Institution: University of Sheffield
Unit of Assessment: A-05 Biological Sciences
1. Unit context and structure, research and impact strategy

1.1 Overview

The collective mission of Sheffield Biosciences is to be an outward-facing centre of broad interdisciplinary excellence. We aim to address the societal and scientific grand challenges encompassed within our two overarching research themes: ***'The Process of Life'*** and ***'A Sustainable World'***. Our strategy has been to assemble a critical mass of researchers with strength in breadth, capable of working across boundaries, forming international collaborations, and creating impact (*see Section 4*). Our six research groups successfully blend fundamental and translational research spanning the spectrum of scale, from the atomic structure of biomolecules to how the living world regulates global climate (*see Section 1.2*). These groups are underpinned by our investment in supporting infrastructure and facilities (*see Section 3*) and our commitment to creating a nurturing and supportive environment for staff, where the rich potential of our skills, experience and diversity can be fully harnessed (*see Section 2*).

We have built on our strong REF2014 performance, extending our position as a leading centre for research across the spectrum of biology:

- ***World-class research:*** >£94M of competitive research income, ↑70% on REF2014. 88 papers published in *Nature*, *Science*, *Cell*, *PNAS* and *eLife* communicating ground-breaking discoveries with impact beyond their immediate field: 1,883 total publications, 24.1/FTE, >54,100 total citations, mean citation rate >28.7. 18 grants of >£1M including ERC Synergy, Advanced and Consolidator, BBSRC LoLa, Wellcome Senior Investigator and Leverhulme Research Centre awards. University investment of >£18M since REF2014 with a focus on bio-imaging, bio-analytics, and growth facilities; strategic targets that support our research themes.
- ***A pipeline of future talent:*** 59 externally funded research fellowships (for 78.1 FTE staff) with a total value >£18.8M and appointment of 17 ECRs (9 female). 353 Postgraduate Research Students (PGRs) trained (51% female, 28% BAME) through 6 DTPs with first-author contributions to major submitted outputs in (e.g. in *Nature*), evidencing our successful culture of PGR recruitment and training.
- ***Embracing diversity:*** Development of a collaborative, nurturing and supportive research environment where diversity is valued, as evidenced by our Top 100 position in the Sunday Times Best Employers List, Top 20 position in the 2020 Stonewall Employers list and Athena SWAN Silver awards.
- ***Impact:*** A pipeline for developing our science into real-world impact with successes including influencing policy on environmental pollution, tropical biodiversity, arctic science, global fuel security, UK invasive species control and effective cancer treatments.

1.2 Unit structure, research strategy and progress towards REF2014 objectives

Our strategy is based around tackling the fundamental questions and scientific challenges associated with our research themes:

'*A Sustainable World*' asks: *How do we sustain our planet* and *achieve food security while reducing CO_2 emissions?* By understanding how organisms interact and evolve in response to natural and man-made change, we are devising new approaches to improve agriculture, secure environmental resources and maintain biodiversity. We are developing sustainable technologies and interventions to maintain food and energy supplies, support manufacturing, understand and change human behaviour and to monitor, predict and alleviate the effects of human activity on the planet.

'*The Process of Life*' asks: *How is life generated and maintained?* Our aim is to elucidate the complex processes that underpin the emergent behaviour of molecular networks and how these generate the robust properties that define life across scales. Working with bacteria, fungi, plants, animals and humans, we seek new knowledge on how organisms interact to shape each other's destinies and behaviour. Moreover, we study the effect of technological, behavioural, and clinical interventions designed to improve wellbeing, charting how life develops and functions throughout its course in health and disease, and how it evolves across the generations.

To achieve these aims, we have organised our researchers into six natural groupings which reflect areas of research strength (Fig. 1). Each group encompasses researchers over a range of academic career stages, enabling and encouraging mutually beneficial interactions, mentoring and support. Shared labs and group meetings promote best practice in research, grant writing, PGR training, academic responsibilities, and joint research projects. Interdisciplinary collaboration and synergies between these groupings and colleagues in chemistry, physics, medicine, and engineering enable nimble responses to a changing external research environment. A brief summary of the six groupings, their strategy, composition and achievements is provided below.

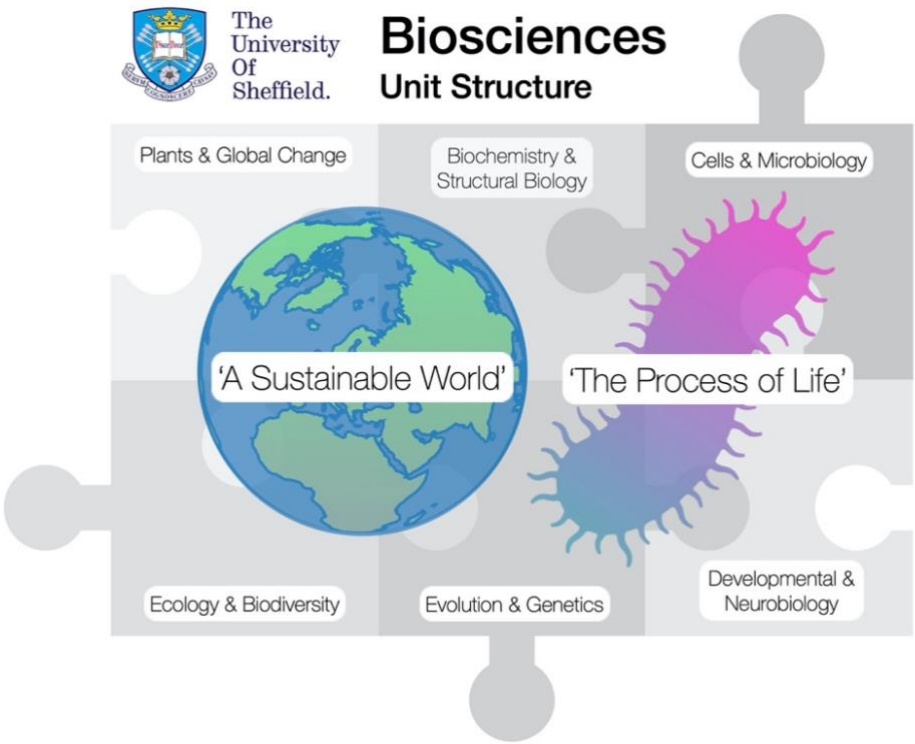


Fig 1: Biosciences unit structure

Evolution & Genetics

Comprising 5 Professors, 3 Reader/Senior fellows, 5 early career researchers (ECR), and **attracting £17.6M grant income**, including £3.5M from NERC to support our Environmental Omics Facility and major fellowships to Butlin (ERC Advanced), Cooney, Wright and Dunning (NERC) and Hemmings (Royal Society). This research group addresses the evolutionary, genetic, and functional bases of behaviour, adaptation, and speciation.

Reflecting our REF2014 strategy of exploiting NextGen sequence data to understand functional aspects of speciation and adaptation, achievements include key findings on adaptive radiation in birds (Cooney, ***Nature 2017***; Slate, ***Science 2017***, Thomas, ***Nat. Commun. 2020***), co-operativity in breeding (Hatchwell, ***Nat. Commun. 2016***), honeybee virus evolution (Butlin, ***Science 2016*)**, mimicry in butterflies (Nadeau, ***Nature 2016***), supergenes in male reproduction (Burke, ***Nat. Genetics 2015***), herbicide resistance (Childs, ***Nat. Ecology & Evolution 2018***); lateral transfer of DNA (Christin, ***PNAS 2019***) and the role of the methylome (Zeng, ***Nature Commun. 2016***) and sexual selection (Wright, ***Nat. Commun. 2017***) in evolution.

The global importance of evolutionary genomics in a changing world will remain a key strategy driver for this group over the next five years; we will support its continued success through further investment in advanced genomics facilities (*see Section 3*).

Ecology & Biodiversity

Comprising 7 Professors, 1 Senior Fellow, 3 ECRs, and attracting **£10.8M grant income,** including major EPSRC (Edmondson) and NERC (S.Campbell) fellowships, this group is at the forefront of addressing key environmental challenges currently facing humankind.

Building on the last REF period, our strategy has been to translate our fundamental research into a strong impact agenda, with REF2021 impact case studies from Maltby on **EU environmental policy**, Rees on **controlling invasive species**, and Edwards on **tropical forest biodiversity policy.**

Examples of our research achievements in this area include contributions by Freckleton on the role of herbivory in rainforest diversity (***Nature 2014***) and the influence of climate change on nest predation (***Science 2018***), Beckerman on the influence of predation on adaptation (***Nat. Ecology & Evolution 2017***), Edwards on global wildlife trade (***Science 2019***), Webb on global marine extinction (***Curr Biol 2016***), S.Campbell on the influence of herbivory on the nitrogen cycle (***Nat. Commun. 2018***), Hartley on the chemical basis of plant/herbivore interactions (***Nat. Sustainability 2018),*** Maltby on community composition and ecosystem function (***Ecol. Letters 2017***) and Rees on nitrogen deposition and seed banks (***Nat. Commun. 2015***).

The future strategy will be to exploit the wide diversity of research approaches and synergies with Maths and Engineering to research the provision of ecosystem goods and services required by the growing human population in order to achieve a sustainable world.

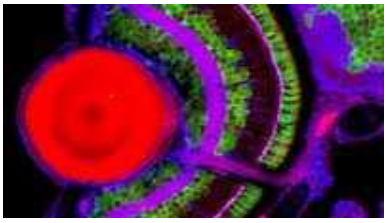
Plant & Global Change Biology

Comprising 10 Professors, 3 Reader/Senior Fellows, 3 ECRs and attracting **£20.8M grant income** including a **£4.8M Leverhulme Research Centre award** to Beerling FRS for Climate Change Mitigation and an ERC Consolidator to Field. Research covers a broad spectrum of plant biology from the molecular to ecosystem and global-scale events. The University has also invested heavily in this area with >£3.4M to extend our world-class plant growth facilities further (*see Section 3*).

Examples of our research achievements include contributions on photosynthesis by Johnson (***Nature 2019***) and Fleming (***Nature Commun. 2019***), plant evolution by Osborne (***Nat. Plants 2016***), Field (***Curr. Biol. 2020*)** and Wellman (***PNAS 2018***), stomatal biology by Gray (***Molecular Cell 2014***) and Casson (***Current Biology 2016***). We also have strengths in understanding signalling in development (Smith*,* ***EMBO Reports 2020***) and in plant-microbiome interactions (Rolfe, ***ISME Journal 2019***), and the genetics and control of disease, as shown by Ton (***eLife 2019*),** Scholes (***New Phytologist 2019***) and Voigt (***Plant Cell 2014***). This group has also achieved success in the area of global climate change, as exemplified by the work of Phoenix (***Nat. Climate Change 2020***), Callaghan (***Global Change Biol 2015***) and Zona (***PNAS 2016***), complemented by bio-inspired mitigation research from Beerling FRS (***Nature 2020***).

A University investment of £2.5M and £6M UKRI funding (December 2020) for our new flagship *Institute for Sustainable Food,* including new posts for ECRs, will underpin future efforts in this area as we seek to build on the impact case studies of Wellman and Callaghan, by creating further synergies between plant scientists, social scientists and engineers to address climate change and food security.

Development & Neurobiology

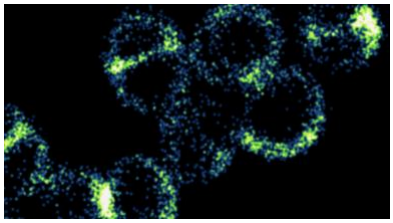


Comprising 3 Professors, 2 Reader/Senior Fellows, 4 ECRs and attracting **£22.9M in grant income** with 5 of the 9 PIs holding major Fellowships from Wellcome Trust and others, and 8 of the 9 PIs winning grants >£1M. This group focuses on the processes of epithelial morphogenesis, patterning, and differentiation, as well as neural development, studying mechanisms at the level of single cells up to whole tissues and organs.

Research achievements in this area are exemplified by the work of Lin on odour discrimination (***Nat. Neuroscience 2014***) and Marcotti on hearing (***Nature 2018***), epithelial differentiation by Bulgakova (***Nat. Commun. 2019***), K.Campbell (***Nat. Commun. 2019***) and Strutt (***eLife 2019***), limb development by Towers (***Nat. Commun. 2015***) and the hypothalamus by Placzek (***Development 2017***). The group's work extends from research at the molecular scale, e.g., Noël's research on RNA tomography (***Cell 2014***) to Simons' work on germline development (***Nat. Commun. 2019).***

During the next five years our aim is to exploit the fundamental biology of regeneration to develop stem cell technologies for therapeutics, with a particular focus on the treatment of deafness. These efforts will be underpinned by a £2.5M University investment in the flagship *Neuroscience Institute*, providing PGR studentships, new posts for ECRs and a collaborative forum for scientists and clinicians.

Cell & Microbiology

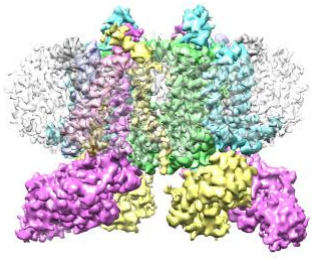


Comprising 5 Professors, 5 Reader/Senior Fellows, 6 ECRs and attracting **£21.2M in grant income**, with **funding of over £4.6M to Foster** and **£2.4M to Cameron**. The group is elucidating the complex processes, from basic to translational, that define the behaviour of host/pathogen and symbiotic interactions influencing human health and the environment.

Addressing our strategic aim from REF2014 of bringing together clinicians and microbiologists to apply fundamental mechanistic biological insights into treatment of antimicrobial-resistant diseases (e.g. MRSA), we established the *Florey Institute* and collaborative *Imagine* consortium (*see Section 1.3*). The success of these interdisciplinary institutes in creating a pipeline of PGR students and diverse interactions is illustrated by influential publications in the areas of antimicrobial resistance (Corrigan, ***PNAS 2016***), bacterial pathogenesis from Staphylococcus and Streptococcus exemplified by Foster (***Nature 2020, Science 2014***), Turner (***Lancet Infectious Diseases 2019*)**, Chaudhuri (***PLoS Biology 2019***), Fenton (***Nat. Microbiol 2017***) and Mesnage (***Nat. Microbiol. 2020***) to Salmonella by Humphreys (***PNAS 2017***) and Mycobacterium by King (***Current Biology 2020***). The work of Durham and Hoiczyk addresses bacterial crowding (***Nat. Physics 2020***) and oxidative stress in bacteria (***PNAS 2015***) respectively. Research by Ayscough (***Curr Biol 2015***) is providing new understanding of the eukaryotic cytoskeleton, secretion and endosome recycling, while Peden (***Science 2020***) has identified promising targets for broad coronavirus inhibitors for the treatment of COVID-19.

Microbial interactions in the biome are a further strength of this group as illustrated by the work of Daniell (***ISME J 2017***), Leake (***Curr. Biol. 2020***) and Cameron (***Current Biol 2016***), while Harrison is giving new insights into plasmid dynamics (***Current Biology 2015***). Our future aim is to translate this fundamental science into impact in the form of new antimicrobial treatments and to develop links with the agri-tech industry to exploit soil microbiome research for food security.

Biochemistry & Structural Biology



Comprising 8 Professors, 3 Reader/Senior Fellows, 5 ECRs, and attracting **>£18M in grant income** including **major BBSRC LoLa and ERC Synergy awards of >£6M** to Hunter FRS. This group has strengths in deciphering the structural basis of biological mechanisms at the atomic level.

Achievements of this group include contributions of Hunter FRS (***Nature 2018***) and Hitchcock (***PNAS 2020***) on the molecular basis of photosynthetic light harvesting, Rice on herbicide structure/function (***PNAS 2018***), Baker on pore formation by toxins (***Nat. Commun. 2019***), Waltho (***Nat. Commun. 2020***) and Grasby (***Nat. Chem. Biol***) on enzyme transition states, and Williamson on peptidoglycan recognition (***Nat. Commun. 2017***). Research on nucleic acids ranges from that of Bose on histone acetylation and transcription (***Cell 2017***), Wilson on RNA regulation of transcription (***Molecular Cell 2019***), Thomson on targeting of exosomes to RNA (***Cell 2015***), El-Khamisy on the role of topoisomerases and neural function (***Nat. Commun. 2017***), Reid on C4 photosynthesis (***Molec. Biol. & Evolution 2018***), Rafferty on endonucleases (***Nat. Struc. Mol. Biol. 2016***), Bryant on the role of DNA repair mechanisms in cancer (***Clinical Cancer Research 2014***) and impact case study, the chemical

control of cell cycle entry by Smythe (***Ang Chemie 2017***), and the development of new imaging technologies by Jayasinghe (***Nat. Commun. 2017***).

Biosciences future research strategy

In our recent strategic review of the Biosciences we have renewed our commitment to our central research themes ***'The Process of Life'*** and ***'A Sustainable World'*** for the next five years, with aspirations to build further on our success. We will increase the opportunities for staff to engage in interdisciplinary research through a **£20M investment in four University-wide Flagship Institutes** (*Sustainable Food, Healthy Lifespan, Energy* and *Neuroscience*), creating collaborative bridges to the physical sciences, engineering, medicine and beyond. These flagship institutes will further be underpinned by the **University's recent announcement of a £150M campus plan** that will modernise the science estate, equipping our research clusters to deliver 21st century bioscience. To deliver our **future impact strategy** we will continue to target our investment, commercial training, and support to areas such as sustainability, plant science and antimicrobial treatment, where we have research strength and a promising pipeline of future projects. To achieve our wider strategy, we recognise the need to **ensure the sustainability of our research groups** and provide new impetus to our programme by continuing to recruit a diverse and talented pool of ECR fellows.

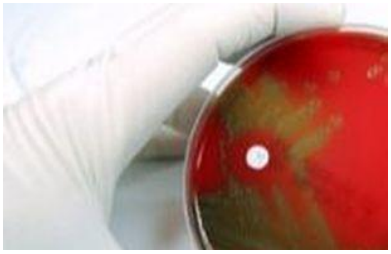
1.3 Approach to supporting interdisciplinary research

Our groupings enable a focus on particular research strengths, yet it is also clear that much of the most exciting research involves working across traditional boundaries, both across the breadth of the Biosciences and beyond to other disciplines. Over this assessment period our strategy has been to **promote interdisciplinary interactions** through an **investment of >£18M in three major initiatives that cover the breadth of our research:**

- ***Imagine: imaging life*** applies cutting-edge super-resolution fluorescence, atomic force, and cryo-electron microscopy to address important biological and biomedical problems. Three new PIs were appointed to bring together teams with the interdisciplinary skills required to exploit these new technologies (*see Section 2.2*). Notable successes of this program include new insights into the MRSA cell wall assembly *(Nature 2020),* the structure of the Campylobacter flagellum (*Nature Commun. 2020*) and photoprotection in plants (*Nat. Plants 2018*), projects which involved interactions between colleagues in Biosciences, physics, chemistry, and engineering

- The ***Grantham Centre for Sustainable Futures*** brings together expertise in fundamental aspects of plant and soil science to address UK and global challenges in sustainable agriculture and food security. An investment of £8.7M has allowed us to upgrade plant growth, mass spectrometry and light microscopy facilities, fund two new PIs and attract three ECR fellows. Working with our impact team, groups interact with a range of stakeholders (from the Soil Society to major agri-tech business). The Centre has funded 70 PGR studentships, each with an interdisciplinary supervision team. Successes include unravelling the molecular mechanisms underpinning photosynthetic light harvesting (*Nat.*

Plants 2019), plant-microbial soil interactions (*Nat. Plants 2020*) and mesophyll porosity in wheat (*Nat. Commun. 2019*). These achievements underpinned the December 2020 award of £6M UKRI funding won by the new University-wide ***Institute of Sustainable Food***, bringing together Biosciences, social scientists, and engineers.



- The ***Florey Institute*** addresses one of the world's biggest challenges: infectious disease, set within the context of developing antibiotic resistance. Working with collaborative partners, activities are coordinated to bridge fundamental science and clinical application. This was facilitated by hiring two ECR PIs (Turner, Fenton) and two independent research fellows (Corrigan, Humphreys). Successes include new insights into cell cycle control (*Science 2014; Nat. Microbiology 2018)* and bacterial cell morphology (*Nat. Commun. 2018*).

In addition, Sheffield Biosciences host three major UKRI-funded DTPs (NERC Adapting to the Challenges of a Changing Environment, ACCE, BBSRC White Rose in Mechanistic Biology, MRC Discovering Medicine North (DiMeN)), and two charity funded DTPs: the Advanced Biological Modelling (Leverhulme) and Grantham Centre for Sustainable Futures (Grantham Foundation), all of which provide PGRs with interdisciplinary supervision, training and research (*see Section 2.4*).

1.4 Impact strategy, support mechanisms and outcomes

Impact strategy: During this assessment period we have laid special emphasis on translating fundamental science associated with our *'A Sustainable World'* research theme into policy change at a national and international level, as exemplified by our impact case studies focused on Arctic climate change (Callaghan and Phoenix), pesticide risk assessment (Maltby), controlling spread of invasive species (Rees) and protecting biodiversity in tropical forests (Edwards). The case studies of Wellman (*Oil Exploration*) and Bryant (*Cancer Therapeutics*) further demonstrate how critical biological insight can have significant impacts for industry and healthcare, respectively.

Support mechanisms: Success in research impact has been enabled by investment of £200k per annum in the Impact Support Team (4.5 FTE). The team's diverse and complementary skills base brings wide-ranging experience in knowledge exchange, research, funding, and commercialisation to the Biosciences. The team creates a pipeline (Fig. 2, using Bryant case study as an exemplar) providing guidance, training and help in identifying potential impact in our fundamental research. They then facilitate identification of potential partners and knowledge exchange with industry with promising cases selectively supported through appropriate internal and external investment, including £131k from the University's IP Development and Commercialisation Fund (IPDaC), £83k on patent expenditure, and Higher Education Innovation Fund (HEIF) investment of £1.4M. Support is not only financial but also includes staff time to acquire the contacts and ideas needed to develop impact (see Section 2.4).

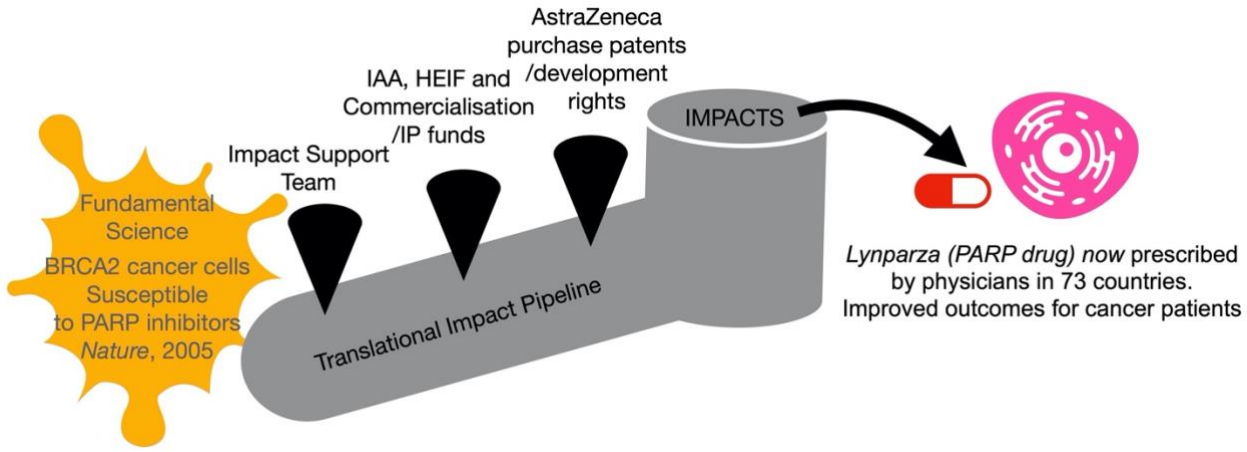


Fig.2 Impact strategy pipeline exemplar

Future impact strategy: Recognising that impact is usually co-produced, we will continue to build upon and sustain our interactions with key stakeholders and partnerships to ensure research is relevant to identified priorities, leveraging appropriate investment and research support as required. We currently have a healthy impact pipeline (*see Section 4.2*) with ongoing projects likely to lead to significant future impact including Peden's highly sensitive cell-based assay for tetanus, a patented technology that has been developed over several years of grant and industrially linked research funding and is now subject to a University commercial opportunity. Further promising prospects include the anticipated Q1 2021 spin-out of Plume Biotechnology from Rafferty manufacturing natural food colorants from algae, which we supported through business training and business accelerator schemes via Innovate UK. We are currently in the process of licensing stomatal density manipulation technology (Gray), using IPDaC funding to bring in an external consultant to broker this deal. At an earlier stage of development, projects that have received financial and impact support include novel RNA-based treatments in collaboration with AstraZeneca (Wilson), Farmplan collaboration with IBM to prevent crop damage (Childs), new methods of microcosm farming (Cameron) and biofuels for aviation (Rolfe). These future prospects will provide us with the springboard for continuing our impact development agenda over the next five years.

1.5 Open research and research integrity

We embrace open science approaches to research and see these as key to raising and maintaining standards of research integrity across the sector. Our strategy for developing an open research culture in the Biosciences is based around the following three pillars:

1. Generating a culture of integrity in research, embedding rigour, experimental design principles and reporting principles into a research culture underpinned by ethics, honesty, collaboration, and trust.

2. Supporting open access (OA) publishing to ensure publicly funded research is made accessible to the public, businesses and the wider academic community.

3. Supporting open data/open methods/open-source software – the core of reproducibility – which is intimately linked to the culture of research integrity we are building.

Our ultimate aim is to act as a low-bias source of credible evidence, promoting informed, data-driven decision-making that benefits society as a whole

During the current assessment period we put in place mechanisms to support these aims, including:

Training to generate a culture of integrity: All 353 PGRs undertook mandatory training in research professionalism, ethics and integrity. PGRs review recent case studies of professional malpractice and hear from senior academics who provide leadership and guidance on the challenges and dilemmas involved. The modules also describe the support available to ensure that PGRs meet our open research and integrity expectations, demonstrating how to catalogue and store data properly. Moreover, while the procedure for whistleblowing is outlined (see *REF5a*), these modules emphasise the importance of honesty and creating an environment where, if a mistake is made, researchers can come forward without fear of reprisal. For research staff we set clear expectations by providing a range of online resources covering research integrity, best practice and professional conduct. These training resources are reinforced via ethics training during induction, mentoring from senior colleagues and regular opportunities for discussion, critical debate and constructive internal peer review. Since ethical issues are often discipline-specific we have invited Bioscience speakers to educate and encourage debate around issues of integrity amongst our staff and PGRs. Further opportunities for discussion and training are provided by our PGR journal clubs and via Biosciences seminars.

Supporting OA publishing: Our research adheres to the University-wide principles (see *REF5a*) of OA for outputs. To ensure maximum discoverability of our research, we aim to deposit author accepted manuscripts of all outputs in White Rose Research Online (WRRO), our shared repository with Leeds and York (green route). The 2,272 outputs deposited over this submission period were downloaded over 87,000 times. This is our preferred route, ensuring equity in publishing opportunities regardless of available funding; we also publish outputs in green-compliant or fully OA journals, where required for funder compliance. In addition, staff increasingly post manuscripts on preprint services such as medRxiv or bioRxiv to ensure timely dissemination of research findings (33% of staff deposited their work, with engagement increasing each year).

OA publishing is now standard across the biosciences, with 69 staff (of 81) playing editorial roles in journals promoting and supporting open research over the assessment period. Several of these are exemplars leading the development of OA/OData/OResearch principles with the publishers, e.g., Slate (*Evolution Letters*) and Beckerman (*Ecology and Evolution*) (both fully OA journals), while a significant number also play Senior Editorial roles in hybrid journals e.g. Beerling (*Biology Letters*), Freckleton (*Meth. Ecology & Evolution*), Hartley (*Ecological Reviews*), Hatchwell (*Behavioural Ecology*), Maltby (*Environmental Pollution*), Mesnage (*Front. Microbiology*), Rees (*J. Ecology*), and Warren (*Ecological Reviews*). Since 2008 we have also required that all PGRs deposit their thesis in our eThesis repository, with appropriate embargoes available to cover commercial, scientific, or political sensitivities.

Supporting open data: In the current assessment period, training was provided to all 353 PGRs on biostatistics and bioinformatics, including the use of R and Python, together with discussions of the merits of these techniques and their fit within our wider strategy. To embed a culture of understanding about data openness and access, we work with all PGRs to develop data management plans for long-term storage, OA and reproducibility in line with UKRI and other funder guidelines. Staff provide training both within the Biosciences and to the wider scientific community (e.g. *Beckerman* and *Childs*, *Getting Started with R*, 2nd ed. 2016) and have played roles in promoting standards for improving the accessibility, reusability and reliability of code used in journal publications (e.g. Freckleton, Meth. *Eco & Evolution*, 2018). Nationally, the University joined the UK Reproducibility Network - promoting open science across disciplines - as one of 13

inaugural members and simultaneously established the University-wide Sheffield Reproducibility Network (with a 0.2 FTE centrally funded academic appointment as Research Practice Lead). The Network leads reproducibility events for both ECRs and senior staff, featuring internationally renowned experts to promote open science principles and approaches.

Future strategy: We recognise there is still more work to do and will expand our established training programmes to research staff at all career levels, highlighting the benefits of preprint platforms as a means to share data sets rapidly and openly (including replication studies and negative results), providing training on open-source software (R and Python) and sharing best practice for promoting open science externally via journal editorships. We will also strengthen internal structures and guidelines to foster the responsible use of metrics, both internally for promotions and externally for recruitment, according to DORA principles.

2. People

2.1 Overview

Sheffield prides itself on its collegiate and supportive community, strong work ethic, and an environment where blue-sky ambitions can be realised. We strive to uphold the principles and implement the responsibilities of the 2019 *Researcher Development Concordat*. As a signatory (2019) to the *Civic University Agreement*, our strategic priorities align closely to those of the city of Sheffield and the local region. Indeed, this sense of place in the wider community, combined with a supportive and balanced research culture, is at the crux of why our staff choose Sheffield. An overview of our achievements is provided in Figure 3.

The unit consists of 81 staff (78.1 FTE): 38 Professors, 19 Senior Lecturers, Readers or Senior Research Fellows, and 24 Lecturers or ECR independent fellows (28% female, 5% BAME, 6% with a declared disability). Scholarship is spread evenly between our six research groupings. Each comprises a mix of established leaders, mid-career scientists and promising ECRs, as summarised in *Section 1*. We have returned all Category A Eligible researchers.

Fig. 3 People, staffing and recruitment strategy infographic

2.2 Staffing and recruitment strategy

Our recruitment policy ensures we have the breadth in research skills necessary to address our research themes effectively. Diversity in our research workforce further enables this by harnessing a wider range of perspectives, approaches, and experience. During the current assessment period we have targeted our recruitment towards attracting independent research fellows to sustain our groups and provide a foundation for continued research excellence.

To achieve these aims **we developed an attractive and distinctive support package for ECRs.** New recruits with independent fellowships lasting at least five years are offered guaranteed progression to an open-ended contract, subject to meeting standard probation requirements (*see Section 2.3*), together with a fully-funded PhD studentship. Administrative and teaching loads are kept low, and each ECR is allocated an experienced academic mentor to provide intellectual and pastoral support. New ECRs can, therefore, dedicate themselves to establishing their nascent research groups and developing outputs.

Consequently, we have been successful in attracting the very best talent in the form of 17 ECRs with independent fellowships (37% female) who complement our existing strengths. Examples include Wright (NERC) and Hemmings (Roy Soc Dorothy Hodgkin) in *Evolution & Genetics*, Edmondson (EPSRC) and S.Campbell (NERC) in *Ecology & Biodiversity*, Field (ERC Consolidator) in *Plants & Global Change Biology*, K.Campbell (Henry Dale) and Towers (Wellcome SRF) in *Developmental & Neurobiology*, Corrigan (Henry Dale/ Lister), Turner (Henry Dale) and Humphreys (UKRI Future Leader) in *Cell & Microbiology*, and Hitchcock (Royal Society URF) in *Biochemistry & Structural Biology*. The result is a fantastically energetic cohort of future leaders, whose influence on the scientific community is already evident. Notable examples include Hitchcock's contributions on photosynthesis (*Nature 2018, 2019*, *PNAS 2020* and *Nat. Commun 2018)*, Towers on limb development (*Nat. Commun. 2015)*, and Humphreys on typhoid toxins (*Nat. Commun 2019)*, together with the organisation of a Royal Society discussion meeting by K.Campbell, Noël and Bulgakova in 2019.

Fellows funded for 2-3 years remain on fixed-term contracts, while we actively encourage and mentor them to apply for independent fellowships of longer duration. We provide feedback and interview practice, leading to success (e.g. Turner, who obtained a Henry Dale Fellowship following initial three-year University support via a Florey Institute Fellowship, and Cooney, who obtained a NERC fellowship, following an initial 3-year early-career Leverhulme Fellowship).

We also recruited specific expertise enabling new technologies to be applied to our research themes. For instance, the University's £10M investment in Bioimaging (*see Section 3*) was underpinned by new recruits in Cryo-electron microscopy (Hoiczyk, appointed at Senior Lecturer) and super-resolution fluorescence microscopy (Jayasinghe, UKRI Future Leader, appointed at Senior Fellow). Field (ERC consolidator, appointed as Professor) underpins efforts to exploit plant-fungal symbioses in sustainable agriculture. The recruitment of Jayasinghe, a STEM LGBTQ+ and BAME role-model, demonstrates the success of new strategies in diversifying our researcher base (see Section 2.3).

Support from skilled and experienced technical staff is vital to all academics. In this assessment period, we instigated a **technician apprenticeship scheme** and recruited new staff with excellent potential. Apprentices train over two years, rotating between research laboratories and facilities. The result is an exceptionally versatile cadre of technical staff, with potential for deployment in any area (e.g. Hodder has assisted Peden with COVID-19 research). Sheffield is a signatory to the Technician Commitment (REF5a) which ensures visibility, recognition, career development and sustainability for technical staff. We have a recognised route for technical staff to gain a PhD. Six registered technicians in the Biosciences have successfully completed their PhD within the reporting period.

Future recruitment strategy: Our aim over the next five years is to continue to attract the best ECRs, filling gaps in our research groups that will appear due to forthcoming retirements. We will innovate by recruiting new expertise in burgeoning areas such as eDNA, long-read RNA and single-cell sequencing. Evaluating and enhancing staff support and development (see Section 2.3) will remain central to recruitment along with further development of our policies on ED&I (see Section 2.4).

2.3 Staff development and support for ECRs

ECR career development: New lecturers undergo three years' probation. This is a supportive process, in which the member of staff is assigned a mentor, with whom they meet monthly. Teaching loads are reduced during probation to allow staff to establish their independent research programmes. In addition, Biosciences provides new academics with a start-up grant and a PhD studentship. We also draw on the University's 'Think Ahead' development programme, which highlights employment opportunities and professional career development in line with the Concordat to Support the Career Development of Researchers. For postgraduate research assistants (PDRAs) we have developed a specific role for academics to champion their interests, encouraging them to participate in setting research strategy. For example, a flagship scheme enables PDRAs, with the mentorship of an academic, to act as primary supervisors for funded summer undergraduate research projects. Less formal mechanisms also contribute to ECR development, including a number of relevant societies such as "Researchers in STEM". These are run by ECRs for ECR benefit, organising seminars and events to foster cohesion and wellbeing among these communities. This integrated approach to managing the work and welfare of ECRs is considered key to maximising career development opportunities, including transition from

academia to clinical or industrial settings. Our PDRAs have been particularly successful in forging research partnerships via Global Challenge Research Fund (GCRF) schemes such as the Royal Society Newton Fellowships (e.g. Bah, Chater and Caine with projects in the Philippines, Vietnam (food security) and Ghana (antimicrobial resistance)). We further support ECR career development by utilising courses, such as the Innovate UK scheme 'Innovation of commercialisation of university research (ICURe)', that promote the development of impact. Prominent examples include Burns, who explored commercialisation opportunities and undertook business management training, assisting Rafferty with the anticipated spin-out of Plume Biotechnology in early 2021 (*see Section 1.4*).

Mid-career progression: Our recruitment strategy during this assessment period ran alongside a proactive process of mentoring and nurturing the career development of ECRs appointed during REF2014 to ensure their progress and retention. Examples of success include El-Khamisy (Lister Fellow 2013, now Professor, attracting £2M grant income including a Wellcome Trust Investigator Award), Christin (Royal Society URF 2012, now Senior Lecturer, attracting £2M) and Johnson (former Leverhulme Fellow 2012, now Reader; £1.8M grant income including a Human Frontiers Science Programme collaborative grant).

Our **Sheffield Leader programme** provides further development opportunities for our mid-career and professorial staff, jointly run by University Human Resources and Research Services departments. In this assessment period, 16 mid-career staff in the Biosciences benefitted from this training e.g. Ayscough (female), served as Head of Department. We enhanced career development of our senior researchers through recruitment of teaching-only staff to free their time for developing programme level grants. We protect 20% of academic staff time for research activities and give teaching relief for those engaging in significant impact activities (for REF and others). Internal discretionary funding (Research Enhancement Fund, Impact Fund) is also available to support research and impact activities. In addition, some staff have benefited from sabbaticals to develop their research, e.g. Baker who followed a role as Director of Teaching with a study leave that led to a paper in *Nat. Commun. 2018*, now forming the basis of a grant proposal and Fleming, who followed a REF2014 coordinator role with study leave leading to papers in *Development* 2016 and *Plant Phys.* 2016.

2.4 Support and reward for research and impact

Staff progress is appraised biannually in the University's Staff Review and Development Scheme (SRDS). Through SRDS, staff set goals for all aspects of academic life and identify any training and support needs. Research achievement, whether through outreach, impact, publication and/or grant income is recognised and rewarded through the Academic Careers Pathway (ACP) (see *REF5a*), which sets out clear and transparent procedures for career progression. Since 2014 we have worked to ensure that promotion decisions make responsible use of academic metrics following DORA principles, ensuring expectations are appropriate to the career stage and taking protected characteristics into account.

In this assessment period, **22 staff (27%) have been promoted, including seven to personal chairs,** demonstrating the quality of our personnel, the support they receive, and our readiness to recognise and reward achievement. The success of the mechanisms in place for rewarding impact (*see Section 1.4*) is exemplified by Cameron, an LGBTQ+ role model, promoted to Professor in the current assessment period in part due to impact and role in developing the new *Institute for Sustainable Food*. Since REF2014 we have strategically increased the number of talented mid-

career researchers who will play a vital role in achieving our future objectives by taking up key positions of research and organisational leadership e.g. Johnson, Director of Research.

2.5 Research students

Recruitment strategy: We aim to attract the best and brightest UK and International PhD students. Actively seeking to increase the diversity of our intake maximises the skills and range of perspectives available. Students are recruited on the basis of excellence, with emphasis upon their research experience, motivation and fit to the research proposal. To drive recruitment, we have developed a range of Doctoral Training Partnerships (DTPs) receiving substantial investment from UKRI and other sources (*see Section 3.1*).

The success of our PGR recruitment policy is evidenced by the diversity of our student cohort (51% female, 28% BAME, 43% international) and their authorship of ground-breaking and interdisciplinary studies, including first author contributions such as Pasquina-Lemonche, *Nature* 2020; Malone, *Nature* 2019; Wood, *Nature Plants* 2018; Gonzales-Delgado*, Nature Chem. Biol. 2019*; Fu, *Development* 2017; Mendonca, *Biophys. J.* 2019.

PGRs have given numerous presentations at international conferences leading to prizes (e.g. Hethcoat, best talk, Society for Tropical Ecology/British Ecological Society Joint Meeting 2019; Palmer, poster prize, Society for Molecular Biology and Evolution 2017; Malone, best talk, Biochemical Society Bioenergetics Meeting, 2019). PGRs regularly present their work and receive feedback at departmental seminars, and benefit from 'Meet the Speaker' sessions. As a community, PGRs organise their own journal clubs, retreats, and symposia, to which external speakers are invited, allowing them to build an academic profile and develop key networking skills (e.g. Imagine DTP students organised two international conferences on bioimaging, 2018 and 2020).

Monitoring and support: All students are assigned a primary supervisor and one or two independent advisors as impartial mentors and follow the University's Doctoral Development Programme. As a measure of effectiveness, over 87% of PGRs submit within four years.

Skills training & preparation for future career: All PGRs must pass formal training courses in open research, research integrity (*see Section 1.5*) and research-specific skills prior to progression beyond year 1. In addition to attending research seminars, preparing reports, and giving regular presentations, students are given the opportunity to acquire teaching skills as laboratory demonstrators or small-group tutors. All PGRs are provided with dedicated bench and computer space and participate fully in the research activities of the unit. Success is evidenced by the breadth of professional careers that our PGRs pursue after graduation. These include PDRA positions or independent research fellowships in the UK or overseas e.g. Hitchcock (former BBSRC DTP PhD student during last assessment period; now Royal Society URF). They have also taken up positions in industry, including in leading bioscience companies such as Syngenta and AstraZeneca, and transferred their skills to management roles in retail (e.g. Amazon) and petrochemicals (Shell).

Interaction with end-users: Our UKRI studentships have been supplemented by iCASE awards, leading to interactions with >30 partners such as AstraZeneca, General Electric, Evotec, NeuroBiom, Medimmune, Proteinmetrics, Green Biologics, Fujifilm Diosynth Biotechnologies, Limagrain, Summit Therapeutics, Agriculture and Horticulture Development Board (AHDB), Albumedix, and C4X Discovery in this assessment period. As a result, students have contributed to

six patents, including as named inventor. We are further supporting PGR career development by utilising courses, such as the Innovate UK scheme ICURe, that promote development of impact. We have implemented short-term industrial placements or other professional internships for all our BBSRC DTP students, providing the opportunity to apply their research expertise and develop employability skills.

2.5 Equality, diversity, and inclusion (EDI)

Our EDI strategy underpins our recruitment, support and development to ensure we can fully harness diverse talents and perspectives to advance our research. We have embedded this strategy into our operational organisation in the Biosciences, creating departmental posts of EDI Director, who have *ex officio* roles on the Departmental Executive Committees and Promotions Review Panels to ensure that **EDI considerations are represented in all key decision-making**.

Our recruitment strategy has particularly been influenced by EDI and DORA agendas with a shift to debiasing job advert language, unconscious bias training for all panels and chairs, encouraging candidates with diverse backgrounds to apply, and independent scoring of candidates against the essential criteria of the job. We now ensure that recruitment decisions make responsible use of academic metrics assessing candidates on the merit of their specific outputs, rather than their h-index or journal impact factors, while ensuring expectations are also appropriate to the career stage and take protected characteristics into account.

Addressing gender equality: We have achieved bronze and silver Athena SWAN awards over this assessment period. Women in the unit have taken leading roles in the University e.g. Hartley OBE (Vice-President for Research); Maltby OBE (Deputy Vice-President and Head of Department); Ayscough (Head of Department); Grasby (Faculty of Science Athena SWAN lead) and Gray (Chair of Women@TUoS). Several have actively contributed to and/or benefited from our Impact Mentoring and Researcher Development Programme and our flagship **Women Academic Returners' Programme (WARP)**, which provides financial support for women to mitigate the impact of maternity leave on research activities. Ten academic staff across the Biosciences have received WARP awards totalling £70k in the last five years. The success of this scheme is illustrated by Hemmings, who captured a Royal Society Dorothy Hodgkin Fellowship and achieved a *Nat. Commun. 2020* output following two periods of parental leave (2015, 2018). In addition, staff returning from parental leave are routinely given teaching relief. Evidence of the success of this approach can be seen in our rising maternity return rates for Lecturers and Senior Lecturers (from 67% in 2015/16 to 100% in 2017/2018). To facilitate the return to work of nursing mothers, dedicated rooms for expressing and storing milk, and infant feeding, have been specifically refurbished within easy reach of labs and offices.

In the current assessment period **an increasing number (~37%) of our fellowships were won by female ECRs** including Field (ERC Consolidator), Turner and K.Campbell (Henry Dale), Corrigan (Henry Dale, Lister), and Jayasinghe and Croft (UKRI Future Leaders); others have won fellowships to support flexible working (Hemmings, Dorothy Hodgkin) and will act as positive role models and mentors going forward. We have improved the gender balance of the applicant pool for academic positions, increasing from 28% female applicants to 40% between 2013 and 2018. Indeed, in the current assessment period, >50% appointments were female (10/19 total appointments) and 75% (3/4) of those appointed at Professor or Senior Research Fellow level were women. Overall, the proportion of female staff at Lecturer level is now 50% (Senior Lecturer/Reader/Advanced Fellow 21%; Professor 19%).

Support for LGBTQ+ staff: Sheffield's commitment to eliminating discrimination and promoting diversity includes active support for our LGBTQ+ staff and students, as evidenced by our ranking of 23 in the Stonewall *Top 100 Employers* 2019 survey. This is testament to the importance the University places on LGBTQ+ inclusion and frames our own efforts in the Biosciences, with Cameron and Jayasinghe acting as LGBTQ+ role models. Cameron hosted a 2020 regional award ceremony for LGBTQ+ and delivered a keynote at a 'Bio-diverse' festival, celebrating under-represented scientists in biology and conservation.

Support for BAME staff and addressing diversity: During this assessment period the University launched an action plan to effect transformational change targeting under-representation, progression, and attainment of BAME staff and students, aiming to create a community that is diverse and inclusive. A key goal has been to increase diversity of the staff body and support the career progression of BAME staff through sharing and developing good practice to improve representation through affirmative action e.g. progression of Siva-Jothy as Head of Department.

Seminars: We have also taken active measures to ensure a greater representation of women as invited seminar speakers, with a target of 50:50 male/female and increased representation from BAME and other protected groups. In 2019, the proportion of seminar speakers in biosciences who were women was 46%, with 9% from BAME groups. A new Biosciences-wide seminar series 'Biosciences Inspire' and from 2014 onwards the annual 'Margaret Savigear Lecture' give a voice to historically underrepresented groups in HE, and an opportunity for frank and open discussion about issues of diversity and inclusion. Recent speakers include Professor Bugewa Apampa from Birmingham City University, who discussed inclusion for Black students in HE. Inclusivity and diversity is also promoted and celebrated through our DTPs (e.g. DiMeN *Diversity in STEM* workshop 2020, Jayasinghe guest speaker).

Parental leave and childcare: In addition to statutory family leave, staff on parental leave are entitled to 10 'keeping in touch' days to keep abreast of any developments and activities, and line managers keep in regular contact. Where staff wish to continue to supervise PhD students during leave, the University works to facilitate this.

Support for neurodiversity: We have actively taken steps to help neurodiverse staff through technological and mentoring support, prioritising tasks that make the most of their inherent strengths, facilitating flexible working arrangements and adjustments to workspace or encouraging homeworking where possible.

Support for disabled staff: Disabled staff and PGRs are supported via the University Disabled Staff Network. Within the Biosciences there is provision for Disability Leave, a form of reasonable adjustment to enable disabled staff to be absent from work in certain circumstances, for example to undergo treatment, assessment or rehabilitation as part of managing their disability and maintaining their fitness/health and wellbeing at work.

Preparation for the REF2021 submission: The University has a Code of Practice that stipulates processes to ensure equality and diversity in preparation of our assessment submission. All members of REF Committees undertook REF-specific EDI training including material on recognising and countering implicit bias. Our REF team is as inclusive and representative of gender as possible, with peer review of outputs undertaken by staff with a breadth of expertise. Following our Code of Practice, outputs were selected on the basis of ranked quality. When the cut-off was reached for the number to be submitted, we considered the protected characteristics of the attributed authors for all outputs at that particular star rating. The University has undertaken

equality impact assessment of our output scoring and attribution, and on our independent researcher decision-making, and found no evidence of bias. The institutional process for disclosing equality-related circumstances was highlighted to staff to ensure awareness of the support available. Clear University policy statements ensure that there will be no detriment to staff either in their classification as an independent researcher or in the number of outputs submitted, and REF submission data are not used during recruitment, review or promotion.

3. Income, infrastructure and facilities

3.1 Overview

Our research income has increased from £55M for REF2014 to £94M in the current assessment period **(↑70%).** This has been achieved through active recruitment of independent research fellows, mentoring ECRs to consolidate and expand their funding portfolios, enhancing our PDRA base, increasing our capture of UKRI and charity DTP funding, and recruiting teaching-only academics to free up time for the development of larger collaborative projects and programme grants by our senior staff (Fig. 4). The income generated has been supported by institutional investment in key facilities allowing us to bring new technologies to bear on our research themes.

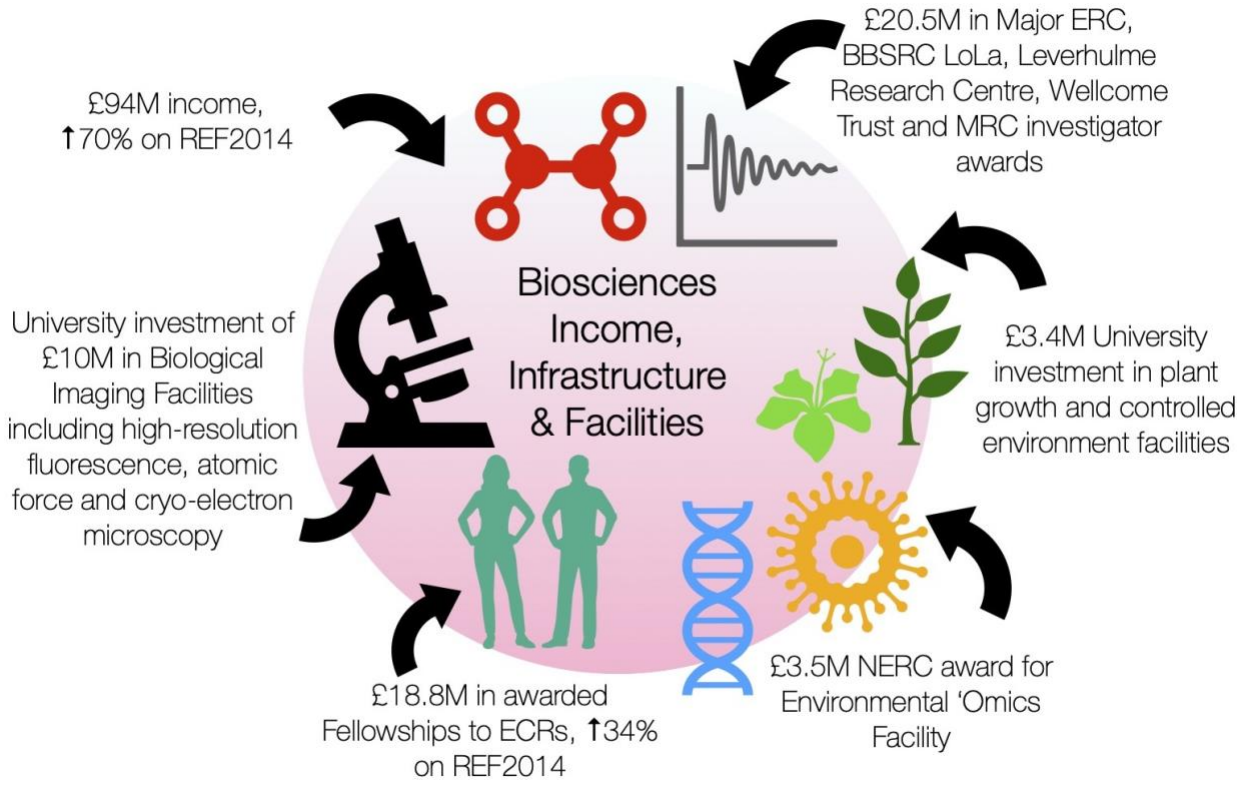


Fig. 4 Income, infrastructure, and facilities infographic

3.2 Income

Funding sources: Over the assessment period we have won new grant awards of £111M distributed across a broad portfolio of sources including £24.2M BBSRC (↑91% on REF2014), £16.6M NERC (↑80%), £15.9M Wellcome Trust (↑114%), £13.4M European Commission (↑11%), £13.7M MRC (↑78%), £8M Leverhulme Trust (↑519%), £5.9M Royal Society (↑168%), £3.2M EPSRC, £2.9M Central Government and £7.4M from over 40 separate sources. We have seen UKRI spend/year increase by over 40% during this assessment period (*REF4b*) and we have achieved the highest UK NERC bioscience income (HESA). The diversity of funding reflects a critical mass of research spanning fundamental and translational science, with income split fairly evenly between the research groupings (*see Section 1*). Our income and investment have also led to broad impact, from developing novel cancer therapies to changing policies on climate. We received £926k in research funding from industrial partners such as Syngenta, AstraZeneca, MedImmumne, Enza Zaden, Definition, Airbus, and Amey. This success has been enabled by **impact support structures and mechanisms** including an investment of £200k p.a. in the University Impact Support Team (4.5 FTE) (*see Section 1.4*).

Advanced and programme grant awards: Major single grant awards are widely distributed amongst our research groupings, portraying individual success of our senior research leaders within these teams. For example, an ERC Synergy of £3.7M and a £3.3M BBSRC LoLa to Hunter, £4.6M from the Leverhulme Trust to Beerling, £3M from the MRC to Moore (retired 2017) and £2.2M to Marcotti, and Wellcome Trust awards to Strutt (£2.3M), Foster (£1.6M), Towers (£1.1M) and Placzek (£1.1M). In total four PI's won research income of >£4M, 8 PI's £2-4M, 31 PI's £1-2M and 23 PI's >£500k, with a mean of £0.2M/ year/ FTE. Compared with spend/year/FTE over the assessment period of £0.17M, we are in a very healthy position for the upcoming phase of our research strategy.

ECR & fellowship income: Our continued strategy of ensuring a future pipeline of talent by developing ECRs in the current period is evidenced by securing **£18.8M (59 successful bids) in competitive research fellowships** compared with £14M in the previous REF period (↑34%). This represents 20% of our current REF return, ensuring a solid pipeline of future talent. Our fellowships span a broad spectrum of funders, including 3 ERC, 7 Royal Society University Research, 6 Wellcome Trust Sir Henry Dale and 10 Marie Curie.

PGR income: Our success in generating support for PGR studentships, a key driver of our research, has been the diversity of income streams developed, including UKRI-funded DTPs such as: BBSRC White Rose DTP in Mechanistic Biology (awarded in 2015 and 2020; total £7.5M) tied to our research groups in *Cell & Microbiology*, *Biochemistry & Structural Biology*; NERC Centre for Adapting to the Challenges of a Changing Environment (ACCE) DTP (total £6.4M) which supports *Ecology & Biodiversity* and *Evolution & Genetics* research groups; MRC Discovery Medicine North (DiMeN, total £4.7M) which supports *Developmental & Neurobiology* and *Biochemistry & Structural Biology* research groups. We also attracted charitable funding for PGRs via the Grantham Centre for Sustainable Futures DTP (Grantham Foundation, >£2M), the Leverhulme Advanced Biological Modelling DTP (>£1M) and the Dunhill Medical Trust DTP.

Internal strategic investments in PGR recruitment (> £6M total over this assessment period) align with our priorities in high-resolution biological imaging (**Imagine DTP**) and antimicrobial resistance (**Florey Institute DTP**), funding a total of 15 studentships in these areas. We have augmented our PGR cohort through attracting funding from a range of sources including the US Department of Energy, Teagasc Walsh Scholarship, A*STAR, Bangabandu Overseas Scholarship, Chilean

Government, China Scholarship Council, CONACyT (Mexico), Iraqi Government, Kuwait Institute for Scientific Research, Ministry of Government Qatar, Ministry of Health Malaysia, Schlumberger Foundation, TETfund Nigeria, Science without Borders (Brazil) and the Saudi and Libyan Governments. Our staff also contribute to international PGR training through Marie Skłodowska-Curie Innovative Training Networks (e.g. Rolfe, *INSPIRATION* ITN), and train external students through international collaborations, internships, and practical courses.

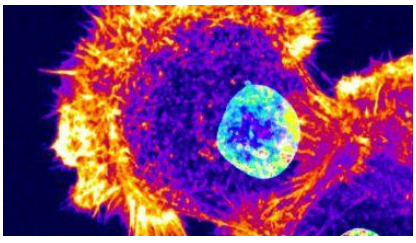
Our PGR training extends to NHS staff and clinicians, as testified by winning five clinical PhD studentships from diverse funding sources including the Pathological Society and the 4Ward North Wellcome Trust Clinical DTP.

Overall, our PGRs/FTE has increased from 4 to 4.5 since REF2014, providing both increased training and contributing to the capacity required to achieve our strategic objectives.

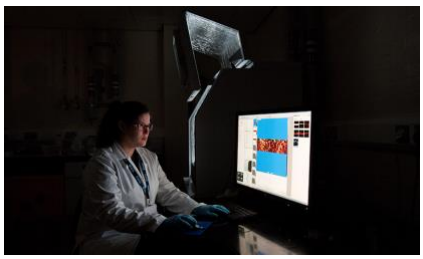
3.3 Infrastructure and facilities

We attracted substantial external funding for our facilities, backed by infrastructure investment from the University. The aim is to create a flourishing environment in which all our researchers have access to cutting-edge technologies, bringing new understanding and insight to our key research themes. A critical component of our strategy has been establishing a total of 16 dedicated support staff (10 FTE) to manage specialist research facilities and to provide key skills and training supported by our new technician-training scheme (*see Section 2.2*). Key investments and new funding for specific facilities are highlighted below:

Cryo-electron Microscopy. Research in *Biochem & Structural Biology* has been facilitated by University investment of ~£3.2M to establish a Cryo-EM facility including a Tecnai Arctica microscope, which has so far attracted >£3.4M grant capture including £236k from Wellcome Trust Institutional Strategic Support Funds for high pressure freezing technology. We also updated our 200 kV Transmission Electron Microscope. We have supported this investment with appointments of ECRs such as Bose and Hitchcock. The facility is a focus of synergy across multiple research groupings: exceptional outputs include papers elucidating new photosynthetic electron transfer complexes in *Nature 2019*, bacterial cell wall architecture *Nature 2020* and flagellum structure *Nat. Commun. 2020*.



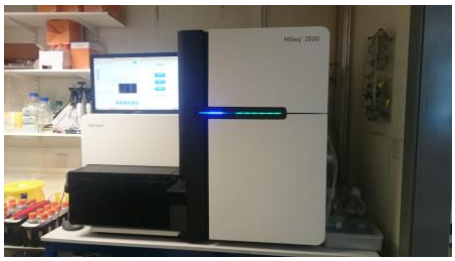
Light Microscopy Facility (LMF) provides an array of fluorescence microscopy instruments, including deconvolution and laser-scanning confocal microscopes, and a wide-field system for FRAP and FRET. During this assessment period we added to our existing Nikon A2 TIRF/confocal microscope and two super-resolution STORM and SIM (OMX) microscopes, with a light-sheet microscope (funded by BBSRC, £367k) and Airyscan system (Royal Society, £275k). The LMF is about to be extensively refurbished to create a state-of-the-art facility using £200k of Wolfson Foundation funding. We have supported this investment with matched funding and appointments of ECRs such as Jayasinghe (*Biochem & Structural Biol)* and Humphreys (*Cell & Microbiol*). Key relevant outputs include research on coronaviruses including SARS-CoV-2, *Science* 2020 and host-pathogen interactions including MRSA in *Nat. Microbiology 2018* and typhoid in *Nat. Commun. 2019.*



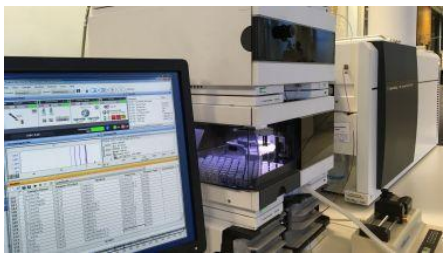
Biophysical Imaging Centre, established during REF2014, was further augmented with new tools and capabilities including the latest Fast-Scan high-resolution atomic force microscopes. Funding of £1.2M was provided by a combination of University and £0.5M EPSRC and Wellcome Trust, complementing the six other AFMs in the facility. This provides a UK-leading biology-focussed AFM facility and outstanding capability in super-resolution microscopy. This is an exemplar of interdisciplinary collaboration between Biosciences and Physics with outputs including new insights into bacterial cell wall structure in *Nature 2020*, *Nat. Commun. 2018* and *Nat. Microbiol. 2020.*

Plant growth and environment facilities: A substantial University investment of >£3.4M in 2016 was made to expand our Controlled Environment Research Centre with 2000m^2 of plant growth space and associated laboratories, together with a further £0.8M for upgrading our 32 Conviron growth chambers to manipulate and monitor temperature, light, humidity and CO_2. Together these provide infrastructure for environmental, plant and ecology research, facilitating our strategy in food security and environmental change. We have supported this investment with appointments of ECRs such as Voigt, Smith, Field (ERC) and Croft (UKRI Future Leader). These investments have driven outstanding grant capture of £20.8M in this submission period in the *Plants & Global Change Biology* research area, supporting outputs in journals such as *Nature 2019, Nat. Plants, 2016, 2018* and *Plant Cell 2014* covering evolution of C4 plants, stomatal developmental and plant-pathogen interactions.

Nuclear Magnetic Resonance (NMR) Spectroscopy. The University has invested £0.4M to improve this facility together with funding from BBSRC (~£0.5M to upgrade our 600 MHz spectrometer) and EPSRC (£1.1M to upgrade our 800 MHz spectrometer). This investment led to high-impact publications in *Nat. Commun. 2020* on verifying protein structures and *Nat. Chem. Biol 2020* on peptidoglycan recognition. 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 with synergies between *Biochemistry & Structural Biology* and *Cell & Microbiology* resulting in outputs in *Nat. Commun. 2020* and *Nat. Struc. Mol. Biol. 2016* on endonucleases and pore-forming toxins.



Next Generation Sequencing Facility: Our research in *Evolution & Genetics* is enabled by our Next Generation Sequencing Facility which has received a further £3.5M funding (2020) after selection as NERC's Environmental 'Omics Facility. Platforms include Ion Torrent, Miseq and HiSeq in, and DNA sequencing/TILLING/SNP. This investment has facilitated cutting-edge research and cemented fruitful collaborations within and across Biosciences, Engineering, Medicine and Chemistry with exemplar outputs in *Science 2016* on honeybee virus evolution and *Nature Genetics 2015* on supergenes in male reproduction. In addition, we host a Wellcome Trust RNAi screening facility, providing a national service for identifying genes affecting cellular processes in *Drosophila* and human cells.



Mass Spectrometry Facility: We have further strengthened our 300m^2 >£5M biological mass spectrometry facility with the purchase of a £0.75M Waters G2/G2Si Synapt for metabolomics and proteomics. Additional funding in this assessment period has come from the Wolfson Foundation/University matched funding of £0.5M for a High Definition MALDI Mass Spectrometer and a GC-MS, £121k BBSRC grant for portable MS equipment. Collaboration with colleagues in our Engineering faculty and Sheffield Hallam University provides Sheffield with outstanding resource and expertise in this area. This facility has supported our research efforts across the biosciences with >35 publications including discoveries in peptidoglycan synthesis (*Cell 2019*) and apoptotic signalling (*Nat. Commun.* 2019).

Zebrafish facility: one of the largest and best-equipped in Europe, housing a globally important collection of mutant and transgenic lines. The aquaria and associated quarantine rooms have capacity for >112,000 fish, and are complemented by a comprehensive genotyping service, microinjection rooms, cryogenic storage, a behavioural analysis suite and a small molecule screening unit with high-content imaging and robotics for liquid handling. The facilities are used by 29 research groups (>120 users) across the University, with collaborative links worldwide. Published highlights include research on hypothalamic development (*Development* 2017) and sensory hair cell function (*EMBO J* 2019).

High Performance Computing (HPC): is central to a number of our activities with University investment of >£2M in a shared facility ('Bessemer'), allowing access to high-speed parallel filestore and providing cloud computing capabilities on campus. The University is a partner in the N8 Tier 2 HPC facility, a joint venture between the eight leading research-intensive universities in the north of England to provide UK-leading computational capacity, facilitating sharing of resource and expertise in this key technology for the future of large-scale biological research.

Future strategy: The University has recently established major Flagship Institutes in Health Lifespan, Neuroscience, Sustainable Food and Energy, areas of notable interdisciplinary strength for Sheffield and all closely aligned to the Bioscience research themes. These institutes, together with a research workforce enhanced by the recent recruitment of 17 ECR fellows, are key to developing further local, national, and international collaboration, knowledge exchange and partnership with industry, ensuring we can continue to attract funding from a broad variety of sources. We will support this through continued development of our research facilities, further upgrading those in areas of strategic relevance, such as high-resolution microscopy, plant growth and genomic sequencing. This targeted investment will be further underpinned by the **University's recent announcement of a £150M campus plan** to modernise the science estate.

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

4.1 Overview

Researchers in the unit have played leading roles internationally, nationally, and locally in driving forward major collaborative research ventures with academic partners, industry, government organisations and charities. Indeed, **66% of the 195 outputs returned involve international partners, 65% with researchers in another UK institution and 47% with partners in another non-biology unit** demonstrating the collaborative and interdisciplinary nature of our research.

4.2 Research Collaboration, Networks and Partnerships

International: Beerling FRS established the **Centre for Climate Change Mitigation with £4.6M in Leverhulme funding**. Bringing together researchers from around the globe, including Princeton and Illinois, and focussed on bio-inspired processes to counteract outcomes of global climate change on agriculture, Beerling has established the foundations for future applications of bio-geoengineering technology (*Nature 2020)*.

Hunter FRS, via major grants from ERC Synergy (£3.7M) and BBSRC LoLa (£3.3M), has established international initiatives including partners in USA, Germany, and the Czech Republic to **enhance photosynthetic light harvesting for increased biomass production 'PhotoRedesign'**, leading to significant advances in synthetic biology approaches and our understanding of the fundamental principles of life (*Nature 2018, 2019*).

Foster was involved in the £1M MRC-funded UK-India Centre for Advanced Technology for Minimising the indiscriminate use of Antibiotics (UKICAT-MA) to establish materials for both detection and treatment of ocular infections.

Scholes (funded by UKRI-GCRF, BBSRC and the International Maize and Wheat Improvement Centre) has led agricultural improvement projects across sub-Saharan Africa e.g. *Striga* infestation, *Nature Plants 2020*. Gray and Casson have established and led research networks on crop improvement in the Philippines, Thailand, China and Mexico (funded by BBSRC-Newton, Royal Society and Horizon 2020, total >£2M) with outputs in *New Phytologist 2019*. Fleming has led international collaborative efforts with China and Malaysia on improving photosynthesis (*Nat. Commun. 2019*), supported by BBSRC-Newton and Royal Society GCRF.

Humphreys is a member of the Human Infection Challenge (HIC-Vac) Network accelerating vaccine development with partners from 30 countries including China, USA and Canada. Johnson developed collaborations with Massachusetts Institute of Technology (MIT) and Japanese partners through an HFSP Grant ($1.1M), while El-Khamisy developed the Middle East and North Africa Research on Healthy Ageing network (MENARAH). Rolfe is a member of EMPHASIS, an EU-funded plant phenotyping infrastructure project.

In the area of biodiversity and conservation, Webb is PI on the EMODnet Biology, a European marine observation and data network and multi-European-institution consortium with total funding of €1.77M. Edwards has established highly successful collaborations with researchers across Central and South America, and Malaysia, with a focus on conservation of tropical forest (NERC-funded), while Butlin's ERC-funded research on ecological divergence (*Science Adv. 2019*) involves major collaborations in Sweden, part-funded by the Swedish government. Research on

Arctic climate change (e.g. *Nature Climate Change 2020*) led by Callaghan and Phoenix involved major collaborative efforts with countries of the far north, in particular Russia. These contributions to **leading international scientific diplomacy underpinned the award of CMG to Callaghan (2018)**.

National: Cameron and Daniell played a leading role in the £8M N8 agrifood research program tackling food security issues including partners in Manchester, Leeds, and Lancaster, with linked outputs in *Nature Plants 2020 and 2017*. Foster is involved in the £2.1M EPSRC-funded *The Physics of Antimicrobial Resistance Network* with partners in Edinburgh, Cambridge, and Newcastle leading to publications on MRSA wall structure (*Nature 2020*). Freckleton is involved in BBSRC LoLa-funded blackgrass herbicide resistance project with partners including Rothamsted, York and Newcastle and collaboration with AHDB (*Nat. Eco and Evo 2018, Nat. Sustainability 2019*). Childs is involved in the Soay Sheep £3.1M NERC Network on gut ecosystem dynamics with partners including Aberystwyth University and Moredun Research Institute.

4.2 Relationships with Key Research Users, Beneficiaries & Audiences

In addition to the six impact case studies supporting this submission (*see Section 1*.4), the following section gives further examples of interaction with industrial, charity and governmental partners in addition to the wider public.

Collaborations with industry: Our *Cell & Microbiology* and *Biochemistry & Structural Biology* research groups have made excellent progress translating fundamental science into industrial impact. These groups have been particularly agile in their **response to the COVID-19 pandemic** e.g. Peden has studied SARS-CoV-2, SARS-CoV-1 and MERS-CoV to identify commonly hijacked cellular pathways and detect promising targets for broad coronavirus inhibitors, *Science 2020*, generating interest from pharmaceutical companies. Wilson is developing mRNA therapies with **AstraZeneca** via a £0.84M MRC grant (Nov 2020), further augmented by two AstraZeneca BBSRC CTP studentships and one EPSRC studentship. This project benefits from £150k direct funding from AstraZeneca for research on development of synthetic 3' UTRs for improvement of mRNA therapeutics and intronless expression systems for production of biopharmaceuticals. Biosciences staff have also contributed to testing and detection. Burke is involved in the NERC-funded National Wastewater Epidemiology Surveillance Programme (N-WESP) and consultant to the Joint Biosecurity Centre developing new methods for detection of SARS-CoV-2, including the use of digital PCR to detect new variants. Smythe has worked with **Paraytec/Braveheart** who contributed £100k the development of a fluid analysis testing platform for COVID-19 detection for which a patent has now been filed. This work has underpinned a recent application to Innovate UK (pending, £1.5M) and the expectation is that Sheffield will host the pivotal clinical trial required to validate the product to MHRA standards.

Other strengths include pioneering the development of innovative vaccines to prevent and treat life-threatening bacterial infections such as *S. aureus*, *C. difficile* and *C. tetani*, e.g. Peden has developed a patented assay for tetanus detection, attracting significant interest from end users including vaccine regulators (e.g. **National Institute for Biological Standards and Control (NIBSC)**) and **Merck**. Foster was CSO of the spin-out company **Absynth Biologics** during the REF2014 period, now with >35 registered patents, two iCASE PhD studentships and a collaborative Innovate UK grant (£460k) with linked output appearing in *PLoS Pathogens 2018*.

Our *Plant & Global Change* research group has forged partnerships with the agri-tech industry to improve crop yield and resistance to biotic and abiotic stresses e.g. Gray's technology for reducing

stomatal density in cereals, granted a patent in 2017. The project featured in the BBC World documentary Series 'Follow the Food' aired in >100 countries and viewed by 454 million households. This work led to the award of a 2018 Newton Prize to Gray. Cameron, through collaboration with the **AHDB**, has developed the bacterial diseases strategic priorities programme addressing crop pests, supported via a £1.6M BBSRC award; Voigt has established a partnership with **Syngenta** to develop inhibitors of fungal β-glucan cell wall biosynthesis via assay-based compound screening, a joint project that resulted in an iCase PhD studentship; Childs has developed the Farmplan collaboration with **IBM** to prevent crop damage; and Rolfe is working with **Airbus and Conidia** to develop aviation biofuels via the CONCAWE project funded by the EU.

Learned societies and government agencies: we have provided scientific guidance and advice to the Government and various national institutions. For example, **Hartley is a Board member of Natural England**, the UK Government's statutory agency for the natural environment in England, a Trustee of the Royal Botanic Gardens, Kew, and provided an 'Evidence-based assessment of challenges and opportunities on **environmental policy post-Brexit**' to the House of Commons. Rees is a member of the Non-Native Risk Analysis Panel, which advises the government and devolved administrations on risks associated with non-native species and served as a scientific expert for the European Food Safety Authority (EFSA). Leake contributed to the Parliamentary Office of Science and Technology (POST) Note on Sustaining the Soil Microbiome, the iCASP Evidence Review on Soil Health, edited text for the iCASP Response to DEFRA Committee consultation into the scope, provisions and powers proposed in the Agriculture Bill, and led two written submissions to the UK Government Soil Health inquiry; Beerling FRS served as a member of Greenhouse Gas Removal Technologies Working Group, Royal Society-Royal Academy of Engineering, and Foster is a member of the UK Vaccine Network. Members have held 30 **Learned Societies** posts during this assessment period, including **five Society presidents** (Wellman, President of the Palaeontological Association; Butlin, President of the European Society for Evolutionary Biology; Hatchwell, President of the International Society for Behavioral Ecology; Scholes, President of the International Parasitic Plant Society; Hartley, President of the British Ecological Society).

Wider societal impact: Interaction with the general public has involved all staff in a range of outreach events such as **Discovery Night**, **Researchers' Night** and **Festival of the Mind** with an annual audience of >50,000 and widespread national and international coverage. Cameron presented 'Social Experiments with Living Sculptures', a sculpture/video installation about symbiosis (with Laurence Payot) in 2014, and 'Gaiamycota', a sculpture/performance/video installation about soil degradation and food security which was visited >10,000 times at Sheffield's Millennium Gallery and also exhibited at Usagi New York (Brooklyn) and the Gorilla Zoo Gallery, London.

KrebsFest 2015, organised by Foster and Johnson, had >100,000 visitors, received external funding from multiple sources and won **Highly Commended status in 2016 in the Public Engagement and Advocacy category** at the Association of Research Managers and Administrators awards. Many aspects have been re-used at other events (e.g. artist Luke Jerram's giant inflatable *E. coli* (illustrated,

Sheffield Winter Gardens) at the Cheltenham Science Festival, Eden Project, and the Natural History Museum).

In 2019 Cameron organised AquaKulture, a public musical performance, video, and scientific talk that won the **Colin Pillinger Award for Public Engagement from the Royal Society**. Hemmings was awarded the **Society of Biology UK Science Communication Award 2014** for science outreach. Cameron, Hemmings, Osborne and Hatchwell each gave a University Christmas Lecture to 1,000 local school children (many from deprived backgrounds in South Yorkshire) an event which involves numerous demonstrations and audience participation.

Edmondson runs a large-scale citizen science project (MYHarvest) with >1,100 people signed up to submit own-grown fruit and vegetable crop yield data. This will result in the first UK-wide estimate of the production of own-grown fruit and vegetables since the Dig for Victory campaign during the Second World War. This research has received considerable media attention (e.g. >25 radio interviews, including live on BBC Breakfast). Edmondson also held stands at the Harrogate Flower Show (2017, 2018) and BBC Gardeners' World (2017) to promote this research in collaboration with the National Allotment Society. Thomas runs two online citizen science projects 'Mark My Bird' and 'Project Plumage', both with >3,000 registered volunteers.

4.3 Contribution to sustainability of the discipline

We contributed to major international science publications through **69 editorial positions held by members of this unit during this assessment period** including **11 senior positions as Senior/Executive or Editor-in-Chief** (Beckerman, *Ecology and Evolution*; Beerling, *Biology Letters*; Freckleton, *Methods in Ecology & Evolution*; Hartley, *Ecological Reviews*; Hatchwell, *Behavioural Ecology*; Maltby, *Environmental Pollution*; Mesnage, *Frontiers in Microbiology*; Rees, *Journal of Ecology*; Slate, *Evolution Letters*; Ton, *Plant Physiology*; Warren, *Ecological Reviews*). Staff have also authored books aimed at broad audiences, notably Beerling ('*Making Eden: How plants transformed a barren planet',* 2019). This reflects a wider engagement by the majority of unit members in outreach and public **understanding of science** *(see Section 4.2).*

Grant panels: Staff have contributed their expertise on >90 grant committees (**an almost 60% increase from REF2014**), six as chair. These cover a very wide geographic range (UK, France, Czechia, Norway, Finland, Ireland, Portugal, New Zealand, Canada, Italy, Switzerland, Germany, USA) demonstrating the breadth of influence and high esteem of our staff, and includes all the relevant UK councils (BBSRC, EPSRC, MRC, NERC), the Wellcome Trust and Learned Society funding panels (e.g. Royal Society). Approximately **50% of our staff participated in research council committees** and all have been involved in the actual review of grant applications.

Our staff were also involved in **organising 48 conferences** (↑**23% on REF2014**), 26 conference sessions and chaired 44 conference sessions. Foster, Harrison and Butlin were all involved in organising or chairing sessions at Gordon Research Conferences (GRCs), amongst the most prestigious conferences in biology. Over 440 invited talks were given, of which about 17% were either plenaries or keynote presentations. Due to the breadth and number of these conferences, we can only provide a flavour of the contributions made. Ayscough, Beerling, Butlin, Christin, Fleming, Foster, Gray, Hunter, Johnson, Marcotti, Nadeau, Osbourne and Strutt all presented at GRCs. Hunter gave a plenary lecture at the 2018 European Photosynthesis Congress, Butlin gave the Presidential address at the European Society for Evolutionary Biology, Hartley gave the Royal Society of Medicine annual lecture and the opening plenary and President's lecture at the British Ecological Society annual meeting, and **Beerling FRS gave an invited talk at COP24**.

The **esteem and success** of our staff have been reflected over this assessment period by the award of many prizes and fellowships. Two of our leading female academics were awarded OBEs: **Hartley, for services to ecological research and public engagement** and **Maltby for services to environmental science. Beerling was awarded FRS**, **Callaghan a CMG for scientific diplomacy** and **Cameron received a World Economic Forum's Young Scientist Award**. Butlin was awarded the Darwin-Wallace Medal from the Linnean Society, became a Foreign Member of the Royal Swedish Academy of Sciences, and a Distinguished Fellow of the European Society for Evolutionary Biology. Johnson received the Biochemical Society's Colworth Medal, Wain Medal in Biochemistry, and the Society of Experimental Biology President's Medal. Wellman received the President's Medal of the Palaeontological Association, both Warren and Freckleton received the British Ecological Society's (BES) President's Medal, Beckerman received the BES Award for Service to the Society, and Marcotti became a Fellow of the Physiological Society. In addition to those awarded to ECRs (see Section 2), more senior scientists also won fellowships. For example, Burke, Fleming and Rees all received Leverhulme Research Fellowships, while Slate won a Royal Society/Leverhulme Trust Senior Research Fellowship. Gray won a Newton Prize, Grasby the Steven Shaw Turner Prize 2019 and K.Campbell The Betty Hay Award.

As a community, we are immensely proud of these contributions and achievements over this assessment period. With our strategic plan and our talented workforce, we are well placed to build on our strengths over the next decade to make a significant contribution to UK bioscience.