Institution: Royal Holloway University of London

Unit of Assessment: 05 Biological Sciences

1. Unit Context and Structure, Research and Impact Strategy

1.1. Research Structures

Royal Holloway's Department of Biological Sciences is a research-led unit (28.4 FTE) embedded in the School of Life Sciences and Environment. Our individual and collective research activities are underpinned by a shared research strategy and commitment to supporting and training our researchers, especially ECRs and PGRs. The department has a total of 34 members of academic staff.

The unit supports a diverse and vibrant research environment, represented by three centres of research excellence:

1. **Centre for Biomedical Sciences** (16 members of staff) focuses on fundamental and applied research into the molecular mechanisms of disease.
2. **Centre for Plant Molecular Sciences** (7 members of staff) addresses fundamental and applied research into mechanisms that determine plant traits with agronomical, nutritional and health benefits supporting sustainable production and the bioeconomy.
3. **Centre for Ecology, Evolution and Behaviou**r (11 members of staff) studies the way that organisms react, adapt to, and interact with their environment, addressing both fundamental and applied problems.

Our ambition is to generate world-leading research and deliver impact across communities and professional stakeholders. Our research addresses key strategic priorities of the UK government, research councils, and non-HEI partners in areas that include resilient food security, sustainable agriculture and healthy ageing.

During this REF period our unit has secured >£22M (see *REF4b*) in research income with a more diverse funder portfolio (*Figure 1*) compared to REF2014, with 1.8-fold and 1.6-fold increased RI from Industry and Charities, respectively. We have had notable success in a variety of grant schemes from individual prestigious grants (e.g. Leadbeater's €1.4M ERC Grant) and in leading large consortium projects: examples are the large EC consortium led by Brown (€9M total value of consortium award); industrial biotechnology and biochemistry of natural products (€9mio EC, £3.6M ERA-IB consortium with Syngenta led by Fraser), malnutrition and food security (£1M GCRF consortium with the International Institute of Tropical Agriculture and World Vegetable Centre led by Fraser), seed science and technology (€2M ERA-CAPS consortium, £1.4M industry and AgriTech/ISCF-funding) led by Leubner and a €7.5M EC vaccination consortium led by Cutting. *Figure 1* summarises the diversity in acquired project funding (UoA5 research income awards) including for research into new techniques for gene therapy of muscular dystrophy (£4.7M Popplewell/Dickson) and addressing global challenges with partners in developing countries (>£2.5M). Finally, a mixture of research council, charity and industrial-based funding supported ~100 PhD students during this assessment period.

During the REF period our unit published over 700 papers in internationally recognised peer-reviewed journals (~75% Open Access). In addition, 22 patents have been generated in the area of advanced therapies, drug development, plants and food chain resilience, nutritional products and seed technologies. Our patent portfolio is closely connected to our impact strategy and choice of impact case studies.

Research planning is led by the Departmental Research Lead (Koricheva) and Centre Directors, all of whom work with the unit's Research, Planning and Resources Group. The unit has a close relationship with the School Director of Research and Knowledge Exchange, Research & Innovation and relevant Senior Vice Principal (Academic Strategy, Partnerships and Resources).

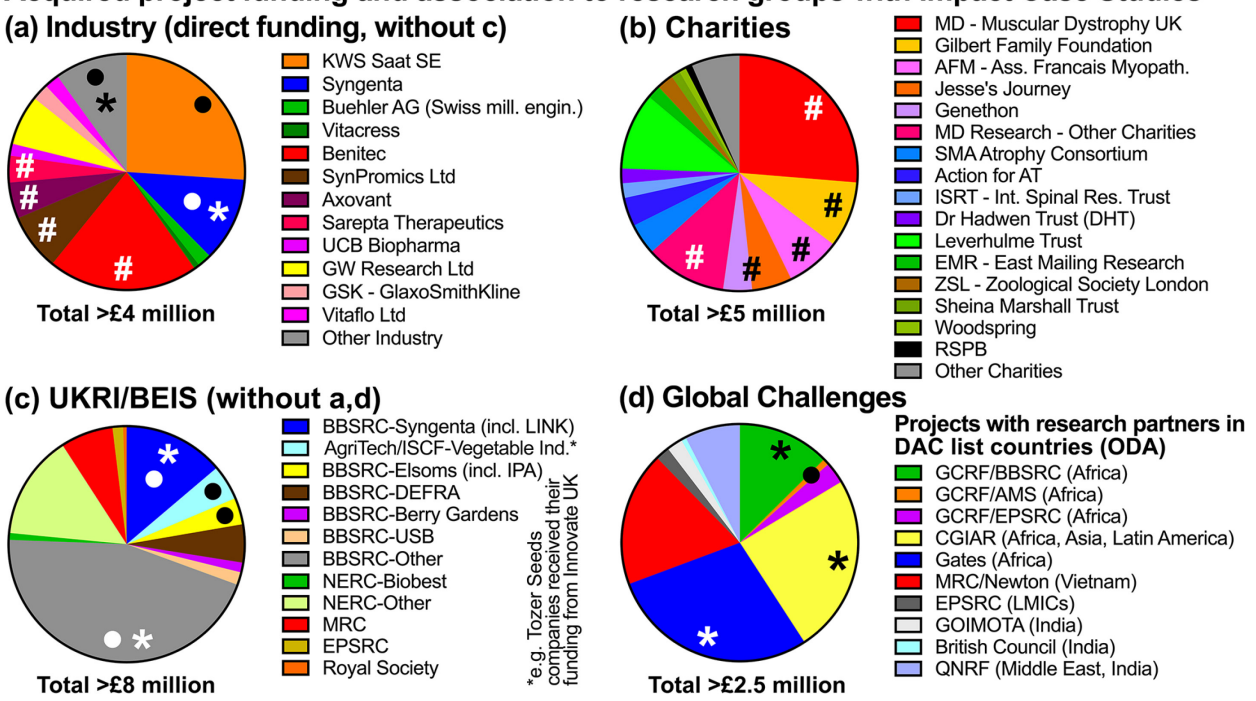

Figure 1: Research Income, by value of award and funder, including the association with Impact Case Studies.

1.2. Research Objectives

Advancing on our REF 2014 strategic priorities, we consolidated areas of strength in gene and cell therapy, plant and crop resilience and pollination biology. We also made significant investment in new appointments (12 staff of which 7 were category A staff appointed in this REF period and 5 teaching-focussed), research infrastructure (£2.1M investment by the College), and introduced research support mechanisms designed to enhance our ability to deliver research engagement, impact, including the launch in 2018 of a Centre for Gene and Cell Therapy.

Since 2014, we have enhanced our commitment to agenda-setting research by establishing the following objectives:

- To conduct and disseminate research that is of the highest quality and is focused on our main themes of food security and sustainability; health, well-being and quality of life; ecosystem functioning and services; environmental change; and systems and integrative biology.
- To ensure that our research is publicly engaged, impactful and committed to knowledge-exchange through open access research.
- To encourage further cross-disciplinary and inter-disciplinary research reach in cognate disciplines in the School of Life Sciences and Environment, and the School of Engineering, Physics and Mathematics.
- To seek out industrial funding and an array of collaborative partnerships which consolidate our fundamental research strengths in biological sciences.
- To review and update our research group structure if it merited innovation.
- To achieve all of these objectives in a research environment that is equal, inclusive and supportive.

We delivered on our objectives by developing and implementing an ambitious plan of action:

(i) We grew the department through strategic appointments in our research themes in biomedical, molecular and ecological research.
(ii) We increased our grant funding, patent generation and impact-related activities.
(iii) We built on our tripartite research structure by establishing in 2018 a new **Centre for Cell and Gene Therapy** (led by Yanez) and an **Institute for Cardiovascular Research** (led by Sharma). This responded to emerging areas of research and impact strength in advanced therapies (see impact case study by Popplewell).
(iv) We supported cross- and interdisciplinary research by building new bridges across the College with groups within Psychology, Earth and Computer Science, including the Centre for Systems and Synthetic Biology, as well as with Drama, Theatre and Dance, Management and Economics.
(v) We asserted and implemented the values of inclusivity, equality and diversity in our environment, as well responding proactively to the open access agenda in our research management and research outputs.

The College's strategy for Open Research (*REF5a*) is supported by the unit in that almost all of our REF-submitted output (including the supportive publications of the impact case studies), and ~75% of our overall output, is published Open Access in peer-reviewed journals. Reproducibility is further supported by making the raw data of publications available via public repositories (confirmed by data availability statements in the journal articles).

Research Objectives 2021-2026

First, we will continue *to expand our capacity and expertise in public health and disease treatment*. The establishment of Centre for Cell and Gene Therapy (2018) acknowledges our sustained record of industrial collaboration and academic funding partnerships involving Duchenne Muscular Dystrophy and the UK Spinal Muscular Atrophy Research Consortium (£1.3M RI). We appointed a category A staff member (Popplewell), with financial support from Muscular Dystrophy UK in this area.

For gene therapy related research, 6 patents and £4.7M research income were secured in this REF period, with contributions from industrial partners such as UCB, Benitec, SynPromics, Sarepta Therapeutics as well as one impact case study on therapies for muscular dystrophy (Popplewell/Dickson). This work has been further underpinned by research funding for vaccine development using therapeutic techniques (Cutting, MRC, BBSRC, EU and general UK-COVID funding, RI £2.8M) and neuro-pharmacological research into improving the treatment of drug-resistant epilepsy through both novel drug and dietary treatments (Williams, £0.6M).

Second, we embed further our *strategic appointments* policy which is designed to strengthen our competencies in gene therapies (Popplewell), metabolomics application to health (Snowden), neurobiology (Augustin), ecophysiology (Portugal), conservation biology and human impacts (Papworth), and evolutionary biology (Riesch). A joint appointment in 2018 with Ashford and St Peters Hospitals Trust (Sharma) enabled the establishment of the Institute of Cardiovascular Research with links to these hospitals.

Third, we will continue to pursue a *research income strategy* to enable a step-change in areas of potential research and infrastructural-driven growth such as pollination ecology. An ERC Starting Grant (€1.4M Leadbeater) and the €9M PoshBee EU consortium project involving 43 academic and non-academic partners (consortium led by Brown) enabled investment in new laboratories to investigate insect cognition and behaviour studies in controlled environments. Repeated external grant income capture also led to the refurbishment and expansion of a seed science laboratory, a new glasshouse facility (2017, ca £1M), and an upgrade of the mass spectrometry suite (2019, £1.2M).

Fourth, we will embed further our *impact-related activities* in our work with industrial partners, especially in the field of industrial biotechnology, seed technology and bio-refining. Major companies such as Syngenta, KWS SAAT SE, Unilever, UCB, Burpee, MRM Health, Tozer Seeds, Elsoms Seeds and Vitacress collaborated with academics in our unit, resulting in funding

(Fraser >£2.9M; Leubner/Steinbrecher >£2.3M) and biorefining as well as pharmaceutical applications leading to industrial funding from biopharma (UCB, Devoto and Popplewell; GW Pharmaceuticals, Neem Biotech and Vitaflo, Williams). The engagement with industrial partners combined with global challenges funding enabled impact in this REF period (see impact case studies) as depicted in *Figure 1*.

Finally, our *working partnerships with regional research-led charities and organizations,* such as the Royal Horticultural Society (RHS Wisley), Royal Botanic Gardens Kew (RBG Kew), Rothamsted and CABI remain a priority for this unit. Increasing PhD collaborative studentships and enabling access to specialist facilities including Kew's Millennium Seed Bank, the Jodrell Laboratory in Richmond and Kew Spatial Analysis and Data Science team for our staff and students were our two main objectives. This ability to network with colleagues and their specialist institutes across London and the South East has been instrumental to cross-departmental impact generation and wider scholarly and public engagement.

1.3 Supporting Interdisciplinary Research

Interdisciplinarity is inherent in the work of the unit. Our approach is informed by a series of commitments. First, our work with collaborative partners and stakeholders in academia, research organizations (e.g. CABI, NHS, RBG Kew) and industry (e.g. KWS, Sarepta Therapeutics, Syngenta) are founded on an interdisciplinary and cross-disciplinary approach to knowledge-creation and generation. Our impact case studies bear evidence to this. Second, we have actively sought collaboration with engineers and social scientists (e.g. political scientists and biomechanical engineering at Royal Holloway) and this led to new funding success via GCRF and led to the establishment of our Global Challenges Networks in sub-Saharan Africa. Colleagues secured >£2.5M funding from GCRF, CGIAR, Gates and Newton foundation for collaborations with partners in ODA countries between 2017-2020 (*Figure 1*)**.** Interdisciplinary work with colleagues from Psychology led to the analysis of over 200 million Tweets as part of a project exploring how users change language habits depending on their community membership (2015). It also led to new social media search algorithm and a spin out company “GroupSeer” through joint investment with Parity Group PLC. Third, large grant success such as ERC starter award to Leadbeater (2016-2021) led to the integration of research methods from the social sciences into analysis of bee social networks. Finally, PhD studentship projects funded by the BBSRC and NERC Doctoral (DTP) and Collaborative (CTP) Training Partnerships that we are members of (*The London* NERC DTP, *The Imperial College London-Royal Holloway* BBSRC DTP, the *London Interdisciplinary Doctoral Programme* BBSRC DTP and iCASE partnerships funded directly by industry and CTPs are being actively used to promote and encourage cross and inter-disciplinary research. As a result of the inherently interdisciplinary DTPs and the studentships pledged to them, more than half of our PGRs conduct cross and inter-disciplinary research. They are supported by formal training, which addresses the generation of impact and knowledge exchange across the life and environmental sciences.

Following the establishment of the School of Life Sciences and Environment in 2019, our departmental Research Lead and Director of Impact have been instrumental in expanding existing inter-disciplinary research, including working with colleagues in Geography, Earth Science and other departments to expand the Royal Holloway-Kew collaboration in the field of plant humanities, food security and sustainable agri-technologies. Second, we have consolidated our links with Psychology through joint funded projects that address ageing, health and wellbeing, from the molecular to the functional and the psychological perspectives. Third, we are working with Geography and Earth Sciences to generate an integrated understanding of the impact of climate change on people, communities and ecosystems as well as addressing how attitudes and behaviours can change in those environmental contexts.

The launch of a new college catalyst for research and knowledge exchange, Living Sustainably, in spring 2021 offers further opportunities to develop cross-cutting research in the life and environmental sciences. It will build on our School’s record of success with GCRF funding and bring that into contact with our record of industrial and commercial funding in areas such as threats to biodiversity, food security, infectious disease, and health and well-being.

1.4 Approaches for Enabling Impact

Our approach to enabling impact involved three fundamental steps. First, we have made a concerted effort to raise awareness of impact and public engagement across the department. We appointed a Director of Impact (Gange) in 2015, and held a series of impact-related networking events for staff and PhD students. Second, colleagues involved with impact case studies were provided with relevant training and support through the university Research and Innovation Department (which was reorganised and strengthened further under the Integrated Academic Strategy 2017-2020). Finally, we have developed a longer-term departmental strategy for enabling impact. The Director of Impact in collaboration with the research centre and institute directors works closely with School Director of External Engagement and the College's Vice Principal for Research Impact and Interdisciplinarity. Department- and School-wide meetings are used to raise awareness of impact and this is complemented by discipline-specific training at unit level.

The Department has supported areas of impact excellence by initiating and supporting a range of activities that facilitate two-way interactions between researchers and stakeholders, such as stakeholders from the sports turf industry, horticultural industry (e.g. herb producers, RHS Wisley, RBG Kew) and industrial partners. Areas of impact excellence are also showcased at Department and School level via the Royal Holloway website and dedicated social media (@RHULBioSci and Facebook). The Director of Impact works with academic staff to ensure that relevant training resources/networking opportunities within College are available. Our aim is to encourage all colleagues, but particularly early and mid-career colleagues, to be the next generation to build a portfolio of research with high-level impact. Potential areas where future impact and knowledge exchange that support the bioeconomy and planetary health include microplastic pollution, the effects of pesticides on pollinators, novel agri-technologies for weed management, and the treatment of epilepsy through dietary additions.

Research governance is overseen by the School (*Research and Knowledge Exchange Strategy*) with strategy 'owned' by departments. It provides training and access to the UKRI/RCUK *Policy and Guidelines on the Governance of Good Research Conduct* and the revised 2019 *Universities UK Concordat to Support Research Integrity*. Any research requiring ethical approval is scrutinised by the institutional Ethics Committee. All staff are expected to aspire to the highest standards of excellence, integrity, ethical behaviour, transparency, rigour and reproducibility in conducting research. Colleagues liaise with learned societies and hold regular workshops on ethics, impact and due diligence.

1.5 Research and Impact Strategy 2021-2026

Respectful of the academic diversity of the unit, our research and impact strategy is informed by a commitment to nurture research partnerships, promote and support impact, and support both investigator- and challenge-led research. Our research centres will continue to adapt to evolving research interests and collaborations.

Our specific objectives for post-2021 are:

1. *Investing in our facilities and advancing our capabilities.* To invest in our laboratories, core facilities, diversity in technology platforms and bioscience expertise to perform internationally competitive research and innovation. Through the Living Sustainably Catalyst, and supported by investment in a new breeding facility, we will explore multi-disciplinary cross-cutting technologies and contributing to interdisciplinary projects on the relationship between the food security, the environment, health and well-being.
2. *Enhancing policy-relevant research by engaging with external communities*. Investment in pollination ecology, evolutionary biology and habitat conservation has led to high-impact ecological research with further potential to inform UK and global conservation and ecological services agendas. Upgraded facilities in biochemistry, biomechanics, and plant biotechnology platforms will enable closer co-operation with affected communities in areas such food supply chains, food security and seed systems in Africa and South America.
3. *Cross-disciplinary research in Metabolomics and Neurobiology*. New techniques for gene therapy of genetically inherited diseases such as Duchenne Muscular Dystrophy is the

topic of one impact case study (Popplewell). Other impactful research is into improving the treatment of drug-resistant epilepsy (Williams), stroke (Sharma), the microbiome to develop novel vaccines (Cutting). We aim to identify further synergies with psychology through neuroscience research also through the recent appointment of an academic staff member in Neuroscience using *Drosophila* as a model system for research on ageing (Augustin), and a new staff member to advance the research into metabolomics applied to health (Snowden) using the investment in capital equipment in this area.

4. *Interdisciplinary Research Networks.* To expand and sustain our local, national and international networks and interdisciplinary collaborations that address the global challenges associated with the UN sustainable development goals. This will be delivered by working with our local partners (Kew, CABI, RHS) and excellent networks in ODA countries. For example: Cutting is leading an MRC-funded collaboration project (2020-23) with Vietnamese institutions into the control of *Heliobacter pylori* infections; Sharma established and maintains a DNA repository of stroke patients with partners in India, Qatar and Sri Lanka.

2. People

Our Department has grown since 2014 and now has 34 academic staff (23 men, 11 women). Together with ~50 postdoctoral research staff (31 women, 61%), 20 technicians (9 women, 45%), ~100 PhD students of which 57% are women and 27% BAME men and women (*Figure 2*), together representing >22 nationalities. 85% of our academic staff are Category A; others have chosen teaching-focused contracts. Our approach to our staff and students aligns with college's strategy of inclusiveness as noted in the REF5a statement. Our structures support the career progression and development of our staff and research students. In this REF period, we supported ~50 postdoctoral researchers, ~110 PhD and ~140 MSc students (61% women, >22 nationalities). Notably, we have seen promotions and research leadership in our female category A staff who started as ECRs. Popplewell was appointed as lecturer on a Muscular Dystrophy UK fellowship, promoted to reader in 2020. She leads the Translational Genetic Medicine Laboratory, and manages a team of 11 researchers who develop genetic medicines in connection with pharmaceutical industry. Leadbeater (joined the department in 2014 as a Leverhulme Early Career Fellow) was promoted to senior lecturer in 2015, reader in 2016 and professor in 2019. She leads the Insect Cognition lab with 7 PhD and post-doctoral researchers.

2.1 Staffing Strategy and Staff Development

During this REF period, we appointed 12 new staff (8 men, 4 women). The 7 category A staff were appointed in research priority areas including biomedical sciences (Augustin, Popplewell, Sharma, Snowden) and organismal biology (Papworth, Portugal, Riesch). The appointment of Popplewell to a permanent position was made possible with financial support of Muscular Dystrophy UK and served to ensure the succession of our research in advance therapies after the retirement of Dickson. We hosted a Leverhulme Early Career Fellow (Grinsted, 2017-2020) who has now taken up a permanent position as a senior lecturer at another HEI.

Staff career development strategy:
Our approach to staff development has been informed by a series of commitments to understanding the research, research impact needs of our staff, and their ambitions for future research plans. We use research plans, workload model transparency and professional staff training.

Research plans:
The research of staff is reviewed in the annual development review, in which work objectives, including research and teaching, are set for the following academic year. Training and career development needs are identified at these appraisals and longer-term career goals are set. All staff receive feedback on their research plans.

Workload model:
Workload allocation takes personal circumstances (e.g., return from parental leave and exceptional caring responsibilities); and substantial impact-related and research funding activities into account.

EDI and other professional staff training:
The unit is fully committed to EDI training. In 2017, every member of academic staff attended a training session on 'Unconscious Bias'. A key part of the staff development programme is 'Advance' (previously 'On Track') training programme for researchers which is key to our commitment to the Concordat for the Career Development of Researchers (Concordat). The 'Advance' programme offers c.15 workshops per year devised to enhance skills such as grant writing, working with the media, and project management. These workshops are complemented by more focused department-level training as appropriate (e.g., sessions on research impact, industrial partnerships). All our ECR staff participated in the Advance programme.

Staffing and recruitment policies:
Our strategy was informed by the following commitments: first, recruit researchers with disciplinary expertise, experience of stakeholder relationships and ambition to initiate projects that had interdisciplinary and cross-disciplinary potential. Second, to make strategic appointments that added value to our established research centres and areas of excellence in areas such as food security and sustainability; ecosystem dynamics and environmental change; and health and well-being. Third, we want to foster new research opportunities with cognate disciplines such as psychology, in neuroscience and health. We also made a number of teaching-focused appointments (Hanna, Lucchesi, Thomas) to ensure that our research and teaching portfolios aligned with one another. Finally, we ensure that all our staff, current and newly appointed, are inducted into our working environment and offered training conducive to EDI priorities. For example, all our new staff have been offered appropriate departmental and college-organised training in areas such as unconscious bias, research ethics and data protection. During this REF period our staff attended in excess of 120 College organised training courses.

The unit organises regular staff and research student surveys, which are designed to better understand any concerns about issues such as career development, flexible working, experience of maternity leave, and return to work.

Supporting Early Career Staff:
Upon recruitment new academic staff are typically given a 3-year probationary period, with probationary conditions including evidence of research output generation and grant funding activity. A probationary advisor is appointed, who will assist and mentor the new staff member, and progress is reviewed yearly. After successfully completing the probationary period positions are tenured. New academic staff is provided with laboratory and office space, and they receive a start-up package (typically in the order of £10-60k depending on their research needs, which includes purchasing new equipment) as well as matched funding for major equipment on research grants. New staff have a reduced teaching and administrative load, and a plan is drawn up at the time of appointment to increase teaching loads from a minimal load to the departmental average after probation. Every member of staff is offered a comprehensive staff induction at departmental and institutional levels. Our research centres are integral to the research environment and offer a wide range of seminars, annual lectures, postgraduate networking events and employability sessions. Since 2019, our departmental research seminars are followed up by the informal 'meet the speaker' sessions which provide our early career researchers (postdocs and PGR students) with opportunities for networking and getting career advice.

Policies for Research, impact leave/sabbatical leave:
Our sabbatical policy is based on the norm of one term for every nine or ten terms served. During this REF period, 18 staff were awarded at least one sabbatical (one full teaching term

in duration). During sabbatical, several staff were awarded fellowships and awards and/or appointed as visiting scientists at prestigious research institutes in the UK or overseas, e.g Bogre has a continuous connection with the Semmelweis University, Budapest (received honorary doctorate 2016); Devoto with the John Innes Centre and the Center for Sustainable Resource Science, RIKEN Japan (JSPS award, 2016) and The University of L'Aquila, Italy, (visiting professor 2020). Leubner was appointed visiting professor at the University of Olomouc, Czech Republic (2013-2020).

Recognition and Reward: Academic and professorial staff promotion criteria actively reward excellence in research, external engagements and impact-related activities. We have an excellent record of retaining and promoting our staff: Leadbeater (originally a Leverhulme ECR fellow) was promoted rapidly to Reader in 2016 and to Professor in 2019. Popplewell, appointed as lecturer on a fellowship in 2015, promoted to Reader in 2020. Devoto was promoted to reader in 2015 and professor in 2018. Overall, in this REF period, there were 23 promotions. The Women in Biology initiative that we launched in 2018 (see Equality & Diversity) to promote personal and professional development of female staff, particularly ECRs, through combination of activities including workshops and one-to-one mentoring, contributed to the process. Our long-serving senior staff remain integral to research centre development over the last 10-15 years, as well as research support.

Our promotions review group invites all colleagues to submit their CVs every year and offers recommendations on the basis of the College's promotional criteria. There has been an overhaul in the promotion criteria in 2016 and 2019, which has improved equity, parity and fairness. During this REF period, 26 promotions applications were made by academic staff members (15 by men and 11 by women) academic staff members. We achieved in this REF period a step-change in equity in promotion chances and success for women. Of all promotions during this REF period 9 were to men and 9 were to women. The latter included 2 promotions to professor, 3 to reader and 4 to senior lecturer. The College has recognition and reward policy to recognise exceptional performance by awarding financial rewards or extra salary increments.

2.2 Research Students

During this assessment period, we supported ~100 PhD (degrees awarded) and an increasing number of MSc by Research students: these numbers are up about 2-fold (compared to REF2014 (*Figure 2*). The postgraduates by research (PGR) are from ~30 different countries and 57% are female, which compares well to the sector average in Biological Sciences; 27% are of BAME background which is above average.

PhD student recruitment for College funded studentships involves advertising via 'FindAPhD' website and interviews of the top candidates. In 2019 we have joined the London Interdisciplinary Doctoral Programme (LIDo) Biosciences Consortium which is the largest BBSRC funded DTP in the UK. LIDo operates a strict equal opportunities policy and monitors the selection process to ensure that the selection process does not discriminate directly or indirectly. The Programme also offers a range of support to students from local universities, including funded summer placements in research laboratories. The scheme has driven an increase in applications from Black and Minority Ethnic students for fully-funded PhD studentships in the Programme. LIDo has been held up by UKRI as an example of good practice and the piloting of innovative solutions in the context of widening participation.

Our PhD students are immersed in a supportive working environment. Most research training takes place in the supervisor's laboratory and via supervisory team meetings. All students are required to present their research in poster displays and through oral presentations in a formal internal setting twice each year during their PhD study. Our students participate in generic and specific skill-building sessions provided across our BBSRC/NERC Doctoral Training Programmes. We monitor closely postgraduate provision and our departmental research committee using data from the Postgraduate Research Experience Survey. Each student is given access to all of the equipment and laboratory space required for their project.

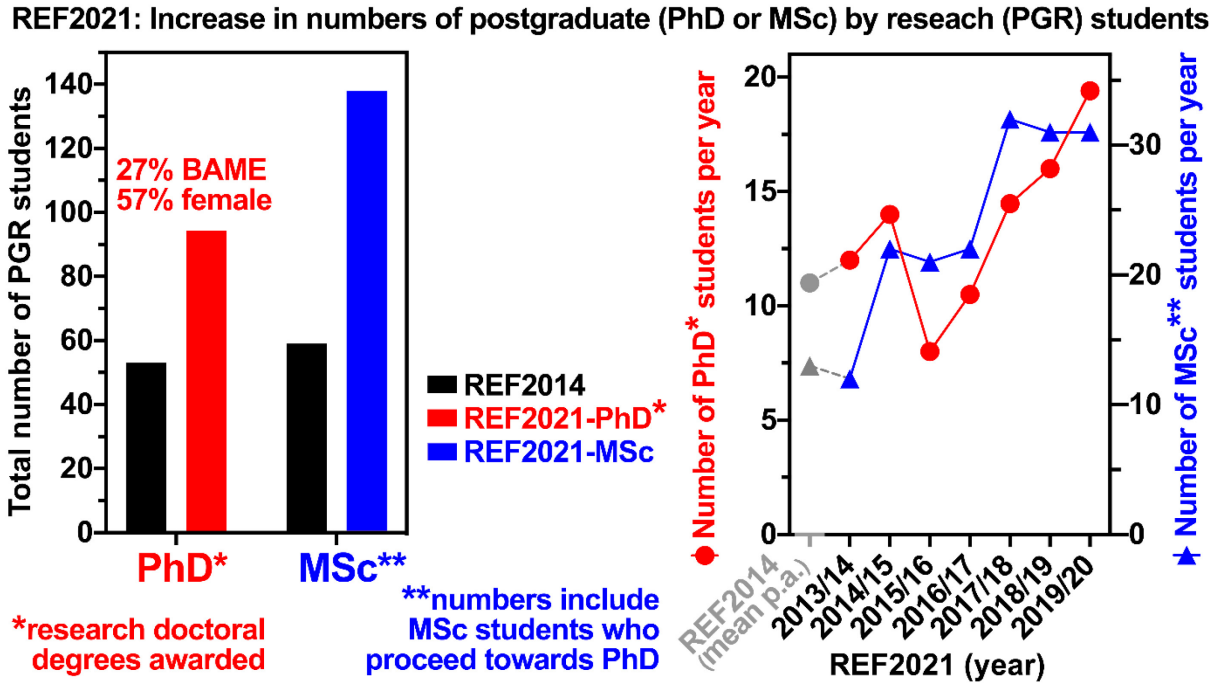

Figure 2: Postgraduate student numbers compared to REF2014.

Our students are encouraged to seek out teaching opportunities and many participate in the College-run Programme in Skills of Teaching to Inspire Learning (INSTILL, HEA-approved qualification).

As part of our training support, we organise an annual postgraduate symposium with talks and posters, prizes, invited speakers and a departmental social event. Examples for invited speaker in 2019 include Nobel Prize talks by Sir Paul Nurse (Physiology or Medicine 2001) and Sir Gregory Paul Winter (Chemistry 2018). Each year, our postgraduates are prompted to seek external sponsorship for the event and attracting trade exhibitors to a small exhibition. Any financial surplus generated each year is used to provide financial assistance to our finishing PhD students.

Our completion rate for PhD students is in excess of 82% within four years equivalent.
The outstanding work our PhD students produce has been recognised by way of publication in prestigious academic journals (e.g Siviter et al. *Nature* 2018), prizes, visiting scholarships/fellowships (e.g. Ahmad's JSPS scholarship for research in Japan) and commercial/industrial placements. In this REF period, our PhD students published approximately 200 outputs and over 30% of our REF2 outputs include (former) research students.

Finally, we are committed to supporting the health and well-being of our students. We have robust procedures in place to support our students in terms of interruption of studies, maternity and paternity leave, placement support, and/or special educational needs. Our PGR and departmental research leads ensure that students and supervisors are aware of any mental health-related support that is available at college level.

2.3 Equality and Diversity
We are committed to the principles of equality and diversity amongst our staff and students. Our unit was awarded an Athena Swan Bronze in 2014 (renewed 2018) by the Athena Swan Gender Charter. The activities carried out within the remit of Athena Swan have improved awareness towards several policies and their implementation (e.g. flexible working, promotions, recruitment, childcare support) and above all led to increased transparency and inclusivity. The progress made towards the elimination of unconscious bias towards women, early careers researchers and those with equality-related circumstances has had positive impact in recruiting, career

progression and promotion. The number of women academics in the Department has increased with more women in senior leadership roles, contributing to narrowing the gender gap. This has been achieved also through open advertisement of all positions. Increasing the number of female colleagues at senior levels, alongside addressing the pipeline from 'researchers to academics' and increasing female academic applicants remains a priority. Actions to address these include targeted mentoring schemes and highlighting examples of good practice in job adverts.

In 2018 we launched the Women in Biology initiative as part of our commitment to improve further our support for female staff and students. The initiative, that included training in mentoring, career workshops and a wide range of seminars to widen participation to all staff and students of all gender categories acted as a beacon for the entire School and was expanded as the Women-in-Science initiative with an increased ring-fenced budget (c. £3k) which is coordinated by staff from our unit (Koricheva/Devoto).

As part of the recent activities of the Women-in-Science scheme, the SPRINT personal and professional development programme, initially adopted only by the Department of Biological Sciences in 2017 for female UG and PG students, has been extended at School Level for PG students. The unit also led activities at School level such as the media training for women academics and research staff. These activities received extremely positive feedback boosting the students' and staff experience and providing complementary skills for future employability.

Our unit also has driven the establishment, at School-level of an ECR working group in 2019, to provide networking opportunities for career progression. For REF 2021, all staff involved in reviewing research outputs underwent mandatory training on unconscious bias, and equality and diversity data was provided to REF leads, and departmental research leads to be examined and included in the assessment. We follow Royal Holloway's code of practice for REF 2021, and work with staff to identify relevant special circumstances to ensure wide participation.

3. Income, Infrastructure and Facilities

Our funding strategy builds on our commitment in REF2014 to improve grant capture and diversify our funding sources (*Figure 1*). We have been successful on both counts. First, in this REF period we secured ~£22M total research income (this figure excludes PhD studentship funding, several of which generated by iCASE directly funded by Industry DTPs). We have almost doubled our research income success from industry and charities (*Figure 1).* Second, we diversified our funding portfolio by securing a mixture of investigator and challenge-led activities. The >£8M comes from UKRI/RCUK/BEIS (including ISCF/AgriTech/Innovate UK), 76% of this total was from BBSRC (*Figure 1*). In addition, we obtained ~£5.2M in grants from EU government bodies and ~£1.2M grant funds from an array of overseas and UK governmental and non-governmental organisations. Funding (>£2.5M) for Global Challenges projects with partners in ODA countries (REF2021) is new compared to REF2014 (*Figure 1*). Third, we secured highly competitive and prestigious awards, including large consortium projects (which funded additional investment in facilities, output generation, impact and knowledge exchange activities).

3.1 Strategies for Generating Research Income and Facilities

Our planned step-change in research income capture involved a series of planned interventions. First, to work closely with the Research and Innovation (R&I) Department who administer the College's *Research Strategy Fund* and encourage our staff to seek pump-priming financial support for innovative projects. The Department contributes a minimum of 25% to each project and during the assessment period, 95% of applications by staff in the School have been successful, 9 projects were awarded to category A members of staff in this REF period. RSF-funded projects have been essential in supporting our early career staff and colleagues wishing to engage in new, high-risk projects.

Second, work closely with R&I to enhance and diversify sources of research and contract income from grants, consultancy, licensing, research sponsorship to spinouts, identifying new funders,

approaching specialised sources of funding, building a research consortium, calculating the costs of the project and the price for the work as well as dealing with industrial funders and partners. R&I also negotiate contractual terms and agreements, assist in seeking finance for commercial projects, arrange input from specialist consultants, if necessary, and arrange for intellectual property protection where appropriate. R&I assist with all aspects of pre- and post-award finances and research governance.

Third, to encourage staff to bid for research consortia; challenge-led funding involving UK and global partners; and finally, seek industrial funding designed to tackle areas of commercial and public health priority.

Addressing Equality and Diversity:
Over the REF period, the unit submitted over 360 grant funding applications with a total value of £97M. Of these 77% were submitted by men as PI and 23% by women as PI. The funding success is in-line with the applications with 77% of the grants awarded to men and 23% to women.

3.2 Organisational Infrastructure
Our unit is organised around three well-established research centres with a model of research leadership designed to support staff and PhD students secure funding for projects. There have been notable large-scale successes for each of our research centres (for consortia total award value is given):

Centre for Ecology, Evolution and Behaviour
- €9M PoshBee EC consortium led by Brown (2018)
- £1M ERC project starting grant led by Leadbeater (2016)

Centre for Plant Molecular Sciences
- €9M DISCO EC, £3.6M ERA-IB PROCAR consortia fruit quality research with Syngenta led by Fraser (2013-17)
- £1M GCRF NUTRIFOOD consortium with the International Institute of Tropical Agriculture and World Vegetable Centre led by Fraser, awarded in 2020.
- €2M ERA-CAPS consortium SeedAdapt led by Leubner, awarded in 2014.
- £2.3M, including two AgriTech/ISCF/Innovate UK projects and >£1M direct funding from the company KWS for several projects led by Leubner and Steinbrecher awarded in 2013-20.

Centre for Biomedical Sciences
- €7.5M EC consortium CDVAX, and £1.3M MRC/BBSRC-funded projects led by Cutting and awarded in 2020.
- £3.3M by Cutting and others involving partners in developing countries around global health challenges.
- £4.7M from charities and industry projects led by Popplewell and Dickson around advanced therapies for muscular dystrophy.

Research Income for the unit was complemented further by >£240k for consultancy by 7 staff (Brown, Cutting, Fraser, Leubner, Steinbrecher, Dickson, Williams) for Natural England, Johnson & Johnson, DEFRA, and KWS. This contributed to strengthening our links with industrial, government, and charity partners as well as providing opportunities for staff and research student development. A notable development in this REF period has been *in-kind contributions and benefits* from companies, organisations and research institute partners equivalent to >£1.5M (value includes income-in-kind), in the form of field trials space, matched or fully funded PhD studentships, soil food web analyses and plant growth facilities, high-throughput genome and transcriptome analyses, oligonucleotides and testing of novel pharmaceuticals by the US Government-funded Office of Translational Research. Examples for this include US Government epilepsy therapy drug screening (Williams), RNAseq and bioinformatic costs (Kunming Institute China, Syngenta USA, KWS Germany) for plant transcriptomes (Devlin, Leubner), growth and development of plant breeding populations by MRM Health and Syngenta (Fraser), SRXTM 3D Imaging of seeds at the Paul Scherrer Institute in Switzerland (Steinbrecher), high throughput live

cell imaging and high-throughput sequencing (Devoto) and matched PhD studentships with the RSPB and ZSL (Papworth).

3.3 Operational and Scholarly Infrastructures

Biological Sciences at Royal Holloway focused its investment in operational infrastructure and facilities designed to enhance our research strengths. In the unit there are 20 technical staff, led by a technical operations manager and 3 administrative research support staff for our research environment. Large research groups have institutionally funded technician posts. Our technical staff include active researchers contributing to the unit's outputs. The unit possesses state-of-the-art facilities for molecular biology, biochemical analytics and imaging/microscopy which are maintained by institutionally funded technician posts providing training and research support. Their use is associated with operational costs which come from the grants and scholarships that we are awarded. During this REF period, major investments included the new glasshouse (ca. £1M) providing state-of-the-art control of plant growth, the upgrading of the mass spectrometry suite (ca. £1.2M) for metabolomics and proteomics, dedicated pollinator laboratories, the refurbished aquarium facility and seed science laboratory, and we upgraded our autoclave facilities. This was underpinned by a commitment to "environment, food and sustainability" as a strategic priority area for the School. The latter was further supported by investment by College into new glasshouses (£1M), the refurbishment of the seed science laboratory, and the expansion of biomechanics facilities.

Alongside investment in departmental infrastructure and facilities, the College invested in large capital investments (£57M) to provide a new purpose-built state-of-the-art library in the Emily Wilding Davison building and the new Beatrice Shilling building (£18M investment, opened 2018) accommodating the Electronic Engineering department. Our IT infrastructure has been overhauled within the assessment period with investment in the staff intranet and professional research services such as Dropbox for Business support our research projects and impact activities (see REF5a).

3.4 Impact Activities: Linking Income, Infrastructure, Partners and Facilities

Research income growth helped us to develop our impact further for this REF period. Funded projects by Fraser, Leubner and Steinbrecher underpinned two impact case studies**:** "Industrial, educational, and scientific beneficiaries of novel carotenoid technologies" (Fraser), and "Improving crop seed quality through environmentally sustainable technologies to benefit the seed industry and promote food security" (Leubner/Steinbrecher). The impact achieved was commercial, environmental and humanitarian, with industrial partners investing in improved technologies in order to generate environmental-friendly solutions designed to secure resilience in food chains. Repeated project funding from UKRI/BBSRC, ISCF/AgriTech, GCRF, CGIAR, Gates, and the doubling of direct funding from industry enabled the underpinning research (*Figure 1*). The funded projects by Popplewell led to the third impact case study, "Transforming therapeutic outcomes of fatal Duchenne Muscular Dystrophy with genetic medicines" and was based on funded projects from industry and charities (*Figure 1*). Further impactful research on human society and health with novel therapeutic techniques was achieved through development of novel vaccines by Cutting, and neuropharmacological research into improving the treatment of drug-resistant epilepsy through both novel drug and dietary treatments by Williams.

Our impact activities also built on our operational and scholarly infrastructures. Firstly, we carefully considered the *impact of our research* by working with applications and stakeholders (as well as end users) at all stages of the research cycle. We recognised that interdisciplinary and multi-party partnerships were integral to future research success and consulted closely with our partners via consultancies and networking. We increased our involvement with industrial collaborators and enhanced our funding by industry partners. Through our partnerships, we created new opportunities such as a fellowship position for Popplewell with Muscular Dystrophy UK. Together with funding from charities and industrial partners such as UCB, Benitec, SynPromics, Sarepta Therapeutics, our collaborative work led to new techniques for gene therapy and treatment of genetically inherited diseases being generated by Popplewell.

Secondly, through direct responses to national and international priorities and initiatives, we developed and won a number of large research contracts over this REF assessment period, e.g. for impactful research into *global challenges* in partnership with ODA countries funding from GCRF, CGIAR, MRC and Bill Gates Foundation and for impactful research into industrial challenges in partnership with companies funding from Innovate UK (Agri-Tech/ISCF - Industrial Strategy Challenge Fund) and directly from industrial partners (e.g. Syngenta, KWS Saat SE) was decisive (*Figure 1*). It led to a step-change in our activity involving ODA countries when compared to REF2014. Together with our CASE studentships (funded by BBSRC, NPIF, industry) this led to significant impact in Food Security and Environmental Change.

Thirdly, we prioritised *interdisciplinary collaborations.* We actively promoted work at the intersection between molecular seed biology and biomechanical/electrical engineering (Leubner/Steinbrecher collaboration with the "gas plasma" engineer partners at Loughborough University), and between molecular plant biology and computer science ("omics" collaborations Fraser, Devoto) or human diseases (cancer and fibrosis, Devoto). Beyond STEM, interdisciplinary collaborations have been established with social scientists including political scientists, geographers and economists and investigators in drama, theatre and dance through the Global Challenge Networks and Newton Fund Institutional Links Grants (e.g. Devoto, Fraser, Gange, Leubner, Steinbrecher) which will be enhanced in the post-REF2021 period, to address further the relationship between food security, ecosystem services and gender equality in projects with ODA countries.

3.5 Future Plans for Infrastructure and Facilities

The future sustainability of the unit is evident from significant investments in infrastructure and facilities during this REF period. This has included significant investment in the college's operational and scholarly infrastructures. In our unit, we developed a 5-year vision for diversity in bioscience research (2018-2023) which is aligned with the School's "Research and Knowledge Exchange Strategy" (2020) and emphasises further the need for interdisciplinary research in food security and sustainability, health and well-being and environmental change. The unit will be involved in the launch and implementation of the Living Sustainably Catalyst from 2021 onwards.

4. Collaboration and Contribution to the Research Base, Economy and Society

Our unit is dedicated to collaboration and to the contribution to wider society and economy, and our research is informed by a commitment to public service and social responsibility, especially to the most vulnerable communities in the world. In order to operationalise that ambition, our unit established collaborations with a diverse array of non-academic stakeholders, including charities, industrial partners, researcher-led communities, and policy makers. These strong reciprocal relationships enable our non-academic partners to contribute to our research and enable us to make targeted academic contributions to the wider economy and society, both nationally and internationally, via knowledge exchange, industrial patents, policy formulation and research practices. Located in South East England, our unit works with local partners such as Kew, Syngenta and CABI to create an ecosystem of regional innovation in the biological sciences.
Our research centres and associated bodies, such as the Institute for Cardiovascular Research, drive forward our collaboration and contributions to the research base, economy and society.

4.1 Research Collaborations and Partnerships

Our research strategy is outward-looking and encouraging of international collaborative ventures and interdisciplinary consortia designed to facilitate the widest possible dissemination and engagement with partners and public policy agendas across Europe and beyond.
Notable achievements in this REF period are our competitively funded international consortia with European partners. In the Horizon 2020-funded project "Pan-European assessment, monitoring, and mitigation of stressors on the health of bees" (PoshBee) led by Royal Holloway (Brown) 43 partner organisations in 14 European countries are conducting policy-relevant research designed to better understand how healthy bee populations, sustainable beekeeping and healthy pollination services across Europe can be realised.

A further example involves a series of EU consortium projects into industrial biotechnology in collaboration with industry which established a next-generation pipeline for the sustainable generation of high-value plant products: DISCO (€9M, lead PI Fraser), ERA-IB PROCAR (£3.6M, lead PI Fraser) and £3.4M fruit quality research with Syngenta led by Fraser. The work of Fraser was supported by grants with 11 postdocs and associated PhD students and led to consultancy, 8 patents and 53 publications in peer-reviewed Open Access journals.

A third example is a €2M ERA-CAPS consortium SeedAdapt (led by Leubner) with seven other EU partner institutions. The consortium's research into the mechanisms and responses of seed and fruit germination to unpredictable environments was conducted by 10 postdocs, several associated PhD students and led to 15 publications, and the establishment of an analysis pipeline for transcriptome data which was used in follow-up applied projects in collaboration with some of the international partners.

Finally, Cutting was led a large EC-funded consortium CDVAX (€7.6mio) involving 5 partners, 4 of whom are SMEs), two MRC-funded projects, and a coronavirus project designed to generate new oral vaccines. International collaboration has been realised by Cutting in an MRC-funded consortium (£460k, awarded in 2019) into "*Helicobacter pylo*ri in Vietnam: Prevalence, AMR and Vaccination" which works directly with Vietnamese partners (Nha Trang University, Institute of Vaccines, and the SME Biopharco). In Asia, and Vietnam in particular, *H. pylo*ri infection is widespread with over 70% of people carrying the bacterium. This UK-Vietnam initiative led by our unit used a novel method for oral vaccination which has been shown to be highly effective in reducing the human cost of intestinal diseases.

4.2 Relationships with Research Users, Beneficiaries and Audiences

Our relationships with academic and non-academic beneficiaries are informed by our impact strategy and impact development for this REF period. Working with our Director of Impact, we have sought to embed further three types of relationships with our beneficiaries and users. First, we work closely with our academic and non-academic partners in producing public-facing work that informs professional and policy practice. Morritt's work on microplastics involved close collaboration with Natural History Museum and the Zoological Society of London. His work has quantified the amount of submerged plastic items in the river Thames (e.g Marine Pollution Bulletin 2014). These findings have informed the debate about single usage plastic items, in particular about the environmental damage that so called "unflushables" (wet wipes, nappies etc.) cause to our river systems and waterways. Working with Natural England, Brown has advised on bumble bee reintroduction policies for the UK. Research in the unit has also contributed towards better understanding of causes of pollinator decline, including the importance of diseases (*Nature* 2014) and the sublethal effect of neonicotinoid pesticide thiomethoxam (*Nature Ecology and Evolution*, 2017) and the pesticide sulfoxaflor (e.g. *Nature* 2018). This has informed and influenced the debate on the use of pesticides and its impact on pollinators. Second, our unit's work has involved specialist advice to industrial partners on drug and vaccine development as well as food or seed-related technologies. Cutting advised for Johnson and Johnson as well as SporeGen. Leubner and Steinbrecher advised the international seed producing company KWS. Finally, knowledge exchange was promoted by organizing and hosting research networks, public engagement events and seminar series that actively draw in professional stakeholders in civil society, UK government departments and professional organizations (contribution to economy and society).

A step-change for the unit in this REF period has been our work with the global South and ODA countries. Working with Ethiopian and West African partners, two GCRF-funded grants - Food Systems Grant NUTRIFOOD (Fraser, £991k) and a Networking Grant with Ethiopian partners - enabled a new knowledge exchange partnership to develop in the area of seed technology and food chain resilience of the cereal staple crop teff (Leubner, £22k). Other projects funded by the Gates foundation, CGIAR and World Bank (Fraser, £1.4M) address biotic stresses and bio-fortification of staple food in Africa and South America working with local partners such as the International Institute of Tropical Agriculture in Ibadan, Nigeria. The GCRF funded NUTRIFOOD project (£1M in collaboration with the International Institute of Tropical Agriculture, World Vegetable Center and International Center for Tropical Agriculture) aims to improve nutritional

properties of food systems in Western Africa. We have established and reinforced knowledge exchange and public engagement strategies also in Vietnam (Cutting), Japan (Center for Sustainable Resource Science (RIKEN) and Indonesia (Devoto) and India/Qatar (Sharma).

4.3 Contribution to the Economy and Society

Biological Sciences at Royal Holloway has strong and long-standing links with a number of UK and overseas companies in the plant and seed, health and well-being and pharmaceutical sectors. Our partnerships involve new health-related products being generated (e.g. Williams with Neem Biotech and Vitaflo Ltd; Devoto with UCB); seed improvement (e.g. Leubner/Steinbrecher with KWS); sustainable agriculture (Gange with Plant Works Ltd, Everris International, ICL, Bulrush Plc); ecosystem management (Brown with Berry Gardens and Biobest) and the pharmaceutical companies Sarepta and Synpromics. Patents generated by the unit have been licensed to the pharmaceutical company Sarepta Therapeutics Inc. and have resulted in two commercially available drugs for treatment of Duchenne muscular dystrophy. Following the approval of ExonDys-51 in 2016 and VyonDys-53 in 2019, sales have exceeded $800M.

4.4.Contribution to the Sustainability of the Discipline and Research Base

The unit contribution to the sustainability of biological sciences is evidenced through its research collaborations and partnerships alongside wider contribution to the research base. One notable shift in the unit's performance in this REF period has been public engagement – ensuring that our research achievements including those of our PhD students, are promoted to the widest audiences (e.g. Cooper in *Nature* on fieldwork in COVID era, Dissayaneke and McEvoy in *The Conversation* on hand-sanitiser). In 2020, for instance, our research into breast cancer and medicinal plants; bumblebee health; microplastics in the River Thames and seed life in outer space received wide media coverage. We believe that the sustainability of our discipline is in part dependent on effective communication of our science.

Our unit strongly supports staff taking up research leadership and membership opportunities, including journal editorships, funding and research panel memberships.

Editorial appointments: 13 category A members of staff have held editorial roles in major journals during this REF period including: *BMC Plant Biology, Conservation Letters, Evolution, Frontiers Microbiology, Frontiers Plant Sciences, Insect Conservation & Diversity, Insectes Sociaux, Nanobiotechnology, PLOS One, Phytochemistry, Soil Biology & Biochemistry, Weed Research, Proceedings Royal Society B: Biological Sciences (3x), Proteomes, Journal Theoretical Biology, Functional Ecology, Basic and Applied Ecology, Research Synthesis Methods, Ideas Ecology Evolution, Animal Behaviour, BMC Evolutionary Biology, Frontiers Behavioural Neuroscience, Planta, Journal Experimental Botany, Biomedicines, Frontiers Plant Sciences, Plants, Functional Ecology, Scientific Reports, Biology Letters, Current Zoology, Journal Royal Society Medicine Cardiovascular Disease*, *Current Bioinformatics, Evolution, Medicine and Public Health, Journal Evolutionary Biology, Gene Therapy , Human Gene Therapy.*

Panel membership: Staff from the unit have served on ca. 40 grant national and international committees, such as: NERC Peer Review College, NERC International Opportunity Fund and Global Partnership Seedcorn Fund, Innovate UK, European Research Council, Marie Skłodowska-Curie Individual Fellowships panels, Life EU panels (ITN, MSCA, RISE), EDCTP Research & Innovation Vaccines for Poverty Related Diseases, Global Committee for Ketotherapeutics, Evaluation of the Research and Professional Activities of the Institutes of the Czech Academy of Sciences, Expert Evaluation Panel, Belgian Ministry of Health, OTKA Hungarian Grant Agency panel, DFG (German Research Foundation) Scientific Networks, DFG Biodiversity Exploratories Board, Selection Committee for the Institut Universitaire de France, The Japan Society for the Promotion of Science. During the REF period Yanez has served as the Chair of Trustees of Genetic Alliance UK (umbrella organisation for 230+ patient societies) and is Treasurer President Elect of the British Society for Gene and Cell Therapy. Williams is a founding member of the International Neurological Ketogenic Society. Fraser chairs of the management board of the BBSC's High Value Biorenewables Network and is a member of the Food Standard Agency's Advisory Committee on Novel Foods and Processes and the UK Government's Expert advisory committee FSA - Novel foods and processes & DEFRA food authenticity.

Prizes and esteem indicators: Portugal won the 2019 Linnean Society Bicentenary Medal, awarded to a biologist under the age of 40 years in recognition of excellent work. Koricheva was named in the 2018 Highly Cited Researchers list by Clarivate Analytics in a cross-field category. Bogre received an Honorary doctorate from the Semmelweis University, Budapest (2018). Leubner was appointed Visiting Professor at the University of Olomouc, Czech Republic (2013-2020). Devoto renewed the visiting scientist appointment at the Center for Sustainable Resource Science RIKEN, (2012, Japan), won a BRIDGE Fellowship award to strengthen collaborative linkages with the Japanese academic community and was awarded a visiting Professorship at L'Aquila University (2020, Italy). Popplewell received a fellowship (5 years, 2014-2019) from Muscular Dystrophy UK. Grinsted received a Leverhulme Early Career Fellowship (2016-2019). Williams was invited to brief the Home Office Minister on 3Rs initiatives. Our PhD students Eleanor Warren and Joseph Damstra-Oddy (supervised by Williams) were selected as winners of the 2020 *Dictyostelium* Graduate Award. Alexandra McGoran (supervisor Morritt) was chosen the winner of the speaking competition at the 2019 Linnean Society Student Conference, Harry Siviter (supervised by Leadbeater) shortlisted for the STEM for Britain competition.