

Institution: Cardiff University
Unit of Assessment 5: Biological Sciences
<p>1. Unit context and structure, research and impact strategy</p> <p>CARDIFF SCHOOL OF BIOSCIENCES (Biosciences) is one of seven Schools within the College of Biomedical and Life Sciences (CBLS) and forms the complete REF2021 submission for Unit of assessment 5: Biological Sciences. At census (31 July 2020), the School comprised a diverse and vibrant community of 342 total staff (47% male & 53% female), spread across four contract categories (Teaching & Research, Teaching and Scholarship, Research and Professional Services). Of this total, 99 were eligible Category A staff (94.8 FTE; 67% male and 33% female), including 20 Early Career Researchers (ECR) defined as independent researchers appointed on/after 1 August 2016.</p> <p>Our mission is to understand and exploit fundamental biological mechanisms, with the aim of delivering the research knowledge and technologies to support a healthy growing population in a sustainable world. Our Unit's research and impact strategy delivers across three broad research themes, spanning molecular to global scales of biological understanding:</p> <ol style="list-style-type: none"> 1. Molecular mechanisms of life and disease: Explores the developmental origins of disease, the influence of prenatal, genetic and epigenetic factors, and physiological, connective tissue, neuropsychiatric, cancers and microbiome-based disease mechanisms. 2. Modelling and engineering living systems: Examines molecular and cellular systems, using multiscale approaches to model growth and processes in microbes, stem cells, insects, mice and plants and interdisciplinary approaches to their imaging and engineering. 3. Global change and its impacts: Explores the effects of climate change and other processes (e.g. resource competition) driven by man on organisms and ecosystems and evaluates how disease, parasitism and habitat loss affect species survival. <p>1.1 Progress since REF2014: Building our research environment</p> <p>Our strategic objective from REF2014 was to “foster and develop Centres of Excellence” across biological sciences and build our research power. Furthermore, the REF2014 UOA5 Overview Report, identified the national need for “enhancing research productivity and translation of research findings into societal impact”. These local and national UOA5 strategic directions align well with our Unit mission and we have pursued three Strategic Aims to enhance our research environment:</p> <p>Aim 1: To build a vibrant and inclusive research culture, supporting research excellence and researcher career development and delivering national and international impact.</p> <p><i>Examples of success:</i> Our inclusive research environment was recognised by an Athena Scientific Women Academic Network (SWAN) Silver Award in 2016 and retained in 2020 (Section 2.3).</p> <p>Aim 2: To expand collaboration, build mechanisms and capacity for innovation and deliver research and impact within the Unit, across the University, and beyond.</p> <p><i>Examples of success:</i> Creation and leadership of the new University Water Research Institute (WRI) and Medicines Discovery Institute (MDI) and building greater engagement with existing research institutes in Cancer, Neurosciences and Sustainability (Section 3).</p> <p>Aim 3: To maximise on existing strengths and identify interdisciplinary areas for investment that will sustain and build research excellence.</p> <p><i>Examples of success:</i> Establishment of academic-led Technology Hubs to ensure access to state-of-the-art technological resources, equipment and collaborative expertise which has driven training, outputs and impacts (Section 3).</p> <p>1.2 Research strategy</p> <p>To deliver our strategic aims during the REF2021 period, and to sustain progress into the next decade, we produced a Research Strategy created in full knowledge of and with alignment to the</p>

University's Way Forward. In alignment with our inclusive research environment (Aim 1), our Research Strategy drew from a Unit-wide consultation with all members of staff and affiliated Institutes. It incorporates how the Unit interfaces with institutional investments, spanning multiple Units and University Research Institutes (URIs) and Centres (Aim 2, Section 3), and delivers and supports the University's research ambitions (see Institutional Statement).

The review confirmed areas of strength and highlighted gaps where bridging interdisciplinary research would enhance our research activity and build capacity. Our strategic approach strongly supports the career development of all its researchers and was a key attractor for the recruitment of new staff from across the globe (Aim 3, Section 2). The strategy guided decisions for new investments, such as establishing the Unit's Technology Hubs, extensive space refurbishment and research equipment support (Aim 3, Section 3). Our investments aimed at enhancing our vibrant research environment and resulted in multiple interdisciplinary research outputs for our staff, improved grant application rates and awards in targeted areas (Section 3) and facilitated significant impacts on the wider research base and society (Section 4).

1.3 Structure and growth in strategic components of the research environment

The structure and growth of the Unit's research environment is shown in **Figure 1**. It builds on the four Research Divisions established during REF2014 and implements a series of internal enablers that support staff aspirations, expertise and success.

The Divisions, affiliated URIs and centres (Figure 1) drive interdisciplinary research and its translation to impact. Since REF2014, Biosciences led the development of two new University Institutes, the **WRI** and the **MDI**. The Unit is also a major contributor to the new **UK Dementia Research Institute's Cardiff Centre (UK DRI)**. Additionally, the Unit has continued investment and growth in Centres of Excellence described previously in REF2014 (Figure 1), including leadership of the European Cancer Stem Cell Research Institute (**ECSCRI**) and Danau Girang Field Centre (**DGFC**), and enhancing involvement in the Neuroscience and Mental Health Research Institute (**NMHRI**), Sustainable Places Research Institute (**PLACE**), and Biomechanics and Bioengineering Research Centre Versus Arthritis (**BBRCVA**; for details on affiliated institutes see Section 3.3).

Delivery of research strategy is managed by the Directors of Research (Mahenthiralingam and Harwood) and Heads of each Division (see below). Further input is provided by the Unit's Research Committee, that includes aforementioned leads, Head of School (Murray), Technology Hub lead (Kille), Director of Postgraduate Research (Watson), and representation from the Early Career Researchers (Section 2.5). The Research Committee also receives reports from each of the Unit's affiliated Research Institutes and Centres (Section 3.3).

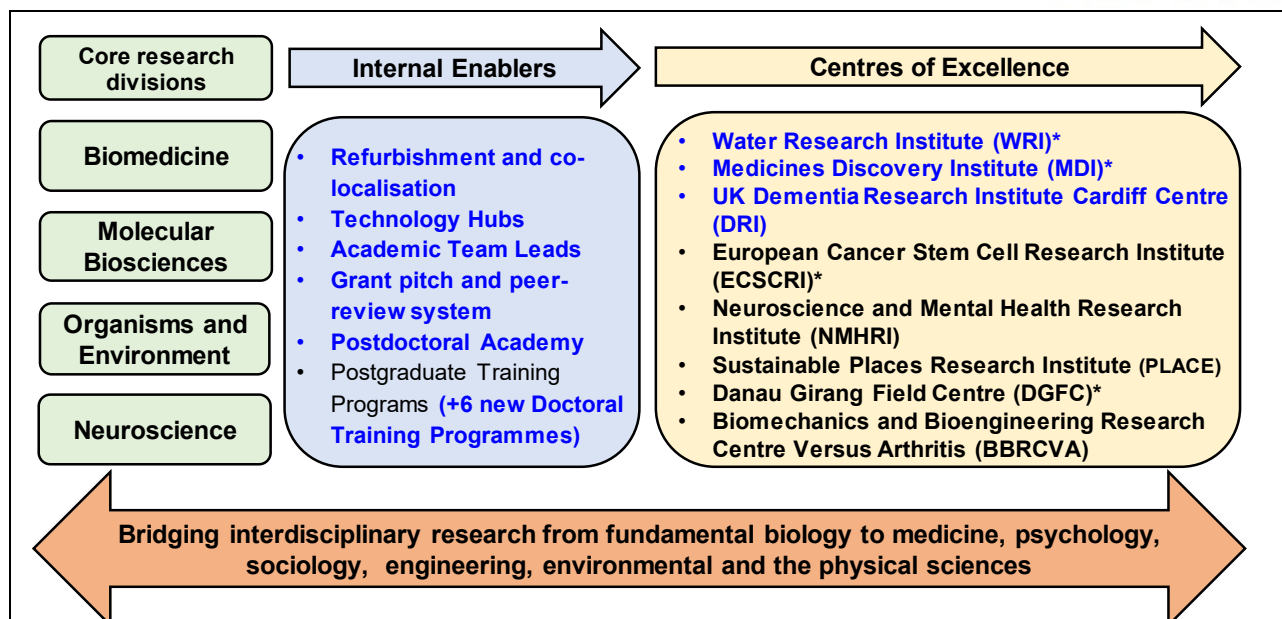


Figure 1: Strategic growth of the Unit's Research Environment. The core and new components (in blue) of our environment are shown, with Centres of Excellence led by the Unit indicated (*).

1.4 Research Divisions

The core research organisation of the Unit is its four **Research Divisions** as follows:

1.4.1 Biomedicine Division (Pathophysiology and Repair Division in REF2014)

Leader: John (25 Category A staff including 8 ECRs)

The Biomedicine Division lies at the interface between basic and preclinical research. The Division aligns to the 'Molecular mechanisms of life and disease' research theme investigating life-long health from conception to old age. Key questions are the association of early life adversity with later life disease, and the co-occurrence of non-communicable diseases and disease prevalence with ageing. Divisional researchers lead the ECSCRI and also play a key role within the BBRCVA (Figure 1; Section 3). Examples of Biomedicine's research activity are: Riccardi's studies of calcium receptors in the development of asthma and chronic obstructive pulmonary disease, and repurposing of calcilytic drugs for the treatment of inflammatory lung diseases; and John's leadership of the "Grown in Wales Pregnancy Study", which established a role for placental endocrine insufficiency in foetal growth restriction and perinatal depression to improve diagnostics and therapeutic intervention for these common disorders of pregnancy in partnership with University Hospital of Wales.

1.4.2 Molecular Biosciences Division

Leader: White-Cooper (23 Category A staff including 4 ECRs)

Molecular Biosciences research spans the research themes 'Modelling and engineering living systems' and 'Molecular mechanisms of life and disease'. Divisional research staff are also active in technology development and innovation, including molecular engineering, imaging and diagnostics, and lead on five of the Unit's **Technology Hubs** (Section 3). Examples of Molecular Bioscience's research activity are: Dale's development of colon organoid cultures for cancer drug screening leading to formation of the spinout company Cellesce Ltd (Impact Case, Section 4), and Borri's work in the field of biophotonics in collaboration with the School of Physics, applying advanced photonic techniques to cell imaging and next generation biosensors.

1.4.3 Organisms and Environment Division

Leader: A. Weightman (31 Category A staff, including 4 ECRs)

The Organisms and Environment Division focuses on the research theme 'Global change and its impacts' applying a combination of ecological and genetic methodologies to study animal and plant

communities. This research is driving efforts in global sustainability, for example, Bruford's leading role in use of genetics to protect and conserve endangered species, and Goossens' (Director DGFC) work with the Malaysian government to implement conservation action plans for key local species in Borneo. The Division also addresses the 'Molecular mechanisms of life and disease' theme, through its research on microbiome-associated diseases and use of viral genomics to improve public health. For example, Connor was instrumental in the establishment of an accredited bioinformatics service for the clinical diagnosis and tracking of viral and bacterial pathogens with Public Health Wales (PHW). Divisional staff are also closely engaged with the WRI (Figure 1) and were instrumental in the creation of a new water resource management scheme for Dŵr Cymru Welsh Water (DCWW).

1.4.4 Neuroscience Division

Leader: Sengpiel (20 Category A staff, including 4 ECRs)

Neuroscience is an internationally recognised strength of Cardiff and research within the Unit addresses the Research Theme 3 challenge of understanding the cell and molecular mechanisms that underlie function of the healthy brain and the pathophysiological mechanisms leading to mental health disorders and dementia. For example, Lloyd-Evans identified a novel therapeutic approach for a neurodegenerative childhood epilepsy (Battens Disease). Biosciences staff are major contributors to the NMHRI (Figure 1), where they are working with colleagues from Medicine and Psychology to integrate mechanistic studies of cell and animal systems with Cardiff's world leading research in neuropsychiatric genetics and brain imaging (see Institutional Statement). The expertise of divisional research staff was also a major driver in the recruitment of Atack (Biosciences) and Ward (School of Medicine) as the Sêr Cymru Chairs who established the MDI (Figure 1). They are facilitating expansion of major translational research programmes for drug discovery for neuropsychiatric disorders. For example, Atack and the MDI have obtained Wellcome Trust funding for the treatment of schizophrenia (£1.3m) and MRC awards (£2.8m) to evaluate novel modulator therapies based on Valium.

1.5 Impact Strategy

The Unit enhanced its opportunities to develop and deliver research impact at multiple levels as follows:

- **Support for individual researchers:** At the grass roots level individual researchers are supported to develop and maximise impact via reflection during regular Performance Development Reviews (Section 2), with additional support from a dedicated School Impact Officer, and the University's Research and Innovation Services (RIS) and Impact Delivery Team (see Institutional Statement). All of the Unit's Impact Cases have benefited from this tiered support structure enabling them to grow and deliver outcomes in partnership with external stakeholders.
- **Collaborative and academic-led investment in technology:** Growth in sequencing technology, quantitative and molecular biology methods and imaging technologies has continued to accelerate. We used our academic expertise to lead and establish key **Technology Hubs** (Figure 1), resulting in the growth of internal research collaborations and also driving impact with external stakeholders. The academic translation of genomics into public health diagnostics, industry, and conservation biology are exemplars of these technology-driven impacts (see Impact Cases).
- **Staffing strategy for recruitment in strategic interdisciplinary areas:** To harness the full potential of our investment in new technology and Centres of Excellence, gaps in our staff expertise were identified through our Research Strategy review. Data science (including systems biology, statistics, bioinformatics, and predictive biology/modelling) and novel technologies were identified as key areas to bridge knowledge gaps and support interdisciplinary collaboration and have driven key recruitments during the period (Section 2). The **Welsh Government Sêr Cymru** initiative to build scientific excellence in Wales supported the recruitment of the MDI chairs (Section 1.4.4) and the Sêr Cymru II programme supported 12 ECR recruitments via Rising Star and COFUND Fellowships

(Section 2.5.4). These programmes are match funded by HEIs by approximately 50% (see Institutional Statement).

- **Growth in Centres of Excellence:** The wider reach and resources of our research centres and affiliated institutes (**Figure 1**) have also driven interdisciplinary research income and impact (see Section 3).

1.5.1 Environment exemplar in the rapid delivery of impact during the COVID-19 crisis

Our response to the coronavirus (COVID-19) pandemic is a powerful illustration of how our ability to respond to new challenges benefited from our interdisciplinary expertise, support for innovation and significantly enhanced research environment. Although most staff were unable to access research facilities between March and August 2020, Connor with PHW mobilised his accredited bioinformatics service for diagnosis of viral pathogens to create a data pipeline for sequence-based COVID-19 surveillance. This was deployed for all COVID-19 tracking in Wales, directly influencing the COVID-19 strategic response of Welsh Government. It also contributed to the COVID-19 Genomics UK Consortium (COG-UK) with Connor advising SAGE/the UK Government on viral tracking and spread (Connor Impact Case).

The Unit's inherent strengths in research technology also enabled Cardiff University to establish its own COVID-19 testing facility for surveillance-level testing (accredited by the Public Health Test, Trace and Protect (TTP) service and validated as a parallel service to the NHS system). Jurkowski (recruited to Molecular Biosciences in 2019) applied his Bio-on-Magnetic-Beads (BOMB) platform to streamline COVID-19 RNA purification and create a rapid quantitative PCR test, which together with Kille's expertise in informatics, and the Unit's biocomputing infrastructure, was used to deploy COVID-19 surveillance screening for University staff and students. Further, a consortium of Cardiff Biosciences (Weightman & Connor), Bangor University, Dŵr Cymru and PHW established new wastewater monitoring of COVID-19 circulating within Wales.

1.6 Open research and fostering a culture of research integrity

Staff are actively encouraged to publish outputs and archive research data in open access formats. Cardiff University holds central funds to support the publication of peer-reviewed Gold Open Access articles (see Institutional Statement). Three professional services staff in the Unit's Research Office monitor and support Open Access compliance through regular contact with staff, citation alerts and author emails. This process maintained our >97% Open Access compliance towards REF2021. The Unit's Research Ethics Committee works with researchers to improve research quality and ensure compliance with all ethical considerations. The Committee comprises a School Ethics Lead (Swann) plus four members of research staff, an independent member of University research staff, a lay member, and a 'reserve' member to be called upon when an application from a committee member requires discussion. All staff and researchers are also supported by mandatory online research integrity training (see Institutional Statement).

1.7 Delivery of REF2021 within the Unit

Since 2015, the Research Directors have actively engaged postgraduate, postdoctoral, ECR and academic staff on REF2021. Additional support was delivered via the Research Divisions and staff performance development structures (see Section 2.2). Our support was aligned to the University (see Institutional Statement) and includes help with the delivery of:

- Open Access for research outputs.
- Impact case development (see Section 4).
- The Unit followed all principles of the University's REF2021 Code of Practice which focuses on inclusion, transparency and strong engagement with staff.
- The San Francisco Declaration on Research Assessment (DORA): the Unit held dedicated training sessions on DORA for its output review panels (12 staff) that internally scored publications and also engaged all staff and postgraduates via workshops.
- Regular research strategy workshops with the Directors of Research (see Section 2.5.3).

1.8 Progress of strategic aims and future activity

Since REF2014, we refined our mission to focus on three research themes that draw on our collective expertise of fundamental biological mechanisms. This was implemented through a long-term Research Strategy (informed by staff consultation) and delivery of our defined aims for REF2021 (Section 1.1). We have built an inclusive and supportive research community (Aim 1), expanded our mechanisms for collaboration and innovation through interdisciplinary Centres of Excellence (Aim 2), maximised our existing strengths and invested in interdisciplinary areas and technology (see Figure 1) to sustain future excellence (Aim 3).

To sustain and enhance our future research we will:

- Further support our staff via enhanced investment in Internal Enablers of research (Figure 1), such as access to the latest technologies, high-level training, and delivery of our Equality, Diversity and Inclusion (EDI) Action plan (Section 2).
- Bring together new inter-disciplinary research teams via strategic interdisciplinary networks to fill research gaps identified in our Research Strategy, such as bioinformatics, and systems and predictive biology.
- Ensure maximum engagement with the next developments for University Centres of Excellence (Figure 1);
- Expand our interactions with industry and opportunities for translation and spin-out of our research expertise and resources (Section 4).
- Expand our research that addresses global challenges and sustainable development goals in biological sciences and aligns to our research themes. We will seek to increase the national and international impact of our climate change, living systems, and life and disease research (Section 4) by collaboration and harnessing international funding.

2. People

Overview: During the REF period **building a vibrant and inclusive research culture** was a key strategic priority (Aim 1) and we have made a strong commitment to staff and researchers by enhancing their career development support and recognising performance. This was delivered as follows:

2.1 Managing change: inclusive senior leadership

With the appointment of Murray as Head of School (April 2015), both management structure and research infrastructure underwent significant changes to deliver our strategic vision. **EDI** was embedded in all activities of the School, led by a new and gender balanced six-member **School Executive Team**. The Deputy Head of School, Riccardi (female) sits on the Executive Team, and was pivotal in establishing a new **Staff and Work Environment (SWE)** Committee in 2015 to champion staff support, development, and EDI. Completing the Executive Team are **the two Co-Directors of Research** (Mahenthiralingam [Black, Asian and Minority Ethnic, BAME] and Harwood), Hughes (Strategic Director of Education, female) and Burgess (School Manager, female). This core senior leadership group meet weekly, and then monthly as part of an expanded team, that includes the four Heads of Division (two female; Section 1.4), Director of Education (Rutherford & subsequently Jones), and the Unit's Postgraduate Director, Watson. These changes have begun to address EDI balance in the Unit's senior leadership, which through REF2014 had comprised solely white male Professors, with exception of the School Manager.

2.2 Supportive performance development

Good EDI practice was further disseminated via implementation of a new **Performance Development Review (PDR)** structure in 2015. Instead of 20+ academic staff undertaking an annual PDR with a single Professorial Head of Division, new **Academic Team Leads (ATLs)** comprising multiple levels of seniority were selected to undertake this vital management and staff support activity. The ATLs promote mentorship and leadership within smaller, discipline-related staff groupings (three to six staff), undertaking annual PDRs and meeting regularly with their assigned staff. ATLs encourage researcher development and promotion by helping staff to set clear objectives aligned with the institutional '**Cardiff Academic**' benchmarks (see Institutional

Statement). The gender balance of the 24-member ATL team (25% female) more closely matches the composition of all academic staff (39% female), and while still not completely balanced, is more inclusive than previous annual appraisals taken by the Heads of Division who were all white male Professors through to REF2014. To facilitate support, ATLs receive leadership training, a workload allowance, and meet regularly with Heads of Division and the Executive Team. This improves bottom-up and top-down communication and supports ATLs to maximise their potential to be the next generation of research leaders within the Unit.

2.3 Building Equality, Diversity and Inclusivity in our research environment

Our commitment to EDI is evidenced by our two consecutive **Athena SWAN Silver** awards which recognises success in recruiting, retaining and promoting women in Science, Engineering and Technology. Female researchers currently comprise 51% of the postdoctoral research staff in the School; ensuring this balance remains during career progression is a long-term School objective. This process has begun at the top, with women scientists now in senior leadership roles (e.g. Deputy Head of School and two out of four Heads of Division), leading by example and working with all colleagues to set a strong ethos for research leadership. In our annual School **“Positive Working Environment” (PWE)** 2020 survey, 84% of staff agreed that the School of Biosciences promotes gender equality (compared to 40% in 2016). An important driver of gender balance is our family-friendly working environment that allows for flexible working arrangements (see Institutional Statement), with 83% of staff, irrespective of gender and career pathway, agreeing there was flexibility in working hours (2020 survey).

2.4 Next steps: beyond gender equality and action plan for Athena SWAN Gold

Biosciences has nearly twice the average (8%) for BAME academics in Wales (4.4%), and further improving opportunities for existing and prospective BAME staff is a long-term goal. Despite Brexit, the Unit continued to attract international staff, with five out of eight staff recruitments during the period originating from the EU. Cardiff University has made a strong commitment to equality for lesbian, gay, bisexual and trans employees (see Institutional Statement), and the Unit has formal BAME and LGBT+ networks for both staff and students. School EDI leads, Disability and Dignity, and Wellbeing Contacts work with our staff and student communities to ensure all aspects of equality are addressed.

Uptake of training on EDI (see Institutional Statement) within the School is at 78% for the three-year cycle to July 2020; through further support and engagement our goal is to achieve 100% compliance for this vital component of our inclusivity strategy. Beyond REF2021 we will continue to actively review, monitor and, if necessary, adjust support for growth and intersectionality of BAME, LGBT+ and non-UK citizenship groups. **“Aiming for Gold”** is a strategic objective of our **Athena SWAN Action Plan** to address the gender and ethnicity gaps in students and staff.

2.5 Staff development strategy

This has three major components:

1. **Promoting inclusivity and support for professional development**
2. **Recruitment by attracting staff to our interdisciplinary vision for bioscience**
3. **Development of ECRs**

2.5.1 Promoting inclusivity and support for professional development

Cardiff University has a strong and externally recognised commitment to the career development of its researchers (see Institutional Statement). During the REF2021 period, 65 biological sciences staff (49.2% female) were promoted (16 to Professor, 20 to Reader, 27 to Senior Lecturer, and two to Senior Research Fellow). This is a substantial improvement over REF2014 where a total of 25 staff (44% female) were promoted (seven to Professor, nine to Reader and nine to Senior Lecturer). Academic standards for promotion remain extremely rigorous, are externally benchmarked and evaluated via a process independent from the Unit. Our success in promotion is a direct impact of ATL support and management, reflects the enhanced EDI practice for all staff, and begins to address a residual historical gender imbalance for the next REF period.

Staff support and professional development builds on both the annual PDRs conducted by our ATL team which identify training needs and ongoing mentoring. For the REF2021 period, the School extensively supported staff development training, spending a total of £134K (£22K per annum) in addition to that supported by the University's professional development programme. The latter includes training in confidence building, specifically aimed at BAME and/or women (see Institutional Statement). The Unit's staff have benefitted from senior development training:

- **Professorial Leadership Programme** (three of four trainees were female): Prepares senior staff for leadership roles. Examples of School beneficiaries include Hughes (2017) who joined the Executive Team as Strategic Director of Education and John (2017) who is Head of the Biomedicine Division.
- **Cardiff Futures** (5 of 6 trainees were female): Directed specifically at ECRs to support their independent career establishment. Examples of staff benefitting from the training include Chadwick (2018) as a research fellow successfully transitioning to a lecturer and Perkins (2017) who subsequently was successful in promotion to Senior Lecturer in 2019.

2.5.2 Recruitment by attracting staff to our interdisciplinary vision for bioscience

Since REF2014, Biosciences has recruited 21 new staff (57% female), attracted 12 Fellows, and mentored eight early career Fellows to permanent core-funded academic appointments. These have included 17 (47% female) Category A eligible appointments in **strategic interdisciplinary areas**:

- **Bioinformatics, systems & predictive biology and novel technologies**: To expand staff expertise in bioinformatics, Menzies was recruited from a Sêr Cymru II Fellowship held at the UK DRI. Masia was also successful in converting a postdoctoral Fellowship into a Sêr Cymru II Rising Star Fellowship, adding to Unit expertise in novel imaging technologies. Further expertise in quantitative biology was provided by the transition of Chadwick from ECR to appointment as a Lecturer. Systems and predictive biology was historically supported by Scheres and significantly enhanced in REF2021 by recruitment of A. Jones, Grieneisen and Maree.
- **Expanding translational research with the Medicines Discovery Institute**: The establishment of this Institute (see Section 4) was supported by recruitment of Atack (Chair), Bax (Reader), and Grubisha (Lecturer).
- **Growth in fundamental biological mechanisms expertise**: Further new appointments (Lecturer/Senior Lecturer level) aligned to our strategy of understanding and exploiting fundamental biological mechanisms, including Berger, Peters, Hailer, Jurkowski, Petrik and Jurkowska.
- **Disglair lectureships**: In 2019, the University launched the 'Disglair' Lectureship Programme (see Institutional Statement) designed to support ECRs wishing to pursue University lecturer roles. The School appointed three lectureships (all successful applicants were female) in this initiative, enhancing research in epigenetics (Boque-Sastre), infection and immunity (Smith) and plant development (A. Jones).

2.5.3 Professional development within the School

In addition to the training and support offered by the University (see Institutional Statement), the School organised bespoke support activities for its staff and researchers as follows:

Scientific writing support: A two-day workshop from the Nature Masterclass team was held in January 2018 to provide training in scientific writing and publishing. The workshop was delivered by journal editors from across the biomedical and biological themes of the Nature Publishing Group. Academic staff, research staff and PhD students with material reaching completion for publication were encouraged to apply for the training, and their research abstracts were reviewed and ranked for participation in the workshop. Of the 30 participants, 16 were academic staff (at all levels), seven were Research Fellows, five were postdoctoral researchers and two were PhD students. The workshop developed a pool of expertise in our researchers to sustain support for

high quality scientific writing and review. Multiple draft outputs discussed at the workshop were subsequently published by the attending authors, including high quality research from:

- **PhD student** Mullins, on microbial biopesticides (Mullins et al. 2019; <https://doi.org/10.1038/s41564-019-0383-z>).
- **Postdoctoral researcher** Milczarek on neuronal adaptation and memory (Milczarek et al. 2018; <https://doi.org/10.1016/j.cub.2018.05.002>).
- **Academic staff**, John, on epigenetics and maternally imprinted genes (Creeth et al. 2019; <https://doi.org/10.1016/j.yfrne.2018.12.003>).

Improving internal grant pitching and peer review: To support staff to submit competitive grant applications, regular early stage “**Grant Pitches**” were established as a part of overall Grant Peer Review support. Staff are required to ‘pitch’ their ideas for new grant applications to an audience of peers, gaining critique of the basic ideas and suggestions for improvements. This was initially applied to our BBSRC grants from 2015, resulting in a significant uplift in BBSRC funding (see Section 4). With this initial success, the pitch and peer-review was extended to all large grant applications and Fellowships, such as Global Challenges Research Fund (GCRF) collaborative projects and UKRI Future Leader Fellowships (the latter additionally benefiting from significant University mentoring and support, see Institutional statement). Once grant applications have passed through the Unit’s initial development phase, applicants work with a team of peer reviewers and University support structures to develop their grant applications further.

Regular Research Strategy Engagement: The School runs “BioConnect” workshops for regular training and engagement on multiple aspects of career development. Sessions on research are run by the Research Directors (four+ times a year) to engage staff on topics including delivery of research equality via DORA and consideration of author contribution (the CReDIT author taxonomy; Section 1.6); REF2021 delivery (Section 1.7); grant applications and awards success; research collaboration and working impact (see Section 4).

Dedicated Research Leave: The University Research Leave Fellowship Scheme is a University-level, competitive research leave scheme (see Institutional Statement) that is actively supported by the School. Nine Biosciences staff were successful in obtaining research leave awards during the REF period. The scheme encourages staff ambition and highlights included:

- **Vaughan** (2016 to 2017) developed software packages for the community-driven statistics platform R (Vaughan et al. 2018), published a significant body of research on how climate driven pressures on stream invertebrates can be reduced by improving water quality (Vaughan and Gotelli 2019), and developed a new international collaboration with University of Vermont. This research productivity supported his successful promotion to Senior Lecturer (2019).
- **Mahenthiralingam** (2018-2019; nine months) successfully led a responsive mode BBSRC grant on bacterial biopesticides (>£1m award, £660K at Cardiff and £440K at Warwick), published three high quality papers (Mullins et al. 2019, Masschelein et al. 2019 and Weiser et al. 2019), and contributed significantly to BBSRC grant panel B (Plants, microbes, food and sustainability), leading to the invitation to serve as a core Panel member.
- **John’s** (2019 to 2020) research leave award enabled her to focus on developing her leading epigenetic and maternal biology research programmes. With dedicated time away from teaching and the Division leadership, John developed three UKRI responsive mode grants (submitted before 31 July 2020), resulting in a successful BBSRC award (£705K on Prenatal adversity and the intergenerational transmission of atypical maternal caregiving).

2.5.4 Development of early career researchers

During the period, the Unit hosted 20 Research Fellows, of which 10 were in position to return as independent staff at the census date. As part of our commitment to the Sêr Cymru II funding programmes (see Section 1.5, impact and staff strategy), the Unit invested £1.22m in supporting:

- Nine Early Career Postdoctoral COFUND Fellows (£583K investment; four male: Cheng, Parfitt, De Carvalho Ferreira, Masia; five female: Dingsdale, Paterson, Paziewska-Harris, Pearson, and Ellison).
- Two Senior Research Fellows (Hardinge and Jathoul).
- Two prestigious senior Rising Star Fellowships (Hamaratoglu and Masia's successful conversion of his COFUND Fellowship; £637K investment).

Beyond this Welsh Government funding scheme, Shelkovnikova obtained a Medical Research Foundation Fellowship (2015), followed by a Motor Neuron Disease Fellowship (2018). In addition to externally funded Fellows, the Unit hosts seven University Institute Fellowship positions (Parry, Siebzehrubl, Dos Anjos Afonso and Hogan within ECSCRI; Sanderson-Bellamy within PLACE; and China Medical University-Cardiff Fellowships, Phesse [ECSCRI] and Syed [NMHRI]).

2.5.5 ECR mentorship and career progression

All new starters and Fellows are assigned an independent mentor on joining the School and participate in our dedicated research staff development programmes, and those of the University (see Institutional Statement). Five Fellows have successfully progressed their careers including: Phesse (ECR fellow to Senior University Fellow), Menzies (COFUND Fellowship to a Lecturer), Pearson (CO-FUND to five-year Cancer Fellowship; see Section 3.1.1), Shelkovnikova (postdoctoral Fellowship to a senior non-clinical fellow in the MDI) and Ellison who successfully converted her COFUND fund Fellowship into a BBSRC Future Leaders Fellowship, and subsequently secured a lectureship at the University of Bangor (2019). Support for Fellows to maximise their potential is not restricted to ECRs. For example, we supported the career progression of Durance, a former Daphne Jackson Research Fellow, to a Personal Chair and Directorship of the **WRI** (2019). Additionally, during the period we supported non-Fellow researchers from past postdoctoral positions on research grants to staff positions, with Goossens (DGFC Director) securing a lecturer appointment (2015), promotion to Reader (2017), and ultimately securing a Personal Chair (2019).

ECR support and development provision within the School include:

Postdoctoral Academy Programme (PDAP): The Unit's historical Research Staff Group (representing fixed-term research staff) was revitalised into the Unit's PDAP led by the Deputy Head of School (Figure 1). The PDAP contributes to Unit decision making by direct representation on the Research and SWE committees, and also established multiple postdoctoral support programmes. These include workshops within the BioConnect series on topics including 'How to engage with politicians', careers advice, engagement and social media, 'from academia to running your own business', 'becoming a successful academic via the fellowship route', CV clinics, grant-writing workshops, and organization of a postdoctoral programme Annual Research Away Day. The PDAP also runs its own online blog to post information and internal/external job opportunities. Multiple PDAP research staff have benefited from University training schemes and eligibility to be PIs on Wellcome Trust Institutional Strategic Support Fund (ISSF) grant applications (see Institutional Statement). For example, Weiser successfully obtained a one-year ISSF (£50K; 2017 to 2018) to gather preliminary data on the microbiota of lung infections in children with cystic fibrosis, which enabled her successful co-investigator application to the US Cystic Fibrosis Foundation (£157K; 2019 to 2022).

To support postdoctoral development, the School funded the PDAP to establish an annual **seedcorn funding scheme** (£20K per annum) to give research staff experience in applying for and reviewing grant proposals, and then delivering on the independent funding. 10 to 13 seedcorn projects are funded annually, each aiming to yield data for use in high quality publications, grant or fellowship applications. The seedcorn scheme was externally recognised as a key facilitator for research development in our Athena SWAN Silver award feedback (2020).

C. Jones serves as an exemplar of postdoctoral support by the PDAP and University programmes. He used a Seedcorn Award (2016) to obtain toxicity data on a novel *Burkholderia* bacteria-derived antibiotic, successfully publishing this in Song *et al.* 2017. During the summer of 2017, C. Jones was also awarded a Cardiff University Research Opportunities Programme (CUROP; see Institutional Statement) summer studentship. This funded undergraduate student Yap enabling

her to construct an antibiotic biosynthesis pathway mutant. This significant research contribution was recognised by co-authorship in a high-quality publication (Masschelein et al 2019) and greatly assisted in Yap being able to obtain an International PhD Scholarship at the University of Manitoba, Canada (October 2020). This productivity and supervisory experience also enabled C. Jones to successfully obtain an independent lectureship at the University of South Wales (2018).

2.6 Support, training, and supervision of postgraduate researchers (PGRs)

Biosciences has a thriving culture for postgraduate education with students drawn from a wide variety of backgrounds and supported by multiple funding sources. Over the REF2021 period, **468 PGR students** (297 PhD, 20 MPhil, 2 MD, 149 MRes) have received training, a substantial increase over the 192 postgraduates supported within the REF2014 period. A key facilitator in increasing our PGR numbers is the substantial growth in **Doctoral Training Partnerships (DTPs)**; Figure 1; n = number of PhD students):

- **Existing DTPs:** Wellcome Trust funded four-year PhD Programme in Integrated Neuroscience (n=10), European Marie Skłodowska-Curie PhDs (n=10), International Training Scholarships (n=58; Saudi Arabia, Malaysia and India as major participants), and School investment of £2m (£662K fees/£1.35m stipends) in 93 PhDs.
- **New DTPs:** BBSRC GW4 SWBio Doctoral Training Partnership (n=24); MRC GW4 Biomed Doctoral Training Partnership (n=8); NERC GW4 Doctoral Training Partnership (n=23); NERC GW4 FRESH Centre for Doctoral Training (n=5; led by the Unit's WRI); EPSRC Doctoral Training Programmes (n=4) and Knowledge Economy and Skills Scholarships (KESS; n=32; a pan-Wales European Social Funds initiative aimed specifically at linking local companies and NGO stakeholders with universities).

2.6.1 School PGR support and development

To ensure our increased number of PGRs are supported, Watson (PGR Director), four Divisional PGR Tutors and two professional services staff within a dedicated Postgraduate Office assist with recruitment, communication, progress monitoring and examination. Prospective students are interviewed by a panel comprised of supervisors and the PGR Director/Tutors, to ensure EDI, protected characteristics and academic quality are assessed fairly. All supervisors must undertake mandatory supervisor training (every three years) for eligibility to supervise PGRs. Student progression is actively monitored using the institutional progression monitoring system (four- and nine-month annual reports; see Institutional Statement), where PGRs also benefit from the impartial development advice via independent School assessors. Our students actively engage with Cardiff University's **Doctoral Academy** (see Institutional Statement) that provides skills development programmes, interdisciplinary community events, funding opportunities and dedicated PGR space.

Within the School, each research Division holds a funded annual **Postgraduate Away Day** organised by the PGR students to showcase their research and develop management skills. A dedicated School intranet centralises information for PGRs and links to the University's Doctoral Academy. Training such as the "**Thesis Best Practice**" document and workshop were originally developed within the Unit but are now used centrally by the Doctoral Academy to benefit all University PGRs. The Unit also runs dedicated **training in R statistics and bioinformatics** for all postgraduate researchers, as bespoke support in addition to skills development programmes in the Doctoral Training Academy and within each DTP. A new PGR training element since REF2014 is our **Technology Hubs** (see Section 3), with students developing hands-on skills in cutting-edge technology, and following up with academic-led training in the analysis of biological and quantitative data generated by these techniques.

2.6.2 Successful postgraduates are key facilitators of our interdisciplinary and collaborative research strategy. PGRs are integral to the Unit's research strategy, with multiple students bridging discipline boundaries and working impactfully with a range of stakeholders as follows:

- **Interdisciplinary research:** PGRs frequently undertake research across the Unit's Research Divisions, Centres and University Institutes, and external stakeholders, and hence actively drive the diversity and reach of biosciences research (see Section 4.4).
- **Working with industrial or stakeholder impact:** In addition, multiple students have industrial sponsors ranging from small local companies (Cultech Ltd, Baglan) to large international companies (GlaxoSmithKline, Unilever Research and Development UK; see Section 4.4). Active sponsorship of PGRs by external stakeholders has also been fundamental to facilitating impact. Exemplars include students working with Unilever to improve standards for the identification of bacterial contaminants within industrial products (Mahenthiralingam Impact Case), and international non-governmental organisations such as the Zoological Society of London to bring about conservation programmes for endangered species (Bruford Okapi Impact Case).
- **Next generation researcher skills:** Quantitative biology expertise (R statistics, bioinformatics and data modelling) are actively embedded in our PGR community via training, addressing skills gaps highlighted by our own research strategy review and that of the UKRI. With the recruitment of additional staff expertise in informatics, modelling and systems analysis (see Section 2.5.2), PGR training in these skill priority areas will be further enhanced in future via new Masters' programmes and bespoke PGR training workshops. All our PGRs, like staff also undertake mandatory research ethics training (Section 1.6).

2.6.3 PhD success

During the period, our positive PGR training development environment sustained high standards within the Unit, with the **on-time rate** of PhD submissions averaging **81%** (range 75% to 94% within four years), and the overall **completion rate reaching 88%** (submission, viva, corrected thesis and final award; allowing for delays due to extenuating circumstance). Overall, a total of 202 research doctoral degrees were awarded in the REF period.

2.7 Progress since REF2014: Investing in people, addressing EDI, and growth in training

Our strategic aim was specifically to invest in our people, and ensure EDI is embedded in all aspects of the Unit's research (Aim 1; Section 1). Highlights of our progression since REF2014 include:

- Provision of a wide range of support to enhance research excellence and output has increased our submission from a selection of 66 Category A staff in REF2014 (18 female) to an inclusive Unit return of 99 (94.8 FTE) staff (33 female).
- Establishing a greater diversity of staff in senior leadership to champion EDI, and successfully transitioning from an all-white male Professor senior management group in REF2014, to a gender balanced Executive Management Team (including 1 BAME member).
- Substantial improvements in promotion and career prospects for all staff including our leading female researchers (e.g. six promotions to Reader, 67% female; an increase from 17% to 24% of Professors being female). In addition, of the 17 Category A staff appointed since REF2014, eight (47%) are female.
- Recruiting staff to fill areas of need, sustain growth of our interdisciplinary research (bioinformatics, systems & predictive biology and novel technologies) as part of our research impact strategy (Section 1.5).
- Significantly increasing the number of doctoral training programmes for postgraduate researchers, enhancing opportunities for postdoctoral researchers to develop their careers towards independence and offering more training with staff to improve research excellence.

3. Income, infrastructure and facilities

3.1 Research Income

A key performance indicator (KPI) of our Research Strategy was to increase research grant income. This is both driven by, and an enabler of, our three strategic aims (see Section 1). During the REF2021 period, total **grant income averaged £11.8m per annum** across the period, **a 25% increase** over the £9.4m average per annum for REF2014. The Unit successfully improved income from UK research councils, charities, UK Government, and the European Union despite the uncertainty arising from Brexit (Figure 2). The improvements reflect our enhanced research environment (Figure 1) and result from the following facilitators of success:

- **A supportive, reflective and discipline-specific PDR process:** ATLS encouraged staff to be ambitious in seeking funding to support their research, specifically helping them with clear objective setting in relation to strategic areas, targeted funders and deadlines (Section 2.2). The Unit also ensures the University (see Institutional Statement) and local (see Section 2) EDI measures are implemented in the evaluation of applications and support for awards.
- **Detailed peer review and mentoring** for all UKRI submissions over £50K in total value.
- **A focus on submission of larger grants** and collaborative interdisciplinary working where possible to strengthen grant teams (see Section 3.1.1 below).
- **Grant Pitch Workshops** organised quarterly for all staff planning to submit large applications to UKRI/other funding agencies. The workshops provide staff with the opportunity to pitch research ideas and receive feedback, improving grant development ahead of internal peer review.
- **Grant writing one to ones** organised by Research and Innovation Services provided to researchers who wish to receive detailed feedback on their applications.
- **Positive messaging** on applying for research funding via a sustained series of staff engagement Research BioConnect workshops with our Research Directors. Despite low national rates of funding and reduced UKRI funding rates, analysis of application data showed that researchers from the Unit had **a 50% success rate for submitted grants** (at all application values).
- **Access to state-of-the-art technologies** via our new **Technology Hubs** to obtain preliminary data, demonstrate feasibility and facilitate innovation.
- **Infrastructure investment** to improve research space and co-localise teams of researchers.

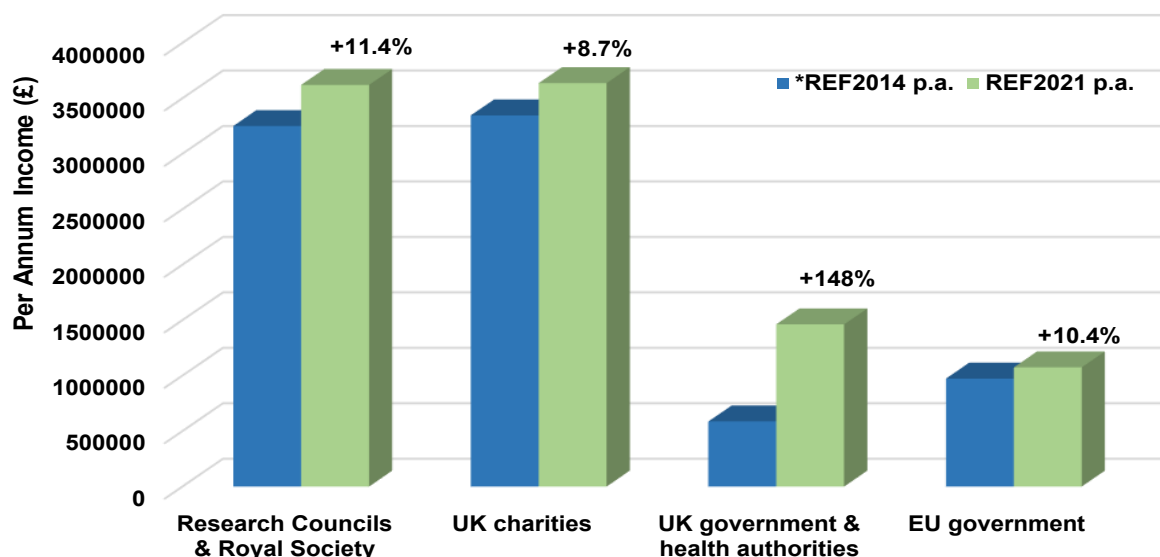


Figure 2: Improved research income across multiple funding sources. Income per annum for REF2014 (blue) was compared to REF2021 (green) and normalised for FTE (*94.8 FTE in REF2021 versus 91.7 FTE in REF2014). Improvements for the four largest sources of income are indicated

3.1.1 Improved application and award rates

During the REF2021 period, the School achieved progressive increases in grant awards per annum which reached a high of £18.3m (2018 to 2019). Total grant applications from all staff to internal and external funding programmes increased by 20%, from an average of **260 per annum** (REF2014 period) to **311 per annum** for the current period. This resulted in a **37% increase** in the total number of funded awards, from 108 awards per annum for REF2014, to an average of **148 per annum** for REF2021. Awards have been obtained from a broad portfolio of funders (Figure 2), and notable grants in line with our research themes (Section 1) and the funding support structures (see Section 3.1 above) include:

Molecular mechanisms of life and disease:

- Lelos and colleagues (with Rosser, School of Medicine) in the Brain Repair Group attracted MRC programme funding to investigate cell therapies for Huntington's disease (£1.5m; 2020 to 2025).
- John led on three successful grants (BBSRC £630K and £705K; MRC £900K; total £2.2m) interrogating the association between prenatal adversity, placental endocrine dysfunction and detrimental behavioural outcomes for mothers and their children.
- Mahenthiralingam obtained his first BBSRC responsive mode award in 2014 (£420K) and followed up with Murray to obtain a second BBSRC (2019; £620K), establishing a new interdisciplinary *Burkholderia* antibiotic and biopesticide discovery programme.
- Pearson successfully followed her early-stage CO-FUND Fellowship with a highly prestigious Senior Cancer Research Fellowship from Cancer Research UK (£1.5m; 2019 to 2025).

Modelling and engineering living systems:

- Borri continued to lead interdisciplinary research in multiphoton microscopy and spectroscopy supported by extensive UKRI funding (EPSRC; £1m).

- White-Cooper and colleagues are investigating how nucleosomes regulate gene expression in *Drosophila* during cellular differentiation with BBSRC funding (£488K). Kent and the Genome Technology Hub played an instrumental role in this award.
- Harwood and collaborators at University of Manchester developed an Illumina Sequencing-based method for *Dictyostelium* mutagenesis (funded by Wellcome Trust, £499K) and utilised the Genomics Research Hub to generate 40,000 mutants, expanding the community resource for this biological model four-fold to more than 5,000 mutated genes (>40% of total gene complement).

Global change and its impacts:

- Scofield leads an international consortium via Global Challenges Research funding (£750K) developing essential oil products from menthol with researchers in Uganda (establishing a key international collaboration; see Section 4.2).
- Connor secured a collaborative Cloud Infrastructure for Microbial Bioinformatics (CLIMB) MRC award (£1m; 2014 to 2020), as a flagship resource for computational analysis; CLIMB is now extensively used nationally and internationally. The Unit match funded £75K of computer infrastructure for CLIMB and committed to support of two FTE server engineer positions, because it addressed our strategic aim to increase big data analysis infrastructure. Connor's expertise and our investment also helped underpin the renewal of CLIMB (2020 to 2025; £580K) and attract a COVID-19 Genomic-UK Consortium (COG-UK; £980K) award for sequence-based viral tracking. Overall, the School committed extensively to increasing its capacity for biocomputing (Figure 2) and new academic expertise in bioinformatics, quantitative and systems biology (see Section 2.5.2).
- Durance was awarded £2.14m in 2018 to lead the NERC Freshwater Biosciences and Sustainability Centre for Doctoral Training. This new DTP is led from the WRI (see Section 2.6) and will ultimately train 24 PhD students (2018 to 2024). Co-supervision with external stakeholders is implicit within the DTP to ensure impact and training in the breadth and depth of skills needed to tackle real-world water-related challenges.

3.1.2 Larger grants and learning from BBSRC success

Given the track-records and interdisciplinary expertise of our staff (see Section 1) from 2015 BBSRC was targeted as a specific UKRI funding body with funding priorities in line with our strategic research themes (Section 1). Via our support mechanisms (see Section 3.1) a progressive, **44% increase** by value, in **BBSRC awards** was achieved over the period (REF2014 = £7.7m; REF2021 = £11.1m). With approximately the same number of BBSRC awards over each period (34 in REF2014 versus 36 in REF2021), this success also validated our focus on building well planned, ambitious, and larger collaborative grant applications. The same strategy is being applied to all larger bids targeting other UKRI and funders, encouraging staff to work collaboratively and build interdisciplinary strengths into their proposals, as well as ensuring applications are high quality and peer reviewed. The MRC Programme award to Lelos and Rosser is an exemplar the further success of our grant development support (see Section 3.1.1).

3.2 School infrastructure investment

In addition to enhancing our research culture to be more inclusive and supportive, the School and University (see Institutional Statement) have made substantial investments in physical environment and Centres of Excellence to support our Research Strategy (see Section 1) as follows:

3.2.1 Refurbishment

Over the REF2021 period the School developed business cases with the University supporting investment of over **£14m in the refurbishment of 2,500 m²** of laboratory and research office space. This enabled the following major projects to be delivered:

- **Co-localisation of researchers to the Sir Martin Evans Building (SMEB):** During REF2014, the Unit's staff were spread across four buildings making interdisciplinary collaboration and resource sharing difficult. A strategic move to co-localise the majority of

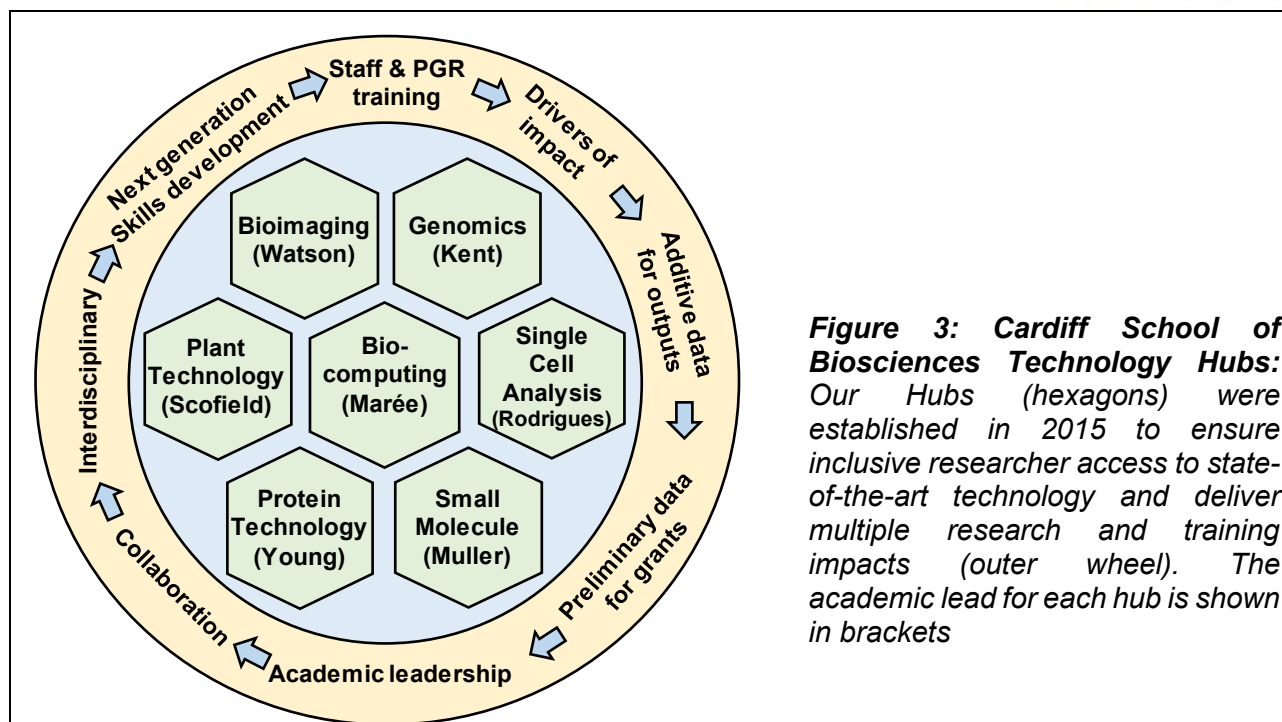
researchers to SMEB was set in place and funded via successful business plans submitted to the University. The plan started with four microbiology staff housed in dispersed locations moving to a single newly refurbished multi-user microbiology suite at Class 2 Level forming a new Microbiomes, Microbes and Informatics group (Connor, Mahenthiralingam, Marchesi and Weightman). This was completed in June 2016 as part of a £2.6m investment to update 960 m² of research space that included establishing the Technology Hubs (see Section 3.2.1). Subsequently, a further £1.4m business plan was approved to co-localise researchers from the Molecular Biosciences division into a newly refurbished wing of SMEB (813 m²). With the exception of staff working within the University Research Institutes, these investments allow co-location of all divisional staff within the SMEB. 17 academic staff and their respective research groups (>80 staff and PGRs) have benefited from greater collaboration opportunities with the majority of School colleagues. The high-quality research space also acted as a key attractor of new staff (for example Maree, Juskowska, Grieneisen and Jurkowski were all shown the refurbished space available to house their research at interview).

- **A single “front of house” location for the WRI:** Refurbishment of an underutilised administration area on the ground floor of SMEB (£20K investment for 134m²) was undertaken to provide offices for 10 staff, with space for PGRs, ECRs and interdisciplinary stakeholders to meet and foster collaborative research.
- **Medicines Discovery Institute:** £14m was invested in establishing this interdisciplinary institute within Cardiff University Main Building (adjacent to the School of Chemistry). This funding upgraded 774 m² of laboratory, office space and meeting space, and enabled purchase of £5.5m in equipment/capital infrastructure for the 40+ researchers within the MDI.

3.2.2 Technology Hubs as Internal Research Enablers

As part of Strategic Aim 3 (maximising existing strengths and investing in interdisciplinary areas to sustain and build future research excellence; see Section 1), in 2015 Biosciences created a series of academic-led **Technology Hubs** within the School (Figure 3). A wing of the Sir Martin Evans Building was refurbished as part of the £2.6m business case noted above to house the hubs in a purpose-designed and co-localised space. Over the REF2021 period, the School invested £3.4m in new equipment for the hubs including multiple short and long read sequencing platforms, high resolution light/confocal microscopes, analytical chemistry instrumentation and growth facilities.

The Technology Hubs combine equipment access with integrated academic and technical research expertise (Figure 3). A key feature of the Hubs is that they are led by academics to facilitate innovation and collaborative interdisciplinary research across our research themes (Section 1). All users can access resources and support from any Technology Hub at essentially cost price as each HUB is self-sustaining, but with underpinning technical positions supported by the School. Strategic planning for the Hubs is coordinated by the Unit’s **Technology Committee** (newly created in 2015; chaired by Dale and then Kille) which reports to the Research Committee. The Technology Hubs act as central drivers of our strategic research aims by facilitating inclusive technology access for all staff and researchers, working innovatively across disciplines, and enabling impact internally and externally (Figure 3).



Exemplars of the impact of the Technology Hubs on our research strategy include:

- The majority of our successful funding awards (and all our highlighted awards; see Section 3.1.1) result from data generated within the Hubs. In particular, our successful BBSRC awards (see Section 3.1.2) were heavily dependent on the technology, expertise and interdisciplinary research capability offered by the Hubs.
- Multiple high quality publication outputs have resulted from research carried out within the hubs (see Section 2.5.3).
- The Hubs are key drivers for training that benefiting all levels of the School, particularly offering our PGR community the opportunity to develop next-generation skills (see Section 2.6.2).
- The Hubs have enabled external stakeholders to access cutting-edge technology and academic expertise to drive impact (Connor and Mahenthiralingam Impact Cases).

3.3 University Research Institutes & Centres

To expand our facilities beyond the Unit and deliver research with interdisciplinary impact across the University and externally, we have engaged strongly with University Research Institutes (see Institutional Statement). These provide dedicated physical research environments to support interdisciplinary and translational research, acting as a vehicle for cross-University recruitment, career progression and training.

3.3.1 Enhancing existing University Research Institutes

At the REF2014 submission, five Centres of Excellence were affiliated to or led by the Unit (Figure 1):

ECSCRI: This Bioscience-led institute created in 2011 is led by Smalley. Its goal is to study cancer stem cells (CSCs) as therapeutic targets for improving cancer patient outcomes, translating this emerging field into medical advances. The institute has a critical mass of eight academic staff and through its substantial support for ECRs has successfully transitioned three into independent positions (see exemplars in Section 2.5.5);

NMHRI: This is led by the School of Medicine and was established in 2011 as an interdisciplinary Institute with the Schools of Psychology, Bioscience and Optometry. It is led by Hall (Medicine) with Harwood (Biosciences) as a Co-Director and integrates Cardiff's world-leading neuropsychiatric and neuroscience research into a single internationally recognised centre of

excellence for genomics-led, translational research. Its research spans neurodevelopmental disorders (attention deficit hyperactivity disorder, autism and schizophrenia) and neurodegenerative disorders (Alzheimer's disease, Huntington's disease and Parkinson's disease).

PLACE. This Institute created in 2011 is led by Hales (Earth Sciences), with Bruford (Biosciences) as a Co-Director. The institute works across 11 Schools within the University to address planetary sustainable development challenges. Through collaborative research, it identifies, understands and offer solutions to urgent social, economic and environmental challenges of global sustainability. PLACE was integral in delivering impact on biological conservation (Bruford Impact Cases).

DGFC: This Unit-led field centre was established in July 2008 (Goossens, Director) and gathers data on the tropical ecological systems in the highly fragmented and oil-palm dominated landscapes of the Kinabatangan floodplain in Sabah, Malaysian Borneo. DGFC provides extensive capacity building opportunities for international and local scientists paired with its close collaboration with the Sabah Wildlife Department. Within South-East Asia, DGFC is a major driver of public engagement and government interaction to foster biological diversity and sustainability, resulting in multiple impacts (Goossens Impact Case).

BBRCVA: The Arthritis Research UK Research Centre was established in the REF2014 period and successfully renewed as the BBRCVA. This multidisciplinary Centre investigates osteoarthritis and related musculoskeletal diseases. BBRCVA utilises state-of-the-art research laboratories including the Musculoskeletal Biomechanics Research Facility, with a motion analysis laboratory and a Biplane X-ray system, and the Research Centre for Clinical Kinesiology, with a virtual reality system in situ.

3.3.2 Leadership and key roles within new University Research Institutes

Since REF2014, Bioscience researchers have led or played active roles in establishing the following new institutes with both School and University investment (see Institutional Statement):

WRI: Led by Durance, the Institute was established in 2015 in newly refurbished space within Biosciences (see Section 3.2.1). Through interdisciplinary research across multiple Schools, the Institute addresses the complex challenge of sustaining water for both people and ecosystems in a changing world. It successfully launched a regional freshwater biology DTP in 2018 (see Section 2.6) and directly engages with government agencies and industry to translate research on sustaining water resilience (Durance Impact Case).

MDI: The Unit's and University strength in translational neurosciences was a key factor in establishing this interdisciplinary institute in 2018 (see Sections 1.4.4, 2.5.2, and 3.2.1). Atack (Biosciences) leads the institute with Ward (Medicine), and they have successfully established a multi-disciplinary team of four staff investigators and 50 researchers to drive forward drug discovery for neuropsychiatric disorders.

UK DRI: Cardiff was awarded one of the six centres within the UK Dementia Research Institute. The national institute is a £290m investment by the MRC with founding charity partners the Alzheimer's Society and Alzheimer's Research UK. Biosciences is one of three Schools in the UK DRI centre with Medicine and Psychology, and specifically host Peters as a lecturer appointed through a Momentum Award to the University (see Institutional Statement).

3.4 Institutional and GW4 infrastructure

The School of Biosciences benefits from access for multiple projects to additional University infrastructure support such as the University's **Advanced Research Computing @ Cardiff (ARCCA)** and **Cardiff University Brain Research Imaging Centre (CUBRIC)**. ARCCA was established in 2007 to provide high performance computing and Big Data services for researchers. This augments our School level data processing and storage capacity (see Biocomputing Hub; Figure 3), supporting multiple data-intensive analysis and modelling projects, for example our interactions with PHW for genomic-based infectious disease diagnostics (see Section 4). The *in vivo* imaging capacity of CUBRIC provides research translation capacity for studies within the Neuroscience and Biomedicine Divisions, and the Medicines Discovery Institute. Within the GW4

Alliance (see Section 4.1), the GW4 Facility for High Resolution Cryo-Microscopy, hosted by University of Bristol and part funded by this Unit, provides options for the drug discovery activity offering state-of-the-art capacity protein structure studies. It can be accessed by bioscience researchers via the Protein Technology Hub (Figure 3).

3.5 Progress since REF2014: improved grant applications, refurbished and new research space, and technology investment

The REF2021 period saw improvements in our grant income (Figure 2), and substantial expansion in infrastructure within Biosciences (Figure 1 & 3). This increased our research productivity and interdisciplinarity by:

- Enhancing staff mentorship and training in developing high quality research grants, increasing application rates through staff support and positivity, and improving the targeting, focus and size of research bids (Figure 2).
- Improving School infrastructure by building high quality cohesive research space, aligned to the needs of researchers and new Centres of Excellence (Figure 1).
- Increasing access to the latest technology and training by investing in Technology Hubs as local enablers of research (Figure 3).

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

4.1 Research Collaborations, Networks, Partnerships

As evidenced in Sections 1 to 3, our fundamental Biosciences Unit is closely connected with other biomedical and environmental Units at Cardiff. Here we focus on collaborations and contributions outside our Institution.

4.1.1 Regional and National Research Networks

GW4 Alliance Partnerships: Beyond the University, Unit members are active in a wide range of research collaborations within the **GW4 Alliance** of Bath, Bristol, Exeter and Cardiff (see Institutional Statement). This includes:

Leadership of the GW4 Water Security Alliance (WSA). This directly projects our Research Theme 1: Global change, via linkage to the Organism and Environment Division and our hosting of Cardiff's WRI (Figure 1). Durance (WRI Director; Section 3) fostered research interactions at the regional level to establish the GW4 Water Security Alliance (WSA) and was appointed as the WSA's first director. With more than 200 researchers, the WSA is the largest water research consortium in the UK and one of the largest in the world. It promotes interdisciplinary research across multiple sectors and creates a forum for direct interaction with key stakeholders in water use and sustainability. The Unit directly contributes to WSA leadership and hosts the new NERC GW4 Fresh Water DTP (Section 2).

Steering roles in the GW4 Antimicrobial Resistance (AMR) Alliance: At Unit level this builds from the Organism and Environment Division's Research Theme 3: Molecular Mechanism activity, and its University-level interface via the internal Antimicrobial Resistance and Infection Network. Mahenthalingam and Connor served on a cross-institutional steering group to establish a new GW4 AMR Alliance (October 2020). Capitalising on regional strengths, the Alliance will tackle the global antimicrobial resistance (AMR) priority by pursuing One Health approaches to managing AMR infections, tackling resistance in relation to global sustainable development goals, and understanding drivers of AMR selection and transmission.

Active support for GW4 Doctoral Training Partnerships. Our researchers play key roles in organisation of GW4 DTPs, including local leadership by Durance (NERC FRESH) and White-Cooper (BBSRC SWBio). The Unit's researchers also actively contribute to annual research training via BBSRC's SWBio DTP Statistics training module (1 week; Chadwick [lead] assisted by Lello and Vaughan), and Grant Evaluation training sessions (1 day; White-Cooper and John).

Beyond regional networks, our researchers are leading on National UK networks, including:

- **Genomic Arabidopsis Resources Network (GARNet):** GARNet is a BBSRC-funded UK research network led by Murray. It supports UK Arabidopsis research and the wider plant community by coordinating access to community tools and biological resources and directly feeds into our Molecular Biosciences Division and Research Theme 2: Modelling and engineering living systems. GARNet aims to ensure that the plant science research community remains productive at both the national and international levels. The network also promotes the use of systems biology and synthetic biology methodologies in plant science, with Scheres providing key international input into the Unit's training and systems biology strategy.
- **CryoArks: A sustainable resource for genetics and genomics of animal species.** This £1m BBSRC Bioinformatics and Biological Resources award (2018-2021) is led by Bruford, who is Director of the facility. It is underpinned with stakeholder partnerships with the Natural History Museum, the National Museums Scotland, RZSS Edinburgh Zoo and Highland Wildlife Park. CryoArks created the first systematic national resource and biobank providing access to tissues, cells and DNA from endangered species, and aligns with our Research Theme 1 mission.

4.2 International Networks

Strategic institutional partnerships with KU Leuven, Xiamen University and Brazil's Universidade Estadual de Campinas (UNICAMP), as well as pump priming for Global Challenges research, have also benefited our researchers in delivery of our Research Strategy (see Institutional Statement). Examples include:

- **The Brazilian Water Research Centre:** Following an exchange programme-funded visit with UNICAMP, our WRI supported the creation of the Brazilian Water Research Centre (BWRC). Durance is a lead member of the BWRC International Advisory Board, and this links to our future strategy to expand the reach of our research beyond the Unit.
- **New Mint Crops to Boost Rural Economies in Uganda:** Scofield, our plant technology hub lead (Figure 3) successfully used his expertise, supported by Unit resources, to obtain BBSRC-GCRF award (£816K): "Enhancing essential oil feedstocks and high-value products from *Mentha* species for local Ugandan economies (MENUM)" (2019-2022). This aims to increase production of natural oil compounds, specifically the terpenoids menthol and nepetalactone from the *Mentha* plant species to create high-value products for the rural Ugandan economy. This will deliver strong international Impact, aligned to our Research Theme 2: Modelling and engineering living systems.

The Unit has extensive interactions in the European research arena delivering both leadership and contributions to collaborative research projects as follows:

- **Academia Europaea.** Former Head of School, Petersen, leads the Cardiff Knowledge Hub of the Academia Europaea, organising multiple engagement, collaborative and funding activities for this international body. Petersen and Durance have also contributed to European Commission Science Advice for Policy by European Academies (SAPEA) reports on current biological challenges as part of the Academia Europaea.
- **European Cooperation in Science and Technology (COST):** International reach of our research expertise is also evidenced by engagement and leadership in multiple COST actions. Harwood was the main proposer and Action Chair of CA16210: Maximising Impact of Research in Neurodevelopmental Disorders (MINDDS) and Bruford is a Working Group leader in CA18134: Genomic Biodiversity Knowledge for Resilient Ecosystems (G-BIKE). Both international networks align with our strategies to increase research initiatives in Research Theme 3: Molecular Mechanisms for Neuroscience Division and NMHRI, and Research Theme 1: Global change for Organism and Environment Division.
- **European Horizon 2020 Research Programmes:** Multiple researchers are active in both Excellent Science and Societal Challenge Pillars of Horizon 2020, spanning our research mission. Borri is the project coordinator of Marie Skłodowska-Curie Innovative Training Network (MSCA-ITN): Multiphoton Microscopy and Ultrafast Spectroscopy - Imaging meets

Quantum (MUSIQ; 2019-2024). This network is building interdisciplinary capacity in photonics and microscopy aligned to strengthening our reach in bioimaging and sensors research. Researchers from Biosciences also actively partner other MSCA-ITNs including the Female Investigators in Non-linear Optical Nanoscopy (FINON; 2013-2017) and Calcium-Sensing Receptor Therapeutics for Non-Communicable Diseases (CaSR 2016-2020). In the Societal Challenge (Pillar 2), Biosciences were partners in Climate Genomics for Farm Animal Adaptation ClimGen; 2015 – 2018) a project that focuses on the identification and use of 'omics technology for building livestock resilience to climate change (Bruford, Orozco-terWengel and Russo) and Comorbidity and Synapse Biology in Clinically Overlapping Psychiatric Disorders (COSYN, 2015-2020) probing synaptic function in patients pluripotent stem cells (Harwood).

4.3 Contributions to the Research Base

Unit staff have clear and strong support for extra-institutional activities which contribute to the national and international research base. This includes dedicated administrative support, guidance and training and 200 workload hours of ring-fenced research citizenship time. This enables our researchers to serve on major national and international grant panels and stakeholder steering groups, plus research strategy boards. During the REF2021 period Biosciences staff held 49 committee and board positions on external organisations, including 15 UKRI research council positions, 13 learned or scientific society steering groups, five charities and 15 government advisory bodies. Reflecting our guiding principle of inclusivity (Section 2), 55% of these positions were held by females. UKRI contribution roles include:

- **MRC:** Fox (Neuroscience and Mental Health Board); Atack (Therapeutic Target Validation, Experimental Medicine, and Industry Asset review panels); and John (UK Nutrition Research Partnership for health and disease Collaborative Awards; GCRF Health and Context Panel).
- **NERC:** Bruford (Chair Panel C - Ecology and Evolution); and Durance (CDT and TPO funding Task and Finish Group).
- **BBSRC:** Harwood (Chair, Follow-on-Funding Committee; Impact Acceleration Awards [IAA]; GCRF IAA; and Neuroscience and Animal Behaviour Task and Finish Group); White-Cooper (Deputy Chair Responsive Mode Committee C; ad hoc work on Strategic LOLA and shortlisting and interview panels for the TDRF and BBR committees); Mahenthalingam (Core panel member Responsive Mode Committee B).
- **ESRC:** Harwood (Mental Health Network Advisory Guidance and Review Group).
- **UKRI Future Leader Fellowships:** John and Harwood (Sift and Interview Panels); Mahenthalingam (pool of reviewers).

Additional contributions to national and international bodies include Petersen (European Commission [EC], Board of Science Advice for Policy by European Academies and Co-ordination of Chief Scientific Advisors); T.H. Jones (BiodivERsA Panel – European funding for EC on biodiversity and ecosystem services); Ramji (International Academy of Cardiology) and Sengpiel (Physiological Society, Council Member).

4.4 Contributions to the Economy

Interactions with industry are supported by an Innovation and Partnerships officer, Ian Horton, and by institutional RIS services (Section 1.5; see Institutional Statement). More than 25% of Unit staff engage in a wide range of industry-focussed activity funding support for PGRs, service contracts and UKRI-industry partnerships. These range from Small to Medium Enterprise (SME) to global multinational companies, with a total award value of £7.4m for REF2021. Examples include:

- **SME partnerships:** Ramji worked with local SME Cultech Ltd (CASE PhD; £46.7K) to provide research evidence for their nutraceuticals reducing risks for inflammatory and cardiovascular disorders. Weightman is working with Volac on a Knowledge Transfer Partnership (2018-2021: £223K) using bacterial genomics to understand the diversity of bacterial strains in their commercial inoculants and improve silage production. This Innovate

UK-funded industry partnership specifically benefitted from our strategic investment in the Unit's Genomics and Biocomputing Technology Hubs (Section 3; Figure 3). Similarly, Young exploited his expertise and the facilities of the Protein Hub to work with Mikota Ltd to improve protein adjuvants used in vaccine and anti-cancer applications (£80K).

- **Working with global companies:** Unit researchers also have successful partnerships with global industrial companies. Mahenthalingam worked with Unilever Research and Development UK (total of £406K in awards) to improve standards of microbial identification associated with the costly contamination of industrial products (Mahenthalingam Impact Case). The Unilever projects were also facilitated by access to the Biocomputing and Genomics Technology Hubs (Figure 3). The Unit's expertise in neurosciences led to funding from Takeda Ltd (Harwood with colleagues in Medicine; £840K) and Boehringer-Ingelheim Pharma GmbH (Barde; £210K) for neurological drug development and screening.
- **Commercialisation:** During the REF2021 period, the School was successful in enabling spinout of **Cellesce Ltd** (currently valued at £15m), a company now based in Cardiff on the ground-breaking research of Dale in generating stable 3D colon cancer organoids (Dale Impact Case). The underpinning research was greatly enhanced by use of the Bioimaging and Single Cell Analysis Technology Hubs (Figure 3). Dale's interdisciplinary collaboration with engineers at the University of Bath enabled Cellesce to produce stable organoids cultures on a scale suitable for use in high throughput cancer drug discovery platforms.

4.5 Contributions to Society

Delivery of our Mission necessitates our researchers engaging with society to educate and deliver change, support for which is described in Section 1. Examples of societal benefit from the Unit in public health, policy, education and engagement of the general public are given below.

4.5.1 Public Health Delivery: Arising from our Research Theme 3: Molecular mechanisms of life and disease (Figure 1), we have delivered substantial impact for public health. Since 2014, Connor developed a close translational research partnership with PHW. To create a step-change in conventional diagnostic practice and implement a genomic strategy for pathogen diagnosis in Wales, Connor was granted partial secondment from 2017 onwards. His expertise enabled PHW to implement new clinically accredited, genomic-based, infrastructure and diagnostic pipelines to identify and track viral and bacterial pathogens. Genomic services for Influenza and HIV diagnostics are now live in Wales, are used by Public Health England, and provide real-time global scale tracking of influenza. These accredited viral sequencing and analysis pipelines were then directly translated to enable tracking of COVID-19 with impacts on Welsh, UK and international governmental policy (Connor Impact Case). The Unit's investment in the Genomics and Bio-compute Technology Hubs (Figure 3) were vital for beta-testing the diagnostic pipelines ahead of rollout in accredited public health testing. In addition, our researcher training in bioinformatics and data analysis led to PHW recruiting two staff from our postdoctoral (Bull) and postgraduate trainees (Southgate).

4.5.2 Policymakers

Working with policymakers is integral to impact from our Research Theme 1: Global Change. Bruford, Russo and Orozco-terWengel have led on international conservation programmes and policy for multiple endangered species with the International Union for Conservation of Nature (IUCN; Bruford Impact Case). Work from DGFC with the Sabah Wildlife Department led to multiple endangered species conservation policies being adopted by the Malaysian Government (Goossens Impact Case and Section 3.3.1). Durance and the WRI have worked with the Welsh Government, Welsh Water, and Natural Resources Wales to develop new policies for water sustainability in Wales. The WRI research strategies have also been adopted internationally within the African Cubango-Okavango river basin project to build sustainability and resilience internationally in the use of water (Durance Impact Case).

4.5.3 Public Engagement and Education

The Unit has an active public engagement programme supported by a dedicated officer, Wyllie (Section 1.5). Engagement with secondary school children is a particular focus, with the Unit supporting multiple events promoting science, technology, engineering and mathematics (STEM)

in local schools. For example, in 2016 our engagement activities reached 1,846 pupils, engaging schools from across Wales and two schools in England. These included Welsh-medium events via dedicated schools, and engagement of students from ethnic minority backgrounds and designated Welsh Deprivation areas. Multiple staff actively engage on their research with the public, and with our expansion in BBSRC awards (Section 3.1.2), these include UKRI-funded impact activities, for example Mahenthiralingam presenting to multiple schools on antibiotic resistance and discovery as part of his funded research. Notable contributions to public engagement were provided by:

- R. Jones presented three series of the successful BBC One programme "Rhys Jones's Wildlife Patrol,"; this was recognised with a BAFTA Cymru nomination (Best Presenter) in 2014. He also presented two series of "Rhys to the Rescue" on the BBC.
- Boddy worked extensively with the British Mycological Society education and outreach programmes to raise awareness of fungi and their role in global sustainability; this work was recognised in the 2019 Queen's Birthday Honours (see below).
- T.H. Jones educational work on ecological research was recognised in 2018 by award of the Scientific Medal at the National Eisteddfod for promotion of science through the medium of Welsh.

4.5.4 Indicators of Wider Influence

Prizes: Research leadership and Biosciences staff achievements have been recognized through external, prestigious fellowships, prizes, medals and awards. Illustrative examples include:

- Boddy was awarded an MBE for services to Mycology and to Public Engagement in Science (June 2019).
- Barde was elected Fellow of the Royal Society (2017), joining two other Royal Society Fellows within the School (Petersen, Davies).
- Ormerod was Chair of the Royal Society for the Protection of Birds (RSPB) from 2012-2017 and is currently RSPB Vice-President and Deputy Chair of Natural Resources Wales.
- Petersen received the American Physiological Society's 2018 Walter B Cannon Award, which is the top award offered by this international society.
- Borri's work in biophotonics (2015-2020) was recognised with a Royal Society Wolfson Research Merit Award (2015), joining Murray's ongoing award in plant systems biology (2012-2017).
- J. Harwood was awarded the Chevreul Medal by the Société Française d'Etude des Lipides, France in 2014 and also received the Morton Lecture Award (2016) by the Biochemical Society.
- T.H. Jones received the 2018 Scientific Medal National Eisteddfod.
- Bruford was awarded a Chinese Academy of Sciences President's International Fellowship (2018) and ZSL Marsh Award for Conservation Biology (2020).
- Martinez-Garay received the Burgen Scholarship Award (Academia Europaea) (2016).
- Connor and CLIMB received the major international HPCwire award for Best High Performance Computing Collaboration (2020) for its supporting role for the COVID-19 Genomics UK (COG-UK) Consortium.
- Multiple PhD students received external recognition for their studies such as Christofides (né Johnston) winning the Best Article of 2019 Award from the journal FEMS Microbiology Ecology.

Editorial Board Service: The Unit's researchers also contribute to the research base via editorial board contributions as follows:

Molecular mechanisms of life and disease:

- AIMS Cell and Tissue Engineering Advances in Regenerative Biology (Lelos)
- Stem Cells (Barde)
- Neurogenesis and Frontiers in Neuroscience (Martinez-Garay)
- Frontiers in Cell and Developmental Biology, and Developmental Epigenetics (John)
- Cell Calcium and Journal of Physiology (Petersen)
- Journal of Cardiology and Current Research (Ramji)
- Journal of Experimental Botany (Murray)
- Plant Molecular Biology (Murray)

Modelling and engineering living systems:

- Annals of Botany and Journal of Experimental Botany (Rogers)
- Reproduction (Swann)
- American Journal of Clinical and Experimental Immunology (Ramji)

Global change and its impacts:

- International Journal for Parasitology: Parasites and Wildlife (Perkins)
- Agricultural and Forest Entomology (T.H. Jones), Global Change (Jones)
- International Society for Microbial Ecology (ISME) Journal (Marchesi)
- Molecular Ecology (Symondson)

Interdisciplinary journals:

- Current Biology (Sengpiel and Petersen)
- Genetics and Genomics Next (John)
- Scientific Reports (Dewitte)

Closing statement

Cardiff School of Biosciences, Cardiff's UOA5 submission, is a vibrant centre for biological research, driven by its inclusive and supportive research community. We have created an environment that enables research excellence, innovation, impact and real-world change in the biological sciences. We have a clear mission to investigate the fundamental mechanisms of life, and utilise this knowledge to contribute to a healthy and sustainable world. We have focussed on three major biological themes (climate change; modelling and engineering living systems and analysis of molecular mechanisms), as key global challenges in which we have critical research mass and interdisciplinary expertise.

To deliver these objectives we have developed a research strategy (Section 1) that specifically aims to: support an inclusive research culture; expand our delivery of innovation and impact; and create internal enablers for research excellence, particularly at the interdisciplinary interfaces (Figure 1). We provide evidence that this strategy fostered greater research excellence and: (i) delivered positive change since REF2014 in our research culture and environment (Section 2); (ii) invested in technology, infrastructure and interdisciplinary skills to support current and future research (Section 3); (iii) enabled all our researchers to enhance their research output quality, income (Section 3) and their ability to deliver impact (Section 4).

Our strategy takes a long-term view, extending into the next REF period and is sufficiently flexible to meet the changing agendas dictated by the climate emergency, post-COVID-19 world, and the new era of data-driven biology and biomedicine. In the next period, we will:

- Build on our investment in the next generation of bioscience technologies and skills training to support all staff and PGRs.
- Implement our Athena SWAN 2020-2025 action plan for an enhanced EDI culture.
- Bring together new inter-disciplinary research teams via cross-cutting networks, further development of our University Centres of Excellence, and increased interaction with industry/stakeholder to deliver research translation.
- Provide research and leadership to address the biological aspects of global challenges of the next decade and beyond.