Union Council Member. *Blanchard* is a Trustee of the National Biodiversity Network. *Warren* is on the FBA Data Services Advisory Group.

Prizes and recognition: *Cameron* received the World Economic Forum 2013 Young Scientist Award. *Maltby* was awarded the SETAC Environmental Education Award in 2009, and Callaghan received the Swedish Society for Anthropology and Geography's *Vega Gold Medal* in 2011, and *The Polar Medal* for services to the Arctic by H.M. Queen Elizabeth in 2013, a double accolade shared only with the Antarctic explorers Scott and Shackleton. An international symposium and a special issue of Ambio was dedicated to *Callaghan* as his festschrift in 2012. He has been made a Fellow of The Royal Swedish Academy of Sciences.

Concluding Summary: Our research environment has been impressively strengthened since 2008 by outstanding staff appointments, winning £4M of prestigious fellowships, >£10M investment in new facilities, and major growth in income, publications, citation rates, international collaborations, engagement with policymakers and industry partners. We have a clear strategy and vision, lead a £9M 5-year NERC-DTP, and have already secured over £3M of research funding post REF2014.