Institution: University of Sheffield

Unit of Assessment: 5 - Biological Sciences

a. Overview

The University of Sheffield has achieved an outstanding international reputation for excellence in biological science. This UoA comprises 47 staff (44.9 fte) within six research groups who are performing world-class work across the whole spectrum of biology, from the molecular to global scale. These groups encompass (1) Ecology & Evolutionary Genetics, (2) Plant & Global Change Biology, (3) Development, Disease & Stem Cell Biology, (4) Sensory Neuroscience, (5) Microbial & Cellular Biology and (6) Biochemistry & Structural Biology. The groups are all located in the same complex at the centre of campus and this proximity both with other biologists and cognate disciplines, from chemistry to maths, underpins and facilitates the interdisciplinary nature of our research. Over the REF period we have built on our strengths in each of these research areas and this has led to:

- **New grant income capture of £1.6M/fte**, **equating to £0.3M/fte/y, a 70% increase on our RAE2008 achievement**.
- **60 papers published in *Nature*, *Science*, *Cell* or *PNAS***
  >28 publications/fte, >18,000 total citations, mean citation rate >14, up from 7.5 in RAE2008
- **40% of the UoA awarded externally-funded research fellowships**
- **25% of staff promoted & 14 new academic staff appointed**
  (50% of whom are Early Career Researchers)
- **Ten members of staff awarded prestigious European Research Council (ERC) awards**
- **Three staff elected Fellows of the Royal Society**

b. RESEARCH STRATEGY

Our aim is to extend our position as a leading world-class centre for research across the spectrum of biology, from the molecular level through to understanding the interactions affecting life and its evolution, and its functioning in global scale processes. To achieve this we have assembled outstanding research groups containing leaders in their fields who have clear, agenda-setting goals for the future. Achievement of these goals will often require new interdisciplinary approaches. Thus we are investing in seven research centres with distinct foci that reflect our global goals: the *Florey Institute* for Infection & Immunity; the *Krebs Institute* for Mechanistic Biology; the *Centre for Developmental and Biomedical Genetics*; the *Centre for Membrane Interactions and Dynamics*; the *Centre for Stem Cell Biology*; the *Robert Hill Institute* for Plant Science and the *Evolutionary Genetics* research node. These centres have interdisciplinary, academic excellence at their heart and a translational component to ensure that our research achieves maximum impact. The combination of academic-themed research groups with topic-focussed interdisciplinary centres will allow us to continue to competitively address national and international grand challenges while maintaining our strength in breadth across the whole of biology. Key to achieving our aims in a sustainable fashion is hiring, nurturing and retaining talented young researchers (*see Capacity building* and *People*) and investment in excellent infrastructure (described in *d*).

The research centres lie at the heart of University strategy for biology, as evidenced by recent (2013) University commitments to invest £10M in an advanced bio-imaging programme linked to the Krebs and Florey Institutes to place Sheffield in the lead in high-resolution imaging, and resource to develop a new bioinformatics hub (2014) via three academic appointments to support the genomics approaches that increasingly underpin much of our research. The centres attract significant external funding, as evidenced by the recent (2013) awards of a £7.6 million grant from the UK Regenerative Medicine Platform to fund the Pluripotent Stem Cell Hub (led by *Andrews, Centre for Stem Cell Biology*) and a £2.6M BBSRC grant to develop models for herbicide control (*Freckleton, Robert Hill Institute*). These recent grants contribute to the extremely buoyant income stream we have enjoyed over the entire REF period (*section d*). Together with strong institutional support, this will ensure that we have the means to achieve our strategic objectives. Our specific aims are described in the next section, along with a summary of our achievements since RAE2008.

OVERVIEW OF RESEARCH GROUPS: ACHIEVEMENTS AND GOALS

(1) Ecology & Evolutionary Genetics (*Birkhead FRS, Burke, Butlin, Freckleton, Lummaa, Nosil, Rees, Siva-Jothy, Slate, Snook, Thomas*). This group achieved their RAE2008 goal of advancing our understanding of the genetic basis of adaptation and speciation (*Slate 2008 Science*), with notable advances being made in the ecology of invasive species (*Freckleton 2012 Science*) and the evolution of microbial defences in insects (*Siva-Jothy 2008 Science*). A £2M NERC-investment in our Biomolecular Analysis Facility has contributed to this success. Living with environmental change will continue as a core strategy driver for this group over the next period and our investment in advanced genomics will underpin this work (*section d*), allowing us to build on our outstanding profile in evolutionary biology. The group will especially focus on exploiting NextGen sequence data to gain new insight into functional aspects of speciation and adaptation, synergising with our planned 2014 investment in a new bioinformatics hub.

(2) Plant & Global Change Biology (*Beerling, Christin, Fleming, Gray, Osborne, Sorefan, Wellman, Woodward*). This group has made significant advances in our understanding of global climate change biology (*Woodward 2008 Science)* including ground-breaking work on plant evolution and the role of plants in feedbacks to long-term environmental change (*Beerling 2009 Nature*; *Wellman 2009 Science*), as well as fundamental insights into plant development (*Sorefan Nature 2009*). The 2009 opening of a University-funded £4.5M environmental research centre helped underpin this work, reflecting the priority given to this area by the University. In response to the national/international agenda, this group is increasing its focus on the interplay of food security and environmental change, exploiting our outstanding infrastructure (*section d*). We will use an interdisciplinary research centre for plant science (Robert Hill Institute) to co-ordinate this research and associated translational activities. In particular, we will invest in plant/microbe/climate interactions and create a new environmental translational agritech centre.

(3) Development, Disease & Stem Cell Biology (*Andrews, Malicki, Placzek, Rivolta, Strutt, Towers, Whitfield, Whitworth*). This group has provided striking insights into the processes underpinning development (*Towers 2008 Nature*) which themselves underpin disease. The £2.3M MRC Centre for Developmental and Biomedical Genetics (supported by a further £3M investment by the University), the £1M MRC-funded Small Molecule Screening Facility and the £1M Wellcome Trust-funded Sheffield RNAi Screening Facility enabled research which has led to significant progress in understanding of a range of diseases (*Whitworth 2009 Nat Neuroscience)*. The group has been at the forefront of advances in the translation of stem cell research towards clinical use (*Andrews 2008 PNAS)* and exciting advances have been made in the use of stem cells to treat deafness *(Rivolta 2012 Nature),* achieving our RAE2008 goals in this area. The potential of regenerative medicine to revolutionise patient healthcare is widely recognized and we will fully exploit synergies among our research centres to develop a platform for regenerative medicine. We will use our understanding of the fundamental biology of regeneration to develop stem cell technologies for therapeutics, with a particular focus on the treatment of deafness.

(4) Sensory Neuroscience (*Grundy, S Johnson, Juusola, Marcotti, Nikolaev*). This group made key advances in our understanding of mammalian auditory sensory function (*Johnson Neuron 2011*), how physiological activity shapes development (*Marcotti Nat Neuroscience 2011*) and how microRNAs regulate the differentiation of sensory cells (*Marcotti PNAS 2012*). This complements studies in the visual system that have provided new insight into the neural circuits that govern interpretation of motion (*Juusola Science 2012*). This work builds on to our leading research on information processing in the zebrafish visual system (*Nikolaev Neuron 2012*). The group's future work will focus on electrophysiology, imaging and computational modelling combined with tractable animal models for in vivo studies to bridge the gaps between molecular physiology, systems physiology and behaviour. This capability will provide powerful synergies with our research centres in Developmental and Biomedical Genetics and Stem Cell Biology.

(5) Microbial & Cellular Biology (*Ayscough, Davletov, Hettema, Foster, Green, Peden, Smythe, Sudbery*). This group has achieved their RAE2008 goal by developing novel bioimaging approaches to provide key insights into bacterial cell wall structure (*Foster 2008, PNAS).* In addition, they have significantly advanced our understanding of membrane biology through studies of secretion in clinically important microbes (*Sudbery 2010 EMBO J)*, identification of mechanisms of membrane traffic relevant to diseases such as Alzheimer's Disease (*Peden Cell 2011*), exploiting membrane fusion proteins to generate a new family of therapeutics (*Davletov Neuron 2009*) and

greatly advancing our understanding of endocytosis (*Ayscough Nature Cell Biol 2009*). Our future strategy is to use our outstanding mechanistic biology research as an effective driver of translational impact. In particular, the new Florey Institute will align basic and clinical groupings to ensure advances are made in important areas of infection and immunity, with a focus on the pathogens responsible for key infections (e.g., MRSA). Second, we will capitalize on our strength in membrane trafficking to generate a mechanistic understanding of the myriad diseases (from neurodegeneration to cancer) that have been attributed to defects in these pathways.

(6) Biochemistry & Structural Biology (*Artymiuk, El-Khamisy, Horton FRS, Hunter FRS, M Johnson, Rice, Wilson*) Over the REF period this group has made step-changes in our understanding of the molecular mechanisms of disease, including how *Burkholderia* toxin functions (*Rice 2011 Science),* the identification of *ftsZ* as a target for tackling Staphylococcal infections *(Rice 2008 Science),* as well as key insights into fundamental enzyme mechanisms (*Hunter 2008 Nature*). These ground-breaking studies were facilitated by major grants (e.g., £4M BBSRC-LoLa on imaging photosynthetic membranes). As an indicator of academic excellence, during the REF period *Horton* and *Hunter* were both elected FRS. The group aims to maintain our world-leading profile in photosynthetic membrane biology and build on our outstanding track record of understanding catalytic properties of key enzymes with the aim of designing enzyme inhibitors for agronomic and medical use. The Krebs Institute (a research centre working at the biochemistry-biophysics interface) facilitates the interdisciplinary approaches required to achieve these goals.

Capacity Building Strategy: Our future is based on the development of outstanding young independent researchers and 14 new staff (12 of whom are junior scientists, >25% of this UoA) have been hired to strengthen areas linked to our research strategy. These are: evolutionary genetics (*Nosil*, *Lummaa, Thomas*); plant biology (*Osborne*, *Christin, Sorefan*); development, disease & stem cells (Towers, Malicki); sensory neuroscience (*Nikolaev*, S Johnson); biochemistry (*El-Khamisy, M Johnson*); microbial & cellular biology (*Davletov*, *Peden*). Seven of these new appointments have already won independent fellowships (*section c*), ensuring that they have the time and resource to establish their research careers and contribute to the achievement of our research goals. We are also committed (2014) to hiring three group leaders in bioinformatics to increase our capacity in this key underpinning technology. In addition, we have invested significantly in infrastructure and equipment linked to this strategy (see *d*), ensuring that our researchers have access to the tools required for them to achieve their potential. New colleagues are embedded into research groups to leverage synergy of skills and collaborations, allowing us to build new and sustainable research income streams and continue to achieve research excellence.

Research Student Recruitment Strategy: Over the REF period we have increased PhD awards (>4 PGR/fte compared with 3.7 PGR/fte in RAE2008), reflecting our success in attracting increased numbers of high quality candidates and the provision of an outstanding training environment. A £6M BBSRC Doctoral Training Centre (DTC) awarded in 2012 jointly to Sheffield, York, Leeds is focussed on Mechanistic Biology, and a £5.7M NERC DTC (with York and Liverpool) awarded in 2013 and led by Sheffield is focussed on Adapting to the Challenges of a Changing Environment. In the biomedical arena, we will submit an application for an MRC DTC on models of disease and stem cell biology. These DTCs are important components of our research strategy and will ensure sufficient and sustainable core PhD funding into the next REF period. They will also allow us to build on our existing strategic links with regional partner universities, optimising use of pooled resources and expertise to deliver outstanding PhD training. The UoA is also a main participant in a £4.5M Shine DTC, focused on food security and environmental sustainability in Sheffield, funded by the Grantham Foundation from 2014. This follows a similar £1.3M donation by an alumnus that funded 7 studentships in this UoA, supporting high-risk/high-reward interdisciplinary PhD projects. In addition, University funding supports PhD studentships for the Florey Institute for infection and immunity, and the Centre for Membrane Interactions and Dynamics, providing 17 studentships in 2013. Finally, we provide training for a significant number of overseas students (67 over the REF period from the EU, North America, Africa and Asia) and we will continue our successful recruitment of these students to both increase our research capacity and to extend our international collaborations. The combination of secure RCUK and internal funding, combined with expanding overseas collaborations and a goal of increasing the number of competitively won RCUK-CASE studentships, will ensure a large, sustainable flow of excellent postgraduate researchers.

Strategy for Interaction with End-users: As evidenced by our accompanying *impact template*, increased interaction with end-users is closely aligned with our research strategy. Over the REF period two spin-out companies (Absynth and Asterion) have attracted over £3.5M investment and three new spin-out companies have been formed, with a fourth (in the area of stem cell applications to hearing loss) planned. New and expanded interactions with end-users is a core part of our strategy and will be achieved via a £1.2M university investment in the recently (2013) established Sheffield Science Gateway (SSG). This provides 6 dedicated staff embedded in the research groupings of this UoA to assist and promote translational research, as well as a web-portal to guide and attract potential end-users. In addition, as outlined above, our research centres each have translational science embedded within them and will act as outward facing elements for our research. Engagement with policy-makers and commercial partners will also be encouraged by providing colleagues time to pursue such activities via dedicated sabbaticals. For example, *Quick* is presently on secondment to the International Rice Research Institute to co-ordinate a $20M Bill and Melinda Gates Foundation (BMGF)-funded project on crop improvement (C4 Rice), which has led to increased interaction and new funding from an internationally important science sponsor.

Strategy for Promoting and Sustaining an Active Research Culture: The involvement of over 50% of this UoA in national and international funding and policy bodies (listed in *d*) ensures that we are at the forefront of formulating and responding to new national and international initiatives, and the running of 9 research seminar programmes (linked to the research groupings) facilitates exchange and dissemination of ideas both within the UoA and with visitors from around the globe. At the organisational level, each of the three constituent departments in the UoA has a research director who has an overview of each unit's research and helps make strategic decisions on investment. The research directors meet monthly on a Faculty of Science committee, enabling synergies to be identified and attracting larger-scale university investment into emerging research areas, as exemplified by the £10M cross-department bioimaging initiative linked to success in obtaining RCUK funding for next generation optical microscopy (*see section d*).

Our research fellows make a major contribution to our research culture. A total of 26 fellowships (representing over 40% of the UoA) have been awarded since RAE2008 (*see c*) which led to new research areas being developed covering a very broad spectrum of biology. Eight of our junior research fellows have already been appointed to permanent staff posts, thus providing a clear career trajectory for our future fellows, as well as the promotion of competitive research excellence. We will continue to attract the highest-quality early-career scientists by providing them with an exciting and supportive intellectual environment. Mid-career academics are also strongly supported for fellowship applications and in the REF period 14 colleagues won such awards (*listed in c*). We have an aspiration of maintaining an overall 40% fellowship level over the next REF cycle.

Finally, evidence of the vibrant nature of our research comes from the number of publications and the breadth of co-authored papers. 65% of REF outputs involved partners outside the UK, not only in Europe and America but also in Australia, Asia and Africa. The UoA is exceptionally research active (>28 papers/fte over the REF period) and highly cited (over 18,000 citations to work published by members of this UoA over the REF period at an average of over 14 citations/paper, almost double the 7.5 citations/paper recorded over a longer period in RAE2008). Five staff (*Burke, Nosil*, *Slate*, *Whitworth, Woodward*) gained >1000 citations each to papers published since 2008.

c. PEOPLE

i. 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 nurtures talent. In particular investment in, and support of, young scientists are a hallmark of this UoA.

Permanent staff: We have made 14 new appointments since 2008, both to balance staff turnover and to allow strategic development of research areas identified above. Appointments have mainly been at junior level (8 are Early Career Researchers, >17% of this UoA) with the aim of building future research strengths in specific areas (*described in b*) and supporting the development of young scientists. Junior colleagues are nurtured by a mentoring scheme, targeted resources and reduced teaching loads, helping them establish their research programmes (we have hired 6

teaching fellows during the REF period to allow us to do this). They have access to state-of-the-art labs, excellent facilities (*see d*), and are given start-up funding, including PhD studentships. Administrative loads are kept low initially to allow staff to develop their research programmes and intellectual and pastoral support is provided by allocation of an experienced academic mentor, as well as via the University Staff Review and Development Scheme. The latter allows all staff to set objectives for the future and identify support required for them to achieve their goals. Clear procedures allow for career progression of all staff (including postdoctoral researchers): 25% of the UoA gained promotion during the period (including 7 to personal chairs), demonstrating the quality of our staff, the support they receive, and our readiness to recognise and reward achievement. We will continue our successful staffing policy strategy to ensure that we maintain a vibrant and sustainable balance of early career and more experienced researchers.

Research Fellows: Research activity has been significantly boosted by the award of many highly prestigious research fellowships during the REF period. Thus, 5 colleagues were awarded senior ERC grants (*Beerling*, *Birkhead*, *Hunter*, *Gaston* (now heading a new research institute in Exeter), *Brakefield* (now Director of the Zoology Museum, Cambridge)), and 5 were awarded junior ERC grants (*Lummaa*, *Nosil*, *Slate*, *Whitworth*, *Rolff* (now research leader in FU Berlin)). Six Royal Society URFs were awarded (*Christin*, *Freckleton*, *S Johnson, Marcotti*, *Osborne*, *Thomas*), 2 Wellcome SRFs (*Hettema, Strutt*), 1 MRC SRF (*Ayscough*), 1 MRC URF (*Towers*), 3 Leverhulme Research Fellowships (*Butlin, M Johnson*, *Rees*), 1 Lister Institute Fellowship (*El-Khamisy*), 1 NERC Research Fellowship (*Thomas*) and 1 Krebs Fellowship (*M Johnson*). The academic freedom and resource provided by these fellowships plays a vital role in development of staff at all career stages and contributes immensely to our vibrant research environment. Senior staff play an enthusiastic role in mentoring junior fellows, ensuring a collegiate and supportive environment. Our success is illustrated by the fact that 8 Sheffield-based research fellows have been appointed to permanent staff positions during the REF period (*Ayscough*, *Freckleton, M Johnson, S Johnson, Lummaa, Marcotti, Osborne*, *Rivolta*) of whom three were appointed directly to professorial level, again reflecting our readiness to recognise and reward excellence.

Early Career Researchers: Our strategy is to train and mentor PDRAs and ECRs 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 and, in turn, to obtain successful independent funding for a future career in research. We are proactive in encouraging participation in *Professional Development* activities that facilitate networking across disciplines and provide training, mentoring and support for career planning (including for non-academic positions). Our success in receiving the HR Excellence in Research Award from the European Commission in 2012 signifies the internationally recognized high-quality environment we provide for early career researchers and acknowledges our commitment to the 7 principles of the UK concordat for the development of researchers.

Technical staff: To ensure future sustainability and skills-transfer from our experienced senior technical staff (who maintain central facilities and conduct various analyses) we instigated (2010) a technician apprenticeship scheme and recruited new staff with excellent potential. Apprentices are trained over 2 years, rotating between the main research laboratories and facilities, gaining in-depth knowledge of all the main types of research work conducted, familiarity with staff and their expertise, and being trained to maintain critical research activities as senior staff retire. By this means we have trained an exceptionally versatile and skilled cadre of new technical staff who can be deployed in any area where there is greatest need. The apprenticeship model pioneered in this UoA has been adopted across the University.

Equality: The UoA provides an inclusive environment for all staff. One of the departments in the UoA (Animal and Plant Sciences) was awarded Athena Swan Silver status (2013), with the other two biology departments in this UoA having applications underway. Women have taken leading roles in the UoA (e.g., HoD, Research Directors), actively contributing to and utilising our Impact Mentoring and Researcher Development Programme and our flagship Women Academic Returners Programme. The departments support flexible working practices, enabling, e.g., caring commitments for men and women. As an indicator of our success, of 7 people promoted to

Professor in this REF period, 3 were women, and female colleagues are internationally recognised as role models (e.g., *Placzek* was awarded the MRC Suffrage Science Heirloom (2012) and was invited speaker at the Excellent Woman in Science Symposium in Cologne, 2013).

Ethics: We are committed to high ethical standards in research, and Sheffield is one of the few Russell Group universities to deliver compulsory training in Good Research Practice for all its research students. We aim to continue to fulfil the expectations of the UK's *Concordat to Support Research Integrity*, ensuring that we are at the forefront of supporting all staff and that our researchers are fully aware of their ethical responsibilities. As evidence of our engagement, a member of the UoA (*Burke*) chaired a major review and implementation of the University's policy on Good Research and Innovation Practices (2012).

ii. Research students

Training: As outlined in section *b*, we are developing a number of doctoral training centres (DTCs), using both RCUK and university/alumnus funding sources, that will ensure a large and sustainable funding stream for PhD students closely aligned with our overarching research strategy. The aim of the DTCs is to equip students to become excellent scientists, with the potential to excel both in academic and non-academic careers, and to be able to engage fully with end-users (from industry to policy), ensuring they maximise their potential.

Training is organised via departmental postgraduate committees. Working with supervisors, they implement the University's Doctoral Development Programme, manage mentoring and progress reports, and ensure an excellent level of pastoral care. All students are assigned a primary supervisor and an independent advisor as an impartial mentor. In year one all students must pass specified courses (providing formal training in generic professional and research topic specific skills) prior to progression to years 2 and 3. In addition to attending research seminars, preparing research reports and giving regular presentations, training is also provided to enable them to acquire teaching skills by acting as laboratory demonstrators or small-group tutors. All PhD students are provided with dedicated bench and computer space and participate fully in the research activities of the UoA.

As a measure of the effectiveness of this training, over 90% of RCUK-funded PGRs submit within four years and in its 2012 review the QAA praised Sheffield and had no criticisms. A further measure of the success of our training is the outstanding contribution our students make to academic research. Thus, 17% of the outputs submitted for REF by this UoA have Sheffield-based PhD students as authors, including first authorship on papers in highly prestigious journals (e.g., *Johnston* et al., Nature, 2013; *Cruz-Migoni* et al., Science, 2011; *Aghamohammadzadeh & Ayscough* Nat Cell Biol., 2009). PhD students have given numerous presentations and posters at international conferences (e.g., International Photosynthesis Congress 2013, *Lundgren*), leading to prizes (e.g., European Society for Evolutionary Biology 2013 best talk, *Hutchison*) and awards (e.g., Linnean Society 2013 medal for best PhD thesis, *Pendleton*). Following graduation our PhD students have taken up positions in leading academic groups worldwide, leading to independent research fellowships (e.g., *M Johnson- PhD 2007-* is now a Leverhulme Research Fellow). They have also taken up positions in industry, including in leading companies such as Syngenta and Merck Sharp Dome, as well as SMEs involved in biotechnology (e.g., Munck Astex Pharmaceuticals, Cambridge), and transferred their skills to management roles in major retail companies (e.g., Marks & Spencer, Morrisons) and the petro-chemical industry (PetroStat).

Interaction with end-users: Our RCUK studentships have been supplemented by CASE awards, leading to interactions with over 20 partners in the REF period. These partners range from major international companies (e.g., Syngenta, Pfizer, Astra Zeneca, Shell, Syntaxin, Waters) to SMEs and a range of agencies in the UK and abroad (e.g., Prolysis, Natural History Museum, Beekeepers Association, International Rice Research Institute). As a result of these interactions, students have contributed to 6 patents, including being named inventor. In addition, as part of our BBSRC DTC we have implemented short-term industrial placements for all students, developing employability skills and giving students the opportunity to apply their research skills. Our partners in this scheme (since 2013) include the Food and Environment Agency, and Syngenta, with a further 23 companies and agencies committed to hosting students over the next 5 years. Our NERC DTC (2013) envisages 40% of studentships being with CASE partners. We have 30 external organisations committed to providing partnerships for this DTC, ranging from government agencies (Environment Agency)

through NGOs and charities (e.g., RSPB, Buglife) to companies active in the implementation of environmental policy (e.g., Sercon, Forest Research), based both in the UK and abroad (USA and Norway). Finally, our students have also won open competition RCUK-placement awards with Parliament and policy-makers, such as DEFRA. The partnerships built into our training centres will allow our future students new exciting and expanded possibilities of interactions with end-users, providing vital training experience and potential career pathways, together with impact relevant experience- a key part of our strategy in this area.

d. INCOME, INFRASTRUCTURE AND FACILITIES

Income

Increasing the spread and maintaining a high level of funding, while at the same time recruiting and nurturing outstanding new talent via fellowships to build the foundations for our future research, have been goals which we have achieved over the REF period. New grants of total value in excess of £73M were awarded during the REF2014 period, equivalent to a grant win of over £1.6M/fte. This figure translates into >£0.3M/fte/yr, over 70% up on our RAE2008 achievement. Our strategy over the last few years has been to broaden our sources of funding in order to become less reliant on UK government funding. Our new grant capture is thus split over a spectrum of sources (£12.7M BBSRC, £12.1M EU, £9.2M NERC, £7.7M MRC, £7.4M Wellcome Trust, £2.2M Royal Society, £1.3M Leverhulme Trust and £20M from over 40 other separate sources, including over £0.75M from industry). Notably, we have won grant funding from the NIH in the USA of value over £0.75M and other competitive funding from the USA worth £0.8M. Compared with RAE2008 we have increased our income/fte from the EU 3-fold, which equates to a 4-fold increase in income capture/fte/yr. The number of ERC-fellowships won by members of this UoA (see *c*) is a measure of our success in targeting EU funding, with total fellowship income since 2008 exceeding £14M.

Research income is widely distributed amongst staff, with 4 PIs having secured total funding >£4M during the REF2014 assessment period (including BBSRC LoLa *Hunter*), 5 PIs with funding between £2-4M, 11 PIs with funding >£1M and a further 10 PIs with funding >£500k. This broad income distribution reflects the strength in breadth across the whole of our research activities, ensuring that our research buoyancy is not dependent upon a few specific individuals or research activities. This ensures a highly robust income stream (as demonstrated by our continued high-level year-on-year grant capture and spend over the REF period).

According to HESA data 2008-12, Sheffield biological sciences had the 5th largest income, with NERC bioscience income consistently in the top two in the UK. This excellent level of external funding has enabled us to attract University investment to further strengthen research activities, particularly with regard to provision of new research buildings, equipment and dedicated technical support (detailed below), allowing us to undertake world-leading leading research. Taking our total grant win (>£73M) in the context of a total spend of £53M (Ref4b), we are in a very healthy financial position as we move forward post-REF2014.

Infrastructure and Facilities

Our research is supported by an impressive array of world-class facilities. These comprehensive facilities are a shared resource, ensuring that all researchers have access to the technologies required for the delivery of world-class research.

Since RAE2008 there have been substantial enhancements of our infrastructure. For example, the university invested £4.5M in 2009 to create a new **Environment Research Centre** with 1000m^2 of controlled environment, plant growth space and associated laboratories, together with space for external long-term monitoring studies. This complements the existing Controlled Environment Facility (2004) which contains thirty-two Conviron growth chambers to manipulate and monitor temperature, light, humidity and CO_2. Together these provide unrivalled infrastructure for environmental, plant and ecology research, facilitating our strategy in food security and environmental change.

Biomedical research has benefited from the establishment of the £2.3M **MRC Centre** for Developmental and Biomedical Genetics, from a £1M MRC investment in the **Small Molecule Screening Unit,** which provides a local and national resource for small molecule screening in zebrafish as a cost-effective means to screen compounds for potential toxic effects in advance of rodent studies, e.g. potential therapeutics, and a £1M investment in a **Wellcome Trust RNAi**

screening facility, which provides a national service for identifying novel genes affecting cellular processes in *Drosophila* and human cells These new facilities complement and expand on our excellent infrastructure for biomedical research, including facilities for non-mammalian model systems such as our zebrafish aquaria with capacity for 100,000 fish and environmentally controlled *Drosophila* laboratories, and provide key support for our research on animal models of human disease. In addition, the Biological Services Unit provides a 1000m^2 key facility for mammalian research. They provide a comprehensive range of services for animal acquisition, care and breeding as well as production and maintenance of transgenic stocks and facilities for regulated procedures. Training courses are provided for Home Office Licence applicants.

We have significantly strengthened our biological mass spectrometry capability with the purchase of both a Yorkshire Cancer Research-funded £1M Thermo Orbitrap Elite Mass Spectrometer and a £0.75M Waters Sinap for metabolomics and proteomics. These state-of-the art machines have been integrated into our new (2013) **Faculty Mass Spectrometry facility** with 300m^2 refurbished lab space providing access to 14 mass spectrometers (value >£5M). Collaboration with colleagues in our Engineering faculty and Hallam University provides Sheffield with outstanding resource and expertise in this area. Our new investment complements and extends our facilities for advanced spectroscopy, from NMR (800, 600 and 500MHz instruments) to CD and low-temperature fluorescence. Our instrumentation in X-ray crystallography and crystallization robotics provides a perfect complement to international synchrotron radiation facilities, and our 200keV cryo-EM instruments have facilitated cutting-edge research in membrane biology. These facilities underpin our research strategy in mechanistic biology and biomedical science.

Our **Microscope Facility** provides an array of electron microscopes (scanning and TEM) and confocal instruments. This includes deconvolution and laser-scanning confocal microscopes, as well as a wide-field system for FRAP and FRET, and an Optigrid system for optical sectioning. During the REF period we have acquired a Nikon A2 TIRF/confocal microscope and two super-resolution microscopes, a STORM and SIM (OMX), funded by a total of £1.4M from MRC/BBSRC/EPSRC Next Generation Optical Microscopy and Wellcome Trust grants. This funding has also provided resource to further develop super-resolution bioimaging technology, a major strand of our research strategy. A **Biophysical Imaging Centre** (BICEN) is being established (2013) via a £0.5M university-funded refit and will contain 2 new AFMs (£0.45M, university funded), as well as a 6 other AFMs with total value £1M. This will provide a UK-leading biology-focussed AFM facility and outstanding capability in super-resolution microscopy, a strategic area of excellence for this UoA.

Research in molecular biology, microbiology and genetics is facilitated by advanced facilities for DNA, RNA and protein analysis. This includes multiple platforms, such as Ion Torrent, Miseq and a £0.5M HiSeq in our **New Generation Sequencing Facility** (2013), and DNA sequencing/TILLING/SNP facilities at the £2M **NERC Biomolecular Analysis Facility.** These allow high-throughput screening of DNA samples and genotyping, approaches that underpin an increasing range of research across biology. The purpose-built **Centre for Stem Cell Biology** has advanced facilities for cell culture and quality control, allowing the production of clinical grade stem cells. This is a key part of our research strategy in the area of regenerative medicine, which has been recently boosted by a £7.6 million grant (2013) from the UK Regenerative Medicine Platform to the Universities of Sheffield, Loughborough and Cambridge to fund the Pluripotent Stem Cell Hub (led by *Andrews*).

Bioinformatics and large-scale data analysis are core to our future research strategy. The UoA is committed to investing in a new **bioinformatics hub** through at least 3 new appointments in 2013-14, ensuring competitive excellence in this area. Access to **High Performance Computing** is central to a number of our activities and the University has invested over £2M over the REF period in a shared facility (Iceberg), allowing access to high-speed parallel filestore and providing cloud computing capabilities within the campus. The University is a partner in the N8 Tier 2 HPC facility, a joint venture between the 8 leading research-intensive universities in the north of England to provide UK-leading computational capacity, leading to sharing of resource and expertise in this key technology for the future of large scale biological research.

A critical component of our strategy has been establishing **dedicated support staff** to manage specialist research facilities and to provide key skills and training. Thus, the Microscope Facility, BICEN, Controlled Environment Facility, the Environment Research Centre and NERC

Biomolecular Analysis Facility are each supported by full-time, senior managers and technical staff, and the Aquaria are managed by 4 full-time HEFCE/MRC-funded technicians. Similarly, the Biological Services Unit is supported by a Veterinary Surgeon and a Veterinary Nurse and 15 technical staff, including a senior manager. Our buoyant grant income and our new technician-training scheme (see *c*) will ensure that we can maintain excellent technical support for our core facilities in the post-REF period.

e. COLLABORATION OR CONTRIBUTION TO THE DISCIPLINE OR RESEARCH BASE

Research Collaboration

Sixty-five percent of the REF outputs of this UoA involved research collaborations outside the UK, an increase of 30% on RAE2008. These include joint research with leading universities in North America (e.g., Yale, Stanford), Europe (e.g., Berlin, Zurich), Australia (e.g., Melbourne, Sydney), Asia (e.g., Beijing, Kyoto) and Africa (Cairo). We are also involved in major international research projects (grand challenges) such as the BMGF-funded C4 rice project. Such collaborative work is facilitated by the provision of University travel funds for conferences and support for research sabbaticals. When added to our success in gaining research fellowships, these measures provide colleagues with time and resource to build and exploit national and international networks of excellence. In particular over the REF period we have successfully increased our funding from the EU 3-fold since RAE2008, and these EU networks have contributed strongly to increasing our international research profile. Within the UK we collaborate closely with Leeds and York via the White Rose Consortium (which provides funding for regional collaboration and PhD networks, and which co-ordinates our £6M BBSRC-DTC) and we envisage extending these collaborations via new DTCs (e.g., with Liverpool via our new NERC DTC). The new MRC-funded Stem Cell Hub builds on extensive national and international collaboration in this area led by Sheffield. Finally, the N8 universities Research Partnership has allowed us to collaborate on shared Tier 2 computing system and NMR, with investment in excess of £3M, maximising efficient use of resource.

Contribution to the Research Base

Prizes, Awards and Fellowships: 17 members of the UoA won a total of 25 accolades from learned societies and research councils over the REF period. *Horton* (2010), *Brakefield* (2010, now at Cambridge) and *Hunter* (2011) were elected FRS, and *Beerling* won a Royal Society-Wolfson Research Merit Award (2009-14), as well as being elected Edward P. Bass Distinguished Visiting Environmental Scholar at Yale University (2008). *Slate* won the Zoological Society Scientific Medal (2011) and *Wellman* was awarded the 2013 Palaeontological Association 'President's Medal'. *Birkhead* was awarded the Association for the Study of Animal Behaviour medal 2012 and the Elliot Coues Medal, from the American Ornithologists' Union 2011, while *Nosil* won the Dobzhansky Prize (2008) for the Study of Evolution. *Juusola* is visiting Professor at the National Key Laboratory in Beijing, providing access to support of >£1M and *Foster* was distinguished Visiting Professor, University of Technology, Sydney, Australia (2011-2013), while *Hunter* is Honorary Professor, Shanghai JiaoTong University. *Butlin* was awarded a Tage Erlander Guest Professorship by the Swedish Research Council (2012). A total of 24 research fellowships were awarded to staff returned to this UoA during the REF period.

Learned Societies and Government Agencies: 19 members of the UoA (>40%) contributed to the activities of 24 learned societies during the REF period, ranging from the Royal Society to more subject-specific bodies. They have taken on leading roles (e.g., *Butlin* is President European Society for Evolutionary Biology, 2013-15; *Fleming* is Treasurer of the British Society for Developmental Biology, 2009-14; and *Smythe* was Secretary of British Society for Cell Biology, 2006-11), thus helping shape both the UK and international science landscape. In addition, various colleagues have been involved in working groups linked with both learned bodies and funding councils. For example, *Beerling* was involved in the Australian Research Council Network for vegetation function (2008-10), *Rees* was a member of the Government advisory committee *ACRE* (*Advisory Committee on Releases to the Environment*, 2008-2009) and *Andrews* contributed to the House of Lords Science and Technology regenerative medicine inquiry 2012.

Conferences: During the REF period 26 international conferences were organised by members of the UoA, 5 of which were held in Sheffield. In addition, colleagues organised 30 sessions at international meetings and gave 264 invited talks and over 100 plenary talks at a total of over 350

international conferences. At a national level, 13 conferences were organised (8 in Sheffield) and 27 plenary talks given, as well as 99 invited talks. Overall, the number of conference talks given by members of this UoA was in excess of 450. This equates to more than 10 conference talks/fte over the REF period (compared to fewer than 9/fte in RAE2008). These data indicate both the engagement of this UoA in national and international science and the high regard of the scientists involved. Due to the breadth and number of these conferences, we can only provide a flavour of the contributions made. This has included keynote talks at Gordon Research Conferences (*Hunter, Foster*), plenary talks at international human stem cell meetings (*Andrews*) and at a Keystone meeting on Parkinson's disease (*Whitworth*), as well as organisation of and invited participation in EMBO workshops (*Juusola, Rivolta*). Invited talks at international meetings range across the entire spectrum of biology, from bioinformatics (*Artymiuk*), through yeast molecular biology and genetics (*Ayscough*), and developmental biology (*Placzek*), to global climate change (*Woodward*).

Grant review panels: Members of the UoA have sat on committees for 25 international grant review bodies in Europe, North America and Asia, as well as sitting on 33 UK research council grant committees. These include all the major UK councils (BBSRC, EPSRC, MRC, NERC, Wellcome Trust,) as well as learned societies that provide funding for research (e.g., Royal Society). Over 50% of this UoA have participated in research council committees over the REF period and they have all been involved in the actual review of grant applications, indicating the esteem of members of the UoA and their contribution to UK and international science.

Contributions to journals, books and public understanding of science: Over 60% of the staff in this UoA acted as editors or associate editors for over 67 journals during the REF period. This included the start-up of a new journal in 2009 (Methods in Ecology & Evolution, *Freckleton*) and being editor-in-chief (New Phytologist, 2009-2013 *Woodward*), as well as editorial board membership of, e.g., Stem Cells (*Andrews*), Current Biology and Development (*Strutt*), Microbiology (*Foster*) and BMC Cell Biology (*Peden*). In addition, over 50 books or book chapters were authored by members of this UoA. This has included popular science books, such as The Emerald Planet (*Beerling*), which was the basis for a BBC documentary series "How to Grow a Planet" (2011), as well as standard reference texts, such as The Purple Phototrophic Bacteria (*Hunter*), which since its publication in 2008 has received over 11,000 chapter download requests. Members of the UoA have been involved in 118 outreach activities. Details are provided in our *Impact Template*, but over 40% of the UoA have contributed to these activities. These include events that reach over 5% of all Sheffield schoolchildren every year, many from areas of traditionally poor academic achievement. Outside Sheffield, *Placzek* organised an exhibit showcasing Sheffield research at the 2009 Royal Society Summer Exhibition, a prestigious event attracting over 1500 visitors/day, including politicians and policy makers. Members of the UoA have also been involved in numerous national and international media events, including, e.g., the British Heart Foundation's Mending Broken Hearts appeal. *Lummaa* alone has given over 25 interviews for international TV on her research on human reproduction plus related press articles in 11 countries.

Contribution to PhD student training: In addition to training UK PhD students, 40% of the UoA have acted as external examiner for over 40 PhD students in Europe, Australia and North America, including leading universities such as ETH-Zurich (*Fleming*) and Harvard (*Malicki*). Within the UK, 65% of staff have acted as external examiner for a total of over 100 PhDs from a range of major universities, including most members of the Russell Group. The number and quality of our own students, and our role in examining students at a national and international level represent a significant contribution to the research base.

In summary, the members of this UoA play a central role in UK and international biological research. Their research excellence is confirmed by the outstanding quality of their publications and the number and breadth of accolades and contributions outlined in this section. These achievements reflect the excellent and collegiate research environment that we have created, ensuring a robust, sustainable, high-level of support so that we maintain and advance a world-class research effort which addresses the most exciting and important challenges in biology.