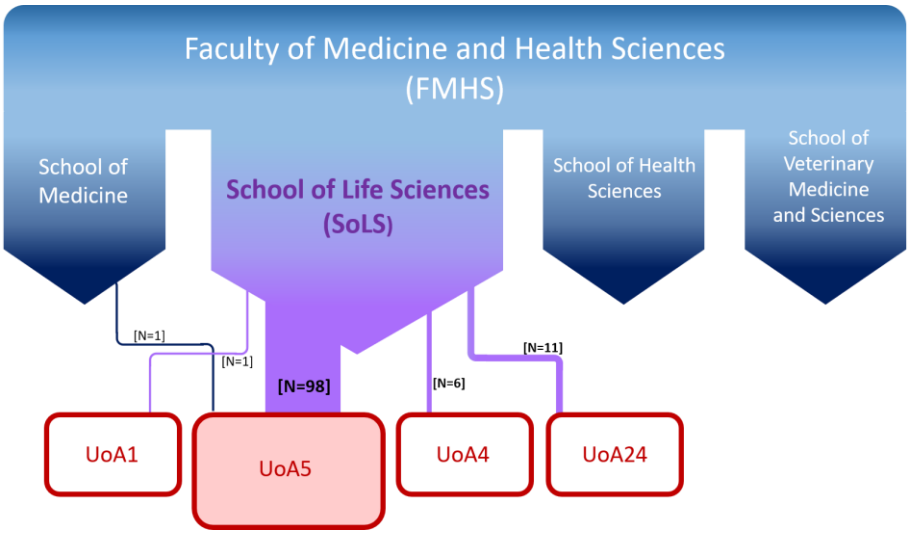
Institution: University of Nottingham

Unit of Assessment: A5 (Biological Sciences)

1. UNIT CONTEXT AND STRUCTURE, RESEARCH AND IMPACT STRATEGY

1.1 Context and Background

UoA5 at the University of Nottingham (UoN) is composed almost entirely of members of the **School of Life Sciences** (**SoLS**), a vibrant multi-disciplinary School in the Faculty of Medicine and Health Sciences (FMHS), with over 400 members of staff and more than 330 PGR students. The majority of Category A research staff in SoLS are returned in UoA5 (Biological Sciences, Main Panel A), with a minority having a strategic fit with other units.



1.1.1 UoA5: Review of the Research Strategy in REF2014

The UoA5 research strategy presented in REF2014 set out to maximise collaborative research, focused on both fundamental and applied research questions at a local (University), national and international level. This UoA5 strategy was further developed following the 2016 SoLS Review of Research by the UoN chaired by Prof John Atherton, Pro-Vice Chancellor for FMHS, and advised by three external leaders in Biomedical Science: Prof Susan Brain (KCL), Prof Nick Hastie FRS (Edinburgh) and Prof Deborah Smith OBE (York). Over 60 practical recommendations provided a framework for the research strategy for SoLS and UoA5, with implementation led by Prof Victoria Chapman. Key steps were to refresh leadership and research focus; to assess research performance focussing on existing areas of success; to ensure long-term planning to balance research and teaching; and to initiate succession planning for longer-term future research and impact success. Strategic priorities were identified and positive action directly relevant to UoA5 followed:

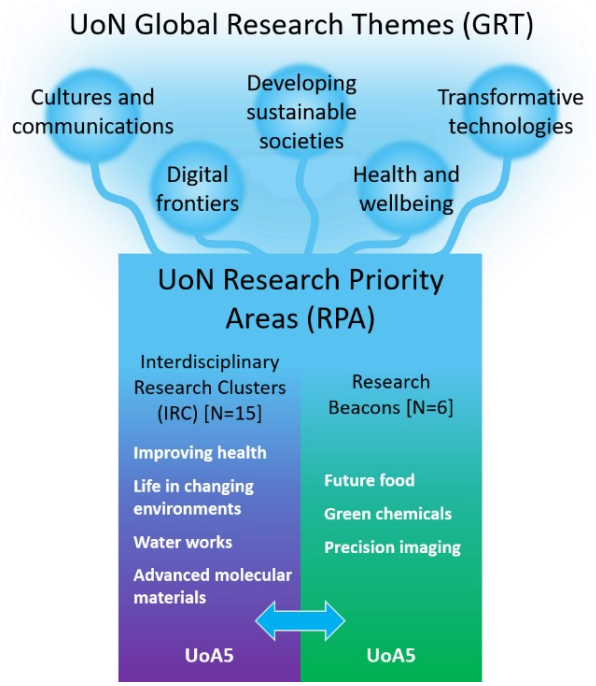
- External recruitment of a new Head of SoLS with a leading research profile, with the appointment in February 2018 of Prof James McInerney, formerly Director of the Evolution, Systems and Genomes Research Domain at the University of Manchester.
- Structural reorganisation: a simplified research organisational structure with three core Research Divisions was created to enhance cohesion within and between UoA5 research and UoN Centres (Future Food and Green Chemicals Beacons, SBRC, COMPARE, BDI – details below).
- Investment in a new ambitious academic staffing strategy (details in Section 2, *People).* A total of 21 R&T academic posts (~20% of UoA5 headcount) including four tenure-track

fellowship appointments (below) were recruited post-2016 in key areas relevant to UoA5, underpinned by Faculty budgetary agreement and future planned staff departures.

- Investment in current academic research success through the buy-out of teaching time *via* a UoN Research Strategy investment. The Research-Enabling Flexible Teaching Support programme (funded by the University Research Committee in partnership with the FHMS) supported five 2-year teaching fellows in core areas underpinning UoA5 research.
- Introduction of the Wellcome Prime Institutional Strategic Support Fund (ISSF) scheme at UoN to support the most productive and innovative members of academic staff at earlier stages of their careers, who UoA5 will develop to become our future generation of research leaders (Section 2.1).
- Implementation of a proactive campaign to attract Nottingham Research Fellows (NRFs) and Anne McLaren Fellows (AMFs, for outstanding female scholars in STEM), as part of a sustainability strategy to recruit high-profile tenure-track early career external academics with a strong fit to UoA5 (Section 2.1).
- Investment in a dedicated Research Development Team at School/UoA5 level: Appointment of a Research and Business Development Manager (RBDM), Impact Development Coordinator and Research Support Officer, collectively to support external funding applications and development of impact relevant to UoA5. A Faculty RBDM, Faculty Research Strategy Manager and Faculty Impact Officers were also appointed to provide joined-up support to all UoAs across the Faculty.

1.1.2 Embedding UoA5 Research Strategy Within the Wider University Context

The current FMHS governance structure includes a pro-active role for the Associate Pro-Vice Chancellor (APVC) for Research, supporting the SoLS Directors of Research to develop and monitor the UoA5 research strategy. UoA5 strategy is aligned to FMHS and UoN research strategies, maximising opportunities for investment arising from University-wide research initiatives. Examples of UoN research strategy actively engaged by UoA5 include: the UoN grant academies for BBSRC, NERC and Wellcome applications; investment in 100 tenure-track Research Fellows (NRF and AMF) to establish the next generation of research leaders; and the creation of the Beacons of Excellence. The diagram summarises how UoA5 research integrates into the broader UoN research strategy and structures:



A total of six UoN interdisciplinary **Research Beacons of Excellence** [*ILS2.1 = cross-reference to Institution-Level Environment Statement, Section 2.1*] each address UN Sustainable Development Goals, and act as foci for innovative cooperation between internationally-competitive UoN research groups. UoA5 members contribute leadership to both the **Future Food Beacon** (Yant, Loose) and **Green Chemicals Beacon** (Minton), and play active roles in the **Precision Imaging for Medicine Beacon** (Irving, Serres).

The University also defined five **Global Research Themes (GRTs)** with interdisciplinary **Research Priority Areas (RPAs)** providing a vehicle for cross-School and Faculty investment at the grass-roots level, pump-priming new areas of research and building future research capabilities. As selected examples of UoA5 environment enabling research

developments, the **Antimicrobial Resistance RPA** catalysed the recruitment of new UoA5 academic Griffin, (2017, vaccine research), the establishment of a £1.2M **NBIC (National Biofilms Innovation Centre**) unit branch at UoN (led by Camara, Section 1.2.2 below), and the award of a £1.18M Wellcome Antimicrobials and Antimicrobial Resistance DTP PhD programme (2017, led by Williams, Section 2.3.2). The **Industrial Biotechnology RPA** (led by Minton) was the background to the recruitment of Heap as Associate Professor (2019) and Blount as Nottingham Research Fellow (2020).

In 2019, 15 UoN broad-based **Interdisciplinary Research Clusters (IRCs)** evolved from the RPA structure [*ILS2.1(a)*]. **Life in Changing Environments** is led by UoA5 (Avery). UoA5 contributes to **Improving Health in Contemporary Society, Water Works and Advanced Molecular Materials.** Engagement with the RPAs and now the IRCs is an important mechanism for UoA5 researchers to build new discipline-spanning collaborations across UoN. In the REF period UoA5 was awarded a total of £424K through the RPAs for interdisciplinary research; in addition, the University-wide UNICAS scheme, pump-priming interdisciplinary equipment for academics and ECRs, funded 8 projects across UoA5, mainly to ECRs. The UNICAS Interdisciplinary Research sandpit events funded basic and translational research in diverse areas, ranging over microbiology, wound healing, virology, zoology, evolutionary biology and ecology.

1.1.3 UoA5: Innovation and Knowledge Exchange

Industry engagement and collaborative interdisciplinary research is embedded across SoLS research Divisions and many of the UoA5 research groups, both with UK-based and EU/International businesses, including Unilever, DuPont, Oxford Nanopore Technologies, Allergan, GSK, Novartis, Promega, Pfizer and Gilead Sciences. External funding for translational and applied research totals over £5M for the period (Section 3), with a broad portfolio including from RCUK, charities, EU and other funders as well as direct research funding from companies. Innovate UK funding supports research in partnership with SMEs/industry, including projects with Chain Biotechnology Ltd, DeepBranch Biotechnology Ltd and Green Biologics Ltd (Minton), Ozo Innovations Ltd (Avery), and Unilever (Williams).

UoA5 holds a portfolio of 11 patented technologies and current research on patents/patentable projects will lead to future impact including further spin-out companies and licensing opportunities, managed through the impact pipeline by our Research Development Team. Current patents include those derived from research into small-molecule therapies for myotonic dystrophy (Brook), therapeutic and other applications of novel materials based on spider silk (Goodacre), novel combinations of agents for targeting microbial pathogens (Avery, [*REF2021ICS* (*=REF2021 Impact Case Study*)]), bacterial expression systems and Clostridia-directed enzyme prodrug therapy (Minton, Heap), controlling bacterial attachment to surfaces (Williams, [*REF2021ICS*]), biomarkers for *Pseudomonas aeruginosa* (Camara, Williams), bioinstructional materials (Ghaemmaghami), and therapeutic applications of targeting mannose receptors (Martinez-Pomares).

Hill launched CellAura Technologies in 2008 built around the use of fluorescent ligands as alternatives for traditional radioligand binding assays. Recent advances include new assays combining fluorescent ligands (for G-protein coupled receptors, GPCRs and receptor tyrosine kinases, RTKs) developed in Nottingham with the NanoLuc technology in partnership with Promega [*REF2021ICS*]. Highly sensitive and specific nanoBRET assays have been devised for binding to cell surface receptors. Bates and Donaldson spun-out Exonate Ltd in 2013 focused on

exploiting VEGF as a drug target for the treatment of wet macular degeneration. Total funding to the company amounts to £9.1M and Exonate holds two patents on novel VEGF-based agents. A collaboration between Exonate and Janssen Pharmaceutical to develop new eyedrops for retinal vascular disorders based on their technology was announced in early 2020 [*REF2021ICS*].

Dyer's research on fungal mating genes resulted in the development of novel strains for the blue cheese industry and the recent formation of a spin-out, Myconeos, producing products to be sold to the dairy industry. Charlton holds a joint appointment between UoN and OMASS Therapeutics (as Vice President Pharmacology) which uses high-resolution native mass spectrometry to drive drug discovery. Charlton and Holliday hold joint appointments between UoN and Excellerate BioScience (founded by Charlton) - a contract research organisation that specialises in developing cellular and molecular pharmacology services to the pharmaceutical industry. These appointments allow rapid transfer of knowledge and expertise, and commercial opportunities between academic and industrial environments. UoA5 also hosts a Royal Society Entrepreneur-in-Residence (Chris Finnis, Research Director of Phenotypeca), based in the SBRC (Section 1.2.3 below), to improve dialogue between academia and industry and support newly-founded companies.

1.1.4 UoA5: Achieving Impact

Over the REF period the application of UoA5 research has been centre stage, with a culture-shift from retrospective and *ad hoc* identification towards prospective planning and continuous sustainable development of research impact. This was achieved with an expanded Research Development Team (Section 1.1.1), with a dedicated Impact Acceleration Coordinator, and internal-administered funding to develop impact and translation of research including awards from the MRC Proximity to Discovery and Confidence in Concept, the BBSRC Impact Accelerator and the Midlands Innovation Commercialisation of Research Accelerator schemes (over £650K to UoA5). Alongside a strong pipeline of projects developing future impact, the seven selected REF2021 Impact Case Studies evidence the approaches to supporting and developing impact, including both examples arising from close ties to industry (Camstent, Lucozade Ribena Suntory, Promega) and clinical impact developed in response to research findings (Hepatitis C, meningitis, eye disease, lung cancer). In line with UoN Global Research Themes, all of our case studies have a direct or indirect impact on human health and wellbeing.

1.2 Organisational Structure of Research in UoA5 – the SoLS Research Divisions

The Directors of Research and Research Committee of SoLS have responsibility for developing the UoA5 research and impact vision and creating effective mechanisms for its implementation and sustainability. Cross-Divisional research collaborations and networking are facilitated by weekly external and internal School seminar programmes which include a social programme, and inclusive School-wide communication of all research events on a variety of platforms.

From January 2014-December 2016, UoA5 members were mapped to one of eight SoLS Research Themes, each with 7-20 academic members and individual leads (Genetics Ecology and Evolution; Cell Biology, Development & Biochemistry; Microbes; Neuroscience; Musculoskeletal; Cell Signalling and Pharmacology; Biological Engineering; Immunology). To maximise collaborative interdisciplinary research (including fully realising the opportunities from existing flagship research centres and groups, as highlighted in the REF2014 strategy), and following support from the 2016 SoLS Review, in 2017 UoA5 research was consolidated into three larger Research Divisions: Physiology, Pharmacology and Neuroscience (PPN); Infection,

Immunity and Microbes (IIM); and Cells, Organisms and Molecular Genetics (COMGEN). These Research Divisions created critical mass and are the primary level at which management, communication, mentoring and support for the UoA5 research strategy and impact are developed and implemented. Nevertheless, cross-Division collaborations are also important aspects of our research effort and are well exemplified by recent responses to the Covid pandemic (Section 4.1.3).

1.2.1 Physiology, Pharmacology and Neuroscience (PPN) Research Division contributes 33 research leaders and independent fellows to UoA5. Research disciplines range from fundamental studies of single molecules and molecular signalling mechanisms to whole-organism studies with a focus on cardiovascular disease, neurodegeneration, CNS disorders and pain.

UoA5 research in PPN has critical mass in G protein-coupled receptor (GPCR) pharmacology and chronic pain mechanisms, whilst sustaining strength in cardiovascular pharmacology, modelling of CNS function, and human disease. Inflammatory signalling is a common theme across all areas. PPN includes two competitively-funded flagship Centres (Centre of Membrane Proteins and Receptors (COMPARE) and the Pain Centre Versus Arthritis) that are focal points for world-leading research with synergy and co-membership across both Centres. As further examples of environment enabling research developments, these Centres have attracted competitive funding (2019, £4.45M Wellcome DTC led by Woolard (COMPARE) and Donaldson (Pain Centre Versus Arthritis)), as well as the recruitment of Prof Meri Canals from Monash (molecular pharmacology of opioid receptors, recently awarded a competitive Professorship from the Academy of Medical Sciences (2019, £493K)), Dr Rob Lane from Monash and Prof Dmitry Veprintsev from Paul Scherrer Institute (molecular pharmacology and biophysics).

COMPARE: the UoN/University of Birmingham £10M Signature Institute (led at Nottingham by Hill and Woolard), was created in 2016 through a competitive process providing investment in facilities and people to study GPCRs and RTKs and develop new approaches to investigate these in health and disease. The decision to support COMPARE was facilitated by the critical mass of GPCR researchers in UoA5, sustained MRC funding, strong links with industry (Heptares, Promega, GSK, AstraZeneca), novel fluorescent ligand and BRET technology development [*REF2021ICS*], and exceptional cell surface receptor imaging research infrastructure. Development is guided by an international advisory board of academia and industry leaders, reflecting COMPARE as a global hub for molecular pharmacology research. Imaging capabilities, STED-FCS and camera-based FCS technologies have been expanded through a British Heart Foundation infrastructure grant (2018, £348K).

Pain Centre Versus Arthritis led by Chapman is the UK Centre of Excellence for osteoarthritis pain research with external funding of £4.5M (2010-2021). It was established to provide a research environment to promote translation between preclinical and clinical pain research in the SoLS and School of Medicine, with a focus on arthritis pain (five-year block funding of £2.5M with £900K for preclinical studies (UoA5)). The Pain Centre was awarded a further £2M competitive renewal in 2015 (£823K for UoA5 for the period up to Dec 2021). Additional project grant funding has supported complementary research projects (£1.8M funding from BBSRC, MRC, Versus Arthritis and industry). PPN also hosts a **Paget's Association Centre of Excellence** (led by Layfield, UoA5) with Prinsloo (Nottingham City Hospital), part of a UK network that promotes translational research collaborations into this common skeletal disorder. ***In vivo* experimental research** expertise remains a critical skill. UoA5 hosts a critical mass of researchers in this area, leading on

research including *in vivo* single and multi-unit electrophysiological recordings of sensory and motor function and functional magnetic resonance imaging (fMRI) regional brain activity and functional connectivity (Chapman, Donaldson; Versus Arthritis, BBSRC and Wellcome funding) plus vascular function and metabolism (Serres). Pre-clinical fMRI is substantially enhanced by UoA5 member's access to world-leading facilities in the Sir Peter Mansfield Imaging Centre and the UoN **Precision Imaging Beacon**. *In vivo* approaches make a fundamental contribution to our cardiovascular research, including real time monitoring of haemodynamics (Woolard, BHF and Wellcome awards). As part of a commitment to delivering 3Rs impact, UoA5 hosts the **Fund for Replacement of Animals in Medical Experiments (FRAME)** Laboratories (£607K, 2018, led by Bennett), with a goal of development of innovative 3D mammalian culture methods and microfluidics approaches (Dajas-Bailador, Bellamy).

1.2.2 The Infections, Immunity and Microbes (IIM) Research Division contributes 31 research leaders and independent fellows to UoA5. Research activities in IIM cover a spectrum of infection and inflammation research from the lab bench to the hospital bed.

IIM hosts the research group of Prof Liz Sockett FRS, who studies the biology of *Bdellovibrio bacteriovorus*, a predatory bacterium that invades and kills pathogens, pursuing research on both the biological processes underlying predation and the potential application of their activity as alternatives to antimicrobial compounds. Prof Sockett was elected a Fellow of the American Academy of Microbiology in 2017 and of the Royal Society in 2019.

The **One Virology** initiative was established to bring together 16 principal investigators and around 40 postdoctoral researchers, technicians and postgraduate students from across UoA5, Veterinary Medicine and Science, and Biosciences (Ball £250K 2018, Wolfson Foundation). One Virology co-locates a new Centre for Global Virus Research at the UoN Sutton Bonington Campus. Collectively, they have secured research funding from sources including the EU, MRC, BBSRC, NIHR, DEFRA and NIH (USA), as well as industry and charities, of more than £16M in total (of which £5M directly supports research at Nottingham).

The **National Biofilms Innovation Centre (NBIC),** aligned to the UoN **Antimicrobial Resistance RPA**, is an Innovation & Knowledge Centre (IKC) led by the Universities of Southampton, Nottingham (Camara, UoA5), Liverpool and Edinburgh. Arising from £26M funding commitment (from BBSRC, Innovate UK, the Hartree Centre, the four HEI partners and industry), it was established in December 2017 with 5 years of initial funding. NBIC's vision is to create a fusion of world-class research and industry to deliver breakthrough technologies in the control and exploitation of bacterial biofilms. Since its creation a further 48 UK Universities (21 from the Russell Group) and Research Centres have formally joined the consortium, together with an industry base of more than 200 companies covering a wide range of sectors.

The UoN **Bio-Instructive Materials Institute (BMI)** created in 2017 and aligned with the **UoN Advanced Materials** IRC is focused on designing and developing bio-instructive materials with immune-enhancing/modulating functionalities to promote healing and minimise the risk of infection. The multi-School initiative led by Ghaemmaghami (UoA5) and Morgan (Pharmacy, UoA3) includes Williams (UoA5), Pharmacy and Medicine, 10 postdoctoral researchers and 9 PhD students. Funding includes an EPSRC Programme Grant in Next Generation Biomaterials Discovery (£5.3M Ghaemmaghami and Williams 2015), FP7 Immodgel and H2020 PanBioRA (Ghaemmaghami), and an EPSRC grant (£2M 2017) for 3D OrbiSIMS: Label free chemical

imaging of materials, cells and tissues (Alexander and Williams). BMI has active collaborations and with academic (MIT, Rice University, Eindhoven University of Technology) and industry (Smith & Nephew) partners.

Translational aspects of IIM research include analysis of meningococcal and other bacterial infections (Wooldridge, Turner, Oldfield), development of immune-competent and biomimetic tissue models (Ghaemmaghami), immune-instructive biomaterials (Ghaemmaghami), and vaccine development and evaluation (Turner, Oldfield [*REF2021ICS*]). Irving has been prominent in leadership of **Hepatitis C Virus (HCV) Research UK**, the national cohort of 12,000 patients with hepatitis C virus infection with an associated clinical database in Nottingham and biorepository based in Glasgow, set up to aid research in all aspects of HCV infection, including guidelines for clinical management [*REF2021ICS*].

1.2.3 Cells, Organisms and Molecular Genetics (COMGEN) Research Division contributes 35 research leaders and independent fellows that study molecular, cellular and whole-organism interactions using a broad range of natural and laboratory systems, and make strong contributions to the University's **Future Food** and **Green Chemicals Beacons of Excellence**.

COMGEN strengths include molecular evolution, genetics and genomics, with strategic new appointments complementing existing expertise. Horizontal gene transfer and pangenomes is a focus of the McInerney group. Yant studies genetic architecture determining physiological adaptation to the environment in plants, with a 2018 ERC-funded programme on hotspots of repeated evolution. The study of protein evolution and adaptation are a focus of both the O'Connell and Ravinet labs. Emerging antibiotic resistance in human pathogens and the human microbiome is the focus of work by Whelan (NRF). Production of commercially relevant microorganisms exploits techniques such as design of artificial chromosomes (Heap and Blount, both aligned to the **Green Chemicals Beacon**), and synthetic biology is also applied to vaccine development (Griffin).

COMGEN hosts world-leading groups using genetics and genomics in human health and disease. Disease processes are studied at the cellular level in the groups of Tewari (malaria parasite development and proliferation) and Brook (cardiac development and myotonic dystrophy). A new NRF (Wilkinson) uses zebrafish to study the genetic control of blood vessel formation. Genomic research is supported by DeepSeq, the Next Generation Sequencing platform (Sections 3.3.3, 4.1.3), led by Loose, a world-leader in the development of nanopore long-read methodology.

UN Global Challenges and Sustainability are at the heart of COMGEN work on functional genomics of livestock species (Hanotte), with close links with the International Livestock Research Institute (ILRI) in Ethiopia and Kenya, and on fish-parasite interactions (Hartikainen). Yant and Goodacre collaborated with the **Future Food Beacon** to establish the ancient/low copy number DNA laboratory at UoN (Paleo-benchmarking for Agricultural Resilience). All this research aligns with the UN Sustainable Development Goal 2: Zero hunger. Sustainability characterises work in SBRC (below) and other work in synthetic biology (Blount) and in the study of traits under adaptation in orphan and underutilised crops (Yant). At the ecosystem scale, immunity and responses to diseases in natural rodent populations are a focus of the Bradley lab; fish speciation and adaptation to fresh water are studied by the MacColl lab; the Reader and Gilbert labs work on evolution of mimicry.

Within COMGEN, the Nottingham **Synthetic Biology Research Centre (SBRC)** is one of six UK SBRCs created in a £300M investment by the BBSRC and EPSRC. SBRC Nottingham (Minton, Winzer, Soucaille, Griffin and Zhang) concentrates on engineering bacteria to make industrially useful products by recycling carbon with a particular focus on the single carbon (C1) gases carbon monoxide, carbon dioxide and methane. The centre's activities have been bolstered by the award to Minton of two successive BBSRC NIBB (Network for Industrial Biotechnology and Bioenergy) grants supporting UK-wide science in this area, C1net (£1M, 2014) and CCnet (£713K, 2019). The Centre has received over £25M in external funding, and has a portfolio of seven patent families with revenue-bearing licences based on these and on plasmid vector sales exceeding £150K gross income. The SBRC has published >130 academic publications in the REF period and will have trained over 100 PhD students in that time. The centre has worked with over 40 companies and has embedded relevant start-ups within its facilities, resulting in funded collaborative research and investment in the companies of over £4M to date. SBRC hosts Royal Society Entrepreneur-in-Residence, Chris Finnis, who facilitates the development of partnerships between industry and academics within the SBRC, and across UoA5 more broadly, including progress towards the commercialisation of synthetic spider silk (work with the Goodacre lab).

1.3 Future UoA5 Research and Impact Strategy

Continued development of our thriving and inclusive research culture, which represents a step-change from REF2014, will support UoA5 members across all levels of research engagement to achieve high quality research in a sustainable environment:

- **Supporting research vitality through strategic embedding of UoA5 researchers into the most enabling spaces** – including the newly-constructed £100M BDI-2 (BioDiscovery Institute phase 2) Building, complementing and extending world-class research facilities already available in the former Centre for Biomolecular Science
- **Promoting individual research achievement and development through a Team Science ethos across UoA5,** building confidence to commit to large-scale higher-risk higher-reward applications
- **Sustaining investment in UoA5 research and impact development** with targeted funding and structured support from dedicated in-house experts in the Research Development Team and UoN Professional Services Teams
- **Valuing People and succession planning**, including giving new academic colleagues and fellows recruited as part of our ambitious academic staffing strategy time to build research leadership capacity

Implicit in these principles lies a goal to harmonise with the UoN's commitments towards an **Open Research** environment [*ILS2.3*] as well as institutional benchmarks for assurance of **Research Integrity** [*ILS2.4*]. Major risks to implementing this strategy are financial uncertainty post-Covid, these risks being mitigated by our recent appointments and a strong research-led teaching portfolio.

2. PEOPLE

2.1 Staffing Strategy

Following the strategic intentions described in the REF2014 Environment Template for UoA5, specific recommendations relevant to UoA5 were made in the 2016 SoLS Review to replace the 20+ recent leavers/retirees with new research-active academic staff at all levels. Appointment processes took account of career breaks in shortlisting and appointment criteria, focussing on quality above quantity; for example, candidates were asked to highlight their four 'best' publications, with emphasis on scientific content/value of impact in line with Declaration on Research Assessment (DORA) principles. Advertising materials highlighted flexible working options and encouraged diversity. Overall success rates from application to acceptance have improved to 7.4% for female (6.1% for male) and BAME applicants (from 2.3% to 3.8%) and this has impacted positively on our staff diversity. Between 2014 and 2019 SoLS (representative of UoA5) had increases in the proportion of female academics (25.8% to 31.9%), BAME staff (11.5% to 15.1%) and staff declaring a disability (2.3% to 4.0%). BAME researchers have increased (14.5% to 23.5%) building the foundations for a more diverse pipeline in the future.

This phase of strategic recruitment included an external appointment of Prof James McInerney as Head of School of Life Sciences, in February 2018, and his arrival accelerated progress on this programme of new appointments. A further 20 appointments into UoA5 since January 2017 include three chair positions, in Synthetic Biology and Metabolic Engineering (Soucaille), Cellular Pharmacology (Canals) and Molecular and Cellular Pharmacology (Veprintsev). There have been six appointments at Associate Professor level, in Computational and Molecular Evolutionary Biology (O'Connell), Evolutionary Genomics (Yant), Molecular Microbiology (Sloan), Molecular Pharmacology (Lane), Synthetic Biology (Heap) and Molecular and Cellular Metabolism (Amelio). There have also been seven Assistant Professor appointments, in Microbial Pathogenesis (Griffin), Adaptation to the Environment (Ravinet), Neuroscience (Sheridan, Steinert), Genome Dynamics (Gray), Evolutionary Ecology (Hartikainen) and Infection Immunology (Coleman). UoA5 also hosts four newly-appointed (tenure-track) NRFs (Nottingham Research Fellows) and AMFs (Anne McLaren Fellows) (Wilkinson, Maiellaro, Blount, Whelan). These 21 new research leaders include 6 women, and in their time at Nottingham since their appointment they have already secured 26 new external research awards totalling over £2.95M, and together contribute 76 (of 236) outputs to the UoA5 REF2021 return.

Staff in UoA5 are prominent in research leadership in the wider University context, including the Associate Pro-Vice-Chancellor for the Researcher Academy (formerly Graduate School) and Researcher Career Development (Donaldson), Co-director of the Researcher Academy in FMHS (Tarr) and the lead for the University's GRT on **Health and Wellbeing** (Section 1, Chapman).

The 2016 School Review specifically recommended actively targeting the University's tenure-track (NRF/AMF) fellowship schemes. This strategy was implemented by recruiting NRF and AMF fellows, with full support and mentoring provided to candidates with a strong track record to facilitate their success through the managed (central UoN) process. These fellowships provide SoLS/UoA5 research with a mechanism to build future research sustainability. In the 2018-19 round we appointed NRF Rob Wilkinson (October 2019, previously at Sheffield), and AMF Isabella Maiellaro (March 2020, previously at Würzburg). Wilkinson has already established excellent collaborative links with the BioDiscovery Institute (BDI-2007, see below) and holds a BBSRC grant on control of vascular development. Maiellaro works in neuroscience using single cell expression

and *Drosophila* models; her start commences following a period of maternity leave. In the 2019-20 round we appointed NRFs Fiona Whelan (July 2020, whose research uses new methods of computational analysis to evaluate associations between genomic features of bacteria and their phenotypes), and Ben Blount (March 2020, whose research applies genome rearrangement technologies to create yeast strains with improved production of high-value products). Other PDRAs in the unit hold independent external fellowship awards from the Research Councils, charities, the European Commission and the Swiss National Science Foundation (Section 4.2.4), and applications are supported by the in-house Research Development Team.

2.1.1 Equality, Diversity and Inclusion (EDI) Strategy

All of the activities to support People within UoA5 are underpinned by the SoLS EDI strategy. SoLS has made training in Equality and Diversity a key focus of staff training provision, with compulsory online training including a module on unconscious bias. Soon after its formation SoLS achieved an Athena Swan Silver Award in 2013, and the award was renewed at Silver level in 2017 at the first attempt. The 2017 Athena Swan application specifies interventions covering key issues such as recruitment, promotions, staff development and workload allocation. Progress is initiated and overseen by the SoLS broadly-based EDI Committee, including members from academic, technical and administrative staff as well as student representation, and its Athena Swan SAT (Self-Assessment Team) sub-group.

Examples commended by reviewers in feedback for the 2017 Silver Award renewal include actions to enhance shortlisting and appointment of women to academic positions (Section 2.1 above), systematic identification of, and response to, under-application for promotion by female staff, mandatory equality and diversity training for all staff (with 100% uptake of unconscious bias training across all groups), implementation of workload analysis, and additional support for staff returning from maternity leave.

The success of support measures is reflected in the achievements and career progression of our staff. Of 34 successful promotion applications (success rate ~70%) 44% were female, above the proportion of female academic staff. Over the REF period 39 technicians have been regraded (73% female), with a 93.3% success rate. Within SoLS, there are specific practical measures for staff support providing for different needs, including availability of an EDI space, a breast-feeding room, prayer rooms, and car parking spaces reserved for after 9.15 a.m. (specifically timed to be available to staff arriving after delivery of children to school).

2.2 Staff Development and Research Support [*ILS3.1*]

Effective allocation of working time and opportunity for personal development is delivered through the University's Workload Framework. For this, extensive and detailed data about individual responsibilities are collated to provide objective information about time allocated to staff for different tasks, with systematic adjustments made for maternity and other career breaks as well as newly appointed or part-time status.

All staff have an individual annual appraisal under the University's ADC (Appraisal and Development Conversation, formerly PDPR = Personal Development and Performance Review). This process provides the opportunity to reflect holistically on achievements through the year and identify training and development needs, with evaluation (but not grading) of performance. Importantly, ADC is an ongoing process with informal review meetings throughout the year.

Sustaining and increasing research income is a key part of the research strategy within SoLS/UoA5. A Research Development Team now comprising two Research and Business Development Managers (RBDMs), an Impact Development Coordinator and two Research Finance Managers support academics and ECRs with funding and impact development. They provide support through a flexible process including:

- Provision of regular, targeted funding alerts.
- Grant Clubs: senior academics that participate in grant panels provide feedback on new research project ideas and the RBDMs provide follow-up support. Since March 2018, 41 colleagues have participated with successes including subsequent prestigious awards from BBSRC and the Academy of Medical Sciences.
- Application development: RBDMs support academics and ECRs through editorial or writing assistance, consortium building and facilitation, securing internal match-funding.
- Advice and guidance on opportunities for development of impact from an early stage.
- Costing, internal approval for submission to funders, award set up and budget monitoring of live awards.

SoLS/UoA5 is a leading participant in the FMHS Mentoring Scheme overseen by a specialist member of Professional and Support staff with four academic colleagues on the steering group. An initial training session is run 6-9 times per year for potential mentors and mentees, after which applicants are paired up. By September 2020, 38 colleagues (21 female) had received guidance through the mentoring scheme, from a total of 26 mentors (11 female).

Funding from the Wellcome Prime scheme (up to £50K over 2 years) can be used flexibly by awardees, including buy-out of non-research commitments, bridging funding for research continuity, or development of collaborative research. For this, SoLS receives funding from Wellcome through its Institutional Strategic Support Fund (ISSF; £500K) with matched funding from the University (£500K) (Section 1.2.1 above). To date, 7 academics in UoA5 have received Wellcome Prime Scholarships (from a total of 17 awarded across the University). Wellcome Prime scholars have used the awards to support their research development in the variety of ways envisaged in the scheme's design including:

- Teaching replacement to allow time to make significant progress with research aims (Wickstead, Loose, Woolard).
- Provision of bridging funding to help overcome the hurdle of moving from an applicant's first significant research grant to the second (Gadelha, Friel).
- Funds to develop international collaborative research (Hume).

With the agreement and support of Wellcome, in the most recent round of funding we have introduced a Fellowship Support Award alongside the Scholarships. This is designed to support postdoctoral researchers to develop their own independent lines of research in preparation for applications to major fellowship schemes. Two awards were made in January 2020, one to an ECR in UoA5 (Urbanowicz).

Training for research staff is available through the University's Professional Development Unit [*ILS3.1*], which offers a wide range of in-person and online training experiences, with female uptake (N=2298; 56.4%) being higher than male (N=1773; 43.6%). The Nottingham Research Leaders Programme is a competitive research-focussed year-long programme with an emphasis on collaboration and team working, led by the APVC for the Researcher Academy (Donaldson, UoA5). Seven contributors to UoA5 have completed this programme since 2013. Research

Integrity courses are strongly recommended for all research-active staff in UoA5 and have high uptake [*ILS2.4*].

2.2.1 Specific ECR Support [ILS3.2]

The University is a signatory to the Concordat to Support the Career Development of Researchers 2008 and holds an HR Excellence in Research award, renewed in April 2020. The APVC for the Researcher Academy and Research Career Development (Donaldson, UoA5) leads on the implementation of the institutional action plan focussing on the principles set out in the Concordat to Support the Career Development of Researchers, with oversight by the University Research Committee. SoLS also offers locally-arranged mentoring, specific events giving opportunities for seminar presentations by ECR staff and workshops highlighting career choices and giving guidance on fellowship and funding applications.

Staff development and training is supported in the individual colleague's ADC meetings, (see above). Training options available to doctoral students from the Researcher Academy and the Medical Faculty Training Programme are also available to ECRs (Section 2.3.4 below). Activities targeted to ECRs in UoA5 are coordinated within SoLS by a dedicated Postgraduate & Postdoctoral Research Development Officer. SoLS has a Postdoctoral Research Committee chaired by an ECR (Urbanowicz, UoA5), organising specific local events targeted to ECRs; these have included sessions on career progression and preparing successful grant and fellowship applications with School Directors of Research (Brook/Sockett), the Researcher Academy Lead APVC (Donaldson) and other colleagues (Hardie).

All our ECRs have access to and are supported to engage with Researcher Academy training programmes, including the ECR Leadership Programme, part of the University's talent management programme, run jointly with the University of Birmingham. ECRs are also able to access further leadership and management development opportunities, including further mentoring and coaching, through the UoN Leadership and Management Academy (LMA), and the highly successful Faculty Mentoring Scheme (see above).

2.2.2 Specific Training for Research Technicians [ILS3.4]

Research technicians in UoA5 are encouraged to engage with local ongoing research training and retain a degree of mobility within SoLS research Divisions, reactively supporting funded research projects. This approach ensures ongoing refreshment and updating of skills. Our ethos (reinforced through the ADC process) is to encourage engagement with professional development short courses, The LMA for technicians that are growing skills in leading a team, and the Midlands Innovation (MI) TALENT scheme (which includes a conference fund scheme, sharing equipment scheme and placement schemes where colleagues can learn how analyses are performed in other institutions). All of these are linked to the University's vision for Technical Talent, and the Technician Commitment supported by the Science Council and the Technicians Make It Happen campaign (Section 3.2.2).

2.3 Support, training and supervision of PGR students

SoLS includes about 100 doctoral (PhD) students per year plus approximately 30 one-year research masters (MRes) students. In the interval August 2013-July 2020 a total of 525 doctoral awards were made to students supervised by staff returned in UoA5, rising from 71 in 2014-15 to 81 in 2019-20. Postgraduate student recruitment, training and support within SoLS is regulated by

the School's Postgraduate Research Strategy Committee. This Committee is led by three Directors of Postgraduate Study (all UoA5), two of whom oversee strategy (Leach and Allers), and one of whom coordinates operational aspects and leads welfare support (Wilson). The PGR Directors are supported by a full-time PGR and Postdoctoral Research Development Officer.

About half of all PhD students are international, either sponsored by a government, another institution or self-funded. Among HEU students there are distinct cohorts in the **BBSRC DTP** (Doctoral Training Programme, Section 2.3.1) and **Wellcome DTC** (Doctoral Training Centre in **Antimicrobials and Antimicrobial Resistance,** Section 2.3.2), and **Wellcome** has recently funded an additional **DTC in Drug Discovery and Team Science** (Section 2.3.3). UoA5 PIs also supervise students on the **MRC Impact DTP** (Integrated Midlands Partnership for Biomedical Training, with Leicester and Birmingham) and the **NERC Envision DTPs**.

2.3.1 BBSRC DTP

The ongoing second phase of the Nottingham BBSRC Doctoral Training Program (DTP2) currently has 240 registered students, including iCASE and National Productivity Investment Fund (NPIF) students. Training is split approximately equally across three areas of Industrial Biology and Bioeconomy, Agricultural Food Security, and Basic Biomolecular Sciences. The £12.5M grant from BBSRC supported this Centre, which connects Schools from across the science, medical and engineering faculties at Nottingham and its key partner Rothamsted Research. DTP2 offers expertise in BBSRC priority research areas and vulnerable skills such as mathematical training and *in vivo* research, and includes a three-month placement (Professional Internships for PhD Students, PIPS) working in an area not related to the PhD. Typically, between 18 and 20 new DTP2 students of the annual cohort of 50 students registered each year in SoLS/UoA5.

Students who completed their (DTP1 or DTP2) training have entered diverse careers in academia (>50%) and science-associated roles; 73% of students submitted their thesis within the 4-year period and 86% within 4.5 years. Students published high-quality papers (mean FWCI 1.73), 5% co-authored with industry partners and 36.7% of outputs with international collaborators (FWCI 3.02). DTP students engaged with diverse PIPS opportunities, including placements in 23 countries (6 on the Development Assistance Committee's (DAC) list of ODA recipients), involving >70 different companies, and 6 students found employment with their PIPS host institutions.

The third round of the Nottingham BBSRC DTP (DTP3, supported by a recent award of approximately £15M from BBSRC) recruited its first cohort of 42 annual students in 2020, and is led by groups at UoN and Nottingham Trent University, with overall leadership and coordination from UoN colleagues in UoA5 and UoA6. In DTP3 successful relationships with our current partners are continued, but add new academic (Nottingham Trent University), and industrial partners (National Biofilms Innovation Centre [NBIC, Section 1.2.2 above] and Biotech Industry). Recruitment in DTP3 was explicitly directed towards a more diverse cohort, through specific recruitment and support mechanisms, including (for example) the current SoLS cohort of PGR students actively mentoring prospective BAME students in making applications to the program.

2.3.2 Wellcome DTC in Antimicrobials and Antimicrobial Resistance

The Wellcome AAMR (DTP) combines the AAMR strengths at the UoN and the University of Birmingham (UoB). The Centre includes 77 (40 UoN and 37 UoB) supervisors with skills and expertise covering the AAMR field and hence can flexibly adapt to student-driven PhD project choices. Wellcome provided funding for 20x4 year studentships (1+3 MRes+PhD) matched by the

two Universities who provided 10 studentships each (total cohort - 40 studentships; 10 per year), with intakes in 2016-2019, with UoA5 playing a major role.

2.3.3 Wellcome DTC in Drug Discovery and Team Science

Wellcome has also recently funded (£4.45M) a new programme in 'Drug Discovery and Team Science' at Nottingham, led by Woolard and Donaldson (UoA5) which will recruit 4 students each year over a 5-year recruitment period. Projects are fully funded for 4 years, with additional funding in place for a 'transition period' following completion of the PhD programme. In line with SoLS strategy the management team have implemented measures to enhance diversity of recruitment, experience and talent that will result from a Team Science-driven approach (defined as promoting working with coordinated teams of investigators with diverse skills and knowledge). The programme will involve close collaboration between several Schools across UoN (including Medicine, Pharmacy and Maths) and students will be hosted in SoLS/UoA5. There will be close interaction with industry, SMEs and other partners to enhance collaboration and training. The programme focuses on the application of a multidisciplinary team science-driven approach to study membrane receptors in the most appropriate cell type and tissue, and each yearly entry of 4 students will study one of a set of disease-related themes.

2.3.4 Doctoral Student Support and Progression [ILS3.3]

PhD and MRes students in UoA5 receive support, training and monitoring through the SoLS Postgraduate Research and Supervision framework, in parallel with the University-wide Researcher Academy. Students undergo annual progress reviews, which include written submissions and spoken examination or presentations. Accurate record keeping of PGR student supervision, annual progress reviews and training portfolios is facilitated by a bespoke database-driven application (PGRWeb), which was developed in-house in SoLS and is increasingly being adopted throughout the University.

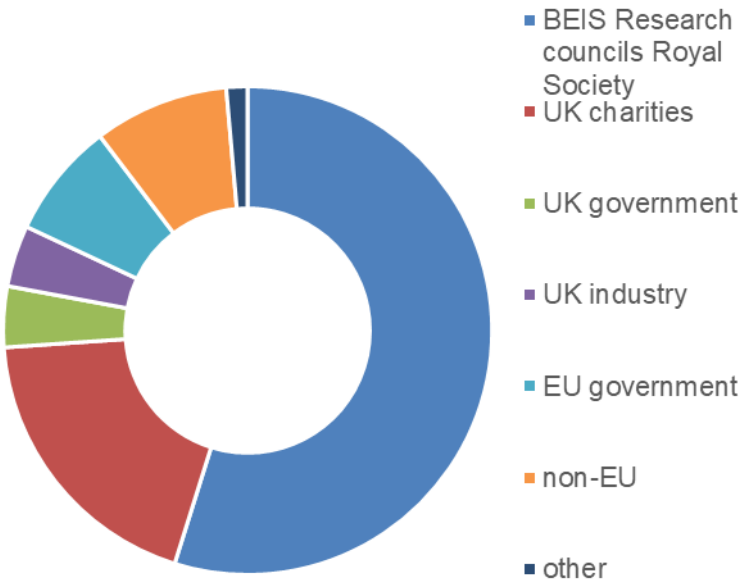
PGRs in UoA5 are supported by the FMHS PGR Training Programme, developed by Schools in the Faculty in conjunction with the Researcher Academy. This is delivered by academic staff and Researcher Academy professional training and development managers, and quality assured by the Researcher Academy. Doctoral Training Programmes also provide tailored training, some of which is available to PGRs not in the DTPs. Professional conduct is an important part of researcher training and development; Research Integrity courses are mandated for all PGRs at UoN and form an integral part of their training portfolio [*ILS2.4*]. There are dedicated careers advisors who hold appointments for individualised career development advice with our PGR and ECR communities. The Researcher Academy also provides reserved social and study space around the University Campuses, including a Graduate Centre within the Medical School; Graduate Centres were reconfigured during 2020 to provide hot-desk facilities for researchers who need to work on-site.

The annual SoLS Postgraduate Conference is held at a venue outside the School (or successfully as an online conference in 2020) and is organised by a committee of postgraduate students with oversight by the PGR and Postdoctoral Research Development Officer. The conference includes the opportunity for oral and poster presentations for second and third-year UoA5 PhD students, forming an integral part of their annual progress review.

3. INCOME, INFRASTRUCTURE AND FACILITIES

3.1 Research Income

Research income for UoA5 staff in the REF2021 reporting period amounted to £72.8M, including £39.9M from UK Research Councils, £13.8M from UK Charities, £5.5M from EU government bodies and £3.6M from industry, businesses and commercial bodies. The distribution across our portfolio for the period is indicated:



Major research awards and investments in the reporting period include The Synthetic Biology Research Centre Nottingham: *Sustainable Routes to Platform Chemicals* (total £16.3M, 2014-2020 from BBSRC, Minton), Bdellovibrio – Bacterial Security Guards Against Dangerous Pathogens (£4.6M DARPA 2015, Sockett), Wellcome Seeding Drug Discovery Award (£2.8M 2016, Brook), the National Biofilms Innovation Centre (£1.2M BBSRC 2017, Camara), £1.4M from the BBSRC for research on sustainable bacterial biofuels (Minton), a £1.8M BBSRC award 2013 for GASCHEM: Optimising Industrial Gas Fermentation (Minton), £1.5M from the MRC 2016 to study fluorescence correlation in GPCRs (Hill), £1.1M from the MRC 2016 to study quorum sensing and virulence in Gram positive pathogens (Williams) and Wellcome Investigator Awards for Bacterial surface sensing (£933K, Williams 2014) and for Combating Gram Negative AMR Pathogens (£1.1M, Sockett 2018). Awards to the Pain Centre Versus Arthritis (£2.5M 2010-2015 and £2M 2015-2020) were shared with the School of Medicine. These major awards evidence the success and vitality of the UoA5 research strategy (Section 1) and have yielded numerous high impact publications which are central to our Outputs return.

3.2 Research Infrastructure

3.2.1 Buildings and Space

Major investments in the period have enhanced the buildings and space utilised for research in UoA5, complementing and extending the existing world-class facilities. The School has three main buildings occupied by UoA5 researchers: The Medical School Building in the Queen's Medical Centre (QMC) complex, is connected by a walkway to the Biodiscovery Institute (BDI), which consists of two buildings completed in 2007 ('BDI-2007') and 2020 ('BDI-2'). The Life Sciences building is a short distance away in University Park. Distribution of staff broadly reflects their disciplines: BDI-2007 is an interdisciplinary research building with a major focus on industrial and medical bacteriology, hosting chemists and biochemists working on human pathogens and

industrial anaerobic fermentation in CL2 and CL3 laboratories (CL = Containment Level); the Medical School hosts a diverse group of biochemists, molecular geneticists and cell biologists, many of whom collaborate with local clinical colleagues and Life Sciences houses organismal and ecological sciences. Selected UoA5 research leaders will be embedded into the £100M BDI-2 building as a priority post-Covid to enable collaboration in line with our future strategy (Section 1.3).

SoLS occupies a total of 19,000 m^2 of floor space, about 95% of which is occupied by academics returned in UoA5 in REF2021. Our research laboratories total 9,600 m^2, plus 2500 m^2 of adjacent offices, meeting rooms and social spaces for academics and research staff. Underpinning core research-support services, such as finance, media preparation, washing-up and stores, occupy 2,500 m^2. The remaining 4,400 m^2 is devoted to teaching laboratories, and computer rooms.

Our research strategy recognises the importance of social spaces to seed discussion and collaboration. The BDI-2007, Life Sciences building and Medical School have their own dedicated social spaces, as well as cafeterias and snack bars; PGR students and postdocs have an additional Graduate Centre with writing and presentation areas and refreshment facilities.

3.2.2 Research-Support Technicians [ILS3.4]

SoLS maintains a cohort of centrally-funded Research Technicians (32 FTEs) ranging in experience from trainees to doctoral level, and encapsulating the full spectrum of skills to support the research of the School. The pool is dynamic and reassignments reflect SoLS research strategy and priorities (Section 2.2.2) but at any one time ~90% support UoA5 research. They have proved especially effective in supporting ECRs in establishing their independent careers, with all new appointments having access to dedicated technical support for the first three years.

SoLS has been proactive in supporting and developing its core of Research Technicians, and in May 2017, The UoN, together with the University of Cambridge, were the first to pledge their support for the Technician Commitment Action Plan to further career development for technicians and technologists, supported by the Science Council and the Gatsby Foundation. This commitment was enacted following significant contributions from UoA5 technical staff.

3.3 Facilities

SoLS provides an extensive range of multi-user instruments and facilities available to all UoA5 researchers. Specialised microscopy and imaging infrastructure underpins research in many areas across the unit, especially for cell surface receptor research in COMPARE. Equipment includes state-of-the-art super-resolution, high-content and cell tracking suites available through the SLIM platform (School of Life Sciences Imaging, Section 3.3.1). World-leading DNA sequencing is underpinned by DeepSeq (Section 3.3.3) and flow cytometry capabilities have been enhanced through the addition of cutting-edge imaging and spectral cytometers (Section 3.3.2). The BDI-2007 has specialised facilities for industrial and medical microbiology such as two bespoke DNA assembly/microbial manipulation robotic suites, gas fermenters and biolectors, 11 anaerobic cabinets split between CL2 and CL3 laboratories plus a DNA Analyser, Q-Tof MS and Raman laser gas analysis. The One Virology initiative (Section 1.2.2) enabled the creation of a cluster of CL3 laboratories dedicated to virology research on the UoN Sutton Bonington campus available to UoA5 researchers.

SoLS maintains several core platforms with dedicated technical expertise that deliver UoA5 research and provide services to external users. They are essential for the support of advanced research objectives and high-impact publications, and underpin successful grant applications and the success of the Impact Case Studies.

During the REF period these platforms have supported many significant UoA5 projects in biomedically important areas. As selected examples:

- grants of >£13.8M to COMPARE and others to study cell surface receptors (BBSRC, MRC, Wellcome, EC, BHF, AMS, GSK and Promega) made extensive use of the SLIM facilities
- the multi-centre grant of £12.5M (2017) to Camara and others for the NBIC (BBSRC and IUK) relied on SLIM, particularly its Super Resolution Microscopy Facilities
- The Pain Centre Versus Arthritis relies on SLIM and BSU (Section 3.3.4) services and since 2015 has been supported by grants of £2M from Versus Arthritis.
- grants of £2.8M, £1.7M and £1.1M since 2013 to Brook and others to study myotonic dystrophy (Wellcome) and congenital heart defects (BHF) with resulting patent relied on SLIM (Section 3.3.1, below) and the Flow Cytometry Facility (FLOW, Section 3.3.2)
- grants of almost £2M to Loose from Wellcome and BBSRC supported DeepSeq nanopore sequencing activities (Section 3.3.3) which have also been a major contributor to UoA5's 'agile response to Covid' (Section 4.1.3)
- grants to Avery relied on SLIM and FLOW to study fungal food spoilage (>£1M awarded since 2016 by BBSRC and LR Suntory Ltd., [*REF2021ICS*])
- DeepSeq services to aspects of the £14M BBSRC grant to the SBRC (Minton and others 2013)

3.3.1 School of Life Sciences Imaging (SLIM)

The SLIM platform underpins advanced research in diverse aspects of cell biology and pathology and has benefited from £1.44M additional capital investment during the REF period. It has a Chief Experimental Officer and four full-time senior technical staff. SLIM is equipped with seven Zeiss microscopes including a top-end Super Resolution suite (below), four confocal and one Non-linear Optical microscope. There are also Zeiss and Nikon deconvolution and TIRF systems, and an Olympus LV200 for long-duration cell bioluminescence. Cell-tracking capabilities are provided by a Phasefocus Livecyte microscope. High-content imaging is provided by MDC confocal and wide-field plate readers with robotic handling and environmental controls. SLIM operates a mixed financial model with imaging staff supported by SoLS, and running costs funded through access charges. There have been >140 Outputs in peer-reviewed journals involving SLIM staff (all UoA5) as authors or as acknowledgements since formation of the facility. SLIM staff run a three-day workshop three times a year on the local instruments, including FIJI Image Processing and a dedicated lunchtime microscopy seminar series. Notably, SLIM hosts an Elyra PS1 super resolution with combined confocal system, the only super resolution system within UoN, purchased as part of a BBSRC Alert13 bid led by Camara (UoA5), and maintained by dedicated research staff. The facility provided support in the REF period for an EPSRC Biomaterials Programmes grant (Ghaemmaghami), MRC Programme grant (Hill), MRC and BBSRC project grants (Tewari), as well as projects in the Versus Arthritis Pain Centre (Chapman), NBIC (Camara), and the SBRC (Minton), as well as research more widely across other UoAs.

An Electron Microscopy Suite is located within the centralised UoN Nanoscale and Microscale Research Centre (nmRC) with scanning and transmission electron microscopes as well as electron micro probe, X-ray photoelectron spectroscopy, confocal Raman microscopy, secondary ion mass spectrometry and spectroscopic imaging ellipsometry. In the most recent academic year for which data is available (2018/19) the facility had a total of 470 individual users from Schools

including SoLS, with the majority of SoLS users from UoA5. In total approximately 250 staff and students attended courses, workshops and seminars organised and delivered by the nmRC which is also currently working with 6 SMEs and 3 HEIs.

3.3.2 The Flow Cytometry Facility (FLOW)

The FLOW platform has benefited from additional £1.4M capital investment during the REF2021 period with an academic lead from UoA5 (Fairclough, chair of the Midlands Innovation Flow Cytometry group). Currently there are three analytical flow cytometers, a 5-laser Imaging Cytometer (Wellcome 2018, £335K) and two high-speed sterile cell sorters in CL2 cabinets. The Facility has recently secured funding for a 5 laser Cytek Aurora Spectral Cytometer (BBSRC 2020, £396K) with the potential for 40+ colour analysis.

FLOW provides a comprehensive support and service plus regular introductory and data-analysis courses, and is extensively used by UoA5 members. One-to-one instrument training and continuous support for operation is offered, as well as access to analytical software Kaluza, FCS express and IDEAS through multi-user network licences. In 2018/19 FLOW had a total of 152 individual users (84 groups from 5 Schools, dominated by SoLS/UoA5). FLOW is currently working with 8 local SMEs and 2 HEIs. The Facility operates a mixed financial model with two full-time staff supported by SoLS, and running costs funded through access charges. FLOW has contributed to > 144 Outputs in peer-reviewed journals over the last 8 years.

3.3.3 DNA Sequencing and Mapping (DeepSeq)

The DeepSeq DNA sequencing platform received £1.7M additional capital investment during the REF2021 period. It is directed by Loose who is a member of the UK BioBank Genomics Advisory Board, Genomics England and the Tree of Life Long Read Sequencing Group, and is the Nottingham lead for the SARS-CoV2 COG-UK consortium (Section 4.1.3). DeepSeq is staffed by a unit manager, two experimental scientists and two bioinformaticians, all SoLS-funded. They provide support to users from concept, through data acquisition and analysis. Sequencing services include MiSeq and NextSeq500 from Illumina, (£280K 2014, BBSRC), Chromium (10x Genomics) and the MinION, GridION and PromethION (£300K 2017, BBSRC) systems from Oxford Nanopore Technologies (ONT). DeepSeq is the only UK service provider for the PromethION system. It is also the UK's only service provider for the Bionano Saphyr, a non-sequencing-based genome mapping technology that images and analyses extremely long DNA molecules, and has made substantive contributions to national Covid-sequencing (Section 4.1.3). As an example of *UoA5's* alignment to the UoN commitment to Open Research [*ILS2.3*], Loose made freely available the open-source software and codes 'Read-Until' and 'minoTOUR' which he developed in 2015-16. Read-Until software enhances the ONT reading devices, allowing selective sequencing of specific regions of DNA, while the minoTOUR is a suite of web-based applications providing control of a MinION and feeds data back to users. Both are extensively adopted by the nanopore sequencing community.

3.3.4 The Bio-Support Unit (BSU)

The BSU platform provides Home Office designated research animal facilities, which occupy three sites within the University and has a staff of 23 FTEs. The facilities relevant to UoA5's *in vivo* research occupy 2,000 m^2 of space within the Medical School building in close proximity to UoA5 labs, housing rodents, rabbits, zebrafish and axolotls. Approximately 24,000 regulated procedures are conducted annually; approximately 43% of these involve breeding of genetically altered mice and fish, and about 90 SoLS staff (the majority UoA5) are personal licence holders authorised to work in the BSU. The unit has separate areas for Barrier Breeding of Genetically Altered mice;

Experimental Rodents; Category 2 Containment Facilities and Aquarium Facilities; with a range of theatre, procedure and behaviour areas. Additional MRI, PET/CT, SPECT/CT and Optical Imaging are available to users of the facility. BSU operates as a cost-recovery service with income streams from both University of Nottingham research projects and commercial clients.

3.3.5 UoA5 use of University Facilities and Infrastructure

Serres and Irving are closely affiliated with the Sir Peter Mansfield Imaging Centre (SPMIC) and the UoN **Precision Imaging for Medicine Beacon**. The GE 3T SIGNA MRI scanners located in the Medical School used by Serres provides hyperpolarising technology with unprecedented signal gain; its high temporal and spatial resolution allows metabolic measurements on MRI scans of human patients and volunteers. Together with his co-investigator at SPMIC, Irving is part of a CRUK program investigating the early detection of liver cancer. Bonev (NMR and membrane modelling) and Loose (DeepSeq) are users of the Augusta high-performance computer (HPC), which has 4,720 cores, 31TB of RAM and 8 GPUs.

4. COLLABORATION AND CONTRIBUTION TO THE RESEARCH BASE, ECONOMY AND SOCIETY

4.1 Interdisciplinary research; collaborations across and beyond UoN; influencing and supporting disciplines

The wide range of expertise of individuals within UoA5 at Nottingham (Section 1.2) naturally enables inter- and multi-disciplinary collaborative programmes at a unit level, but also provides a research hub that actively engages and drives networks across and beyond UoN.

4.1.1 Interdisciplinary research and collaborative research external to Nottingham

Basic and translational research in the area of **Pharmacology** provides a prime example of UoA5 researchers driving interdisciplinary collaborations. UoA5 researchers have major roles in COMPARE (Section 1.2.1), a flagship Signature Institute of the UoN and University of Birmingham, led in Nottingham by UoA5 members Hill (Director) and Woolard (Deputy Director, then Director from January 2021) and including colleagues in the Schools of Pharmacy, Mathematics and Medicine, including clinical academic Prof Ian Hall, Director of the Nottingham Biomedical Research Centre (hosted by the NUH Trust and UoN). Of 12 additional group leaders in Nottingham, over half are within UoA5 (Baker, Bates, Briddon, Canals, Charlton, Lane, Veprintsev; January 2021).

The concept of *Team Science* is embedded within COMPARE's research strategy with the Academy of Medical Sciences using the centre as a CASE study for their 2019 Team Science update report. Major examples of related interdisciplinary work within UoN are evidenced by: (a) a £2.4M MRC Programme grant to Hill, Briddon, Woolard (Life Sciences) with Kellam (Pharmacy, UoA3) in the use of fluorescent ligands for molecular pharmacology and single cell imaging (2016); (b) a £574K MRC Project grant to Hill with Stocks and Kellam in Pharmacy on the synthesis of novel P2Y2-receptor fluorescent ligands (2014) and (c) a £922K MRC MICA grant with Heptares Therapeutics for the design, synthesis and pharmacological profiling of orexin receptor agonists (Baker, Hill, Woolard with Fischer, Kellam (Pharmacy)); (d) Woolard, Donaldson and other colleagues from SoLS, Medicine, Pharmacy and Mathematics have also recently been awarded a £4.45M Wellcome 4-Year PhD programme in Drug Discovery and Team Science.

Collaborative research external to Nottingham is evidenced by UoA5 pharmacologists having extensive international and industry collaborations. Hill and Briddon were members of the €20.8M consortium funded by the EU Innovative Medicines Initiative (IMI) for a study of "Kinetics for Drug Discovery (K4DD)" (2012-2017). This involved 20 academic institutions and companies (including GSK, Roche, Merck, Sanofi, AstraZeneca) throughout Europe. Hill, Canals, Briddon, and Woolard are members of the Marie Skłodowska-Curie Actions ITNs INSPIRE, ONCORNET and ONCORNET2.0 with participants from six other European countries.

Hill and Woolard have extensive collaborative projects with the global biotechnology Promega Corporation (Madison) which have led to a BBSRC Link grant and major outputs in *Cell Chemical Biology* and *Nature Methods*. The UoA5 impact case study "Commercialisation of a novel NanoBRET assay" (Hill, Woolard) is an outcome of this industrial collaboration [*REF2021ICS*]. Charlton and Baker hold an MRC DPFS grant in collaboration with Sygnature BioScience at BioCity, Nottingham (£686K 2020). Hill also holds a $1.8M NHMRC (Australia) project grant with Christopoulos (Monash) and a $500K Australian Research Council Linkage grant with Pfleger (Western Australia 2016), with a joint 4-year PhD degree run by SoLS/UoA5 in Nottingham and Monash.

Research in the **Neuroscience** area within UoA5 is also enabled by and drives interdisciplinary collaborations, a key example being work of the Pain Centre Versus Arthritis established to provide a translational research environment promoting forward and back translation between preclinical and clinical pain research (co-directed by Chapman and Walsh, Professor of Rheumatology, School of Medicine). Examples of further collaboration include grants with the Schools of Pharmacy, Medicine and Maths (PI Chapman, Versus Arthritis 2019, £349K) which stems from a longstanding collaboration between the Pain Centre and the Nottingham Centre for Analytical Chemistry (Barrett, Pharmacy), using in-house developed LC-MSMS methods to quantify levels of bioactive lipids in clinical and preclinical samples and mathematical modelling of complex datasets. The Pain Centre (with the MRC-Versus Arthritis Centre of Musculoskeletal Ageing Research and the Versus Arthritis Centre for Sport, Exercise and Osteoarthritis) contributes to the Nottingham Centre for Doctoral Training in Musculoskeletal Health and Pain in Ageing and Wellbeing (CDT MHPAW), providing PhD training for clinical and non-clinical scientists.

Chapman also holds funded collaborative research with Lilly investigating the effects of aging upon pain processing (BBSRC £99K and Eli Lilly £21K, 2018) and the role of MMP1 in chronic pain (Eli Lilly 2019, £356K). During the REF period Chapman has held grant funding with Malcangio (KCL) to investigate spinal sensitisation mechanisms of inflammatory arthritis pain. Research projects with Pfizer Neucentis and Pfizer (US) led to the demonstration of the potential of new molecular treatments for arthritic pain. Chapman is an active member of the Biomedical Research Centre MSK theme, which funds translational lipidomic studies of specialised resolution molecules and associated enzymatic pathways in clinical samples from chronic pain patients.

UoA5 also includes researchers in the **Biochemistry** area with significant interdisciplinary collaborations and collaborative research external to Nottingham. As specific examples, Layfield (Head of PPN Research Division from Jan 2020) leads interdisciplinary research into ancient bone diseases, combining protein analysis with osteoarcheology, with contributions from 7 partner universities across Europe; this work featured on the Channel 4 documentary series *Bone Detectives* (October 2020) and has resulted in outreach programmes funded by the University of Nottingham and the Paget's Association (Educational Award). Other research on MND has helped attract ECR Scott to UoA5 as an MND Association Lady Edith Wolfson Junior Non-Clinical Fellow (£250K, 2019-22). Bennett has served as Director of the FRAME (Fund for Replacement of Animals in Medical Experiments) Alternatives Laboratory in Nottingham throughout the REF period, with numerous 3Rs-relevant research projects delivered through collaborations with clinical academics within the School of Medicine and the NDDBRC (Nottingham Digestive Diseases Biomedical Research Centre). Kerr maintains extensive collaborative research with Stephens (Engineering) and Lucite (Mitsubishi Research Chemicals). Similarly, Serres holds collaborative funding with colleagues in the School of Medicine totalling £350K, including from MRC-CIC (Confidence in Concepts, as PI). Hume developed collaborative research with colleagues at UCL and CNB-CSIC (Madrid), resulting in a joint output [*Nature Communications* 2020] supported by Wellcome Prime (Section 2.2). Shaw was a recipient of US-DOD (Department of Defence) funding with Wayne State University Detroit (Ratnam; $419K to UoN, 2017-21) for a project to develop new therapeutic approaches for the treatment of androgen-resistant prostate cancer. Amelio is a new (March 2020) joint appointment with the University of Rome "Tor Vergata" where he is also an AIRC (International Cancer Research Fellowship) Start-Up Group Head. Maiellaro is a NRF who transfers expertise in optical mapping of intracellular signalling at the nanometer scale to Nottingham [*Cell* 2020]. Maiellaro's work in *Drosophila* complements that of Georgiou, which supported by Cancer Research UK has led to an (inter)national collaborative

study of novel tumour suppressors [*iScience* 2020]. This work underpins development of an online searchable database representing a fully open-access resource for the cancer biology field.

In the area of **Physiology**, Leach (Honorary Secretary of the *British Microcirculation Society*) contributes to multi-disciplinary research projects, with recent seminal work with clinical colleagues describing for the first time the haemodynamics of the human placenta *in utero* [*PLoS Biology* 2020]. Bates is Chief Scientific Officer and Donaldson founding scientist of Exonate, an early-stage biotech company spun out of the University of Nottingham that is focused on VEGF (Vascular Endothelial Growth Factor) [*REF2021ICS*].

Sockett FRS heads a major interdisciplinary collaboration with collaborative research external to Nottingham in the area of **Microbiology**, funded by a 5-year Wellcome Investigator award (£1.1M to UoN 2018) with Andrew Lovering at University of Birmingham on predatory invasion mechanisms to kill Gram-negative bacteria. This is complemented by a 3.5-year US DARPA Programme ($3.5M, 2014) with Lovering, DSTL Porton Down and Jamie Twycross (UoN Computer Sciences) on Predatory Prokaryotes. Williams held 5-year Wellcome Investigator award funding (£933K, 2014, with Alexander, Pharmacy) as well as leading (with Ghaemmaghami) a Next Generation Biomaterials Discovery Program, a 5-year collaborative EPSRC-funded program (2015-2020) with multiple European and International partners. Ghaemmaghami is a partner in the FP7 Immodgel programme (£512K to UoN) and the EC H2020-funded *Panbiora* project (£525K to UoN), to develop personalised and generalised integrated biomaterial risk assessment) while Camara leads the £1.2M Nottingham contribution to NBIC (2017, Section 1.2.2). Camara also led the JPI-AMR international consortium SENBIOTAR (£358K 2015-2018) on Sensitising *P. aeruginosa* biofilms to antibiotics and reducing virulence through novel target inhibition, with partners from Canada, Sweden and Denmark.

Interdisciplinary collaboration between medical sciences and humanities arises from the work of Diggle, which as part of the *AncientBiotics* project recreated medieval remedies from textual sources towards the treatment of contemporary drug-resistant bacteria [*mBio* 2015]. Bonev held joint EPSRC awards with Kockenberger (Physics & Astronomy), including to develop high-field NMR approaches (£262K, 2014-18), and to maximise sharing of the facility (£162K, 2018-20) with relevance to microbiological research. Interdisciplinary research with practical benefits extends to work led by Hardie (with colleagues in Social Sciences and clinical research) to improve tracking of the spread of infection in patient settings [*J. Infection Prevention* 2019]. The team secured >£50K of research funding, a licence agreement (with Ravencourt Ltd), and contributed to production of an information film for the Royal Society 2019 Summer Exhibition.

Collaborative research in **Virology** is a further strength within UoA5, with Irving part of the EU-funded HepaMAb project, involving seven research teams from across Europe, including collaboration with NDDBRC. Irving also co-chairs the Hepatitis C Virus Research UK (HCVRUK) consortium, which included as of November 2020 clinicians from 59 NHS Trusts; this is a national research infrastructure that integrates a database of detailed longitudinal clinical information of 12,000 HCV-infected patients and a patient sample biobank resource [*REF2021ICS*]. Turner, in collaboration with Dr Christopher Bayliss (University of Leicester) has translated epidemiological research into Public Health England guidance (2016) on the prevention and management of meningococcal disease in Higher Education Institutions across the UK [*REF2021ICS*]. Ball leads the Nottingham Centre for Global Virus Research (One Virology), recently established with £250K funding from the Wolfson Foundation, holds EU (PaleBlu consortium, 19 partners in 15 countries)

and National Institute of Health Sciences (Japan) funding, and with numerous media appearances during the Covid pandemic has contributed widely to public information and debate on the subject.

Research in the area of **Immunology** is highly collaborative, with Martinez-Pomares part of an MRC-funded collaboration (with Leicester and Oxford) exploring-antimicrobial therapy to prevent sepsis in pneumonia patients. Further immunology research with practical, health and economic impact is evidenced by Impact Case Study from Sewell [*REF2021ICS*] who in collaboration with the School of Medicine has development of a blood test for early detection of cancer in high-risk patients, commercialised by the former University of Nottingham spin-out company Oncimmune Holdings PLC [*REF2021ICS*]. Vinkemeier and Coleman work on fundamental research into immune signalling, with Coleman's expertise recently contributing to the debate on the broad use of hydroxychloroquine in COVID-19 patients [*Nature Communications* 2020]. Ghaemmaghami, in collaboration with the School of Pharmacy, has developed a new generation of immune-instructive materials, some of which are now the basis of an industry (Smith & Nephew) funded project for developing bio-instructive wound dressings.

In terms of interdisciplinary collaborations and collaborative research external to Nottingham in **Cells, Organisms and Molecular Genetics**, the SBRC (Griffin, Minton, Soucaille, Winzer, and Zhang, Section 1.2.3 above) is part of a collaborative network of six RCUK-funded units across the UK (Bristol, Edinburgh, Manchester, Cambridge/Norwich and Warwick) with strong links to industry (over 40 documented collaborations and the incubation of five companies: DeepBranch Biotechnology Ltd, Phenotypeca, Zuvasyntha, Chain Biotechnology Ltd and Phase BioLabs Ltd). Under Minton's directorship of the C1net and CCnet NIBBs, the SBRC oversees the funding of UK-wide efforts in gas fermentation, has participated in four European ERA-NETs and coordinates the Marie Curie ITN, CLOSPORE. Griffin has active collaborations with collaboration with GSK on mucosal administration of vaccines against infectious diseases for *C.difficile*, and with KyMAb (Cambridge) towards the development of therapeutic antibodies against infections. Brook's work on therapies for muscular dystrophies has involved cross-disciplinary collaborations with the School of Chemistry (Hayes) supported by Wellcome Seeding Drug Discovery funding (£2.8M 2016). Goodacre's work on producing synthetic spider silk has also seen collaborations with Chemistry (Thomas) and collaborators overseas (Scandinavia). Reader collaborates with Computer Sciences on a UKRI-funded virtual reality project. Tewari's seminal collaborative research on malaria involves significant funding from overseas agencies with Hanotte focussing on developing African talent in genomics, in the context of global food security.

4.1.2 Broader Contributions to the Discipline

Broader contributions to the discipline have been made from UoA5 **Pharmacology** researchers' significant roles with the *British Pharmacological Society* (BPS) including from Hill (President-Elect 2016-2017; President 2018-2019). Woolard was awarded the BPS Bill Bowman Prize in 2019. Canals (2015) and Lane (2019) have been awarded the BPS Novartis Prize. UoA5 researchers also play leadership roles with the *British Journal of Pharmacology* published by the BPS, with Alexander a senior editor. The BJP also publishes the bi-annual *Concise Guide to Pharmacology* (www.guidetopharmacology.org), a database of ~1700 drug targets and >3,500 ligands, collated by >150 collaborators from 22 countries (2018) that represents a resource for the drug discovery community (academic and industrial). The database is 'fed' in large part from a Nomenclature Committee of *IUPHAR*, chaired by Alexander, which has ~90 subcommittees with ~500 scientists worldwide involved.

Broader contributions to the discipline(s) of **Microbiology** include Sockett's numerous public/media engagements and stimulation of debate, including appearance as a guest on Radio 4's *Life Scientific*, contribution to the Science Museum's 'Superbugs' exhibition, Ball also guesting on Radio 4 *Life Scientific*.

In the field of **Synthetic Biology,** undergraduate teams supervised by SBRC have won Gold Medals at the International Genetically Engineered Machine (iGEM) competition, a worldwide synthetic biology competition, in 2018, 2019 and 2020. Other ECR contributions to the broader research environment have included UoA5 PhD students joining the outreach programme *Pint of Science*, which in the REF period had engaged audiences of ~1000 people/year, involved 40 PhD students/year, and had contributions from up to 30 UoN academics/year. The SBRC has delivered over 170 local, national and international outreach events since 2014, including an annual presence at New Scientist Live in London. Communication initiatives in **Molecular Genetics** and **Ecology** include *Open Air Laboratories ("OPAL")*, in which more than 1 million members of the UK public surveyed the biological environment as part of a citizen science project. British Science Association media fellow (Davison) has also been involved in extensive public engagement activities following work on body asymmetry in molluscs, and has been extensively involved in activities such as *Pint of Science*.

4.1.3 Covid-19: A Case Study of UoA5 Environment Enabling an Agile Research Response to the Global Pandemic

Prior support for **One Virology** and the **DeepSeq** platform meant UoA5 researchers were ideally placed to rapidly respond to the pandemic and a strategic decision was made by SoLS Research Committee to re-focus in house genome sequencing, virology and immunology expertise towards tackling immediate Covid-19 research questions. Rapid-response funding (Wellcome £393K 2020; Public Health England £626K 2021) was secured by Loose (DeepSeq) with core platform facilities in SoLS prioritised for return to research to enable this rapid transition. In March 2020 Loose was invited to join the COVID-19 Genomics UK consortium study group (COG-UK, reporting to SAGE), the UK-wide network consisting of the NHS, the four Public Health Agencies of the UK, the Wellcome Sanger Institute and other academic partners. Loose is part of the COG-UK management board (and the sequencing workflows steering group) which coordinates rapid, large-scale whole genome sequencing and analysis of SARS-CoV-2. DeepSeq alone has analysed and contributed in excess of 4700 viral genomes to COG, including rapid-response data that enabled a targeted local lockdown in Leicester, and supports 24-hour turnaround of critical Covid sequences for PHE. Genomic sequencing of archived hospital patient respiratory samples (Ball, Loose and Irving) showed the presence of SARS-CoV-2 in the UK from January 2020 with early cases from a distinct viral lineage and widespread community circulation in February from multiple introductions. The Chair of the House of Lords Select Committee has invited Ball to collect evidence on the first peak of Covid-19 for a report to inform policy for future pandemics. Ball also co-leads (with Prof Chris Denning, School of Medicine) a SARS-CoV-2 testing service on the University campuses to detect and study asymptomatic transmission (MRC £80K 2020) and is also involved in several other Covid studies, including understanding the role of plastic surfaces in transmission and prophylactic treatment in care homes (with Coleman).

Turner is part of the Oxford ChAdOx1 nCOV-19 vaccine trial where the ACWY meningitis vaccine (*REF2021ICS*) is being used as an active control. A review in the British Journal of Pharmacology (Alexander, 2020) urges repurposing of existing drugs is cited by The Publications Office of the European Union in a report: *Lifting Coronavirus Restrictions: The role of therapeutics, testing, and*

contact-tracing apps. Coleman, Ball and Urbanowicz (ECR) joined a consortium led by Scancell (Innovate UK) to adapt their existing cancer vaccine to a SARS-CoV-2 DNA vaccine and with Tighe, Fairclough, Loose, Irving and Tarr pursue ongoing immunological research to stratify interventions and design and validate a new Covid-19 antibody assay (MRC Proximity to Discovery award) that is cheap (25p/test) and rapid (12 hours). The test was used in the UKRI-funded PANTHER study to track and understand infection and immune responses to Covid-19 in healthcare workers, and to screen 600 volunteers in the Nottingham arm of the Oxford vaccine trial (Turner). Fairclough (with Tighe) is leading an asymptomatic testing programme in the student population (UKRI £246K 2020). UKRI-funded collaborations are examining how macrophage-dependent inflammation drives organ damage in SARS-CoV-2 (Martinez-Pomares), environmental sampling of Covid and self-sterilising masks (Coleman).

4.2 Journal Editorships and Research Leadership

Across the REF2021 period, UoA5 academics have acted as Editors/Associate Editors at scientific journals including Gilbert, Editor-in-Chief, *Ecological Entomology*; Brookfield, Editorial Board, *Current Biology*; Hardie, Section Editor, Journal of Medical Microbiology; McInerney, Associate Editor, *Journal of Experimental Zoology*; Amelio, Associate Editor, *Cell Death Discovery*.

4.2.1 International and National Advisory Board Membership

The expertise of UoA5 staff is further reflected in membership of numerous national and international advisory boards during the REF period, with selected highlights including:

Alexander	The Barriers to Research and the 2016 Amendment to the Misuse of Drugs Act
Alexander	The Neurochemistry Working Group, Advisory Council on the Misuse of Drugs (ACMD)
Alexander	The Medicinal Cannabis Re-Scheduling Working Group
Alexander	Chair of the Committee on Receptor Nomenclature and Drug Classification of the Union of Basic and Clinical Pharmacology (NC-IUPHAR)
Bates	Advisor to the South African Medical Research Council
Bates	Chair of the Finnish Academy of Sciences Cancer Panel
Brookfield	Scientific Advisory Board, Institute of Biology, Université Pierre et Marie Curie, Paris
Camara	European Cystic Fibrosis Society Steering Committee
Camara	Cystic Fibrosis Trust Strategic Implementation Board
Ebling	Scientific Advisory Board of The Roslin Institute, University of Edinburgh
Irving	National Strategy Group for Viral Hepatitis
Irving	Advisory Committee on the Safety of Blood, Tissues and Organs
Irving	Royal College of Pathologists Standing Advisory Committee on Virology
MacColl	US National Evolutionary Synthesis Centre Working Group (Chair)
Sockett	2020 Gordon Research Conference on Bacterial Cell Surfaces (Co-Chair)
Sockett	Strategic Advisory Board of Max Planck Institute of Terrestrial Microbiology Marburg
Williams	Scientific Advisory Board of the European Union Joint Programming Initiative on Antimicrobial Resistance

4.2.2 Committee Membership of Professional Bodies, Charities and Trusts

Again UoA5 staff made major contributions during the REF period with memberships in these areas, with highlights including: Armour, Trustee of the *Frozen Ark* (a conservation biobanking charity); Bates, Fellow of the Physiological Society (2017), President of the *British Microcirculation Society* (2020–2022); Brook, Trustee of the *Myotonic Dystrophy Association*; Goodacre, Vice-President of the *European Society for Arachnology*; Hardie, Chair of the Prokaryote Division *Microbiology Society* and Council Member of the *Royal Society of Biology*; Hill, President-Elect 2016-2017 and President 2018-2019 *British Pharmacological Society*; Layfield, Trustee of the *Paget's Association*; Leach, Honorary Secretary of the *British Microcirculation Society;* McInerney, Secretary of the *Society for Molecular Biology and Evolution*; Sockett, member of the *Royal Society Diversity Committee;* and Williams, Member of the *European Academy of Microbiology.* McInerney was elected in 2020 to be the President of the *Society for Molecular Biology and Evolution*, beginning in 2022.

4.2.3 Membership of Grant and Fellowship Awarding Bodies

UoA5 members have contributed significantly to the assessment of funding applications, most prominently by membership of national grant and fellowship awarding bodies. Throughout the REF period this translates to 30 different panel memberships from 20 different staff, with highlights (panel Chairs) including: Hill, Chair UKRI Future Leader Fellowship sift and interview panels; Layfield, Chair of the Paget's Association Research Sub-Committee; and Bates, Chair of the Stoneygate Trust Children's Brain Tumour Research Fund.

4.2.4 Honours, Fellowships and other Awards

From numerous awards to UoA5 members throughout the REF period, highlights include:

Sockett FRS, first at UoN since 2009 and first ever female FRS at UoN (2019)
Leverhulme Trust International Academic Fellowship (MacColl 2017)
Fellowships of the American Academy of Microbiology (McInerney 2015, Sockett 2017)
Fellow of the Linnean Society (McInerney, 2016)
Royal Society Wolfson Merit Award (Minton, 2015)
Fellow, Royal College of Pathologists (Ghaemmaghami, 2020)
Membership of the European Academy of Microbiology (Williams 2017)
Dutch Pharmacological Society's Ariens Award and Lecture (Hill 2019)
Raine Visiting Research Professor, University of Western Australia (Hill, 2015-2016)
Honorary Fellowship of the British Pharmacological Society (Hill 2020)
British Science Association Media fellowship (Davison, 2018)
Academy of Medical Sciences Professorial Fellowship (Canals, 2019)
British Association for the Study of the Liver Recognition of Service Award (Irving, 2019)
Outstanding Scientific Achievement Award, Proteomass Society (Bates, 2018)
MND Association Junior Non-Clinical Fellowship (Scott, 2019)
Marie Curie Fellow and Nottingham Anne McLaren Fellowship (Whelan, 2018 and 2020)
Nottingham Anne McLaren Fellowship (Maiellaro 2019)
Nottingham Research Fellowship (Wilkinson 2019, Blount 2020)
Swiss National Science Foundation Mobility Fellow (Huwiler, 2018)
Jonathan Ball (2019) and Liz Sockett (2017) were each the subjects of episodes of BBC Radio 4's "The Life Scientific" radio programmes
SuperBiomaterials to Fight Superbugs Stand 2019 at Royal Society Summer Exhibition (Hardie, with Morgan Alexander (Pharmacy))