

Institution: University of Leeds (UoL)

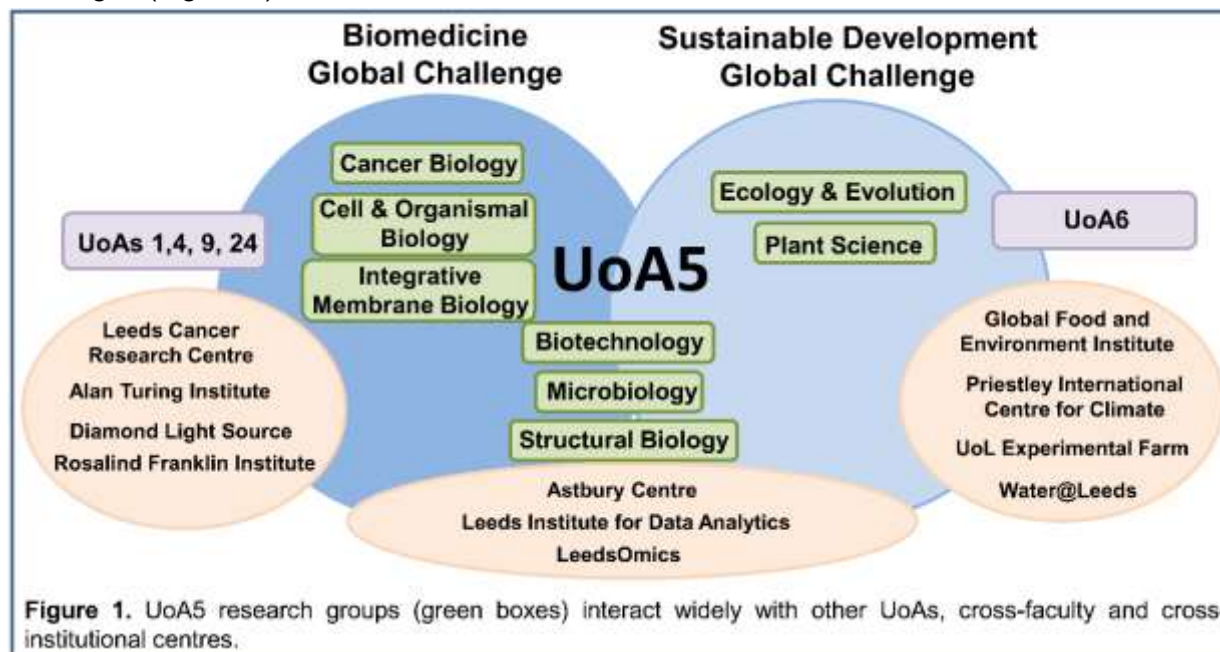
Unit of Assessment: UOA5 Biological Sciences

1. Unit context and structure, research and impact strategy

1.1. Overview

This submission comprises 93 staff (84.93 FTE) within the Faculty of Biological Sciences (FBS). Research focusses on interdisciplinary approaches to address global challenges in biomedicine and sustainable development, underpinned by fundamental discovery bioscience. Building on our excellent fundamental, applied and interdisciplinary research identified in REF 2014, FBS has aligned staff into 8 cohesive research groups, better positioned to address global challenges (Figure 1). We have reinforced the collaborative and translational links of four pre-existing research groups described in REF2014, through recruitment of exceptional new academics (**Ecology & Evolution**:17 returnees, **Integrative Membrane Biology**:12 returnees, **Plant Science**:11 returnees and **Structural Biology**:13 returnees). Critical mass has increased in three new areas (**Biotechnology**:7 returnees, **Cancer Biology**:8 returnees and **Cell and Organismal Biology**:9 returnees). Amalgamation of infectious disease research into **Microbiology**:16 returnees, provides core strength addressing global issues in antimicrobial resistance and infectious diseases. Each group includes senior researchers providing strategic leadership and development, and early career researchers (ECRs) providing long-term sustainability.

We have created an interactive research environment with shared space, support processes, facilities and management, such that our 8 research groups are interlinked and collaborate extensively within and beyond UOA5, increasing research power to address our strategic challenges (Figure 1).



Returnees have primary affiliations to one research group, plus strong associations with other groups. To maximise impact of our fundamental bioscience, all groups now strongly align with and participate in cross-faculty centres (Figure 1, detailed in Section 4.1 and REF5a). These centres transcend faculties and UoAs, tackling global challenges, including climate change, global health and food security, allowing UOA5 researchers to interact more readily across academia, industry and public policy. UOA5 also maintains close collaboration with the Faculty of Medicine and Health (FMH), for example through the Leeds Cancer Research Centre, ensuring our health-related research is driven by clinical needs. This collaborative and translational culture is underlined by some FBS staff being returned in UoA1, 4, 6, 9 and 24 (35.3 FTE). Our interdisciplinarity also enables staff to play leadership roles in external collaborations, such as the Alan Turing Institute,

Rosalind Franklin Institute and Diamond Light Source, allowing our research excellence to be user-informed and have broad relevance.

During the REF period, UOA5 academics were awarded new grants (as PIs or CoIs) valuing £101.4M, published >1700 open-access research articles and received >27,000 citations. We continue to invest in our research environment through improvements in infrastructure (£32.25M) and new facilities (£21.3M), enhancing collaborative research space. Our user-informed, solution-driven research impacts on bioscience discovery, economic growth, policy makers, food security, environmental change and societal benefits in health and well-being.

1.2. Research and Impact (R&I) Strategy

UOA5's over-arching strategy is to enhance our world-class research activity to meet national and international priorities in Biomedicine and Sustainable Development, underpinned by fundamental discovery bioscience. Aligning our research groups to UK Research and Innovation (UKRI) research priorities, Global Challenges Research Fund (GCRF) vision and United Nations (UN) sustainability goals, meets the challenges of health and well-being for all, environmental change and food sustainability. We have aligned UOA5 discovery bioscience with translational mechanisms, enhancing our reach and impact, by fully exploiting interdisciplinary research through interaction with cross-faculty centres (Figure 1, Section 4.1), promoting industrial links and our international outlook. Together this provides the wide array of skills required to address key biological questions of global importance. Since REF 2014, our world-class research activity and global impact has been enhanced through strategic appointments, intensification of interdisciplinary research, national and international links and use of new technologies.

1.2i. Investing in people

UOA5's research capacity has increased significantly by staff recruitment within all research groups, enhancing research vitality, bringing new collaborative opportunities, providing longer-term sustainability and providing key leadership in new areas. Appointments at all levels, include 6x Professors, 8x lecturers and 14 University Academic Fellows (UAFs) (Section 2). We have further enhanced our research capability by recruiting 10 externally-funded independent fellows, with 5 of these joining the UAF scheme and 2 appointed as lecturers. Staff appointed during the REF period are supported by active mentoring, information exchange sessions with other recent appointees, pump-priming funding and the provision of a university-funded postgraduate student. Combined with an initially low teaching load, this approach has underpinned £31M new grants awarded to recent appointees. Staff at all levels are supported to succeed in their research strategy by their School Director of Research and Innovation (DoRI), who coordinates their research environment, space allocation and mentoring. Research group leaders champion everyday research success through strategic alignment with targeted funding avenues. FBS has also invested in bioinformatic infrastructure through LeedsOmics, including dedicated bioinformaticians (2.0 FTE), enhancing Omic-based research across all biological areas.

1.2ii. Investing in infrastructure and facilities

UoL has invested significantly in UOA5-related infrastructure (£32.25M) and facilities (£21.3M), providing a state-of-the-art research environment (Section 3). All UOA5-related research groups now have contiguous research space, the majority of which has undergone, or is undergoing, refurbishment. Research facilities are managed by the Head of FBS Research Facilities (0.6 FTE) and 10 dedicated faculty-funded facility managers (Section 3.2ii).

1.2iii. Enhancing interdisciplinary research

UOA5 staff engage extensively and successfully with other UoL faculties through cross-faculty centres (Figure 1, Sections 1.4 and 4.1) to boost outputs, enhance impact and translation of our research. Our successful collaborative ethos is emphasised by national and international collaborations leading to an increase in outputs with other UK institutions (from 46% to 50%) and international co-authors (from 40% to 59%), since REF2014. Furthermore, >25% of our postgraduate research students (PGRs) participate in interdisciplinary research, taking advantage of cross-faculty centres (Section 2.5). This vibrant cross-institutional research environment,

includes seminars, meetings, roadshows, away days and journal clubs, with multiple faculties, including FMH, Environment, Engineering and Physical Sciences. We participate in Leeds Creative Labs, an innovative programme pairing researchers with Creative Professionals and the Leeds Crucible Programme, helping researchers to collaborate with colleagues from different research backgrounds via residential sessions.

1.2iv. Encouraging an open research environment

Research data is shared openly and extensively, with >90% of outputs complying to REF open access policy (REF5a), through the White Rose Research Online database and publishing in open access journals. We encourage the use of centralised open access public repositories for Omic data (PRIDE, ArrayExpress etc), structural data (Protein Data-Bank, EM Data-Bank, EMPIAR etc) and the production of Leeds-based websites to allow sharing and re-use of data. Researchers deposit their raw and metadata in the Research Data Leeds Repository, providing a unique DOI for public access included in publications or on laboratory webpages. We no longer advocate using any proprietary software and actively encourage open-data platforms and services. We fully adhere to the open sharing of reagents and cell lines, depositing newly generated plasmids in repositories, like Addgene, following publication.

1.2v. Embedding a culture of research integrity and ethical governance

UoL policy requires approval of all research with an ethical dimension by a University research ethics committee. This ensures UOA5 research is conducted according to the principles of academic excellence, community, integrity, inclusiveness and professionalism. UoL is committed to responsible practices in research evaluation by signing the San Francisco Declaration of Research Assessment (DORA). All researchers (PGRs, postdoctoral researchers (PDRAs) and academics) receive guidance through UoL training and local practices. FBS Research Ethics Committee operates under delegated authority from UoL Research Ethics Committee, considering likely benefits and potential risks of research involving human subjects or collecting species in an international setting. Research involving animals is performed under Home Office requirements and guidance and is reviewed separately by UoL Animal Welfare and Ethical Review Body; these committees include research staff and lay members. Administrative support for the ethical review process is provided by the UoL Senior Research Ethics Administrator and Research Ethics & Governance Administrator.

1.3. R&I delivered during the REF period

This is delivered through UOA5 research groups with extensive levels of interaction between groups and cross-faculty centres ensuring high impact. Exemplar achievements and future plans are showcased below for each group in alphabetical order. New appointees are highlighted in bold for each group. Translational impact of our research is detailed in Sections 1.4 and 4.

Biotechnology; Leader: **Tomlinson,D**; Group members: Berry, Brockwell, **Hemsworth**, McPherson (0.3 FTE), Millner (0.8 FTE), Seipke.

Aims to deliver an innovation culture blending fundamental and translational research, integrating academia and industry, to facilitate a technology readiness scale from knowledge creation and discovery to market introduction and products.

Example achievements include the development, characterisation, patenting and commercialisation of novel molecular-recognition reagents, Affimers (UOA5-41;ICS-UOA5-2), development of biosensors (UOA5-93), use of extensional flow and *in vivo* growth assays to predict protein aggregation during manufacture (UOA5-714), discovery and characterization of lytic polysaccharide monooxygenases for biofuel production (UOA5-3424), discovery and improved production of natural antimicrobials (UOA5-2959) and new synthesis pathways for chemical building blocks for drug discovery (UOA5-337). Notably, Hemsworth was awarded BBSRC and Biochemical Society ECR Awards and UOA5-1865 was highly commended for the NC3Rs annual prize (2017): reducing animal use in research.

Future goals will strengthen industrial links and academic collaborations, building new national and international collaborations, particularly focussing on developing novel biotechnology tools and embedding these into standard workflows in industrial and medical sectors.

Cancer Biology; Leader: **Bayliss**; Group members: Boyes, **Ladbury**, **Plant**, Westhead, Wright, **Wu**, **Zeqiraj**.

Aims to integrate genomic, structural, cellular and organismal approaches to interrogate fundamental mechanisms of cancer, enhance existing and identify new targets for intervention. Example achievements include the discovery of a non-canonical mode of oncogenic signalling by Grb2 (UOA5-3035;UOA5-3036), structural insights into EML4-ALK fusion in lung cancer (UOA5-3289), structural mechanisms of spindle assembly (UOA5-3288), structure/function studies of the DNA damage response (UOA5-3477;UOA5-3925), mechanistic studies on genetic recombination (UOA5-1707), tumourigenic mechanisms in ovarian cancer (UOA5-456), genetic dysregulation in cancer (UOA5-721;UOA5-723) and metabolic reprogramming in cancer (UOA5-3712).

Future goals will translate existing structural and biochemical understandings into therapeutic modalities. For example, a recent BBSRC sLoLa aims to understand the dynamic interactions of oncogenic kinases to develop protein-protein interaction inhibitors (Bayliss, Col). This strategy will be enhanced by the new Leeds Cancer Research Centre (Ladbury, Scientific Director), a cross-faculty endeavour integrating research into clinical oncology (diagnostics/biomarkers), novel therapeutic and disease models.

Cell and Organismal Biology; Leader: **van Oosten-Hawle**; Group Members: **Amer**, **Aspden**, Hewitt, Ingham (0.3 FTE), Peckham, Ponnambalam, **Scarff** (0.8 FTE), Stacey.

Aims to improve the understanding of fundamental cell biology in health and disease, using cell culture systems and model organisms.

Example achievements include novel insights into the structure/function of myosins (UOA5-615;UOA5-2531), structure/function of specific tissues and their changes during aging and disease (UOA5-1424;UOA5-2998), translation of sORFs (UOA5-3202), regulation of VEGFR trafficking (UOA5-1105), developmental mechanisms of skin-associated inflammatory diseases (UOA5-2227), developing 3D-culture systems (UOA5-4087) and biocompatibility of medical implants (UOA5-24;ICS-UOA5-1).

Future goals aim to visualise cellular processes in real-time throughout aging and disease, exploiting this knowledge for medical and biotechnological gain, using super-resolution, cryo-EM and cryo-CLEM, as well as high-throughput imaging of cells in culture and model organisms.

Ecology & Evolution; Leader: **Duncan**; Group members: **Beger**, Benton (0.2 FTE), Bretman, Compton, Dunn, Firbank (0.6 FTE), Goodman, Hamer, Hassall, Isaac (0.6 FTE), Kunin, **O'Connell** (0.2 FTE), Peel, Quinnell, Sait, Sankaran (0.33 FTE).

Aims to address fundamental and applied questions relevant to the natural world, working at scales ranging from molecules to ecosystems.

Example achievements include impactful work on global change biology (UOA5-1909;UOA5-2717), conservation biology and invasive species (UOA5-558;UOA5-1710;UOA5-3590), biology of insect pests (UOA5-47;UOA5-1421;UOA5-2698) and insect-borne diseases (UOA5-660), evolutionary biology and adaptation (UOA5-1192;UOA5-3129;UOA5-3179), biodiversity and sustainable agriculture (UOA5-242;UOA5-551;UOA5-1720;UOA5-2473;UOA5-4589). UOA5-547 was awarded RSPB Conservation Science Paper of the Year, 2017. Close ties exist with conservation and policy communities at regional, national and international levels, highlighted by ICS-UOA5-3;ICS-UOA5-4;ICS-UOA5-6;ICS-UOA5-7.

Future goals will address global environmental challenges aligned with UN sustainability goals, enhancing the translation of fundamental research for societal impact. This is combined with enhancing relationships with stakeholders and delivering increased impact internationally, with a particular focus on developing nations.

Integrative Membrane Biology; Leader: Muench; Group members: **Frank**, Goldman, Harrison, Henderson (0.2 FTE), Jeuken, Jiang, Lippiat, **Lukacs**, **Pliotas**, **Richter**, Sivaprasadarao (0.8 FTE).

Aims to use multidisciplinary approaches to study membrane proteins from the atomic to cellular level, leading to fundamental understanding of membrane protein structure/function and their role in human health.

Example achievements include advances in the understanding of proton and sodium pump arrangement and function leading to drug design (UOA5-215;UOA5-1941;UOA5-2916), novel mechanistic insights on transporters and ion channels (UOA5-123;UOA5-261;UOA5-1589;UOA5-1647), understanding of mechanosensitive channels (UOA5-3928;UOA5-3984), developing techniques for assembling bilayers, developing biosensors and super-selective targeting of cell surface receptors (UOA5-1351;UOA5-3440;UOA5-3886).

Future goals will utilise rapidly expanding capabilities for time-resolved methodologies and structural biology, to interrogate disease-associated membrane protein dynamics and developing surface technology for biocatalysis and biosensors.

Microbiology; Leader: Tuplin; Group members: Barr, Blair, **Fontana**, Harris, **Herod**, Macdonald, **Mankouri**, McConkey, McDowall, O'Neill, **Roberts** (0.2 FTE), Rowlands (0.2 FTE), Stonehouse, **Tomlinson,J** (0.8 FTE), Whitehouse.

Aims to understand in molecular detail the biology of micro-organisms that cause disease in animals and humans, exploiting this knowledge to develop new therapeutic strategies, highlighted throughout Section 4.

Example achievements include insights into the fundamental nature and pathogenesis of a diverse range of microbes: including Bunyaviruses (UOA5-1454), Hepatitis viruses (UOA5-652;UOA5-653), Chikungunya virus (UOA5-654), Herpesviruses (UOA5-378;UOA5-3253), Polyomaviruses (UOA5-772), Picornaviruses (UOA5-2919), Noroviruses (UOA5-3523), Enteroviruses (UOA5-68), Papilloviruses (UOA5-33;UOA5-769), *Toxoplasma gondii* (UOA5-530) and *Escherichia coli* (UOA5-546), dramatically expanding the mechanistic paradigm for how pathogenic bacteria resist antimicrobial agents (UOA5-767;UOA5-2477) and evolving novel strategies for therapeutic intervention (UOA5-374;UOA5-599) and vaccine development (UOA5-600).

Future goals will exploit increased capabilities in structural biology and super-resolution bioimaging to underpin structural-based therapeutic design, through strong links with medicinal chemistry and applying Affimers (ICS-UOA5-2) in microbial therapies and diagnostics.

Plant Science; Leader: Kepinski; Group members: Baker, Benitez-Alfonso, **Bennett**, Cuming, Davies, Denecke, **Dixon**, Knox (0.6 FTE), Urwin, West.

Aims to utilise multidisciplinary approaches spanning scales from the angstrom-level analysis of signalling systems to understanding the metabolic basis of plant-fungal symbiosis. Strengths lie in structural and synthetic biology, cell and developmental biology, plant-symbiont and plant-pathogen interactions and rhizosphere processes.

Example achievements are highlighted by work on plant hormone signal transduction and root and shoot architectural control (UOA5-1396;UOA5-1876), DNA repair and genome stability (UOA5-1600), molecular basis of plant immunity (UOA5-60;UOA5-561), the secretory pathway (UOA5-753), synthetic biology (UOA5-493;UOA5-2764), reproductive development (UOA5-4049), plant-microbe interactions (UOA5-275;UOA5-276) and determinants of plant cell wall degradation (UOA5-205).

Future goals focus on Future Crops, an initiative building on the group's fundamental research and discovery base providing knowledge and tools to create new crop varieties for a changing world and developing innovative farming systems delivering net zero carbon food production.

Structural Biology; Leader: Ranson; Group members: **Breeze, Calabrese, Cockburn, Edwards, Krivov, Ochi, Paci, Patel, Radford, Sobott, Stockley, Zhuravleva.**

Aims to provide a central hub in UOA5-based research, linking diverse research questions with the common aim of understanding mechanisms in molecular detail, and developing new techniques enabling the interrogation of those mechanisms. A hallmark of this approach is integrating all major structure determination technologies, alongside a comprehensive suite of biophysical approaches, imaging and computation.

Example achievements include significant contributions to understanding biomolecular function (UOA5-2793;UOA5-2903), elucidating the structure of viruses (UOA5-1411;UOA5-1412), viral proteins (UOA5-1746), virus assembly (UOA5-84;UOA5-85), bacterial outer membrane protein folding (UOA5-1410), molecular chaperone function (UOA5-523;UOA5-2900), amyloid structure (UOA5-524;UOA5-526), cellular kinase function (UOA5-971;UOA5-3048), complex assembly in DNA repair (UOA5-3927) and molecular motors (UOA5-3001). Computational biology also complements these sub-themes (UOA5-1688;UOA5-2252).

Future goals will exploit and further develop state-of-the-art facilities in cryo-EM and solution NMR, to unpick the molecular details of processes as diverse as how virus structure facilitates infection to protein aggregation and degeneration. The group will also develop cryo-CLEM, single molecule and super-resolution methodologies to integrate cell and structural biology.

1.4. Embedding impact

Our current impact strategy is built upon the success of our REF2014 return (ranked 6th for research impact). Translational impact is now supported through the Faculty Research & Innovation Development Manager (RIDM) and Research Impact Officer (Section 3.2i). We have appointed three FBS Impact Champions (2016-onwards), whose role supports UOA5 academics develop and deliver impact from fundamental research discoveries. Stronger interactions with cross-faculty centres (Figure 1, Section 4.1), have provided increased access to external advisory boards and industry engagement events. This strategy has increased our external interactions across academia, industry and public policy, enhancing UOA5's long-term delivery of economic and social impact. Further development of new interactions with companies to increase impact is supported at the university level by the commercialisation team, the Medical Technologies Innovation and Knowledge Centre and the newly completed Nexus Centre (detailed in REF5a), enabling businesses from all sectors to connect with UOA5 academics to maximise innovation and commercial returns (Section 4.4). This step-change in approach has increased the translational impact of UOA5 research, beyond biomedicine and sustainability, by directly impacting on public policy. This is exemplified not only by the strength of our current 7 Impact case studies (ICS), but also the wide range of additional impact detailed throughout REF5b.

We have invested £465K of faculty funds in impact projects since 2014, together with a further £75K from the sale of spin-out companies. This has enabled UOA5 to support impact-related projects through various mechanisms, including pump-priming funding, travel and staffing support, purchasing and maintenance of vital equipment, as well as enhancing staff development by supporting industrial and other secondments, exemplified by Ecology & Evolution:Benton becoming the Champion of the UK's Global Food Security programme (ICS-UOA5-3) and industrial secondments, Cell Biology:Ingham (ICS-UOA5-1). Other projects supported include sea mammal conservation, Ecology & Evolution:Goodman (ICS-UOA5-6); pollinator sustainability, Ecology & Evolution:Kunin (ICS-UOA5-7); a novel confocal microscopy technique (Membranes:Lippiat); vaccine development (Microbiology:Stonehouse); control of plant shoot/root branching angles (Plant Science:Kepinski); wildlife pest and disease monitoring (Ecology & Evolution:Hassall; Biotechnology:Millner).

FBS won the BBSRC Excellence with Impact runner-up award, May 2016. This £35K award was combined with faculty funding (£20K), to support BBSRC-remit impact projects: including a protein aggregation prediction platform (Biotechnology:Brockwell); Invasive non-native species biosecurity, Ecology & Evolution:Dunn (ICS-UOA5-4); Cereals and soil (Plant Science:Knox);

antiviral inhibition of respiratory syncytial virus (Microbiology:Barr/Edwards) and a GCRF Translational project (Plant Science:Urwin).

An EPSRC Impact Acceleration Account (IAA), awarded to UoL (2013-present) provided funding for proof-of-concept projects: £57K to design and manufacture benchtop microfluidic devices for the biopharmaceutical industry predicting aggregation propensity of therapeutic antibodies (Biotechnology:Brockwell), leading to £364K further funding (Medimmune/UoL); a Business Engagement Project in collaboration with Futamura (£32K) (Plant Science:Benitez-Alfonso), exploiting the properties of cell wall components to develop new cellulose-based products. Similarly, UoL MRC Confidence in Concept funds, 2014-present, funded multiple awards in UOA5 (£567K) to support projects: in cancer immunotherapy (Microbiology:Blair); Lupus treatments (Cancer:Zeqiraj); topical disease modifiers for inflammatory skin diseases (Microbiology:Stonehouse) and therapeutic FcγRIIIa-binding Affimers (Biotechnology:Tomlinson,D, ICS-UOA5-2).

1.5. Applying our agile R&I strategy to COVID-19

UOA5 responded quickly to the COVID-19 pandemic. Impact is evidenced by 23 researchers from UOA5 groups volunteering for testing work in UK Lighthouse Laboratories and PHE, with Microbiology:Harris/Stonehouse being awarded COVID medals for organising this response. As part of DECOVID, a major national project driven by the Alan Turing Institute, Cancer:Westhead is leading a group applying data science and artificial intelligence methodology to intensive care unit data from UK hospitals, with the aim of predicting treatment needs and outcomes. Several projects have also been funded focussing on COVID-19: Biotechnology:Tomlinson developing rapid lateral flow COVID-19 antigen tests in collaboration with Avacta (ICS-UOA5-2); Microbiology:Harris in collaboration with FMH, assessing if SARS-CoV2 is present in stool samples and correlating this to transmission; Microbiology:Stonehouse, in collaboration with Oxford, is assessing HepB core and yeast expression systems for vaccine candidates; Cancer Biology:Boyes is developing broadly neutralising antibodies against SARS-CoV2; Structural Biology:Stockley, in collaboration with York and NIH, USA, is identifying packaging signals in the SARS-CoV2 genome to target as a novel therapeutics; Biotechnology:Tomlinson/Millner and Membranes:Jeuken are developing robust and sensitive enzyme-switch-based assays for point-of-care diagnostic tests for SARS-CoV2-specific immunoglobulin detection.

1.6. Future Initiatives

UOA5 will ensure continuity and succession of our excellence in challenge-led research underpinned by fundamental bioscience. Meeting our global challenges requires UOA5 researchers to work together in diverse interdisciplinary teams, bringing expertise in human health, food security, environmental impacts and systems understanding, scaling from the molecular to the ecosystem level. This strategy will be maximised by our interdisciplinary links with two major new initiatives. Firstly, the £32.25M investment in UOA5 research environment infrastructure will develop a new vision for biomedical research, providing shared, interdisciplinary space bringing together UOA5 scientists with engineers, chemists and clinicians to work on common goals. Similarly, an agricultural vision encompassing Smart Agri-Systems and pigSustain (FBS UOA6-based researchers), with Future Crops, will focus work across UoL, bought together through our fully instrumented working farm (£40M investment). Aligned with these initiatives we will grow our industrial portfolio by achieving greater collaboration with industrial partners via research and development contracts, the Nexus Centre and MIT-REAP entrepreneurship programme (detailed in REF5a). Our new Pro-Dean International position (initiated in 2018) will engage with international partners and stakeholders developing trans-national partnerships, raising our international profile and reputation. We also aim to develop the biologists of the future, through our PGR programs and PDRA initiatives, ensuring the vitality of both our own UOA and the global biological sciences community (Section 2).

2. People

2.1. Staffing Strategy and Staff Development

Our well-defined organisational structures and investment in people resulted in buoyant recruitment of leading research academics; including 6x Professors, 8x lecturers, 14 UAFs and 3 external fellows (Table 1). A key aspect of our recruitment strategy is to exploit the interface between our established research activities and new areas of interdisciplinary expertise, combined with the significant investment in our physical research infrastructure (Section 3). This has developed new research areas and built a critical mass of researchers. The recruitment of Professors Sobott and Breeze add to the buoyancy of our world class

Research Group	Professor	Lecturer	UAF and External Fellows
Biotechnology			Hemsworth (UAF and BBSRC) D. Tomlinson (UAF)
Cancer Biology	Bayliss Ladbury Plant		Wu (UAF) Zeqiraj (UAF and Wellcome)
Cell and Organismal Biology		Oosten-Hawle	Aspden (UAF) Amer (UAF) Scarff (BHF)
Ecology & Evolution		O'Connell Duncan (EU)	Beger (UAF and EU)
Integrative Membrane Biology		Lukacs Pliotas Richter	Frank (UAF)
Microbiology	Roberts		Fontana (UAF) Herod (UAF and MRC) Mankouri (UAF and Royal Soc) J. Tomlinson (Royal Soc)
Plant Science		Dixon (UKRI FLF)	Bennett (UAF)
Structural Biology	Breeze Sobott	Cockburn	Calabrese (UAF) Ochi (UAF) Patel (Medical Research Foundation)

Table 1: UoA5 recruitment during this REF period.

Mass Spectrometry and NMR facilities, supporting the work of Structural Biology and Professors Bayliss, Ladbury and Plant provide leadership in Cancer Biology. We also retain research active staff, on part-time contracts, in partial-retirement, to maintain research leadership and experience (7 Professors: Firbank, Henderson, Ingham, Isaac, Knox, McPherson, Rowlands). In total, 93 staff are returned, of whom 36 are Professors, 21 Readers/Associate Professors, 19 Lecturers and 17 Research Fellows. We return 18% of staff aged <40y, 30% aged 40-49y, 30% aged 50-59y and 22% >60y. 23% female and 77% male are being returned. Notably, new appointments during this REF period have an increased female (39%) to male (61%) ratio. 16% of returnees are <1.0 FTE highlighting our flexible staffing approach.

The UoL Great Minds initiative (detailed in REF5a), has invested significantly in UOA5 by recruiting future academic leaders. 14 UAFs have been appointed strategically across all UOA5 research groupings, to increase interdisciplinary research, grow research success and build sustainability by ensuring continued critical mass. An additional 4 UAFs were appointed in this REF period but are not returned in this UOA, as they obtained permanent positions at other universities, including chair level appointments, emphasising the high calibre of this cohort. UAFs receive a five-year development scheme, leading to tenure at Associate Professor level. During their probationary period they receive tailored mentorship by senior academics to stimulate their transition to independence and research success. For the first three years UAFs receive significant workload remission, with a teaching and administration load of 33% in year 1. UOA5 has significantly benefited from the outstanding performance of our UAFs. Recruited in three separate cohorts in this REF period, it is remarkable they have a combined new grant income of £13.4M, representing an average of >£840K.

Aligned with the UAF scheme we have enhanced our research interdisciplinary capability with 10 externally-funded research fellows. Dixon (UKRI-FLF), Hemsworth (BBSRC), Herod (MRC), Zeqiraj (Wellcome Trust), Tomlinson, J, Mankouri (Royal Society), Beger, Duncan (EU), Patel (Medical Research Foundation), Scarff (BHF). 5 of these independent research fellows have also been appointed onto the UAF scheme and 2 obtained lectureships.

To promote inclusivity during recruitment, we embed actions such as debiasing recruitment adverts, diversifying locations of advertising, optimizing use of professional networks and producing short films on life as a UoL employee. To ensure sustainability of staff and infrastructure, each Faculty has an academic and financial 5-year plan agreed annually with a top level University team. To cement our interdisciplinary approach, we recruit to enhance collaboration across

traditional disciplinary boundaries e.g. between biology and mathematics, medicine, engineering or environment.

2.2. Support and continuing professional development

We develop and promote existing staff aligned with our research ambitions. Post-probation, all academic staff are mentored, and development facilitated in an annual academic review meeting between individuals, Heads of School (HoS), DoRIs and Directors of Student Education (DSEs), with input from Research Group Leads. Workloads are discussed, assessed and can be redistributed allowing staff to tackle strategic objectives, as well as leadership training programmes and succession planning. An additional review is undertaken by the university-led “Staff Review and Development Scheme” with trained reviewers. Both forums help staff achieve their full potential, providing the opportunity for 2-way review of work progress, identifying key objectives, providing constructive feedback, recognising success through UoL “Reward and Recognition” scheme, providing support for improvement and identifying appropriate development, as well as allowing discussion of career aspirations. The value of on-going mentoring is reviewed each year and new mentors developed, both within and outside FBS.

To facilitate staff development, a wide range of opportunities are available centrally, through Operational Development and Professional Learning (OD&PL, REF5a), including courses on mentoring, attracting research income, applying for funding schemes, impact partnership with industry, leadership, commercialisation, and UoL “Next Generation Researcher” programme. Our success in staff development, reward of research accomplishments and external recognition is indicated by promotions (8 Professorships and 11 Readerships/Associate Professorships) during this REF period.

We are committed to the Concordat to Support the Career Development of Researchers, adhering to established University Policy on the Employment of Researchers (detailed in REF5a). Our support for PDRAs is enhanced with the appointment of an Academic Postdoctoral Champion (2018), who contributed to the institutional level HR Excellence in Research Award, and a new committee of PDRAs ensuring the needs of these valued members of our community are fully supported. All PDRAs have 10 training days per annum incorporated into their contracts. OD&PL deliver a programme of PDRA career support and opportunities for developing teaching skills, designed in conjunction with a UoL ECR Action Group. We have established local PDRA mentoring circles, aligned with 2 academic mentors from different backgrounds providing informal support for career development and any other issues. The PDRA community organise a “Coffee and Career” series, with speakers talking about careers outside academia after pursuing a PhD and/or PDRA. To foster PDRA’s research independence and grant writing skills we have also initiated the Dean’s Vacation Research Scholarships, allowing PDRAs to gain experience in PI skills including applying for funding, advertising for and interviewing students, supervising them for 8 weeks and writing a final report. UoL is also a signatory to The Technician Commitment and we have realigned technical structures to promote clear, transparent career pathways.

2.3. Creating a supportive environment for R&I

We have established structures enabling staff training and development from the earliest stages, including robust development and review of grant applications, leading to an increase in UOA5 successful grant applications (Section 3). Research groups meet at least bimonthly to discuss R&I strategy and administrative issues. Three external seminars are held each week and research groups also hold internal seminars, journal clubs and symposia, where junior researchers receive feedback on data and develop presentation skills. We provide internal peer review for grant applications, involving panel review, chaired by staff who sit or have sat on grant panels. We provide tips and hints documents and share examples of successful grants. We benefit from university-wide training workshops specifically for UKRI fellowship schemes. This includes peer review of applications, mock interviews, professional coaching and communication skills training. RIDMs (Section 3.2i) also support longer and larger grant applications. Within FBS, our management structure ensures that all research staff have easy communication with management

teams, creating a supportive and nurturing environment. It also facilitates information flow enhancing our ability to identify interdisciplinary opportunities quickly.

2.4. Supporting and promoting Equality and Inclusion (E&I)

We are committed to delivering a supportive and professional working environment for all staff, through embedded practices supporting equality, diversity, protected characteristics, disabilities and flexible working. To set local policy and ensure implementation of local and UoL policy, FBS has its own E&I Committee, chaired by the Executive Dean and attended by Pro-Deans, HoSs and School E&I PDRA and PGR representatives. In 2017, a Faculty E&I Coordinator was appointed and activities coordinated through the E&I Delivery Group include: establishment of a FBS Well-being room; prayer room; introduction of training sessions on unconscious bias and E&I for PGRs, PDRAs and staff; compliance with UoL Race Equality Framework; trans-awareness training: a campaign to represent the diversity of FBS staff and students under the slogan FACES OF FBS; an LGBT STEM event and a Faculty Diversity Award, funding attendance at BAME-ECR conferences for young BAME scientists, and Well-being Works, a peer support initiative run for, and by, PGRs.

We strongly support the development of women's careers in STEM disciplines and gender equality issues, as recognised by the FBS Athena SWAN Silver award, 2020. UOA5 is fully committed to the 'Leeds Gender Framework' (detailed in REF5a). All aspects of EDI were evaluated via a Faculty and University process ensuring no one was disadvantaged with respect to inclusion in REF and choice of outputs. Notably, new appointments during this REF period has an increased female (39%) to male (61%) ratio, over the existing faculty ratio (23% female to 77% male). Athena SWAN-led faculty funding provides PDRAs support for academics on prolonged leave (e.g. maternity leave), supporting to date 3 academics to maintain research output. New initiatives supporting grant writing has increased female staff contribution to successful applications from 16% in 16/17 to 46%. Funding for leadership training for women (e.g. Aurora, Springboard, detailed in REF5a), along with a more transparent application process has contributed to an increase in the leadership roles held by females (55% of roles in 19/20 compared to 26% in 2017), exemplified by the Executive Dean, 1/3 HoS and 3/3 of the DoRI positions within FBS, in addition to leadership positions in cross-faculty centres (Radford: Astbury; Priestley: Beger; LeedsOmics: Aspden/O'Connell).

We review current practices annually through 'Culture Surveys' and focus groups on part-time working, mentoring, career progression and returning to work. These highlight good practice providing action plans to continue improving E&I. We run workshops on flexible working to improve understanding for staff and managers, as indicated by 16% of the submitted academic staff and 13 PDRAs working part-time. Those staff with disabilities requiring specific support or adaptations are supported in conjunction with University Health and Safety and Occupational Health services, enabling them to carry out all tasks as necessary. We also actively participate in workshops discussing perceived barriers to part-time working, including academic speakers from UOA5, who bring their experience of part-time working and offer mentoring to those considering part-time work. All academics undertake compulsory tailored unconscious bias and E&I training, and Trans-awareness training has been taken by members of the Athena SWAN Team. An autism awareness workshop was also run specifically for FBS. Athena SWAN meetings encourage lively discussion of gender equality issues, including barriers to career development, everyday sexism and core hours. Following these discussions we now run an everyday sexism awareness campaign and have created a 'Family Friendly' guide, ensuring parents are fully aware of the facilities and resources available to support them.

2.5. Postgraduate Researchers

UOA5 has a vibrant and active group of PGRs. They contribute to 49% of UOA5 research outputs included in this return (increased from 43% in REF2014), indicating the strength of the PGR research environment. UOA5 PGRs have received multiple awards for their research during this REF period. Highlights include: Microbiology Society Young Microbiologist of the Year; selection

for the Lindau Nobel Laureate symposium; Forbes top young entrepreneurs under 30 2020; Cogent Life Sciences Postgraduate of the year.

PGR numbers have increased 18% between 2014/15 and 2019/20 (217 in 2014/15 compared to 256 currently registered); with ~20% being overseas PGRs (these figures do not include PGRs in their overtime year or under examination). This growth is consistent with the increase in research income (Section 3.1), indicating a further strengthening of the research environment. The ratio of female PGRs has increased from 50% in 2014 to 55% in 2020, there are two gender binary PGRs. Over 25% of our PGRs participate in interdisciplinary research, enhancing the richness of training and widening the scope of future career options. This is indicated by co-supervisors being associated with different faculties, taking advantage of existing links and building new partnerships across faculties and through cross-faculty interdisciplinary centres (Figure 1). PGRs also have co-supervisors at institutes outside Leeds (Public Health England, Centre for Ecology and Hydrology, Agriculture and Food Development Authority and Agri-Food and Biosciences Institute).

UOA5-based PGRs are funded from multiple sources: FBS hosts the BBSRC White Rose Doctoral Training Partnership (DTP) in Mechanistic Biology, a collaboration between UoL, Sheffield and York. UOA5 had a total of 102 DTP PGRs during this REF period, including 9 Leeds CASE PGRs and 4 Leeds National Productivity Investment Fund PGRs. In 2019 DTP3 was awarded, £10M in total, with funding until 2024 with allocations for 2023-2024 and 2024-2025 dependent on satisfactory progress on mid-term review. 12 standard studentships and 7 CASE studentships have been awarded to the DTP per annum. We also host a Wellcome Trust PhD programme aligned with Astbury, funding 6 studentships per annum until 2022/23. Additionally, a number of our PGRs are funded by the MRC DiMeN DTP (with Sheffield, Newcastle and Liverpool). UOA5 has also been instrumental in securing two NERC DTPs; SPHERES (2013-2018) and PANORAMA (2018-2022). PANORAMA is led by UoL in partnership with York and Hull universities. Industrial CASE partner studentships are a priority in these schemes ensuring research is sector-facing. Cross-faculty studentships are also co-supervised with EPSRC Centres for Doctoral Training administered by Engineering.

FBS established the first Graduate School on campus and initiated regulatory procedures that are now followed across UoL. Adopting the University Code of Practice on postgraduate training and supervision, the Graduate School coordinates and administers all postgraduate training and supervision, through training plans and the GRAD system. PGRs have a primary supervisor responsible for direction of the research project and, at least one co-supervisor with academic input. The supervisory team includes two independent assessors from within UoL with relevant experience, meeting formally with the PGR to review progress at defined time points. These include evaluation of a grant proposal or literature review at month 4, a transfer viva at the end of the first year (examined by written report and *viva voce*), which must be successfully completed to transfer to full PhD registration, and a draft manuscript and thesis plan at the end of the penultimate year. Assessors are also available for the PGR if any issues arise, as are the School Directors of PGR. Our successful PGR supervision is reflected in an overall pass rate on first submission of >98% average for 2017-2020. Furthermore, in accordance with UKRI guidelines, 83.2% of our PGRs submitted within 4 years. Our PhD graduate first destinations are principally science-related, with >80% undertaking PDRAs, employed in relevant industries, NHS or in science-related roles, such as science administration, policy, publishing or consultancy.

Complementary to research, PGRs receive the equivalent of 10 days per year of professional development and training. The programme of professional development is designed and delivered through a number of providers: OD&PL provide soft-skills training, including a broad range of workshops and events supporting PGRs as they embark on research, developing key skills for their future careers within or outside academia. Examples include: project management; thesis writing; working with your supervisor; viva preparation; creative thinking and problem solving; effective networking and innovative thinking. More bespoke training is also available, such as introduction to bioinformatics, coding and statistics via LeedsOmics workshops and Good Laboratory Practice. OD&PL have also partnered with UoL Mental Health and Well-being service, introducing a new suite of training sessions around resilience and well-being. External conference

presentations are crucial for development, and research group meetings, interdisciplinary centre away days and our highly successful annual PGR Symposium provides the ideal practice forum. At the PGR symposium, first year PGRs make a “three minute thesis” presentation, second year PGRs present posters and final year PGRs give talks. All presentations and posters are assessed and feedback provided and up to 20 prizes awarded each year.

We actively obtain feedback from the PGRs attending our courses via elected representatives, who sit on the Faculty Graduate Committee, to develop new workshops or improve existing ones. Moreover, the professional development programme is frequently reviewed, reflecting UKRI thinking and employers’ perspectives, leading to new workshops on enterprise, public engagement, pathways to impact and working with industry. The success of these is reflected in one student winning the BBSRC molecules to market award for their business idea and presentation.

3. Income, infrastructure and facilities

3.1. Income

UOA5 research benefited from £101.4M successful new funding applications awarded to researchers within this REF period (Table 2). Income/expenditure in the period was £93M, an increase of 33% over REF2014 (£62.2M) (REF4b). UOA5 holds the majority of UoL BBSRC funding, enabling UoL to be ranked 3rd and 5th in BBSRC number and value funding rates, respectively in 2020, compared to 16th in 2014. UOA5 also contributed significantly to UoL 3rd ranking in GCRF and Newton funding (detailed in REF5a).

	UoA5 in Total	Biotech	Cancer Biology	Cell and Organismal Biology	Ecology and Evolution	Integrative Membrane Biology	Microbiology	Plant Science	Structural Biology
New Awards	£101.4M	£7.6M	£10.2M	£8M	£12.7M	£8.5M	£17.2M	£16.5M	£20.7M
Funding per FTE	£1.2M	£1.2M	£1.3M	£990K	£910k	£780k	£1.2M	£1.6M	£1.6M

Table 2. Successful new funding applications awarded in UoA5 during REF period and breakdown per research group

Each research group has a diverse funding portfolio, contributing to UOA5’s high quality research output and impact. Of these grants, 19% are interdisciplinary, with co-investigators from cross-faculty centres and other institutions. This is exemplified by large cross-faculty awards, such as a BBSRC sLoLa involving Biotechnology, Cancer Biology, Structural Biology, as well as GCRF AFRICAP involving Ecology & Evolution, Plant Science.

Biotechnology: 65 grants awarded, 27 as PI, including UKRI (BBSRC, MRC, EPSRC), UK Central Government (DSTL, Porton Down, Innovate UK), charities (Cancer Research UK, Leverhulme Trust, Wellcome Trust, Yorkshire Cancer Research). Hemsworth holds a prestigious BBSRC David Phillips fellowship.

Cancer Biology: 53 grants awarded, 33 as PI, including programme grants from Cancer Research UK (Bayliss, Ladbury), project funding from UKRI (BBSRC, MRC), EU, charities (Academy of Medical Sciences, Bloodwise, Kay Kendall Fund). Members are recipients of personal fellowships: Wellcome Trust Sir Henry Dale Fellowship (Zequiraj) and Alan Turing Fellowship (Westhead).

Cell and Organismal Biology: 66 grants awarded, 29 as PI, including UKRI (BBSRC, EPSRC, MRC), NIHR, charities (British Heart Foundation (BHF), Wellcome Trust), industry (Depuy International Ltd, Sanofi Genzyme) and NC3Rs. Scarff holds a prestigious BHF Intermediate Research Fellowship. Strong links with Structural Biology to understand human neurodegenerative amyloid diseases is reflected through collaborative grant income from the Wellcome Trust to Structural Biology:Radford/Ranson and van Oosten-Hawle.

Ecology & Evolution: 78 grants awarded, 66 as PI, including UKRI (BBSRC, MRC, NERC), EU, UK and non-EU Government (BEIS, DEFRA), charities (Leverhulme Trust, Gates Foundation),

industry (Aquatera Ltd, Fresca Group Ltd). Benton, Kunin and Sait are key drivers of the £8.9M GCRF AFRICAP grant, making agriculture and food production in Sub-Saharan Africa more productive, sustainable and resilient to climate change.

Integrative Membrane Biology: 60 grants awarded, 38 as PI, including UKRI (BBSRC, MRC), EU, charities (Academy of Medical Sciences, Leverhulme Trust, Wellcome Trust). This includes funding to develop new technologies, including the Leeds integrated atomic force and confocal microscopy for life science applications (Richter).

Microbiology: 87 grants awarded, 64 as PI, including UKRI (BBSRC, MRC), EU, Human Frontier Science Program, industry (Oxford Drug Design), charities (Academy of Medical Sciences, Kidney Research UK, Medical Research Foundation, Wellcome Trust). Three prestigious externally-funded fellowships support the salaries and research activities of Herod (MRC), Mankouri and Tomlinson, J (Royal Society). Research also tackles challenges in the Global South, highlighted by the development of VLP-based vaccines for polio (Stonehouse/Rowlands), continuously funded by WHO since 2010 and Royal Society and Newton funding with colleagues in South Africa on HIV-related cancers (Whitehouse).

Plant Science: 62 grants awarded, 57 as PI, including UKRI (BBSRC, NERC), EU Government, charities (Leverhulme Trust). Dixon holds a prestigious UKRI-FLF; Benitez-Alfonso also applied for a UKRI-FLF during this REF period, which was recently successful. The group has also attracted £622K in industrial funding (Bennett-Geofabrics, Davies-Bayer, Kepinski-Syngenta, Urwin-Sinochem & Syngenta).

Structural Biology: 93 grants awarded, 53 as PI, including UKRI (BBSRC, EPSRC, MRC), industry (Freeline Therapeutics Ltd, MedImmune Ltd, Syngenta), charities (Leverhulme Trust, Wellcome Trust, Medical Research Foundation Fellowship to Patel,) Wellcome Trust investigator awards to Radford and Stockley, multi-user equipment awards (Ranson). Radford is also recipient of a prestigious Royal Society Research Professorship.

3.2. Research Infrastructure and Facilities

FBS concentrates research within 4 connected buildings, containing all infrastructure, enhancing accessibility for researchers, promoting collaboration through shared postgraduate and postdoctoral write-up areas, laboratory space and facilities. During this REF period, FBS commenced a new £32.25M scheme, refurbishing 4900m² of space within our Garstang building, which houses a large proportion of UOA5 staff, providing a flexible working environment adaptable to the fast-moving changes within biological sciences research. This facilitates interdisciplinary work, providing flexible laboratory space for collaborations between biologists, clinicians, physicists and engineers. We provide 'well-found laboratories' through an annual fund for maintenance and purchase of essential equipment, ensuring basic infrastructure and equipment (£50K per annum to this purpose). During this REF period, UoL has made a substantial £17M strategic investment (alongside ~£1.8M from Wellcome Trust) in two UOA5-based facilities, Electron Microscopy and NMR. This positions UoL in a UK-leading and globally competitive position in Structural Biology. A further UoL £2.3M investment in the University Farm enhances agri-systems and agri-tech research, supporting the Plant Science initiative, Future Crops. This significant investment in facilities (£21.3M in total), has contributed to a substantial uplift in successful new funding applications (Table 2).

3.2i. Support for Research and Impact

Support for UOA5 research and impact comprises 35.2 FTE (19.2 FTE administrative and 16 FTE technical support). Administration support for R&I applications and awards is supplied via the Faculty Research and Innovation Office (FRIO; 6.4 FTE), providing a streamlined 'inception to completion and impact' service. FRIO support the costing of applications, provide advice on funders' rules and regulations and help navigate through application systems. They also provide financial support for live awards and submit financial reports to funders. The FBS RIDM (1.0 FTE) identifies funding opportunities and works directly with academics supporting and developing applications and innovation proposals, including working with business partners. The importance of this new role is exemplified by our success in obtaining large interdisciplinary cross-faculty awards (sLoLa 2020 and GCRF AFRICAP, Section 3.1), where the RIDM project manages programmes from start to delivery. A Research Impact Officer (0.5 FTE) assists with impact

delivery, supporting the preparation of impact documents, delivery and training for impact, management of internal faculty impact funds (Section 1.4) and development of REF ICSs. Other FRIO staff (3.26 FTE) provide administrative assistance and secretarial support to UOA5 research groups and cross-faculty centres for seminar programmes, internal peer review, open access, and summer research studentships. These activities are supported by a broader network within Research and Innovation Services (RIS), including the central research development team who support over-lapping activities with UOA5 (Astbury, Global Health, Food), innovation development, contracts and commercial services.

Support for other research-related activities is provided at faculty level. FBS has a core team of technical support (16 FTE) underpinning all of its research activity such as: autoclave & media service; purchasing; distribution and shipment of goods inwards and outwards; waste disposal; inventory and record keeping; correct storage and archiving of samples; addressing compliance with numerous licencing bodies (Home Office and DEFRA). Health and Safety (3.0 FTE) provide induction training, assistance with COSHH, radiation protection and GM work. The Human Resources Office (3.8 FTE) assist with staff recruitment, staff review and development, monitoring of probation. Purchasing of research-related items (including assistance with tendering processes) is conducted via the University Procurement Office. A dedicated team advises on the acquisition of high-value laboratory equipment, undertaking open and transparent tendering when appropriate. An Operational Procurement team support day-to-day acquisitions of lower-value supplies and services. Computing software and hardware is purchased, installed and maintained by University IT Service, and also provide annual IT-based training for research staff, including laboratory safety and on-line security courses.

3.2ii. Research Facilities

FBS advanced research facilities underpin high-quality, impactful UOA5-based research across the university and externally. Making equipment available through open, multi-user research facilities, they promote and enable interdisciplinary research across campus, through cross-faculty centres: Astbury, GFEI and the University farm (Section 4.1). These centres are outward-facing, allowing researchers to work with colleagues in academia and industry, across the UK and internationally. The research facilities work in partnership, providing a network of synergistically aligned equipment and expertise that spans UOA5 research. Research facilities are managed by the Head of FBS facilities (0.6 FTE) and experienced Facility Managers and, in most cases, additional support staff, providing expert advice, guidance and training. The FBS Facilities Committee provides a formal governance structure for the strategic, operational and budgetary oversight of research facilities, combined with a Facility Managers' forum sharing common issues and best practice. In this REF period, UoL has invested £21.3M directly into research facilities upgrades, and invested more in day-to-day operation, staffing and maintenance of equipment. This includes an ambitious £17M investment in EM and NMR which has revolutionised UOA5 research capabilities and placed Leeds amongst the best-equipped institutions for cryo-EM-based structural biology worldwide.

Electron Microscopy Facility offers state-of-the-art technology for imaging biological specimens, with a particular focus on high-end structural biology, housing two ThermoFisher Titan Krios 300 kV electron microscopes equipped with direct electron detectors, to be upgraded in 2021 (£1M Wellcome multi-user equipment grant). These sit alongside three additional transmission electron microscopes and a comprehensive host of ancillary equipment, providing a comprehensive pathway from sample preparation to structure. The facility occupies a newly-refurbished, dedicated space, forming a state-of-the-art facility with a much broader set of capabilities than previously available, providing the ability to image cells, tissues and organisms and perform correlative light-electron imaging (£431K-Wellcome Trust, 2017). Dedicated computational infrastructure allows rapid analysis of data, including on-the-fly data processing pipelines for single particle data. The facility provides high quality training to both internal and external communities, hosting several training courses/year attended by academic and industry researchers. This program is to be significantly expanded from 2021 with a £1M Wellcome/MRC co-funded 5 year program in cryoEM training. Example outputs include UOA5-1943 and UOA5-1413, alongside significant external activity (Section 3.2iii).

NMR Facility hosts a 950 MHz Bruker spectrometer comprising an Ascend Aeon helium-recycling magnet with Avance III HD console, specified with TXO and small-volume TCI cryoprobes; providing capabilities unique in the UK, including ultra-sensitive direct-detection of heteronuclei (^{15}N and ^{13}C). Alongside £433K from the Wellcome Trust, UoL has invested £6M to fund upgrades of existing 750 and 600 MHz instruments with new Bruker consoles and cryoprobes, positioning Leeds in the vanguard for exploiting advanced new methods, including direct N,C detection, for structural studies of large and intrinsically disordered proteins and nucleic acids. Example outputs include UOA5-522 and UOA5-715.

X-ray Crystallography Facility supports sample preparation and data analysis for crystallographic projects, offering expertise to plan and oversee synchrotron data collection at Diamond Light Source and European Radiation Synchrotron Facility. Equipment includes Formulatrix robotic crystallisation systems with two fully automatic imaging and storage systems and a FRAP (Fluorescence Recovery After Photobleaching) imaging system for identifying optimal conditions for membrane protein crystallisation; a liquid handler robotic system allows users to design and prepare optimised crystallisation screens around known conditions. Example outputs include UOA5-1747 and UOA5-3288.

Bioimaging and Flow Cytometry Facility contains cutting-edge super-resolution imaging; iSIM (instant structured illumination microscopy) and 3D PALM/STORM (photoactivatable light microscopy/stochastic optical reconstruction microscopy) via >£2M of external funding. Two LSM-880 instruments with Airyscan technology, a Delta Vision Deconvolution system allowing multicolour automated imaging of live and fixed cells and a unique vertical confocal (LSM-800 with Airyscan) for imaging plants (BBSRC ALERT16) support a large number of users. Light sheet imaging through a LaVision Light Sheet microscope enables 3D imaging of large tissue samples. Two epi-fluorescence microscopes are also equipped with colour CCD cameras providing general fluorescence and histology imaging and an automated multicolour slide scanner enabling high content imaging. Flow cytometry and cell sorting (FACS) capabilities include 2x CytoFLEX flow cytometry analysers and a FACSMelody Cell sorter (BBSRC ALERT 16) allowing multicolour analysis and cell sorting. Dedicated laboratory space including tissue culture facility supports sample preparation. Data and image analysis software for microscopy and FACS is provided on offline workstations. Example outputs include UOA5-614 and UOA5-1865.

Mass Spectrometry Facility specialises in structural capabilities (including HDX-MS, fast photochemical oxidation (FPOP) foot-printing and chemical cross linking-MS), fully exploiting the power of MS alongside cryo-EM and NMR in driving integrative structural approaches for complex biological systems. A Synapt G2S-i, Xevo G2-XS QTOF and an automated HDX liquid handling system has been purchased (£340K-BBSRC). Investment in native and ion mobility MS (£415K-Wellcome Trust) enabled the purchase of two state-of-the-art-systems: the Q-Exactive Plus UHMR (modified for high-mass analysis through collaboration agreements with Thermo-Scientific); and a TOFwerk IMS-TOF, the first commercial instrument for performing conventional ion mobility drift-time measurements in combination with MS. Example outputs include UOA5-644 and UOA5-2903.

Protein Production and Biophysical Characterisation hosts a suite of equipment for the production and rigorous biophysical characterisation of macromolecules and their interactions. Extensive protein production capabilities were bought online, in a recent (2017) addition to FBS' facilities through UoL and Royal Society investment (£630K). A complete gene-to-sample pipeline for generation of structural biology-ready proteins in *E. coli*, insect and mammalian cells is available. It offers high-throughput PCR, cloning and protein expression screening with an 8-channel Hamilton Star liquid-handling robot with on-deck thermal cycle, large scale growth with ten high capacity shaking incubators (two with CO_2 for mammalian expression); and the latest AKTA chromatography systems for purification. Example outputs include Cockburn#1 and Tuma#2. Biophysical analysis includes surface plasmon resonance (BIAcore T200 and 3000), isothermal titration calorimetry (ITC200), microscale thermophoresis (Monolith NT.115) and circular dichroism. Example outputs include UOA5-205 and UOA5-374.

High-performance Computing and Storage is extensively used in UOA5 for data analysis and simulation (e.g. processing of multi-TB datasets from single-particle cryo-EM; molecular dynamics simulations using coarse-grained or experimentally-restrained metadynamics approaches). This is provided at university level, supported by capital investments from the stake-holder Faculties of £1M biennially, and supplemented by ~£90K from UOA5 researchers in 2017 and ~£100K in 2019.

This funding established a 4500 core facility (45 Tflops), with an expansion of 3000 cores (60 Tflops) being added and >100TB for parallel file storage. A multi-petabyte Data Storage Facility has recently been created to archive research data required by UKRI and other funding bodies. These resources are essential for multiple outputs including UOA5-721 and UOA5-1414.

Pathogenic Viruses Suite is a new £1.4M facility funded by a Royal Society Wolfson Laboratory Refurbishment Scheme (£250K, 2016), complemented by UoL contribution of £1.15M. The facility provides two laboratories, one at Biological Safety Level 2 (BSL2), and one at BSL3. Alongside standard equipment, each laboratory contains an Incucyte S3 live cell imaging system (Wellcome multiuser equipment grant 2020, £189K, complemented by UoL investment of £63K). The BSL3 laboratory also contains a Class III cabinet for SARS-CoV-2 work and a confocal microscope with live-cell imaging capability (Zeiss LSM780, Royal Society). Example outputs include UOA5-654 and UOA5-2836.

Plant Growth Suite has extensive plant growth and tissue culture facilities, consisting of 9 containment glasshouses providing temperate, Mediterranean and tropical environments for the contained growth of wild type and transgenic plants, one is adapted for working with aphids. These glasshouses are linked to a suite of plant growth rooms and growth cabinets providing controlled environment conditions with GM containment. Eight additional roof-top containment glasshouses provide growth conditions for temperate and tropical plants. There are also extensive facilities for the maintenance and propagation of plant tissue culture material. Example outputs include UOA5-562 and UOA5-1396.

University Animal Units comprise two state-of-the-art facilities. A high-health status mouse only facility specialising in cancer research and the production of transgenic mouse lines, and a multi-species facility for mice, rats, rabbits, fish, birds and large animals, such as sheep and pigs. Large animals are also held at the University Farm for some procedures. Each unit has highly equipped surgical suites, rooms for behavioural analyses, Category II work and flexible space underpinning UOA5 research, as well as UoAs 1, 4 and 24. Example outputs include UOA5-123 and UOA5-1589.

University Farm provides a new distinctive feature of our research infrastructure, encompassing 265-hectare arable land growing wheat, barley, oil seed rape, vining peas and potatoes in rotation, with 35.5-hectare of permanent pasture and 6-hectare of agroforestry. For Plant Science the farm provides rain out shelters, test plots and field scale sites including field scale trials with GM crops. For Ecology & Evolution it provides pollinator plots, bee hives, pond mesocosms, small mammal trapping, soil sensors and a weather station. The farm is increasingly used in collaborations with York and Sheffield universities, FERA and Askham Bryan College and is a National Institute of Agricultural Botany test site. The farm is a critical component of our vision for food production, agri-systems and agri-tech research, reflected in UoL's recent £2.3M investment in new instrumentation supporting Future Crops, Smart Agri-Systems, GFEI and other initiatives by providing state-of-the-art capabilities in hyperspectral crop imaging and biodiversity monitoring, *in situ* below-ground crop phenotyping and measurement of rhizosphere processes, and real-time monitoring of climate and hydrology. Funding for agricultural robotics and the informatics capacity required to integrate these data streams has facilitated significant new research activity in precision agriculture.

3.2iii. Sharing of FBS high-end equipment with national and international communities

State-of-the-art EM, NMR and MS equipment access is available free at the point of access to international audiences through Instruct-ERIC (from 2019), a pan-European distributed research infrastructure consortium, bringing significant new income and international collaborative opportunities. Cryo-EM equipment and expertise is also accessible through iNEXT discovery, a European Commission Horizon-2020 framework program. Both collaborative and fee-for-service access is provided to external academic and industry users, a significant income stream (>£700K for 2017-2020). As a member of the N8 network, all equipment is advertised via a shared database. This network also promotes collaborative interactions with their N8 counterparts, including the joint running of workshops (N8 Biophysics Symposia and NMR workshops). The NMR facility also has reciprocal access arrangements with other ultra-high field facilities, including the MRC national NMR facility, Crick Institute.

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

The diverse portfolio of UOA5 research reflects the collaborative and collegiate nature of our research. Exemplars are shown below both nationally and internationally.

4.1. Collaborative Research Centres

UOA5 provides leadership in multiple interdisciplinary cross-faculty centres of international repute.

The Astbury Centre (Director-Radford; Deputy Director-Ranson:Structural Biology, Executive Committee-Tuplin:Microbiology), brings together >70 academics from three faculties, FBS, Engineering and Physical Sciences and FMH. UOA5 researchers within the 6 Biomedicine-related groupings and Plant Science are members of the Astbury Centre. It is a major centre for research and training in structural and molecular biology and hosts a Wellcome Trust 4-year PhD programme until 2023. Since 2016, Astbury has successfully hosted the “Astbury Conversation”, a biennial public event promoting the latest innovations in Structural Molecular Biology, including keynote lectures delivered by Nobel prize winners [Michael Levitt (2016), Brian Kobilka (2018), Richard Henderson (2020-delayed by COVID19)].

Ecology & Evolution and Plant Science participate in multiple cross-faculty initiatives, especially with Earth and Environment and Food Science. The Priestley International Centre for Climate (Ecology & Evolution:Beger-management committee), established in 2016, drives climate science and policy across faculties. Priestley received £10M UoL investment in infrastructure, professorial and UAF appointments and PhD studentships. Ecology & Evolution:Hassall/Dunn/Hamer have been instrumental in establishing the Ecology section of Water@Leeds, an interdisciplinary sector-facing centre for water-related research. All are active members and currently supervise four PhD students in this area (with five graduated since 2009). Through Water@Leeds UOA5 researchers have established active collaborations with social scientists and hydrological researchers, leading to a Yorkshire Integrated Catchment Solutions Programme grant (iCASP) with local authorities (Dunn).

GFEI (Plant Science:Kepinski-Associate Director) was established in 2016 with an investment plan of £40M in new staff and instrumentation at the University Farm and terrestrial observatory. UOA5 staff contribute strongly to the £40M research portfolio of GFEI academics, with Plant Science:Kepinski/Bennett/Davies/Dixon; Ecology & Evolution:Benton/Sait/Kunin central to initiatives focussed on the future of agriculture and food production. The farm site is also home to the Centre for Innovation Excellence in Livestock (CIEL) (£10M investment from UoL and industry). The cross-disciplinary Smart Agri-Systems draws together big data analytics and on-farm technology, providing systems-based solutions to agricultural challenges. Colleagues have also benefited from the N8 Research Partnership Agri-Food program, initiated in 2015 with £8M HEFCE funding and a further £1M from each N8 University. N8 funded pump-priming projects (Plant Science:Kepinski/Bennett), networking and learning events across the universities have driven collaborative activity in the agri-food sector and attracted £27M of external funding.

UOA5 members founded and provide academic leadership for LeedsOmics (Cell Biology:Aspden, Cancer Biology:Westhead, Ecology & Evolution:Goodman/Duncan/O’Connell, Plant Science:Kepinski), a cross-faculty virtual institute bringing together researchers and data scientists from biological and health-related disciplines, generating a critical mass of ‘Omics-based’ researchers. LeedsOmics provides training in bioinformatic analysis and coding, seminar series and regular meetings to foster innovative research, exchange of knowledge across disciplines and collaborative grant proposals. UOA5 staff also communicate with the wider data science community through membership of Leeds Institute of Data Analytics (Cancer Biology:Westhead).

4.2. UK Collaborations

Our successful national collaborations have led to an increase in outputs with other UK institutions since REF2014 (increased from 46% to 50%). UOA5 members are integral to a range of UK-wide networks: Ecology & Evolution:Benton/Sait/Kunin and Plant Science:Kepinski/Knox are key members of AFRICAP, a major programme involving Chatham House, The Met Office and African agencies, making agriculture and food production in Sub-Saharan Africa more resilient to climate change.

UOA5 staff are also involved in multi-site UK university networks: Technology Touching Life networks (Cell Biology:Peckham); Networks in Industrial Biotechnology and Bioenergy (Membranes:Jeuken, Biotechnology:Millner); Designing Future Wheat and Wheat Genetic Improvement Network (Plant Science:Dixon); EPSRC programme grant studying protein-protein interactions (PoPPi) (Structural Biology:Edwards); providing structural biology capabilities for CRUK (Cancer Biology:Bayliss); National Pollinators Strategy and Natural England Stewardship Planning consortia (Ecology & Evolution:Kunin); Better start initiative examining how natural environments contribute to health (Ecology & Evolution:Hassall); sLoLA developing new FMDV vaccines (Microbiology:Stonehouse/Rowlands); UKRI Chemical Biology network (PPI-net) (Structural Biology:Radford/Breeze/Edwards); BBSRC-funded sLoLa BRAVO (Plant Science:Bennett); BBSRC/NERC-funded Horticulture and Potato Initiative project to develop disease-resistant potatoes (Plant Science:Urwin) and NPRONET a multi-institute study focussing on artificial photosynthesis and bioenergy (Biotechnology:Seipke).

We work extensively with National Institutes and Centres; Cancer Biology:Westhead serves as UoL lead for the Alan Turing Institute, providing expertise in data science and AI, formed from a partnership of 13 universities in these areas. Westhead is an Alan Turing Fellow, with significant interactions with the Health and Medical Sciences programme, focusing on machine learning in precision medicine. Representation on advisory boards of Rosalind Franklin Institute (Structural Biology:Radford) and Diamond Light Source (Structural Biology:Ranson/Cockburn; Membranes:Henderson) helps shape the direction of their research priorities. We have strong links with N8 research partnerships: Cancer Biology:Ladbury is academic lead, Targets for New Medicines; Plant Science:Bennett/Kepinski/Knox are involved in the N8 AgriFood theme in Sustainable Food Production; UoL hosts the Medical Technologies Innovation and Knowledge Centre, formally known as Regener8, a N8-funded programme at the interface of industry, academia, and clinical applications in regenerative medicine (Cell Biology:Ingham). We work closely with government bodies; DSTL (Biotechnology:McPherson), PHE (Microbiology:Barr) and Agriculture and Horticulture Development Board (Plant Science:Urwin).

4.3. International Collaborations

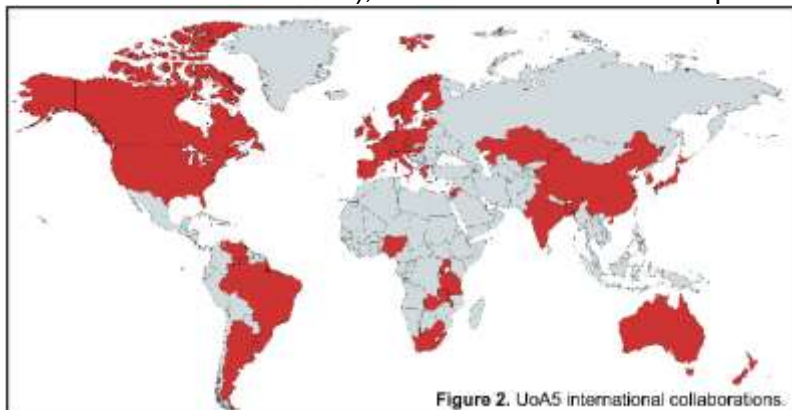
UOA5 has increased our international collaboration during this REF period to enhance our research impact globally (Figure 2), emphasised by an increase in outputs with international co-authors (increased from 40% to 59% since REF2014).

Collaborations include GCRF-funded efforts tackling global infections. Microbiology:Whitehouse is a visiting Professor at Rhodes University, establishing strong links with Rhodes and KwaZulu-Natal universities, South Africa, through GCRF funding focusing on HIV-related cancers; GCRF funding has established new laboratories in Nigeria for vaccine research (Microbiology:Stonehouse); Ecology & Evolution:Quinnell leads a GCRF project developing a national plan of disease control for parasite-associated cysticercosis, with colleagues in Liverpool and Rwanda International Livestock Research Institute; Microbiology:Harris through Newton funding, is developing novel antiviral therapeutics with Federal University of Uberlândia, Brazil; Membranes:Goldman is developing new anti-protozoan drugs with the University of Helsinki, through €1.4M funding (2015-2021; Errko Foundation and Academy of Finland); Biotechnology:Seipke is developing natural products with antimicrobial properties through a BBSRC partnership award with University of Otago and ongoing collaborations with MIT and UC Berkeley.

We engage in multiple European ITNs, including RAMP and ViBrANT (Membranes:Goldman), HONOURS (Microbiology:Barr, Structural Biology:Edwards, Biotechnology:Millner). Other EU initiatives include DROPSA and nEUROSTRESSPEP developing approaches to protect crops from pests using biocontrol agents (Ecology & Evolution:Isaac); EU COST action for marine spatial planning (Ecology & Evolution:Beger) and EU COST action for management of alien invasive species (Ecology & Evolution:Dunn).

Plant Science (Baker/Benitez-Alfonso/Bennett/Davies/Denecke/Kepinski/Knox) established an initiative with the International Crops Research Institute for the Semi-Arid Tropics, India. Supported by a BBSRC India Partnering Award, driving improvements in dryland agricultural systems through proof-of-concept and knowledge transfer. A GCRF translation award has established links in Uganda studying plant parasitic nematodes (Plant Science:Urwin) and BBSRC-NSF funding established clean gene-editing approaches in plants with Purdue University (Plant Science:West). Ecology & Evolution researchers have extensive international interdisciplinary links in mathematical modelling and genetics, Queensland and Stellenbosch universities (Ecology & Evolution:Beger, Kunin), and with social scientists from the Ashoka Trust for Research in Ecology and Environment, India (Ecology & Evolution:Sankaran). Extensive interdisciplinary networks have facilitated large interdisciplinary awards including AFRICAP, VOICE, BioDAR (Ecology & Evolution:Duncan/Hassall/Kunin), and an ESEB-funded Special Topic Network with Liverpool, Stockholm and Muenster assessing the effects of climate change on fertility (Ecology & Evolution:Bretman).

Membranes:Jiang has multiple links with China investigating the role of ion channels in health and disease, through Chinese Scholar Council funding, and a Leeds-Zhejiang strategic partnership award.



Structural Biology:Ranson/Breeze/Sobott are part of iNEXT-Discovery and Instruct-ERIC consortia, comprising 23 partners from 14 European countries, aiming to translate fundamental structure research into bio-scientific applications and provide open access to high-end structural biology services. Further International Partnerships exist with Osaka Institute for Protein Research (Structural Biology:Breeze) and MPI Martinsreid (Structural Biology:Radford).

International collaborations and research capacity in Cancer Biology are strengthened by strong interactions with MD Anderson Cancer Centre (Cancer Biology:Ladbury), where UoL has signed a formal memorandum of understanding forging joint activities including student exchange, joint meetings between junior faculty and wider collaborative projects. Further links include Asian Medical Centre, Seoul (Cancer Biology:Bayliss/Wu) and the Mount Sinai Hospital, Toronto (Cancer Biology:Zequiraj). Ladbury is also a visiting Distinguished Professor, Indian Institute of Technology Bombay (Mumbai), helping to establish collaborative links and student training opportunities.

UOA5 has also benefitted from multiple Cheney Fellowship awards, funded through UoL Alumni, enabling talented researchers to broaden their research network through enhanced interactions with UOA5 academics. Notable Cheney Fellows include Kelly Chibale (University of Cape Town, South Africa), Steve Polyak (University of Washington, USA), Preben Morth (University of Oslo, Norway) and Travis Beddoe (Monash University, Australia).

4.4. Industrial Collaborations

To address our global challenge in biomedicine we have extensive collaborations with the biopharmaceutical industry. Highlights include a collaboration with Avacta Life Sciences who

licensed the UoL Affimer patent (Biotechnology:Tomlinson,D/McPherson; ICS-UOA5-2) and recently signed collaboration deals worth >\$300M to progress Affimers as research reagents and therapeutics. This technology also forms the basis of a £3.75M MRC Industry Collaboration Agreement (MICA), developing novel diagnostics for microbial disease. Research on tissue-implantation, artificial joint replacements and rejection of prosthetics (Cell Biology:Ingham, ICS-UOA5-1), in conjunction with companies including DePuy, Tissue & Eye Services at NHS Blood and Tissue Regenix, continues to have direct beneficial impact for patients. Structural Biology:Radford (with colleagues in Chemistry and Dentistry), developed a non-invasive treatment for early stage dental caries through understanding self-assembling peptides, leading to the formation of private Swiss company Credentis. Credentis licenced the UoL patent and commercialised this technology in Switzerland and EU (2010 onwards, UoA3 continuing ICS).

Further thriving partnerships include: developing assays and devices for predicting the aggregation propensity of therapeutic proteins with MedImmune and Pfizer (Biotechnology:Brockwell); trials testing a small-scale diagnostic in lymphoma patients with high grade disease in collaboration with HTG Molecular Diagnostics, USA (Cancer Biology:Westhead); identification of novel diagnostic biomarkers licenced by BioLegend, leading to the generation of diagnostic tools with Pfizer (Cell Biology:Stacey); developing the first-in-class inhibitors of the BRISC enzyme, reducing interferon signalling for the treatment of autoimmune diseases with JAMM Therapeutics (Cancer Biology:Zequiraj); understanding how bactericidal antibodies target the outer membrane of Gram-negative bacteria with Genetech (Structural Biology:Ranson/Radford); developing next-generation VLP vaccine delivery platforms with Vaxxas, Australia, and Incepta, Bangladesh (Microbiology:Stonehouse); developing novel antimicrobial reagents with Oxford Drug Design and Cubist Pharmaceuticals via MICA funding (Microbiology:O'Neill); developing new MS instrumentation and protocols with Thermo-Fisher and Waters and implementation of these methods characterising biopharmaceuticals and membrane proteins with Astex, GlaxoSmithKline and Vertex (Structural Biology:Sobott); developing approaches for membrane protein studies with GlaxoSmithKline and UCB Pharma and improving EM grid preparation with STP labtech (Membranes:Muench); producing primary monomeric substrates for synthesis of plastics from cheap feedstocks in bacteria as an alternative to petrochemicals with Lucite International, Ingenza and Mitsubishi Chemicals (Membranes:Henderson); developing and commercialising new reagents and techniques to rapidly map protein interactions with Redbrick Molecular (Structural Biology:Calabrese/Radford).

Extensive industrial collaborations also help UOA5 address our global challenge in sustainable development. Highlights include: developing impact evaluation and mitigation measures from icebreaking vessels traveling through seal breeding areas with North Caspian Operating Company and TengizChevroil (Ecology & Evolution:Goodman, ICS-UOA5-6) and implementing risk assessments and evidence-based biosecurity to slow the spread of invasive non-native species with Yorkshire Water (Ecology & Evolution:Dunn ICS-UOA5-4). Collaborations with ADAS and local farmers help to understand practical limits on crop growth (Plant Science:Bennett); increasing the predictability of the vernalization period required for winter wheat with KWS and Limagrain (Plant Science:Dixon); developing technology for inducing steeper, deeper rooting in crops, licenced to PBL Technology (Plant Science:Kepinski); assessing the effects of nematode infestation of coffee plantations with Nestle, developing chemical compounds against nematodes with Enkochem and improving nematode resistance in plants with Syngenta (Plant Science:Urwin); finding plant-based alternatives to plastic packaging in collaboration with Futamura (Plant Science:Benitez-Alfonso); understanding regulatory mechanisms of plant gene expression in response to abiotic signals with Bayer Crop Science (Plant Science:Davies); assessing the impact of offshore wind farms on protected species with Vattenfall and MacArthur Green (Ecology & Evolution:Hamer).

We have had >100 away days during this REF period with industrial partners, enhancing communication between UOA5 members and industrial collaborators. Such events are co-ordinated through cross-faculty centres (Section 4.1) and Sector Hubs (Pharmaceutical and Biopharmaceutical; Medical Technologies), as part of a £6M HEIF funding investment, providing structures to channel larger scale support for activities with high potential for impact and

innovation, marrying external market demand with UOA5 research and innovation strengths. Structural Biology (via Astbury) established an Industrial Advisory Group with ~30 members from relevant industries. Industrial secondments and business engagement activities have also been secured via internal funding schemes; EPSRC IAA, MRC P2D and GrowMedTech. Moreover, our members routinely serve as consultants for a variety of companies: Smith and Nephew (Microbiology:O'Neill); Geofabrics and Fresca Group (Plant Science:Bennett); Novartis (Biotechnology:Seipke) and sit on Scientific Advisory Boards: Blueberry Therapeutics (Microbiology:O'Neill); Tissue Regenix (Cell Biology:Ingham); Credentis (Structural Biology:Radford).

4.5. Wider activities and contributions to the research base, economy and society

UOA5 researchers have a close network of connections with key stakeholders including local government and intergovernmental organisations, allowing UOA5 members to effectively promote our science to policy makers: United Nations Environment Programme initiatives (Ecology & Evolution:Goodman/Hamer); European Food Safety Authority (Ecology & Evolution:Firbank); NGOs (Nature Conservancy and WWF (Ecology & Evolution:Beger); Yorkshire Wildlife Trust, Natural England, Forestry Commission, National Trust, Animal and Plant Health Agency, Centre for Ecology Fisheries and Aquaculture Science (Ecology & Evolution:Dunn/Kunin, ICS-UOA5-4;ICS-UOA5-7); DEFRA, Emeritus Prof Altringham, ICS-UOA5-5.

Staff secondments are encouraged to enhance interactions with key stakeholders, Ecology & Evolution:Benton was appointed Champion of the UK's Global Food Security programme (2011-2016) and joined Chatham House in 2016 as a Distinguished Visiting Fellow and subsequently Director of Energy Environment and Resources Department. Through these appointments he works with the UK government, EU and G20. He is global agenda steward of the World Economic Forum, and an author of the IPCC's Special Report on Food, Land and Climate (2019), and UK's Climate Change Risk Assessment (ICS-UOA5-3). Ecology & Evolution:Benton/Kunin/Sait and Plant Science:Kepinski/Knox have leadership roles in the £8.9M GCRF-AFRICAP project, which aims to improve policy making leading to sustainable, long-term food security in sub-Saharan Africa. AFRICAP involves researchers from multiple UoL UOAs and scientists from Chatham House, Met Office, University of Aberdeen and partner research organisations in Malawi, South Africa, Tanzania and Zambia, coordinated by the Food, Agriculture and Natural Resources Policy Analysis Network (FANRPAN) in South Africa. We further influence the national science strategy via our interactions with the major funding bodies; UOA5 members serve on a number of funding panels (Table 3) and Cell Biology:Peckham took part in the Royal Society Pairing Scheme (2015, with Mr Chris Green, MP).

4.6. Development, promotion and dissemination of research and impact

Promotion and dissemination of UOA5 research and impact beyond traditional academic routes to the public has received >£1.7M of external funding from BBSRC, Wellcome Trust, Physiological Society and Alzheimer's Society. Many of our research findings have garnered substantial public attention. University Communications and Press Office provide widespread media coverage including television and radio (BBC TV, Radio 4, CNN), specialist magazines (Discover Magazine, Science Magazine and Chemistry World), national and international press (Guardian, New York Times, Observer, India Times, Economist). We organise and participate in regular public engagement initiatives (Cafe Scientifique, Ilkley/Otley Science Festival, Leeds Philosophical and Literature Society, The Astbury Conversation, Be Curious, Pint of Science, Quantum Sauce). We promote biological sciences to school students with frequent and regular outreach visits to schools (annually >800 school pupils, via 18 workshops with 48 local schools). For the last 9 years, Plant Science have participated in the annual Gatsby Summer School for 100 undergraduates, fostering an interest in plant science. Moreover, >70 UOA5 academics and researchers deliver 'Discovery Zone' annually. In 2019, 460 Key Stage 2 & 3 pupils participated in hands-on science exploration. Overall, FBS outreach activities annually engage with ~5000 school children, in 92 different events, covering 70 local schools.

4.7. A selection of indicators of esteem and external recognition are outlined in Table 3 below.

Table 3.

Indicator	Selected Examples
National advisory board	Chair/Deputy of UKRI Grant Panel (BBSRC-Peckham; EPSRC-Ingham; MRC-Westhead) UKRI/Charity Grant Panel (Academy of Medical Sciences-Ingham; BBSRC-Jeuken/Whitehouse; CRUK-Ladbury; DEFRA-Hamer; MRC-Breeze; Wellcome Trust-Radford/Stockley/Stonehouse) National Science Facility Panel (Diamond-Henderson; Harwell-Radford; MRC NMR-Breeze; N8-Radford; STFC-Peckham) National Society Committee (Biochemical Society-Zeqiraj; British Ornithologists Union-Hamer; Microbiology Society-Stonehouse; BSCB-Ponnambalam; Royal Microscopy Society-Peckham; UKPSF-Kepinski)
International advisory board	European Funding Panel (EU H2020-Sobott; French NRA-Peckham; Science Foundation, Ireland-O'Neil) European Review Committee (GARDP-O'Neill; HCERES-Knox; Food Safety Authority-Firbank; International Society for Seed Science-West) International Industrial Advisory Board (Mitsubishi-Henderson) International Scientific Advisory Board (Max Planck-Radford)
Editorial membership	Analyst-Sobott, Cells-Jiang, IJO-Whitehouse, IJSAR-Firbank, JBC-Peckham, JGV-Harris, JMB-Radford, JTE-Ingham, MBE-O'Connell, Microbiology-O'Neil MMB-Henderson, Molecular Cancer-Blair, Nature Conservation-Kunin, PeerJ-Paci, PLoS NTD-Quinnell, Plant Journal-Davies, Planta-Knox, Scientific Reports-Edwards, Virology-Barr
Invited keynote speaker	FASEB Conference (Radford) FEBS Conference (Richter) Gordon Research Conference (Jeuken, Radford, Stockley) Pathology UK (Aspden) International Society for Behavioural Ecology (Bretman) Association for General and Applied Microbiology (Goldman) Microbiology Society (Harris, Stonehouse, Whitehouse) European Congress of Virology (Harris) International Conference on Enzymology (Henderson) World Congress of Biomaterials (Ingham) Plant Biology Europe (Kepinski) World Congress: Oxidative stress (Jiang) International Meeting of the ESR (Pliotas)
Organiser - international conference	International Symposium on HCV-Dublin (Harris) International Society of Electrochemistry-USA (Jeuken) International Ion Channel Conference-China (Jiang) Free energy landscapes-Zurich (Krivov) EMBO Pseudoenzymes workshop (Zeqiraj)
Prizes and Awards	Order of the British Empire; Fellow of the Royal Society; Fellow of the Biophysical Society and Royal Society of Chemistry: Rita and John Cornforth Award (Radford) German Ornithologists' Union: Honorary Life Membership (Hamer) European Patent Office: Finalist in European Inventor of the Year; Fellow of the Academy of Medical Sciences (Ingham) International Ferruccio Ritossa ECR Award 2019 (van Oosten-Hawle) Biochemical Society ECR award 2019 (Wu) Fellow of the Royal Society of Biology (McDowall, Stonehouse) Honorary Fellow Society for the Environment (Benton) Honorary Member of Microbiology Society (Rowlands)