Institution: Keele University

Unit of Assessment: UoA5 Biological Sciences

1. Unit context and structure, research and impact strategy

Context, structure and strategic aims

Research in Biological Sciences at Keele, led by the School of Life Sciences (SoLS), has undergone a period of transformational change since REF2014. Substantial University and external investment in infrastructure and key strategic appointments have synergised a step change in research performance (e.g., **96% increase in average annual income compared to REF2014)**, strengthening capacity in specialist areas such as vector-borne diseases that gives the grouping its unique profile. Our principal aim is to address some of the world's major health and environmental challenges and to fulfil our mission to deliver the highest quality and most innovative research in biological sciences, while collaborating widely across disciplinary and geographical borders to ensure maximum long-term impact. Thus, research in UoA5 is strongly aligned with and forms a fundamental component of the University's interdisciplinary Research Institutes for Sustainable Futures and Global Health. Through our research strategy, aligned to the United Nations Sustainable Development Goals (UN SDGs), we have developed world-leading research in our three key research themes: **Applied Entomology and Parasitology**, **Molecular and Structural Biosciences,** and **Neuroscience**. Staff returned to UoA5 have led or contributed to high-impact research on infectious diseases (including malaria, viral infections and neglected tropical diseases), crop protection and food security, breast cancer, immune systems and neurology. This includes work by the multidisciplinary $96.5M Target Malaria consortium which aims to reduce disease transmission by the development of genetic technologies for modifying mosquitoes. Staff from the School are also returned in UoA3 (6 FTE), UoA12 (2 FTE) and UoA14 (1 FTE), with an emerging strength in glycosciences which spans the research interests of the School.

The rising trajectory of the unit compared with REF2014 is evidenced by the following:

- A 7-year research income since 2014 totalling £14,597,257, representing a **175% increase**, an **increase in average total income per year of 96%** and a **26% increase in income per year per staff member submitted**. UKRI now represents 38% of total income compared to 26% previously;
- A **64% increase in staff with significant responsibility for research being returned to UoA5** for REF2021 (19.4 FTE) compared to REF2014 (12.4 FTE);
- A **43% increase in PhD completions per year.** Biological Sciences at Keele was ranked 4th/44 for overall satisfaction in the 2019 PRES;
- Opening of the **new Attenborough Laboratories** (£11M) in 2019, together with internal investment of over £500K in new research equipment;
- Over £200K from the UKRI World Class Labs allocation to Keele University;
- Establishment of a **new Containment Level 3 facility** dedicated to arbovirus work (£800K), funded by a Royal Society Wolfson lab refurbishment grant and internal match-funding;
- Growth of the unit through 10 new strategic academic appointments

Research and contribution to the discipline since REF2014

The unit brings together staff from the Schools of Life Sciences, Chemical and Physical Sciences (SCPS) and Medicine in three research themes that align closely to institutional research priorities of sustainability and global health. SoLS has grown very substantially in size, both in research activity and in undergraduate teaching (total annual student intake increasing by over 100% since 2013/14). In accordance with our strategic plan, we have invested in key staff appointments, building on core capacity and increasing both critical mass and diversity of UoA5 substantially.

The strategic aims for UoA5 set out in REF2014 were to support and grow research activities, income and capacity in areas of strength within the unit and to develop long term impact as a direct result of this work. Identified areas for expansion were the biology of agriculturally important insects, both as vectors of disease and as beneficial insects; and the biology, transmission and pathogenesis of parasitic diseases (malaria, leishmaniasis and trypanosomiasis). We can evidence considerable progress in these areas (as described below), with strategic appointments, institutional investment in infrastructure and a large increase in research income. Our research has resulted in socio-economic, health, policy and social impacts through highly innovative approaches, as exemplified in our two impact case studies: 1) Sustainable pest management in crops: Improved traps for thrips and whiteflies (led by **Kirk**); and 2) Building capacity and infrastructure for controlling malaria transmitting mosquitoes in West Africa (led by **Tripet**).

Centre for Applied Entomology and Parasitology (10.4 Cat A Staff FTE)

Established over 25 years ago, the Centre for Applied Entomology and Parasitology (CAEP) is a world leading research centre for entomology and vector-borne diseases. Led by **Tripet**, the group demonstrates expertise across parasitology and virology, disease vectors and agricultural pests, from fundamental biology to the development of novel control strategies and new drugs. CAEP has an ethos of equitable local, national and international partnerships and capacity building and the theme strongly links to several UN SDGs (Zero Hunger, Good Health and Well-Being, and Life on Land). CAEP staff work with an extensive collaborative network across the UK, Africa, South America and Asia. Research in this theme has high translational impact, has resulted in multiple patents, licensing, and spinout activities (e.g., thrip traps described in Impact Case Study 1) and supports postdoctoral and postgraduate researchers both in Keele and globally. Strategic areas within CAEP can be categorised into two main areas:

- **The biology and control of agriculturally important insects**

This is discipline-leading in several aspects of crop sustainability, especially relevant to low-to-middle income countries (LMICs) in Africa and aligns with the Institute for Sustainable Futures theme Providing Food Security. With funding from UKRI, industry, and other sources (Agriculture and Horticulture Development Board), UoA5 staff have made significant advances on socio-economically important insects that are beneficial for or that threaten food-security, both as vectors of plant disease and crop pests. Projects include: (i) integrated pest management in strawberry crops; (ii) improving food safety by pesticide reduction in Kenya (SAFARI - GCRF/BBSRC) in partnership with the International Centre of Insect Physiology and Ecology (icipe); and (iii) management of thrips (Impact Case Study 1) using semiochemicals (within the Europe Australasian Thysanoptera Semiochemical Network). **Bruce** (appointed as a Professor in 2017) works on novel strategies for crop sustainability (BBSRC/NERC) (see **Bruce** *et al*, 2015, *Sci Rep* 5, 11183) and biological control of the potentially devastating fall armyworm. **Bruce** is driving a knowledge exchange system supporting UK growers in crop protection (CROPROTECT), developing smart cereals for management of stemborer pests in Africa (SCPRID) and managing beetle pests of field beans and peas (via an Agri-Tech Catalyst - Industrial Research Award).

- **The biology, transmission and pathogenesis of disease**

Research on parasitic and viral diseases aligns closely with Keele's Institute for Global Health and aims to generate knowledge and impact through the development and implementation of control tools for malaria, leishmaniasis, African trypanosomiasis and mosquito-borne arboviruses including dengue and chikungunya. As lead of the malaria group, **Tripet** is field entomology technical coordinator on the Target Malaria consortium, a non-profit organisation sponsored by the NIH and the Bill and Melinda Gates Foundation, of which **Galizi** is also a member. **Tripet'**s engagement with key stakeholders, including the UN, has resulted in policy changes on gene-drive technologies across Africa (Impact Case Study 2). His work has been instrumental in development of infrastructure and strengthening capacity for integrated vector management in Mali, Burkina Faso, Ghana and Uganda. Underpinning research projects have included functional speciation genomics of *Anopheles gambiae*, (supported by NERC, MRC and DFID) and the ecology and genetics of mosquito release, funded originally by a Wellcome Trust Programme grant in collaboration with the Malaria Research Training Center in Bamako, Mali. The latter includes application and uptake of gene-drive technologies to reduce vector fitness in malaria.

Horrocks and **Russo** study the human malarial parasite *Plasmodium falciparum* with a focus on the development of vitro approaches to support early pre-clinical drug discovery (e.g., Ullah *et al* 2019*, J. Antimicrob Chemother* 75, 362.

Price investigates fundamental biology and novel treatments for protozoan parasites *Leishmania spp.* and *Trypanosoma evansi* (a major pathogen of camels). Funded by the Wellcome Trust, MRC and Newton Fund, her work has included application of magnetic hyperthermia as a novel treatment for cutaneous leishmaniasis. **Price** is also co-lead with Keele anthropologist Dikomitis on a NIHR funded interdisciplinary programme (ECLIPSE) which aims to reduce stigma and improve the patient journey for cutaneous leishmaniasis, working with teams in Brazil, Ethiopia and Sri Lanka. **Wastling**, funded by BBSRC, researches protozoan and helminth parasites and focuses on host-pathogen interactions, vaccines and drug development. He has played a leading role in developing proteomic research in the field of parasitology, resulting in pioneering discoveries of novel invasion-related molecules of apicomplexan parasites and in developing systems biology approaches for understanding host-pathogen interactions.

Other recent strategic appointments have also expanded CAEP further. **Forrester-Soto** explores arboviruses of medical and veterinary importance, such as chikungunya, Dengue and Venezuelan equine encephalitis virus, aiming to develop new antivirals. **Galizi** applies advanced genetic research to generate novel molecular tools for the genetic control of disease transmission (e.g., Hammond *et al*., 2016, *Nat Biotechnol* 34, 78) using molecular and synthetic biology, functional genetics and genetic engineering such as CRISPR-Cas9.

Molecular and Structural Biosciences (MSB) (6 Cat A Staff FTE)
Launched in June 2019, MSB created a critical mass of complementary research interests via strategically appointed and existing staff. The theme incorporates expertise in protein structure, glycoscience (with UoA3 members), immunology, and cancer, and has collaborative links with world-leading institutions such as the Institut Laue-Langevin (ILL) in Grenoble, Public Health England, and the National Institute of Biological Standards and Control. The group have worked closely with members of CAEP on host-pathogen-vector interactions and the development of carbohydrate-based therapeutics, including drug repurposing for malaria and most recently for COVID-19.

Shrive focuses on the functions and interactions of key molecules of the innate immune system including pentraxins (C-reactive protein) and active fragments of collectins. The group has attracted substantial beam-time funding (£580K) for use of the Diamond Light Source facility in Oxfordshire. **Forsyth**'s group is at the forefront of studies of macromolecular systems using novel physical techniques such as neutron and X-ray scattering methodology at ILL and the European Synchrotron Radiation Facility (ESRF). Current projects with substantial funding (e.g., ILL award of £471,095 in 2019) include structural studies of DNA, DNA-drug interactions and DNA-protein complexes, and self-assembling systems of synthetic and biological origin (see e.g., Berger *et al*., 2015, *Nature Biotechnol* 10, 353). **Winter**, strategically supported by two internally funded PhD studentships, investigates collectins, linking to **Shrive**, and a *Leishmania*-specific galactokinase linking to **Price** in CAEP. She is developing collaborative projects with **Forrester-Soto** to work on arbovirus-host cell interactions. **Traore**, an expert cryo-electron microscopist works between Keele and ILL. His studies include solving the structures of molecules involved in the immune response and the genetics of pathogenic organisms, including development of antibiotic resistance. **Torode**, another recent appointment, has added strength in plant biochemistry and links to a wider cluster within SoLS on glycosciences. **Maarabouni**, funded by the Royal Society and international studentships, researches cell fate, cancer and cancer therapies. She has identified seven novel genes that regulate cell death, including GAS5, a major regulator of cell fate. Projects also include the role and identification of long non-coding RNAs implicated in human cancer (see Hudson *et al*., 2014, *Nature Commun* 5, 5395) and specific cellular and molecular mechanisms underpinning cell migration, invasion, and metastasis in triple-negative breast cancer lines.

Neuroscience (3 Cat A Staff FTE)
The neuroscience group have close links with colleagues in the neural tissue engineering group (UoA12). With internationally recognised expertise in electron microscopy, **Furness** studies functional aspects of hearing and age-related hearing loss. Funded by the BBRSC, his group provided definitive evidence for the localisation of the transducer channel and its accessory proteins in sensory hair cells, and collaborative studies of mutations in the channel (Beurg *et al*., 2019, *PNAS* 116, 20743), with potential impacts in global health and the over 300 million people who suffer from hearing loss. Neuroscience at Keele has been enhanced with new appointments of **Trent** and **Kishkinev**. **Trent** collaborates with Cardiff University on genomic studies in psychiatric populations, identifying synaptic 'risk genes' and the pathways and behavioural consequences of disease-relevant proteins. He discovered that Arc protein is a vital mediator of hippocampal-based fear memory and he uses a preclinical model of reduced Cyfip1 gene expression, mirroring psychiatric-relevant genetic deletions. **Kishkinev** broadens the neuroscience research base by focusing on animal migration and navigation and the role of different sensory systems required for the latter.

Future strategic aims and goals for research and impact
The vision for Biological Sciences at Keele University is to develop world leading research which addresses global challenges in areas of health and sustainability while producing quality outputs, delivering sustainable impact and building capacity across a range of sectors. Looking forward, our strategic aims include the following:

- **New strategic partnerships and collaborative projects**

The **Harper-Keele Veterinary School** has recently been established, with the first intake of undergraduates in 2020-21. There is a huge opportunity for growth and collaboration with the School of Life Sciences and their international partners, both in areas of existing strength (e.g., veterinary pathogens and therapeutics) and moving into new areas such as animal neuroscience and sustainable livestock management which will complement work across the three UoA5 themes. Collaboration across the two Schools and with the School of Medicine gives opportunities in developing innovative One Health approaches for controlling zoonotic infections and addressing major issues such as antimicrobial resistance. A new research cluster in animal behaviour, ecology and conservation will also link Life Sciences, Veterinary Medicine and the School of Geography, Geology and the Environment. The Head of Harper-Keele Veterinary School sits on the SoLS Research Committee, facilitating interactions between the two Schools while the veterinary research base becomes established. Strategic appointments in combination with focused networking and internal schemes for pump-priming joint projects will enable us to complement and strengthen key research themes that align to the priorities of the Institute for Sustainable Futures.

- **Building on areas of strength that give the unit a unique profile**

The solid foundation built from increased investment and new appointments will allow us to take forward a new phase of expansion in key areas within the unit. Mentoring and support of our new early career researchers by staff with a strong track record in research funding and project delivery will be key to further extend the trajectory evidenced since REF2014. The COVID-19 pandemic has demonstrated the critical importance of researching **emerging viral infections**. Key appointments (**Forrester-Soto, Galizi**) and the new Containment Level 3 virology facility at Keele gives the unit new opportunities to investigate mosquito interactions and genetics of arboviruses such as Dengue, the incidence of which has risen dramatically across Asia and Latin America over the last decade. Recently appointed staff in **structural biology** (**Traore**, **Winter**) with joint appointments between Keele and Institut Laue-Langevin have access to world leading infrastructure at Grenoble including cryo-electron microscopy, neutron instruments and the European Synchrotron Radiation Facility. There is also an emerging critical mass of research groups across the Schools of Life Sciences, Chemical and Physical Sciences and Medicine who work on **glycosciences and carbohydrate-based therapeutics** (e.g., Hyatt et al 2020, *Pathogen* 9, 935, with **Winter** on Dengue virus interactions with host glycosaminoglycans). These groups have the potential to lead innovation and translational research and to deliver high quality high impact research across all three UoA5 research themes. The Neuroscience theme is undergoing

a transition period following senior staff retirements. There are growing links between Neuroscience and the new Veterinary School and Schools of Psychology and Medicine and a new strategic position at Chair level is currently being recruited to lead expansion of this area of research.

- **Building impact through interdisciplinarity and stakeholder engagement**

Long-term sustainable impact will be maximised through robust interdisciplinary research and equitable stakeholder engagement, expanding on the existing Impact Case Studies (led by **Kirk** and **Tripet**) and developing emerging leads towards delivery of real-world change. The newly established Keele Centre for Food Security (co-led by **Bruce**) aims to work towards ensuring that everyone has access to the healthy nutritious food they need, using sustainable sources and methods (UN SDG2, Zero Hunger) in close alignment with the Institute for Sustainable Futures. The Centre links with CAEP interests in crop protection and will facilitate interdisciplinary partnerships between academics and key stakeholders at regional, national and international levels. Invasive pest species such as fall armyworm (a focus of **Bruce**'s BBSRC-funded work) cost US$1.4 trillion p.a. according to the UN food and agricultural organisation and control strategies must be co-developed across multiple disciplines and sectors to be effective. **Price** co-leads the £4.6M NIHR-funded ECLIPSE project on cutaneous leishmaniasis with Dikomitis, a leading medical anthropologist at Keele and partners in Brazil, Ethiopia and Sri Lanka. Both ECLIPSE and work by **Tripet** in the Target Malaria Consortium address UN SDG3 (Good Health and Well-being), strongly align with the priorities of Keele's Institute for Global Health and aim to deliver health, economic, policy and social impact in addition to generating new knowledge on human diseases. Expertise in public engagement and influencing policy within these teams will also be utilised broadly at School level to ensure that delivering and evidencing impact is built into new research proposals at the earliest stages.

Open research and research integrity

UoA5 is at the forefront of developing an open research environment. 100% of our research outputs are open access compliant for REF 2021, a process which began in advance of the current REF policy. The Unit works with partners to seek external funding for open research, and where this has not been possible, utilises Keele's research repository. Staff in UoA5 have been involved in developing and implementing the University's research data policy and were early adopters of the data repository (e.g. https://researchdata.keele.ac.uk/28/).

Staff have embraced the concept of pre-publishing with use of online resources, for example BioRxiv, to make data accessible prior to and after publication. This evidences a growing awareness of the importance of open research to the academic and wider community. Staff work with the central Project Assurance Research Integrity team to maintain policies and processes in relation to ensuring legislative compliance and adherence to professional standards.

Research integrity is a major element of UoA5's strategy and activity. UoA5 fully complies with all aspects of the Concordat for Research Integrity and with relevant University, national and international governance requirements and ethical oversight processes, in partnership with the Directorate of Research Innovation and Engagement (RIE). Major roles of UoA5 staff in this regard have been in the governance of animal research. For this REF period, the academic lead of the University's central animal facility (now the Biomedical Services Unit (BSU)), which supplies animals for research at Keele is submitted in UoA5. The role of the lead has been to ensure proper governance and due diligence in application of the Animals (Scientific Procedures) act of 1986, with subsequent amendments, and compliance with Home Office regulatory bodies. The Lead has also been the Named Training and Competency Officer for the unit, a member of the Animal Welfare Ethical Review Body, and with the Faculty Technical Manager, has been involved in line management of BSU staff. Other members of UoA5 have played key roles in University governance processes relating to genetically modified organisms, in radiation safety activities and the human tissue authority. UoA5 academics have served on University ethics committees. Beyond the university, UoA5 staff in Target Malaria consortium have worked with key stakeholders in leading the development of international regulatory structures and processes for the use of gene-drive mosquitoes, as evidenced in Impact Case Study 2.

2. People

Staffing strategy and staff development

The current submission for UoA5 comprises 14 males and 6 females, 19.4 FTE compared to 12.4 FTE in REF2014, a **64% increase in staff FTE returned**. Of the returned staff, 42% are early career researchers (ECR's). Since 2014, there have been 10 new academic appointments, representing more than 50% of UoA5, including staff from both the Faculty of Natural Sciences and the Faculty of Medicine and Health, each with the potential to contribute to one of the themes directly and to expand the overall scope.

Research in SoLS is strategically led by the School Director of Research (**Price**), who reports to the Head of School and the Faculty of Natural Sciences Associate Dean for Research through the School and Faculty Research Committees. The Director of Research is supported by the three research theme leads. In partnership with Advance HE, senior UoA5 staff have been trained in leadership based on the importance of their roles to the Faculty of Natural Sciences research mission. **Price** and **Bruce** are also members of the Keele Research Leaders Network, chaired by the Pro Vice-Chancellor (Research and Enterprise).

A focus on infectious diseases and crop protection has informed new strategic academic appointments in CAEP including two Chairs (**Bruce**, chemical ecology of insects; **Wastling**, protozoan and helminth parasites), one Readership (**Forrester-Soto**, arboviruses) and two Lectureships (**Galizi**, mosquitoes; **Russo**, malaria). The appointment of **Bruce** broadens the scope of CAEP to include new insect pests including the fall armyworm. Infectious diseases impact has been strengthened beyond malaria by **Forrester-Soto** into arboviruses and by **Wastling** into protozoan and helminth proteomics. We have expanded our remit in neuroscience through the appointment of two new ECRs (as Lecturers) with a focus on behavioural neuroscience. They will investigate models of schizophrenia and other neurological disorders (**Kishkinev**), and animal migration and navigation (**Trent**). Two further new Lecturers are joint appointments with ILL at Grenoble (**Traore**, cryo-electron microscopy; **Winter**, protein biochemistry) to expand our expertise in structural biology, strengthen links with Grenoble, and provide new pathways for staff to develop strong new research projects and postgraduate opportunities. The emerging research cluster in glycosciences is supported by appointment of one Lecturer to the MSB theme (**Torode**, plant biochemistry and glycosciences). The new positions also synergise with additional key appointments in SoLS in the areas of glycosciences and genomics (UoA3). Three of the new appointments in UoA5 are female, one appointed at Reader level. The newly appointed professorial Head of School of Life Sciences (Scott, UoA14) and School Director of Research (**Price**) are also both female.

The unit is committed to the principles enshrined in Keele's People Strategy. This strategy commits the university to principles of equality, diversity and transparency. To enhance diversity, we strongly welcome under-represented groups within recruitment of all academic and research staff. All staff are supported towards academic promotion through annual appraisals, research plans and promotion workshops. Promotions and appointments based on 'Research and Enterprise' depend on nationally and internationally leading excellence in research. Successful academic promotions in UoA5 since 2014 include the following: Professor (**Furness**, **Kirk**, **Tripet**), Reader (**Price**) and Senior Lecturer (**Maarabouni**, **Shrive**). In total, three female and three male academic staff have been promoted since 2014. Existing staff are encouraged to strategically develop their research careers through involvement in Keele's staff development programme.

Through the School-based Workload Allocation Model, research time is allocated to all staff who are defined as having Significant Responsibility for Research, according to the University's Code of Practice. Additional research time is allocated to staff with ongoing grants for research. Flexible and remote working, for example to support periods of grant writing, are integral to all staff activity and enable them to maintain a good work-life balance. The Unit is highly cohesive and supportive of each other, working together to make opportunities for individual teaching relief for short periods of leave (e.g., for conference attendance or external research visits).

Equality, diversity and inclusion

Keele is committed to EDI and holds an Athena Swan Bronze Institutional Award and a Bronze Race Equality Charter Award. The School of Life Sciences also holds a Bronze Athena Swan Award. The EDI Committee has representation from all categories of staff and PGR students and is balanced in membership in line with Athena Swan and Race Equality Charter principles. The committee's role is to ensure equal opportunities for members of SoLS, suggest improvements to school policies and act as a point of contact for anyone with concerns about LGBTQ+, gender, disability or racial inequalities. Staff complete a range of training activities, for example in awareness of protected characteristics, disability and unconscious bias. Regular training is mandatory for all staff involved in recruitment training, the Disability Confident Scheme is applied, and there is usually an observer present in interviews to check for unconscious bias. Future strategy is to promote continuing equality through actions such as targeted mentoring of staff from underrepresented groups, ensuring early career staff have strong support to meet career aspirations, through mentoring, supported research planning, training and funding opportunities. To have fair representation and develop inclusive strategies, the SoLS has EDI representatives and considers issues affecting all individuals on all committees that oversee issues relating to research activity. For example, the Health, Safety and Welfare committee oversees all aspects of safety in SoLS but also considers disability adjustments, mental health and wellbeing of staff. This committee includes a Mental Health officer who provides guidance and support directly to members of the school.

The REF2021 submission is highly inclusive and contains staff from diverse backgrounds. Their groups include PDRAs and PGRs from numerous countries that have contributed to research in the Unit, as evidenced in the outputs selected for submission which have multinational authorship (e.g., Epopa *et al*. 2017, *Parasit Vectors* 10, 376, based on work in Burkina Faso).

Support for ECR staff

UoA5 adheres to the principles of the UK Concordat to Support the Career Development of Researchers. This includes providing specific support for ECRs and postdoctoral research assistants (PDRA) and inclusion of early career staff on SoLS committees. Early and middle career research staff (PT and FT) are allocated a senior research mentor and develop an individual research plan (including research activities, outputs and grant applications) over both a 1-year period and the longer term (5 years). In line with the University's Academic Role Expectations, these plans are reviewed by the Head of School and Director of Research, and discussed in the annual performance review. The plans inform allocation of research time, research support and mentoring. These are also used to establish career goals, pathways to promotion and attainment, with appropriate advice given to staff at each level of their careers. New ECRs receive a £10,000 start-up fund and an increased fraction of their time for research compared with existing staff, reducing over a 3-year period (from 0.7FTE to 0.3FTE). This gives them dedicated time to establish research and springboard their research career.

ECRs have a School forum and a representative of the group sits on the SoLS Research Committee. PDRAs also have a forum and are represented in several committees. Staff are encouraged to engage with the Research Vitae via review meetings where their development needs are identified including opportunities for training and experience in line with career goals. This includes university wide research training and specific school training opportunities. Training in grant writing, management and leadership is provided by Keele's Academic Development Team. These programmes have contributed to the University's HR Excellence in Research award (renewed in 2020) and accord with the European Charter for Researchers and Code of Conduct for the Recruitment of Researchers. This sets out principles for good working conditions for researchers. In addition, GDPR training is mandatory for all staff.

This strategic support has led to some significant successes amongst ECRs. Merrick was appointed at Keele as a Lecturer and was awarded £1.7M European Research Council funding that enabled her to obtain a prestigious research position at the University of Cambridge. **Price** (appointed in 2013 as Lecturer and promoted to Reader in 2020) successfully obtained funding

for three major grants worth over £5M from the MRC, Newton Fund and NIHR and is now the Director for Research in SoLS.

PGR support, training and supervision

Keele provides a high quality and effective postgraduate research training environment. UoA5 has a thriving community of PGR students, with numbers steadily increasing since 2014. During the period from 2014 to 2020, the total number of active PGRs in SoLS was approximately 95 (some registered before and some during the period). **PGR awards (48 in total) have doubled compared to REF2014** (24), with the average number of awards per year increasing from 4.8 to 6.9, an increase of 43%. The increase in total awards reflects not only the expansion and addition of research groups within UoA5 but also continued success in recruitment and completion. Faculty of Natural Sciences scholarships are available on a competitive basis and UoA5 has attracted the highest proportion of these in the faculty. External funders for PGR scholarships have included the following: Ministry of Social Justice and Empowerment, Government of India, Petroleum Technology Development Fund, Iraqi Ministry of Higher Education and Scientific Research (MOHESR), Higher Committee for Education Development in Iraq, Target Malaria, Action on Hearing Loss, Nigerian Tertiary Education Trust (TET) Fund and Institut Laue Langevin (ILL).

We had an excellent response in the national **Postgraduate Research Experience Survey 2019**, in which Biological Sciences at Keele was ranked fourth (out of 44) for overall satisfaction, second place for professional development, third for research skills and fourth for supervision.

All PGR students are members of the Keele Doctoral Academy (KDA), launched in April 2020, which provides a unified platform for PGR support, including implementation of the Postgraduate Code of Practice. As well as the KDA, PGR support for UoA5 is provided at faculty level by the PGR Director, and at School level by the PGR academic coordinator who reports to the Faculty PGR Committee and the School Research Committee. Student progress is monitored at regular milestones throughout their studies by a robust and transparent process as documented in the University's PGR Code of Practice and the Faculty PGR handbook. All PGR students develop a training plan as part of their Personal Development and Learning Plan. A **dedicated consumables budget** is provided by SoLS for all PGR students, including those who are self-funded. The Faculty of Natural Sciences has a dedicated **training fund** for PGRs for internal events (e.g., workshops in R and scientific writing) and attendance of external training courses. PGRs representatives are members of committees across SoLS, including the Research Committee, to aid communication and give a voice to the PGR community at the decision-making level.

3. Income, infrastructure and facilities

Research income

UoA5 has had considerable success in growing its research income, as a result of focused investments and recruitment and development of a cohesive, supportive and collaborative research culture. Research income has shown significant growth: 175% increase to £14.6M since REF2014 (on average, 96% higher each year than REF2014). This reflects a strong portfolio of UKRI grants (BBSRC, MRC, GCRF, EPSRC) which now represent 38% of total income (compared to 26% in REF2014). Additional funding sources include the Wellcome Trust, Royal Society, EU and government funding through the British Council (Newton Fund) and NIHR, amongst others. Research income in kind totalled £2,320,396.

The unit has been particularly successful in attracting funding in the areas of applied entomology and food security (aligning with Keele's Institute for Sustainable Futures) and infectious diseases (aligning with the Institute for Global Health). **Tripet** has attracted substantial third sector funding from the Gates Foundation and Open Philanthropy Project Fund of the Silicon Valley Community Foundation, which provide core funding for Target Malaria ($96.5M in total for this consortium, with $4.1M for Keele, plus additional PhD studentships worth £231K). Aligning with global health and social inclusion themes, **Price** has, for the first time in UoA5, obtained NIHR funding (total £4.6M) to support the interdisciplinary ECLIPSE project on cutaneous leishmaniasis, which is co-

led by anthropologist Professor Lisa Dikomitis from Keele's School of Medicine and now employs over 60 people across four continents. **Kirk** has obtained funds from BBSRC, Nigerian Government, industry (Russell IPM Ltd), Innovate UK, and Defra, totalling £588K. The appointment of **Bruce** in 2017 led to income in excess of £1M primarily from the BBSRC. Horrocks has obtained funding from a range of sources (including PhD studentships from the Governments of Nigeria and Iraq) totalling over £200K. The Government of Iraq has awarded several PGR studentships to Maarabouni and Shrive totalling approximately £350K over the period. New ECRs in UoA5 have recently secured funding from the Halley Stewart Trust, Ocean Conservation Trust, Rail Safety and Standards Board (RSSB) (Torode) and the Leverhulme Trust (Kishkinev).

Major grant successes include:

- Bill and Melinda Gates Foundation: Target Malaria (**Tripet**, $1.7M, total award $79M)
- Silicon Valley Community Foundation: Target Malaria (**Tripet**, $2.4M, total award $17.5M)
- BBSRC: Development and Bioactivity Testing of Novel Nanotech Formulations of Plant Secondary Metabolites: A contribution to biorational control of crop pests (**Bruce**, £244,536)
- BBSRC: Hijacking plant immunity: winners and losers in dual pest and pathogen attacks on a shared host (**Bruce**, 280,082)
- BBSRC: Enhancing crop diversity and ecosystem services to promote biological control of fall armyworm in smallholder cropping systems (**Bruce**, £328,418, total award £1,104,433)
- BBSRC: Improving food safety by reducing pesticide residues: developing a pheromone alternative to insecticides for control of thrips on legumes in Kenya (**Kirk**, £455,334)
- BBSRC: Localisation of the mechanotransducer channel and its accessory proteins during development of cochlear hair cells (**Furness**, £370,194)
- MRC: BBSome trafficking: investigating a novel pathway associated with virulence in *Leishmania* (**Price**, £445,635)
- EU Horizon 2020: DNA dynamics in the unusual cell cycle of the malaria parasite *Plasmodium falciparum* (PlasmoCycle) (Merrick, £174,844, total £1,262,300) – now at University of Cambridge
- NIHR: Empowering people with cutaneous leishmaniasis: intervention programme to improve patient journey and reduce stigma via community education (ECLIPSE) (**Price** and Dikomitis, £1,662,035, total award £4,576,819)
- Knowledge Transfer Partnership between Keele University and Russell IPM Limited - Government Contribution (**Kirk**, £161,177)
- Ifakara Health Institute: Population biology and genomics studies on *Anopheles funestus* in Tanzania (**Tripet**, £163,932)
- Royal Society: State-of-the-art Containment-Level-3 Facility for Arboviruses and Parasites functional studies (**Tripet**, £249,500)
- British Council (Newton Fund): Investigating drug resistance and new treatments for *Trypanosoma evansi* infection in Egyptian camels (**Price**, £156,896)
- Wellcome Trust: Nanoparticle-induced Hyperthermia as a Novel Therapy for Cutaneous Leishmaniasis (**Price**, £92,606)
- Institut Laue Langevin: The development of neutron diffraction at the ILL for the study of biological and industrial polymers (**Forsyth**, £471,095)

Internal funding schemes

The unit's three research themes perform a strategic role in setting the future direction of research activity and research income generation, aligned to the wider institutional research priorities. SoLS has a strong collaborative ethos, both within the School and with the wider academic community and strategic internal funding is offered at multiple levels at Keele to build networks, pump-prime research, enhance outputs and accelerate impact.

SoLS has a range of internal funding schemes, including a competitive pump-priming fund to support the generation of preliminary data for grant applications; an output enhancement fund for existing projects; and funding for conference attendance and networking. The research re-

engagement fund supports staff returning to work from a period of extended leave (e.g., parental leave) and links to the School's equality, diversity and inclusivity (EDI) strategy. A total of £40,000 p.a. has been set aside for these streams. Internal school funding is open to all research staff and typically prioritises ECRs. For example, the school's PhD funding scheme prioritises ECR's linked with established supervisors for training in supervision. At the Faculty level, funding is offered via small internal awards and PhD studentships to enable development of new projects. These prioritise development of industrial and third sector links (e.g., Target Malaria). As a result of the pandemic, funding has been made available for research recovery and resilience, which has been used to support extensions of UKRI-funded work in CAEP. At the institutional level, Keele has provided Impact Acceleration funding that has been important for the development of UoA5's Impact Case Study 1 (Sustainable pest management in crops: Improved traps for thrips and whiteflies, led by **Kirk**) by funding industrial networking activities that promote socio-economic impact. Keele also supports interactions with local business in Staffordshire through Keele Research and Innovation Support Programme (KRISP), under which SoLS has two projects, and acceleration of local socio-economic developments via the Keele Deals programme. The University has a pump-priming scheme for new collaborations with partners in LMICs through QR GCRF funds; recent awards have strengthened UoS5's interdisciplinary links in Brazil, Tanzania and South Africa.

Infrastructure supporting research and impact

UoA5 received significant financial investment from Keele University during this REF period for a new build, the Attenborough Laboratories (£11M) which was opened in 2019. An initial £3.75M investment from the HEFCE STEM Initiative was boosted by a £6.75M investment from Keele University for the build plus £500K for equipment, greatly increasing both research and teaching capacity. Additional strategic investment by the University in SoLS has focused on supporting key areas in crop protection and infectious diseases in CAEP (requiring specialist containment facilities) and increasing capacity to expand activities on glycosciences and neuroscience.

UoA5 staff have access to a **dedicated insectary facility** for work on agricultural pests and insect vectors of disease. The suite includes licenced facilities for fall armyworm, behavioural chambers, Y-tube olfactometers for chemical communication studies, GC-MS and LC-MS platforms. Derogated **Containment Level 3 facilities** are available for the culture and genetic manipulation of **human and animal infective protozoan parasites** (*Plasmodium*, *Leishmania* and *Trypanosoma spp.*). We have recently opened a **new secure Containment Level 3 facility for work on arboviruses**, with HSE approval to perform virus cultivation, genetic manipulation and infection of mosquitoes. This suite was funded by a Royal Society Wolfson grant (£250K) led by **Tripet** together with substantial match funding from Keele (£550K). This has allowed us to establish a new strand of work on mosquito-virus interactions and has also enabled work on COVID-19 in response to the pandemic. The new facilities make Keele one of a handful of UK institutions with the capacity to undertake research on major emerging viral diseases such as Dengue fever and chikungunya.

The School's **proteomics suite** includes fully equipped biochemistry labs, in-house x-ray crystallographic data collection facilities and mass spectrometry facilities including MALDI-ToF/ToF and ESI-MS/MS. Researchers are able to **access synchrotron beam time** via the structural biology PIs at both Diamond Light and Grenoble ESRF/ILL. Research capacity has recently been strengthened by allocation of UKRI World Class Labs funding (£145K) to purchase a **Circular Dichoism spectrophotometer and a surface plasmon resonance system for glycosciences**. The acquisition of this equipment will make the facility internationally leading in terms of carbohydrate-protein interaction studies, with broad potential application across the three themes of the unit.

Essential infrastructure for in vivo models is provided by the **animal facility** (BSU), where primarily rodents (including GM mice) are bred and maintained. This facility has exceptional standing with the Home Office for the quality of animal welfare, supported by an active and well-trained staff of four. A recent allocation of UKRI World Class Labs funding (£69K) has enabled essential upgrades to the infrastructure of the facility and the **purchase of new surgical, cognition and motor**

function equipment. The neuroscience theme also benefited from substantial investment in **specialist electrophysiology equipment** as part of the School expansion in 2019.

UoA5 runs an **electron microscope (EM) Unit** housing two-photon/confocal imaging, two transmission electron microscopes and a high-resolution field emission scanning electron microscope. Staff across both Faculties of Natural Sciences and Medicine and Health use these facilities. The EM Unit implements a cost-recovery strategy that includes internal research rates and higher external and commercial rates. The external income supports UoA5 staff by offsetting the cost of internal equipment use and improving the infrastructure in the facility.

The facilities available to staff in the School were enhanced by the signing (in 2017) of a MoU with the **Liverpool Technology Directorate** that provides access to state-of-the art facilities in imaging, protein production, proteomics and bioinformatics support. In addition, Keele is a member of the Midlands Innovation (MI) group of 8 research intensive Universities across the Midlands region of England and staff are eligible to apply to the **technician-led MI Equipment Sharing Fund** for access to specialist facilities across the partner institutions.

Organisational support for research and impact
Research is managed at the School level by the Director of Research, with oversight on strategic development by the Head of School and SoLS School Research Committee. Integrated support is provided by the central Research and Innovation Support Enhancement (RaISE) team, which was established in 2017 to bring together professional services staff with expertise in research development, governance, integrity, ethics, contracts, public engagement, commercialisation and impact. The team provides support for the development and management of research and innovation projects involving Keele University and its external partners. Establishment of the RaISE team has enabled a joined-up approach to research and innovation support, helping us to improve the quality and effectiveness of our research proposals, implementation and impact, and to work effectively across Faculties.

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

National and international collaborations, networks and partnerships
Staff in UoA5 have a strong network of multidisciplinary partners at national and international levels, operating within academic and commercial sectors. Keele's Directorate of Research, Innovation and Engagement (RIE) provides expertise in partnership development, proper governance, contractual arrangements and protection of IP. For collaborations with LMICs, each Faculty at Keele has a GCRF Lead (currently **Bruce** for Faculty of Natural Sciences) who advises colleagues on equitable partnerships, ODA compliance and due diligence.

In UoA5, **industrial partnerships** have developed, and commercialised basic science activities as exemplified in UoA5's Impact Case Study 1 (Sustainable pest management in crops: Improved traps for thrips and whiteflies, led by **Kirk**). This involved a collaboration with Russell IPM (who recently received the Queens Medal for Industry) to develop novel methods for pest management, funded by a Knowledge Transfer Partnership grant from Innovate UK. **Kirk**'s commercial links with Syngenta and Russell IPM has led to patents and products sold across the world for the control of crop pests (e.g., Patent WO/2003/055309).

Our staff collaborate widely with institutions across the UK and **Shrive** is a lead on the Midlands BAG consortium for the use of Molecular Biology facilities at Diamond. We have **strong connections within Europe, particularly with the Institut Laue-Langevin (ILL)** in France, the world's leading facility in neutron science and technology, which attracts significant EU funding. Three staff in UoA5 (**Forsyth**, **Winter** and **Traore**) have joint appointments with ILL and we have joint PhD studentships between the two institutions. We have also developed **strong links with partners in USA and in the Global South**, including regions where malaria and leishmaniasis are endemic. We have MoAs with São Paulo State University (UNESP) in Brazil and University of Ghana to facilitate partnerships.

In **CAEP**, **Tripet** is the entomology lead for the Target Malaria Consortium and has major international links through networking and capacity building projects with partners including the University of Sao Paulo, Institut de Recherche en Sciences de la Santé, Burkina Faso; Ifakara Health institute, Tanzania; Center for Disease Control, USA; Manatee County Mosquito Control District; Bonds Consulting Group, USA; and Sumitomo Chemicals Ltd, Japan. **Galizi** is also a member of the Target Malaria Consortium and has international collaborations with Harvard Medical School, Helmholtz Centre for Infection Research and Massachusetts General Cancer Center. **Kirk** and **Bruce** lead projects with colleagues from *icipe* (Kenya) and UNESP (Brazil), addressing the global challenge of sustainable crop protection. **Price** has links with Alexandria University in Egypt via a Newton Fund/Mosharafa Institutional Links grant to study *Trypanosoma evansi* parasite in camels. This enabled establishment of the first parasite culture facility in the Faculty of Veterinary Medicine in Alexandria and allowed six researchers to receive training at Keele. **Price** also has collaborations with India (EPSRC/GCRF, led by Durham) for a study on the acceptability of drug formulations for treating visceral leishmaniasis. Her NIHR-funded interdisciplinary ECLIPSE project involves collaborators and multiple stakeholders in Brazil, Ethiopia and Sri Lanka. **Horrocks** collaborates with partners at Charnwood Molecular Ltd, and at the Universities of Massachusetts at Lowell and California at Riverside.

In **Molecular and Structural Biosciences**, **Maarabouni** has collaborations on long non-coding RNAs/RNA-protein interactions with Emory University and University of Texas. In **Neuroscience**, **Furness** collaborates with colleagues in Portland (OR), Wisconsin-Madison (WI) and Case Western (IL) (USA) on auditory function and recovery following hearing loss. This work includes novel gene therapy approaches that could have a future impact on reducing hearing loss globally.

Our strong national and international collaborations, networks and partnerships have been crucial for maintaining **high-quality, high-impact publications**. This is evidenced by publications in prestigious journals, including Nature Climate Change (**Bruce**), Nature Communications (**Forrester-Soto**, **Galizi**), Nature Nanotechnology (**Forsyth**), Nature Communications (**Galizi**, **Maarabouni**, **Traore**), Nature Genetics (**Wastling**), Science (**Russo**), PLoS Pathogens (**Horrocks**) and PNAS (**Russo**, **Wastling**).

We have contributed to the research base of Biological Sciences through engaging in **peer review, editorships and editorial board memberships of international journals**. Staff in UoA5 contribute to journal review, editorial boards and grant reviewing bodies. Indicative examples include reviewing grants for MRC, BBSRC, ERC, British Council (Newton Fund), multiple UK and international charities, the French National Research Agency (ANR) and la Caixa Foundation. Journal editorial positions include but are not limited to: **Furness** (Section Editor for NeuroReport and a member of the Editorial Board of Scientific Reports); **Kishkinev** (Associate Editor in BMC Ecology journal 2016–18); **Forrester-Soto** (permanent member of the Vector Biology Study Section for the NIH and Academic Editor for PLoS One); **Price** (Deputy Editor for PLoS Neglected Tropical Diseases); **Wastling** (Editor for Parasitology). Our staff have also contributed to **learned societies**, including the following: **Furness** was Secretary of the British Society of Audiology for 6 years, engaging with clinical and public audiences across the UK with seminars, and showcasing elements of research via their magazine, Audacity and other ENT magazines. **Price** has been a member of Council for the British Society of Parasitology (BSP) since 2015 and is currently the Honorary Communications Secretary. **Horrocks** was also formerly the General Secretary for the BSP. **Winter** is on the Training Theme panel of the Biochemical Society considering future training needs.

Our work has included **public engagement and science communication** on many levels. During the pandemic, virologist **Forrester-Soto** has provided many radio and TV broadcasts about coronavirus, including on BBC's Newsnight. Hearing research by UoA5 staff has been featured in broader science magazines such as Scientia. Many staff participate in outreach activities, taking science out to local schools and colleges and the public, e.g., exhibitions at the Potteries Science Festival and Stoking Curiosity Festival (**Price**). **Maarabouni** has worked with a school to apply for a BA Goldcrest award on apoptosis, and **Furness** hosts school visits to demonstrate electron microscopes. Recent exhibitions at the Victoria and Albert Museum in London (**Furness**) have

brought the research in hearing into the wider public. At the University level, **Price** was a co-investigator on an RCUK **Public Engagement with Research** (SEE-PER) project, led by Keele's PVC for Research & Enterprise. This project aimed to embed public engagement with research into University practice and achieved significant improvements as evaluated by the NCCPE's EDGE tool.

We have provided **expert advice through knowledge exchange** and our research **impact on practice, policy, economy and society** ranges from commercial benefits through development of crop-pest control (Impact Case Study 1), through increasing crop sustainability and reducing economic losses, to reducing health costs associated with vector borne diseases. **Wastling** is one of seven experts appointed to the Science Council, an independent committee of the Food Standards Agency (FSA) which provides high-level, strategic advice to the FSA's Chief Scientific Adviser and to the Board and executive of the FSA. **Bruce** has been invited to comment on BBSRC policy on crop protection, presented his research on food security and sustainability to the House of Commons Science and Technology Committee and provided written evidence to the Advanced Research Projects Agency. **Forrester-Soto** has given evidence to the UK Government on the coronavirus pandemic. **Tripet'**s engagement with key stakeholders, including the UN, has dramatically improved perceptions of gene-drive technologies for malaria, resulting in policy changes across Africa (Impact Case Study 2). His work has been instrumental in development of infrastructure and strengthening capacity for integrated vector management in Africa, notably the construction or refurbishment of core facilities for gene-drive mosquito containment in Mali, Burkina Faso, Ghana and Uganda.