Institution: University of Southampton

Unit of Assessment: 05 Biological Sciences

1. Unit context and structure, research and impact strategy

The portfolio of research in the School of Biological Sciences (SoBS) is highly integrated, spanning genes, molecules, organisms, populations and communities. We deliver global impact for health care, food security and the environment.

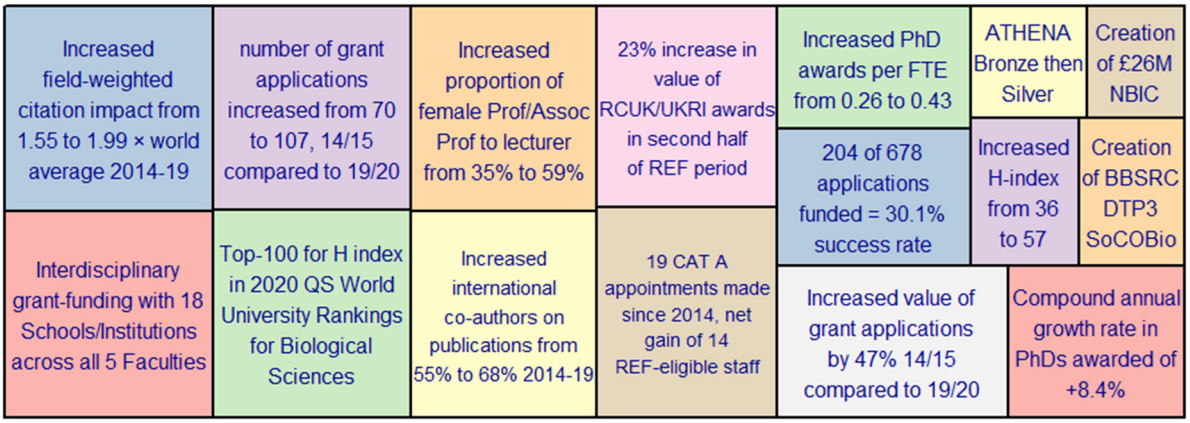
1.1 Growth since 2014

Our research activity has significantly increased since 2014 (Fig. 1) facilitated by the interdisciplinary life sciences agenda (REF5a§2.6; §1.2.2). This is evidenced by £44.07M of our funding held in conjunction with other Units of Assessment (UoA 01, 07, 08, 09, 10, 12 and 14; §3.1) and our impact case studies (ICS) encompassing biodiversity (**ICS 05-01**, **ICS 05-03**), health care (**ICS 05-07**) and food security (**ICS 05-09**).

We lead significant national and international research including a multi-centre doctoral training partnership, the BBSRC South Coast Biosciences (SoCoBio established 2019; PI and Director **Terry**), and the £26M UK National Biofilms Innovation Centre (NBIC established 2017; PI and Co-Director **Webb**; £5M to SoBS), an Innovation Knowledge Centre (IKC), renewed with a top rating in 2019.

We collaborate closely with a new £25M Centre for Cancer Immunology (2018) with funding of £2.2M to SoBS and are the centre for the UK Against Breast Cancer Biobank.

Figure 1. Significant advances in the research environment from REF2014 to REF2021.



1.2 Structure

1.2.1 Size

Our UoA submission is 45.5 FTE, comprising 49 Category-A staff (+14 since REF2014) and 57 level 4 researchers, 15 technicians, 1 experimental officer and 103 PhD students.

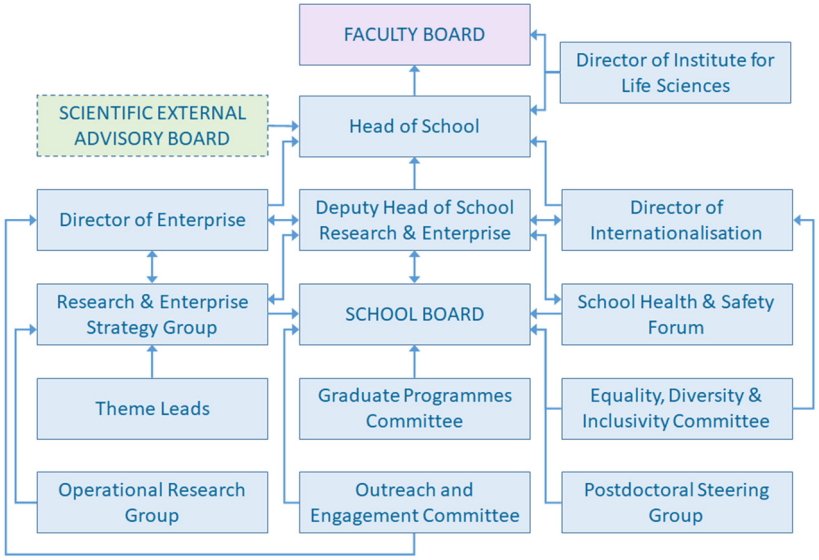
1.2.2 Management and Leadership

We are aligned to the Institute for Life Sciences (IfLS), an umbrella organisation for interdisciplinary research (§1.3.2) that unites ~ 400 staff spanning biosciences, medicine, mathematics and data sciences, engineering and social sciences: Its Director, **Smith**, is a member of SoBS (§1.3.1.1) and its School Board (chaired by Head of School, **Holden-Dye**). **Terry** (Deputy Head of School) leads research and enterprise, with **Teeling** (Director of Enterprise) providing focused leadership for impact.

Early career researchers, technicians and PhD students are represented on School committees including the School Board.

An External Advisory Board (§1.3.3.4) interacts on a regular basis to provide stakeholder input. Overall, this provides integrated management for optimising research and impact (Fig. 2).

Figure 2. A Connected Research Community. We are organised to ensure dialogue across all levels of the organisation, from early career researchers to senior academics.



1.2.3 Research Organisation

Staff align with a primary theme, and multiple subsidiaries (§1.3.1) in a flexible manner relevant to their evolving research profile (Fig. 3). More than half of our research awards (107 out of 204) are collaborative, reflecting the success of this approach.

1.3 Research and Impact Strategy

Our strategy is guided by our core principles of maximising research quality and impact, embedding equality, diversity and inclusion and promoting well-being. Achievements in relation to our strategy are detailed below.

1.3.1 Theme Contribution to Research and Impact Strategy

Our research spans evolution and ecosystems through to biomedical research underpinned by molecular and cellular biosciences and systems analyses. Extensive collaborative activity (Fig. 3) builds critical mass in core areas simultaneously providing the optimal environment for major impact as exemplified by the success of NBIC.

1.3.1.1 Molecular and Cellular Biosciences

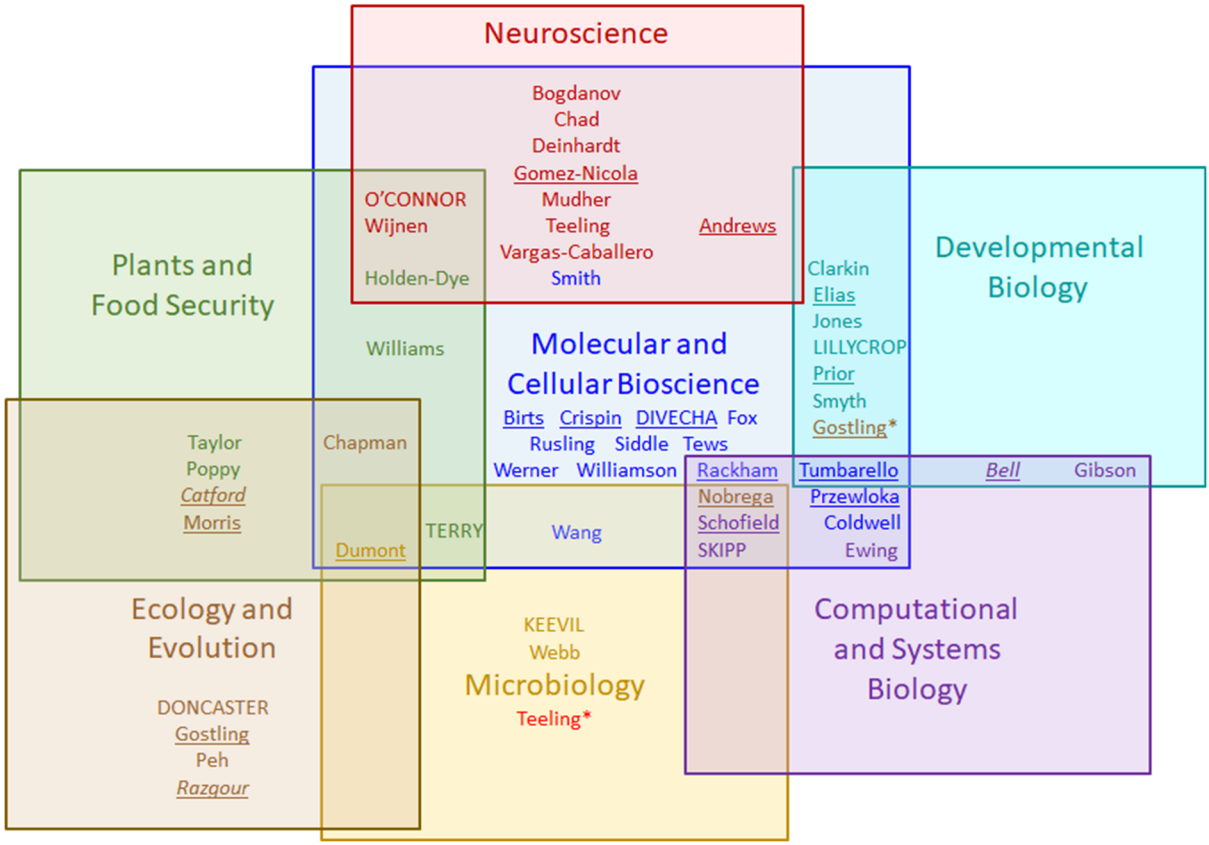
This theme interprets basic properties and genetic coding of macromolecules and applies this to organismal physiology in health and disease. There are strong collaborations with all other themes in the School (Fig. 3). Close working with the newly established Centre for Cancer Immunology (UoA 01) exploits structural and functional studies of the immune system (**Crispin**, **Birts**, **Siddle**, **Tews**) to understand how cancer cells evade it. Research encompasses molecular organisation of proteins and nucleic acids (**Fox**, **Coldwell**, **Williamson**, **Tews**, **Werner**, **Rusling**); cellular metabolism and mitochondrial efficiency (**Smith**); the immune system (**Siddle**); autophagy and cell growth (**Tumbarello**); cell cycle and mechanisms of chromosome segregation (**Przewloka**); membrane proteins and phosphoinositides in the nucleus (**Divecha**); the structure and function of glycoproteins (**Crispin**); metabolic and immunologic targeting on breast cancer development (**Birts**); epithelial-mesenchymal transition (**Wang**). **Crispin** (Thomson Reuters highly cited) has leveraged his expertise in glycoproteins to deliver significant research outputs and impact on SARS-CoV-2 (§4.3.2). Twenty-eight other staff align with Molecular and Cellular Biosciences as their secondary theme (Fig. 3). This, together with new appointments (§2.2), is realising our vision of Molecular and Cellular Biosciences as our unifying core strength.

1.3.1.2 Computational and Systems Biology

Our research harnesses computational and systems-level analyses to address complex biological phenomena and biomedical challenges. This theme is highly collaborative; 87% of its grants (2014-20) are with another School or Faculty. **Ewing** models molecular networks for insight into cancer-related mutations and acts as 'Cancer Champion' promoting interactions with the Centre for Cancer Immunology. **Gibson** uses statistical genetics and bioinformatics to understand disease-related changes in the human genome, and **Skipp** uses proteomics and multi-dimensional data analytics for molecular phenotyping relating to a range of biological problems.

The group analyses sequencing data using open-source tools and in-house pipelines including for several large genetic datasets e.g., 100,000 Genomes project and the UK biobank. **Schofield** extends expertise in molecular phenotyping; he is funded by Against Breast Cancer (ABC) and underpinned relocation of the ABC Biobank to SoBS. Innovation in the analysis of molecular networks inspired the launch of a spinout TOP-MD Precision Medicine Ltd (**Skipp**; §4.3.1.1). **Skipp** leads the cross-University Integrated Molecular Phenotyping Centre. **Rackham** strengthens this important underpinning expertise bringing with him computational approaches for cell reprogramming and disease-gene association and is co-founder of Mogrify which develops cell-based therapies.

Figure 3. **SoBS Research Themes.** Staff primary theme indicated by matching colour of staff name - multiple subsidiary themes by overlap. CAPITALS = Theme leads; new hires are underlined; staff leavers in *italics*, * listed twice for ease of presentation.



1.3.1.3 Developmental Biology

We focus on reproductive and developmental biology and mechanisms underpinning the developmental origins of health and disease. This theme holds 80% of its funding with UoA 01 through its leading role in building the University's distinctive strengths in developmental origins of health and disease (DOHaD; REF5a§1.5) with emphasis on epigenetic processes (**Lillycrop**,

Bell). Research includes embryonic stem cells and fracture repair (**Clarkin**), preimplantation development (**Jones**), extracellular matrix and stem cell biology (**Smyth**) and epigenetic programming and disease risk across the life-course (**Bell**, **Lillycrop**). **Prior** focuses on metabolic influences on cell fate and **Elias** investigates oriented cell division and polarity in mammary epithelia. World-leading expertise in epigenetics (**Lillycrop**; Thomson Reuters highly cited) resulted in our founding membership, with Singapore and New Zealand, of the global EpiGen Consortium, for nutrition, epigenetics and human health (REF5a§2.7).

1.3.1.4 Neuroscience

This theme emphasises neurobiology and includes synaptic and circuit function (**O'Connor**, **Chad**, **Vargas-Caballero**, **Deinhardt**) that overlaps with research in neurodegeneration and regeneration (**Chad**, **Deinhardt**, **Gomez-Nicola**, **Mudher**, **O'Connor**, **Vargas-Caballero**, **Andrews**), sleep and circadian rhythms (**Wijnen**), neuroinflammation and microglia (**Teeling**, **Gomez-Nicola**) and GABAergic signalling in the immune system (**Bogdanov**). Research deploys invertebrate systems *Caenorhabditis elegans* and *Drosophila melanogaster* to address fundamental questions on the neural basis of behaviour and disease (**O'Connor**, **Mudher**, **Wijnen**). Invertebrate expertise links to research on pest control (**O'Connor**, **Wijnen**; §1.3.1.6). Collaboration with UoA 01 and public-private funding through the Dementia Consortium, the Wellcome Trust Consortium for the Neuroimmunology of Mood Disorders, and Alzheimer's Disease (NIMA) have resulted in intervention studies for Alzheimer's Disease (**Gomez-Nicola**, **Teeling**; §4.3.1.1) Collaboration with UoA 04 (**Perry**) on immune-to-brain communication and the Centre for Cancer Immunology is aimed at developing antibody-based immunotherapies for dementia (**Teeling**). Leadership (**Vargas-Caballero**, **Gomez-Nicola**) of the South Coast Alzheimer's Research UK (ARUK) Network facilitates collaboration with regional experts in Dementia research. We are major stakeholders in the Southampton Neuroscience Group (SoNG), uniting ~40 neurobiologists, clinicians, psychologists, health care practitioners, engineers, chemists and computational neuroscientists to implement new experimental and therapeutic approaches in this fast-moving field.

1.3.1.5 Microbiology

We focus on biofilms and microbial communities ranging from the environment to the clinic, speaking to 21st century challenges of environmental sustainability and antimicrobial resistance. **Webb** and **Keevil** are on the steering group of the '*Global Network for Anti-microbial Resistance and Infection Prevention*' (NAMRIP), a cross-Faculty collaboration facilitating international networking to combat antimicrobial resistance. This dovetails with the University interdisciplinary strategy (REF5a§2.6) which leveraged funding for extension of category-2 containment and the appointment of **Nobrega** who adds complementary interest in phage-bacteria interactions and novel approaches for microbe control. Collaborative research with other UoAs includes microbial communities involved in biogeochemical cycling and other important transformations (**Dumont**), molecular ecology of biofilms in environmental and clinical settings (**Keevil**) and how biofilms develop, disperse and respond to environmental stresses and therapeutic compounds (**Webb**). We have a strong multidisciplinary ethos for translational science leading to successful patient treatment regimens, catheter design and management, and surgical instrument decontamination and lead the UK National Innovation Biofilm Centre (**Webb**; NBIC). Research in this theme has underpinned important impact in health care (**ICS 05-07**).

1.3.1.6 Plants and Food Security

Research in this theme advances the UN Sustainable Development Goals relating to population growth and climate change and aims to deliver innovative solutions for food security relating to UN Sustainable Development Goal 2 *'Zero Hunger*'. Research in plant molecular biology investigates the regulation of photosynthesis, nutrition, phytoremediation and biofortification,

evolutionary genomics and food waste and is complemented by basic research on the model plant Arabidopsis (**Williams**, **Terry**) and climate-change impacts on food security (**Chapman**). Agricultural ecology explores plant and soil interactions including the soil microbiome, conservation ecology, ecosystem services, and invasive species (**Taylor**, **Poppy**, **Morris**). Research into crop pests and pollinators focuses on the interaction of crops with beneficial insects such as pollinators, as well as a range of agricultural pests (**Poppy**, **Morris**, **Holden-Dye**). The theme was part of a BBSRC DTP (2013-2018) led by University of Reading (SoBS lead **Poppy**) on food security (§2.4.1). **Holden-Dye** (and **O'Connor**) and **Terry** are inventors on two patents filed for crop protection (§4.3.1.1). Work on nematicides by **Holden-Dye** (and **O'Connor**) supported phase 2 clinical trials for human filarial disease (§4.3.1.1). **Poppy**'s research and secondment as Chief Scientific Advisor strongly influenced government policy (**ICS 05-09**).

1.3.1.7 Ecology and Evolution

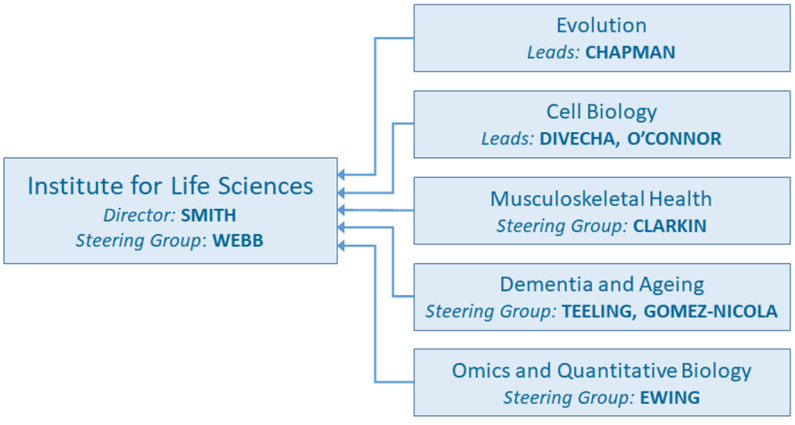
In this theme we address global issues of organismal adaptation to changing environments across all scales of biological organisation. This spans species (**Catford**, **Doncaster**), communities and ecosystems (**Morris**, **Peh**) and evolutionary timescales (**Gostling**, **Chapman**). We study responses to environmental challenges associated with climate change and human population growth, in relation to biodiversity conservation, with emphasis on invasive species (**Catford**); forests and lake restoration (**Doncaster**); trophic interactions (**Morris**); ecosystem services (**Peh**); climate-change impacts on indicator species (**Razgour**). We have expertise in ecological and evolutionary processes, conservation science, and modern analytical approaches for big and complex data. Our societal impact has broad reach, with global uptake of the TESSA toolkit for site-based assessment of ecosystem services, now incorporated into the Policy Portal of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services **(ICS 05-01**). **Doncaster** has developed open-access conservation technology, with AudioMoth acoustic sensors deployed on six continents by government and non-government environmental organisations and citizen scientists (**ICS 05-03**).

1.3.2 Integration with the '*Life Sciences*' Interdisciplinary Agenda

Over 90% of SoBS staff are members of the IfLS, with participation across its 4 themes: *Health and Medicine*, *Living Systems*, *Insights Through Data*, and *Life Technologies*. SoBS is integral to the Life Sciences agenda through its Director **Smith**, steering group member **Webb** and its leadership on interdisciplinary research areas (Fig. 4). The IfLS champions interdisciplinary research by providing administrative support, and pump-priming funding for networking, scoping activity, research proposals and studentships. IfLS has invested £308,670 in collaborative pump-priming projects in SoBS (32% of the total IfLS investment) and funded 13 conferences and 23 interdisciplinary PhD studentships in SoBS during the REF period. This has yielded £2M in grant funding to collaborative teams of which at least one researcher is from SoBS.

Figure 4. SoBS staff are closely integrated with the IfLS.

The IfLS is one of five interdisciplinary research institutes supported by the University strategy (REF5a§2.6).



1.3.3 Culture

Our strategy to realise quality and impact from research activity is underpinned by seven core principles:

1.3.3.1 Collaborative

Success at instilling a collegial and supportive research culture since REF2014 is evidenced by interdisciplinary funding and co-authored outputs (§4).

1.3.3.2 Outward looking

Through line management, we encourage staff to take on external appointments (§2.3.3). For example, **Terry**, in his role as Director of SoCoBio, co-ordinates our BBSRC research across UoA 01, 07, 08, 11, 12, 14 with partners at Universities of Sussex, Kent and Portsmouth, East Malling Research (NIAB-EMR) and extensive industry collaboration. **Smith** sits on the board of the Rosalind Franklin Institute and serves on the EPSRC Value for Money Committee.

1.3.3.3 International

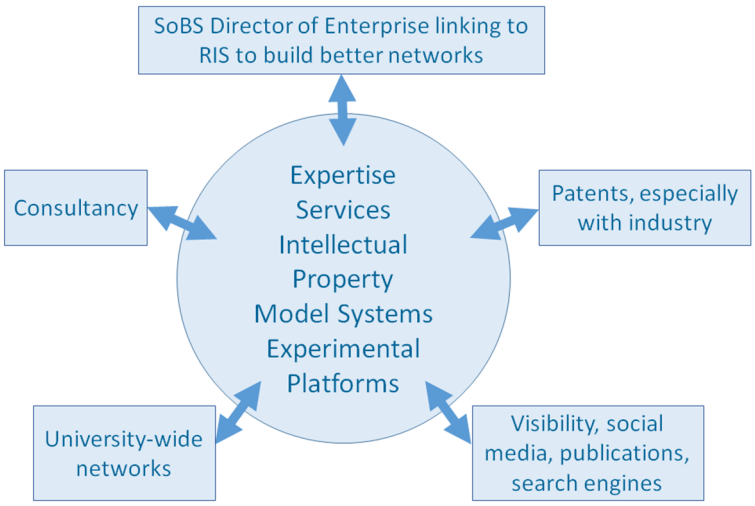
SoBS Director of Internationalisation (**Dumont**; Fig. 2) connects us to University initiatives, including the Worldwide Universities Network (WUN; REF5a§2.7). The signing of two Memoranda of Understanding between NBIC, the Singapore Centre for Environmental Life Sciences Engineering (SCELSE) and the Singapore National Biofilm Centre (SNBC) is an example of internationalisation which is strengthening the UK global position in biofilm innovation. Further evidence of international reach is provided in section 4.

1.3.3.4 Inculcating impact

SoBS Director of Enterprise (**Teeling**) works with Research and Innovation Services (RIS; REF5a§1.5), Public Policy Southampton (REF5a§2.9; Chair **Poppy**) and a Business Fellow (**Clarkin**) to facilitate collaborations with external partners (Fig. 5).

Our External Advisory Board includes senior industry leaders from global companies (Syngenta, Bio-Rad, Eli Lilly, Sal Scientific, Sandoz and Leica Microsystems). They attend strategy meetings, providing input and acting as critical friends. This facilitates enterprise: 65% of staff have industrial collaborations that include Pharma, Animal Health, Crop Protection, Food Production and Conservation. Through our Outreach and Engagement Committee (Fig. 2) we engage undergraduates through to Professors in impact (§4.3.3). Our strategy provides a pipeline for emerging impact to mature into tangible economic and societal benefit (**ICS 05-01**, **05-03**, **05-07**, **05-09**).

Figure 5. Impact Strategy. A wide-ranging approach has been refined and developed through the REF period. See section 4 for deliverables.



1.3.3.5 Committed to Open research

We promote open-access publishing, facilitated by Institutional support (REF5a§2.4). We have increased the public availability of our research tools and data to promote end-user uptake for academic and societal impact. Dissemination of our Open Research expertise also forms an explicit component of our capacity building and extends into our research training: All PGRs are required to develop Open Data Management Plans as part of their progression (§2.4.5). We have published 43 open-data papers or papers with associated open datasets, generating 419 news mentions and 4,534 tweets, and all four of our ICS are underpinned by open data. For example, **Doncaster** contributed to developing novel open-source hardware and software with AudioMoth acoustic sensors (**ICS 05-03**), which sold more than 13,800 units worldwide within 3 years of release. **Doncaster** further developed a framework for sustaining the open-access model, published in *Conservation Letters*. The framework identifies novel solutions for three longstanding barriers to the uptake of open-source hardware: user inexperience with hardware, costly and complex manufacturing and distribution, lapsed creator and user support post development. **Tews**, **Werner** and **Williamson** have contributed to the executive boards of the CCP/CCPN network, public not-for profit projects funded by the BBSRC/MRC that develop software to support the crystallography (20,000 licenses worldwide, >140 industrial users) and NMR communities, respectively.

1.3.3.6 Ensuring Research Quality and Integrity

We rigorously promote a culture for the highest quality and integrity of research through our Ethics Coordinator (**Vargas-Caballero**), membership of the University's Animal Welfare and Ethical Review Body (**Andrews**), the '*Genetic Modification and Biological Safety Committee*' (member **Skipp**), and our Academic Integrity Officer (**Clarkin**). Instruction on publication and co-authorship is given to PDRAs and PGRs, with the expectation that they will be lead author on their work, as per the Vancouver Protocol (evidenced by PGR authorship of outputs, §2.4.6). We promote research reproducibility through accurate logging and archiving of all research records e.g., the School issues laboratory notebooks, and trains all our researchers in research integrity. **Holden-Dye** has overall responsibility for compliance with the '*Concordat to Support Research Integrity*', and for reporting of misconduct, liaising with Faculty and University procedures as appropriate (REF5a§2.8).

1.3.3.7 Providing a Safe and Inclusive Environment

Health and Safety is the responsibility of **Holden-Dye** who chairs the Health and Safety Forum which oversees the risk register, inspections, training records, well-being, incidents and near misses and reports to the Faculty Health and Safety Committee.

1.4 Strategy to 2025

1.4.1 Sustainability and Vitality

Our future has been secured by an upsurge in research income (Fig. 7), major grant funding in the last 2 years (§3.1), an increase in PGRs (§2.4.2) and the adoption of the Life Sciences Strategy by the University in 2018 (led by **Smith**).

1.4.2 Growth

We exceeded our REF2014 ambition with a net increase of 14 Category-A staff, including appointment of two Associate Professors (**Divecha**, **Rackham**) and one Professor (**Crispin**). We plan to match this in the next REF cycle, i.e., 14 new Category-A staff focusing on BBSRC strategic priorities. We have demonstrated that we can recruit world-leaders in their fields that map onto our strengths (§2.2) and will use future appointments to enhance our position as a hub for life sciences research at the University. Importantly, we will be proactive in recruiting early

career researchers to tenure track fellowships (§2.3.4).

Our planned growth will require investment in infrastructure. **Smith** leads the working group that is developing plans to expand biomedical research on the medical campus in a new strategic build (planned completion circa 2027). We will create financial headroom by increasing grant income (supported by staff development, §2.2), careful cost recovery on funding and through generating new income streams including through increasing revenue from enterprise (§4.4).

2. People

We carefully manage staff well-being, recruitment and development creating an environment in which all staff are equipped to deliver international quality research with significant impact. Below we describe our 'people' strategy which strengthens our capacity for impactful research, highlighting the agenda for ED&I, which is embedded in all our activities.

2.1 Equality, Diversity and Inclusion (ED&I)

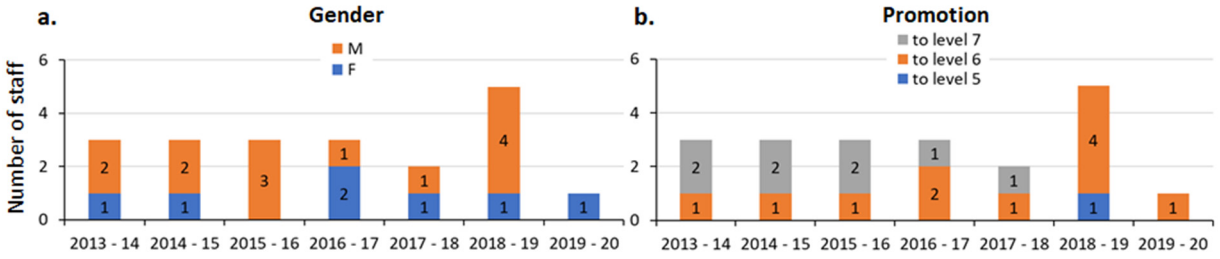
Head of School (HoS; **Holden-Dye**) works with line managers to implement our ED&I agenda including our Athena SWAN Silver Action Plan (awarded 2017). Within the constraints of staff makeup, our committees ensure the best possible gender, age and ethnic representation; additionally, all staff and students take mandatory unconscious-bias training. The ED&I committee chaired by **Elias** leads discussion at monthly all-staff meetings. The ED&I committee draws its membership from across the School, links to Faculty and University committees, and ensures we implement University policies (REF5a§3.8) for all protected characteristics and develop local action plans. We promote work/life balance, mental health and well-being and anti-harassment and anti-bullying policies. We adhere to core hours of 10 am to 4 pm and, after staff consultation in 2019, encourage one day a week (Friday) to be meeting free. We provide mental health first aid training (7 staff trained 2019) and mental health awareness training (workshops 2019 and online training >90% uptake) and engage with a University-wide Mental Health Working Group (**Deinhardt**) aiming to achieve the Mental Health Charter. We have promoted good working relationships, facilitated by external providers e.g., '*Honest Conversations*' workshop. We provide workshops with guidance on maternity and paternity leave and opportunities for job-sharing at all levels. We provide funding for those on family leave to pay for support to sustain their research during their absence (e.g., **Siddle**). Support for female researchers is available through courses, e.g., '*Springboard Development Programme for Women*'. We operate a conference attendance and training fund that prioritises support for students or staff who require additional funding to support childcare whilst undertaking activities for career development. ED&I in staff and research student recruitment is rigorously implemented in line with University policy e.g., with respect to gender representation on panels. ED&I is also foremost in promotion meetings; these are preceded by a reminder of the threat of unconscious bias and concluded with a summary of the impact of the promotion decisions on demography. Collectively, the steps outlined above generate a culture in which ED&I, work/life balance and well-being are high profile with the goal of continual improvement. We are well placed for renewal of our Athena Swan Silver Award in 2021 and on track for our longer-term ambition of achieving Gold.

ED&I has been integral to our REF submission. All staff have contributed and commented on our REF5b and throughout the assessment we have considered the profile of protected characteristics. We have closely followed Southampton's REF Code of Practice (REF5a§3.9) with 100% compliance with unconscious bias training. Our profile of research outputs is representative of the School's male (M), female (F) gender split (gender split of UoA5, 71.4%M, 28.6%F: gender profile of outputs 67.3%M, 37.7%F).

2.1.1 Demographics

We have 35M and 14F Category-A staff; 73% are less than 55 years of age, indicating a good balance between more senior and earlier career staff imparting excellent vitality. Success in our ED&I strategy is shown by increased diversity in our staff since 2014: +7% BAME, +1% EU, +7% 'rest of world'. Overall, the gender balance of the School has improved with a marginal shift towards females by +6%. Additionally, there is evidence of success at tackling the 'glass ceiling' (Fig. 6). The proportion of female staff at Professor and Associate Professor levels relative to Lecturer level has increased from 35% to 59%.

Figure 6. Promotion for Teaching and Research and Research-Only Staff, **a.** by gender; **b.** by level. Since 2013, 7 female staff have been promoted to levels 5,6,7 compared to 13 male staff, improving gender balance in senior positions.



2.2 Staffing strategy

The appointment process integrates with the interdisciplinary agenda, with **Smith** (Director of IfLS) participating in the panel and the panel chair appointed from outside SoBS.

We have made strategic hires (previous appointment is shown in brackets):

- Developmental Cell Biology: **Prior** (Uni Cambridge); **Elias** (Sir William Dunn School Path, Oxford).
- Microbiology: **Dumont** (Max Planck Inst Marburg); **Nobrega** (Delft Uni Tech).
- Neuroscience: **Andrews** (Uni St Andrews); **Vargas-Caballero** (Uni Oxford).
- Ecology and Evolution: **Morris** (Dept Zool, Uni Oxford).
- Molecular and Cellular Bioscience: **Tumbarello** (Cambridge Inst Med Res); **Przewloka** (Uni Cambridge); **Divecha** (Manchester Cancer Institute); **Wang** (Ludwig Inst Cancer Res, Oxford); **Crispin** (Uni Oxford).
- Computational and Systems Biology: **Rackham** (Duke NUS Singapore).

We have facilitated movement of staff between career pathways and post-doctoral staff into Level-5 positions: **Gostling** transferred from an education to balanced pathway; **Rusling**, **Schofield** and **Birts** were postdoctoral fellows developed into Category-A staff; **Gomez-Nicola** progressed from a Marie Curie Fellowship to an MRC NIRG and then a lectureship. Three new hires have left (**Bell**, **Catford** and **Razgour**); overall, however, our research profile remains significantly strengthened compared to 2014. The most recent appointment, **Rackham** is 0.2 FTE due to difficulties in moving from Singapore during the pandemic. He should move to a full appointment by 2022. His move to Southampton is the latest exemplar of our strategic recruitment of high-quality research staff.

Our strategy has resulted in a net increase of 14 (40%) REF-eligible staff compared to 2014.

2.3 Staff: Career development and support

Expert line management, with mandatory training for all managers, is enabling us to deliver on the School's and University's goals for internationally leading, impactful research.

2.3.1 Line management and mentoring

We identify goals and training needs, aided by the University commitment to '*developing our people*' (REF5a§3) and an embedded mentoring scheme for all staff. All line managers receive mandatory appraisal training and the senior team meet bi-monthly to ensure alignment with our strategy. Enterprise is part of each academic's annual performance review. We refine research proposals through a '*Grants Forum*' (leads **Chapman**, **Andrews**) and mandatory internal review prior to submission (grant success rate of 30%). Leadership is developed through nomination of staff for an annual University-wide '*Leadership Circle Programme*'. In the last five years 2M and 3F from SoBS have participated. New appointees are carefully managed through a two-year probation period with clear identification of the expectations to be achieved encapsulated in a formal letter within 3 months of appointment.

2.3.2 Promotion

Staff are guided towards achieving a portfolio of success in research and impact. All staff seeking promotion are able to obtain feedback from the School senior line management prior to submission of their application to the Faculty. Since 2014 we made 1 promotion from Level 4 to 5, 11 from Level 5 to 6, and 8 from Level 6 to 7.

2.3.3 Workload management

We use a transparent job allocation model (JAM) to assist in decision making and manage opportunities for staff to take on external appointments. All research staff have a baseline of 40% time allocated for research. Staff with 'Directly Allocated' hours on external grants that exceed this baseline research allocation receive an equivalent reduction in teaching/administration. The workload distribution is reviewed by the senior line management and modified with two goals in mind: *i*) facilitate the career progression of staff; *ii*) facilitate productivity and external engagement to enhance our global profile and influence. JAM provides oversight of gender equality in workload that is reviewed by line managers and mitigated where needed. Staff may request a sabbatical every 4 years in line with University policy (REF5a§3.2).

2.3.4 Postdoctoral researchers (PDRAs)

We promote the principles of the '*Concordat to Support the Development of Research Careers*' through a Concordat Champion, **Chapman**. PDRAs are appraised annually by trained appraisers (100% compliance). All PDRAs have assigned mentors to develop their career plans. They are represented on the School Board and the HoS holds bi-monthly '*no agenda*' meetings to identify emerging issues. PDRAs have Faculty administrative support for networking and an annual conference, '*Meet the Fellow*' events, and CV workshops. We run an annual '*Dean's Roadshow*' to connect PDRAs to Faculty leadership. We strongly support PDRAs in submission of fellowships, small grants and as co-investigators through writing workshops and internal review, with 7 awards made to PDRAs as PI; for example, Rachel Owen was awarded a grant from the Morris Animal Foundation in 2019 to study vaccination strategies against contagious cancers in Tasmanian Devils. Areas for improvement in PDRA support is monitored via the '*Careers in Research Online Survey*'. Feedback on appraisal completion is excellent (2017). We responded to requests for information on parental leave with a 'drop-in lunch' on this topic (2018).

2.3.5 Technician Commitment

Our Senior Technical Manager is a member of a University-wide steering group for implementation of the Technician Commitment to ensure we improve career development for technical expertise underpinning research. The HoS holds bi-monthly '*no agenda*' meetings with technical staff to facilitate engagement in the School.

2.3.6 Reward and Recognition

We recognise staff achievements with nominations for the Vice Chancellor's Staff Achievement award and host an annual Dean's Prize to celebrate Achievements in research and impact. Achievements in external recognition contribute to career progression. **Crispin** was awarded a Professor Adjunct at the Scripps Research Institute in La Jolla (CA) and a Supernumerary Fellowship (Oriel College, Oxford). **Morris** received a Royal Society University Research Fellowship (2007-2017) bringing expertise in experimental community ecology and tropical ecology and **Fox** was elected Director of the Faraday Institute for Science and Religion in 2020. **Keevil** was awarded a Royal Exhibition 1851 Industrial Fellowship with Bioquell in 2016. **O'Connor** received a Humboldt Fellowship in 2018 for sabbatical research at the Max Planck Institute. A PDRA supervised by **Deinhardt** was elected Early Career Representative for the British Neuroscience Association from 2015-2017.

2.4 Doctoral Research students (PGRs)

We are committed to training the next generation of life scientists by supporting their personal progression and developing talent to deliver economic and societal benefit.

2.4.1 PGR Funding

Our PhDs are funded by UKRI Doctoral Training Programmes (BBSRC, NERC and MRC), charities, industry and international scholarships. We were members of a BBSRC DTP on Food Security (led by University of Reading; 2013-2018; SoBS lead, **Poppy**) and currently lead on the BBSRC DTP South Coast Biosciences (SoCoBio; funded 2019-2024; PI and Director **Terry**). SoCoBio provides 14 PhD studentships and 5 CASE studentships (with numbers enhanced through partnerships with industry), with partners the Universities of Kent, Sussex and Portsmouth, and with NIAB-EMR, an agricultural research institute and an excellent environment for interdisciplinary training with involvement of UoA 01, 08 and 12. We also have students through the NERC Spitfire and Inspire DTPs (2013-2018 and 2019-2023) and an MRC DTP in Translational Immunology (2016-2020 led by the Faculty of Medicine). We invite staff to bid annually for 6 half-studentships from a ring-fenced budget to leverage external funding. In addition, the IfLS, the VC Scholarship and two local charities, the Gerald Kerkut Trust and the Wessex Medical Trust invite bids annually. We are proactive in seeking funding for international students e.g., through Chinese Scholarships and CONACyT (Mexico) (6 and 6 students, respectively since 2014).

2.4.2 PGR Recruitment

Our recruitment is buoyant and growing with international student numbers a steady and significant proportion (average 29.5%). Since 2014 SoBS has enrolled 251 PhDs, an increase from 28 in 2013/14 to 44 in 2019/20. Recruitment follows Faculty policy to ensure gender representation on panels and that quality criteria are met; the M:F split is roughly equal e.g., 20:24 in 2019/20. In 2020, we have 103 PhD students with 43 supervisors and with funding as follows: 12% UKRI, 41% charity, 17% industry, 18% overseas, 5% local, 7% self.

2.4.3 PGR Well-being

We manage this through the Graduate School Committee who liaise with supervisors and signpost to professional support as required. Processes to improve PGR well-being are led by a University-wide Mental Health Steering Group with representation from SoBS (**Deinhardt**). PGRs have bimonthly '*no agenda*' meetings with the HoS and the Chair of the Graduate School and are financially supported in running a highly successful and inclusive postgraduate society (Biological Sciences Postgraduate Society).

2.4.4 PGR Supervision, Mentoring and Progression

This is managed by a Steering Group (chair, **Wijnen**), with PGR representation, integrated with the Faculty structure and the University Doctoral College for governance. This oversees PGR supervision and monitoring at established milestones in years 1 through to 4.

Each PGR has a supervisory team with at least two academics (plus industrial supervisor for CASE/industrial PGRs). New supervisors complete the University PhD supervisors' course and are teamed with experienced staff. Feedback for PGRs occurs at all stages, enhanced by the online PGR Tracker for milestones. In the REF period, the number of PhDs awarded shows a compound annual growth rate of +8.4%, with an overall male to female of 47:53, and an average time to submission of 3.97 years.

2.4.5 PGR Research skills and Training

Training includes induction, generic skills (e.g. bioethics, research integrity, open-data management, health and safety, communication skills), bioscience technologies (aligned with Vitae Researcher Development Framework), networking, team building and outreach activities in schools, research and enterprise centres (e.g. Southampton's award-winning Science and Engineering Day; Twilight sessions and Research shadowing for sixth formers; Biotechnology Young Entrepreneurs Scheme, SET for Britain; University '*Future Worlds*'). These enhance transferable skills (e.g., CV production, job interviews, outreach, IP, entrepreneurship). PGRs have access to our Royal Society Entrepreneur in Residence, James Otter and are required to contribute to research group meetings, journal clubs, and oral/poster presentations at the Annual PGR Conference and external conferences.

2.4.6 Deliverables

100% of PGRs responding to the Destinations of Leavers from Higher Education (DLHE) survey went on to positive employment. Between 2015-2017, out of 27 responders, 11 were in professional/managerial roles with 21 in research roles, the remainder in medicine or business. Our PGRs overall satisfaction rating of 83.8% is higher than the national average (81%; PG Experience Survey, PRES; 2017).

Their success in contributing to our research environment is evidenced by their research outputs: of the 448 PhD students supervised by SoBS staff as principal or secondary supervisor, during the REF period, 116 were first authors on 165 publications originating from SoBS (Web of Science).

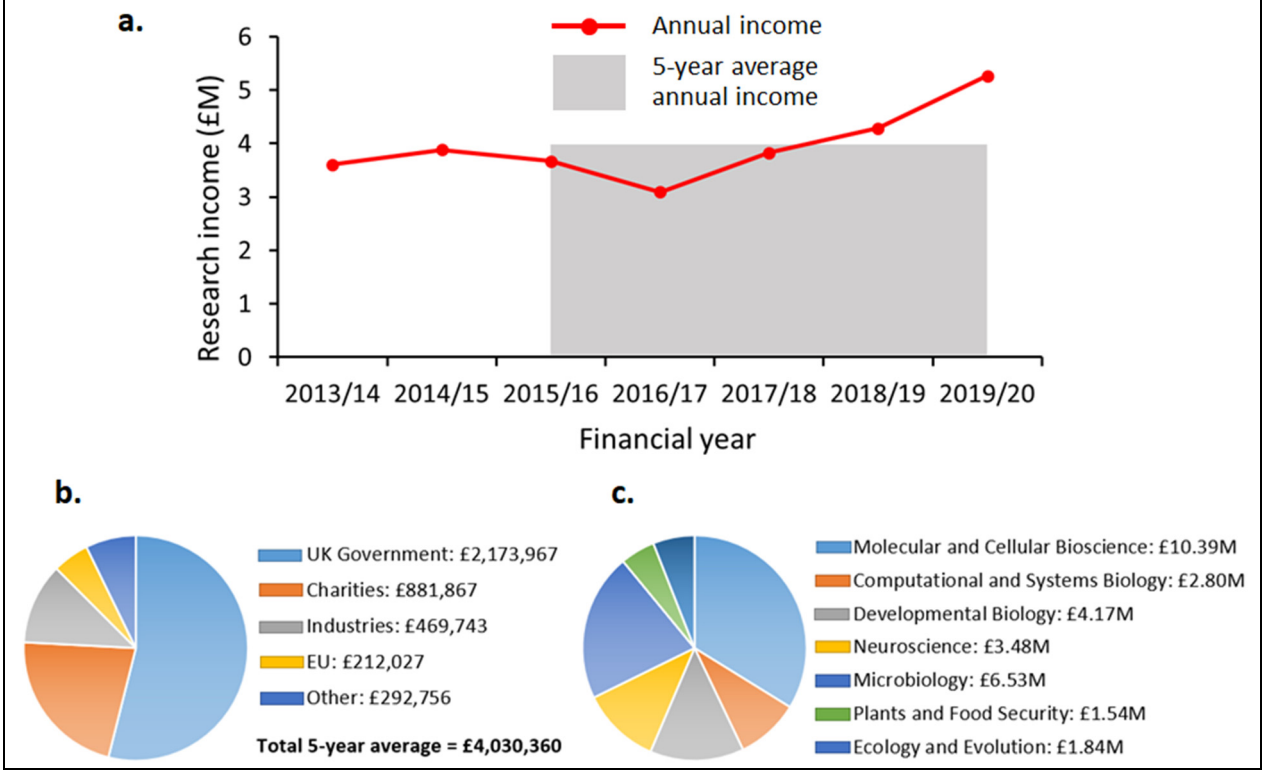
3. Income, infrastructure and facilities

Our portfolio of income substantiates our position as a vibrant University hub for biosciences research. Our income has significantly grown (Fig. 7) and our reach is extensive (Fig. 8).

3.1 Income

Since 2014 we have held 204 grants worth £59.18M as PI or Co-I. The UoA 05 share of £30.75M from these grants is a substantial increase over the value awarded in the last REF which reported a total income of £19.98M from 2008 to 2014. Average income per FTE per year during the REF period was £88,579 (increased from £79,209 in 2013/14). We have seen a year-on-year increase in our research income since 2016/17 (Fig. 7) reflecting the success of our strategy. Highlights include: £5.1M Nestec Ltd (SoBS share £1.1M), £3.2M Against Breast Cancer, £3.1M Global Challenges Fund, £1.7M Bill and Melinda Gates Foundation, £1.2M British Heart Foundation and awards from pharma industry totalling £4.4M.

Figure 7. Biological Sciences research income since 2014. a. All research income by financial year. **b**. Distribution by funder. **c**. Share of awards by theme.



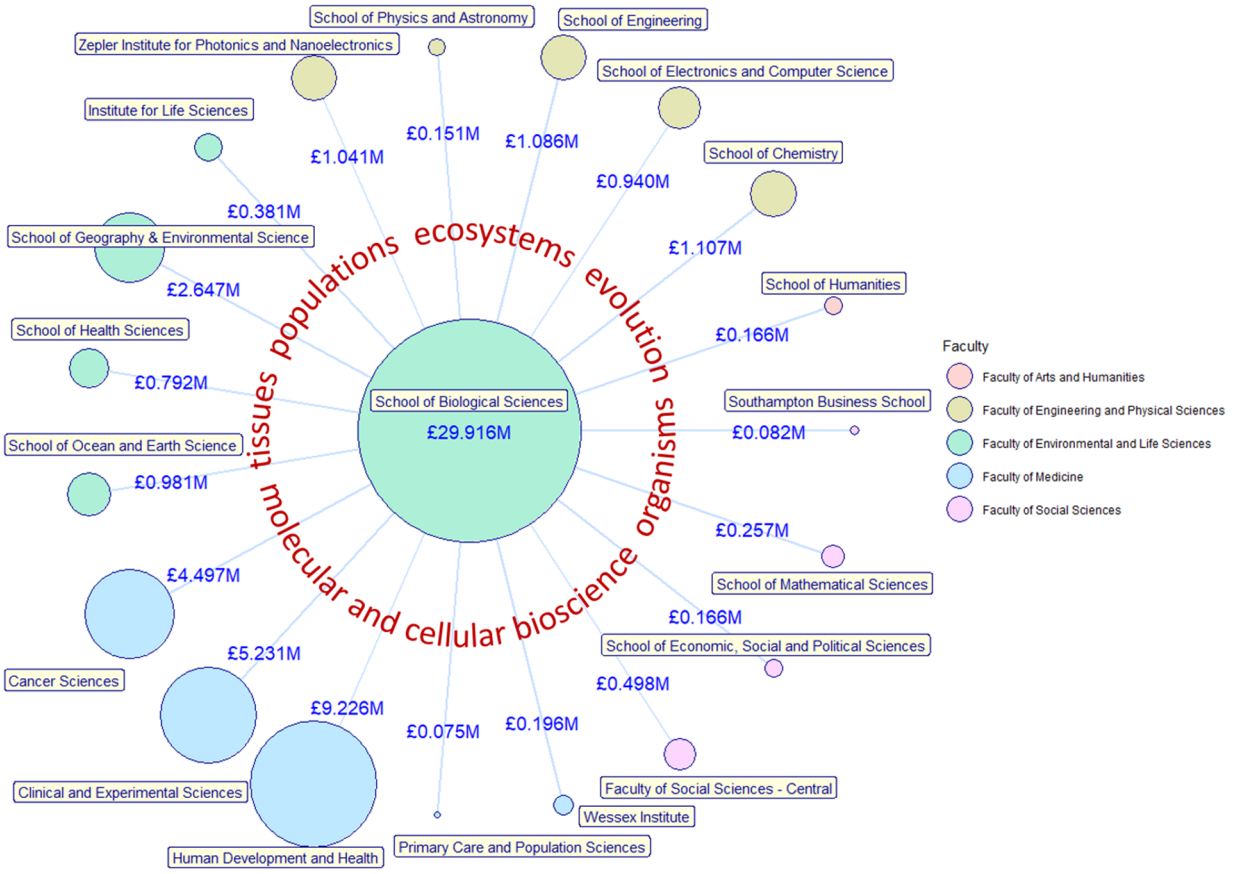
3.2 Infrastructure and Facilities

We continue to benefit from improved research facilities following relocation to the purpose-built Life Sciences Building (LSB) in 2010. All but four research teams are located here with **Lillycrop**, **Smyth**, **Teeling**, **Gomez-Nicola** based at University Hospital Southampton where they have access to facilities via Faculty of Medicine. LSB includes a wide range of advanced facilities with technical support and management structure for operational and financial sustainability and user groups to promote collaborations and drive new equipment grant proposals. In the current period, we have invested an additional £4.01M from internal and external sources. All facilities benefit from support from our technical team (with some specific cases highlighted). These facilities include:

3.2.1 Biomolecular Core (Academic lead **Williamson**) provides access to shared laboratory equipment with the support of a dedicated senior technician. Instruments are provided for the preparation and analysis of biomolecules, with a range of FPLC, HPLC, GC, GC-MS instrumentation, and a protein expression laboratory for production of recombinant proteins with preparative/ultra-centrifuges. A range of techniques are available for the characterisation of samples including UV/visible and circular dichroism spectrophotometers, isothermal calorimetry and multimodal plate readers providing high throughput analysis of absorbance, fluorescence, fluorescence polarization and luminescence. Investment since 2014 includes two real-time PCR systems and a scanning multi-mode plate reader.

3.2.2 Macromolecular Crystallisation (Academic lead **Tews**) includes a suite of liquid handling robotics and microscopes (including a new Oryx 4 Protein Crystallization System and UVEX-m crystal imaging) with associated technical support funded through external income. Macromolecular Crystallisation forms part of a crystal-to-structure pipeline together with high-end X-ray diffraction equipment in Chemistry and through links with the Diamond Light Source, Oxfordshire.

Figure 8. Biological Sciences is a Hub for Interdisciplinary Research. Total award share across 18 Schools/Institutes from all five University Faculties, for all grants in which UoA 05 staff are/were either PI or Co-I, held during the REF period.



3.2.3 Centre for Proteomic Research (CPR) (Academic lead **Skipp**). The CPR supported over £42M in grant funding and increased its capacity and capability (£1.64M for new equipment since 2014) for sample preparation/mass spectrometry and bioinformatics computing. Housed within a dedicated laboratory, instrumentation includes liquid handling robots, two Waters Synapt mass spectrometers with 2D nanoUPLC systems, a Waters Synapt mass spectrometer with automated hydrogen-deuterium exchange capability, a Thermo Orbitrap Elite and Thermo Orbitrap Fusion mass spectrometer's on-line to 2D nanoUPLC systems and a triple quadrupole tandem MS (Waters, Xevo TQ) for targeted analyses.

3.2.4 Imaging and Microscopy Centre (IMC) (Academic lead **Deinhardt**). The IMC has expanded during this period with incorporation of equipment at University Hospital Southampton and the Electrophysiology laboratory in the LSB. In addition, £372K has been spent on new equipment including new scanning confocal and live imaging microscopes. Since 2014 there has been more than a four-fold increase in usage. Over the assessment period the IMC has supported 39 academic staff based in SoBS and 35 from other Schools, demonstrating its central role in our activities and our interaction with other life scientists. The IMC houses equipment to investigate cell structure and function and includes transmitted light, confocal, widefield epifluorescence and bioluminescence microscopes, as well as gel imaging and flow cytometry. It also houses atomic force microscopy, live cell imaging and histology microscopy and laser table attached to a light sheet microscope. It has part ownership and access to a multiphoton microscope in the photonics development laboratory within the facility. There is a containment level 2 area that increases the range of samples that can be analysed. The equipment is served by an experimental officer. A major development is the incorporation of

electrophysiology equipment that has enabled central booking of eight different electrophysiology rigs with a broad range of capabilities including recording together with high powered image analysis. All workstations within the IMC are networked to a RAID server "IMCData" capable of storage and high-speed transfer of large datasets to users.

3.2.5 Biological NMR (Academic lead **Werner**). The NMR Facility, jointly run with Chemistry, has collectively benefitted from investment of £2.1M over the latest assessment period allowing upgrade of a significant proportion of the NMR infrastructure, including that utilized in the biological sciences. The Facility provides access to a 600 MHz spectrometer with cryoprobe and a recently installed 700 MHz NMR spectrometer (£1.05M) equipped with sample changer for the analysis of liquid state NMR samples for structural biology and metabolomics. Solid-state NMR studies have benefited from the upgrade of a 400 MHz console, the purchase of a new triple resonance MAS probe (£303K) and a new fast-MAS probe for the 600 MHz solid-state spectrometer (£40K).

3.2.6 Tissue culture (Academic lead **Clarkin**). This facility in LSB is equipped with CO_2 incubators and biological safety cabinets enabling the culture of cell lines, stem cells, primary tissue extraction and viral transduction in separate laboratories. Since 2014 we have seen an expansion of the facilities to four laboratories, comprising two containment level-1 and two level-2 laboratories, the latter adjacent to the animal holding facility.

3.2.7 Invertebrate Facility (Academic lead **Wijnen**). This FERA-licensed facility (University award, £800K) comprises insect (e.g., Drosophila, *Plutella xylostella*) and nematode (plant parasitic nematodes) suites plus 9 controlled-environment rooms (CERs) for organism culture and bioassays and a preparation space. One CER houses several wind tunnels. Data are logged automatically and can be accessed remotely, improving energy efficiency of the lighting.

3.2.8 Plant Growth Facility (Academic lead **Williams**). This has 9 CERs (2 FERA compliant) specialised for plant-insect interaction studies and a glasshouse (300 m^2) located on the LSB roof (£1.8M University investment with £800K from the largest-ever, at the time, donation to the University) and is supported by a horticultural technician. The CERs have individually computer-controlled light, temperature and humidity with permanent environmental monitoring and remote access. The glasshouse (Cambridge HOK) comprises 8 separate growing zones with independent constant environmental monitoring and a potting area with autoclave. In 2019 we invested £150K to purchase 2 GeoClima air cooled water chillers for the CERs in the Plant Growth and Invertebrate Facilities.

3.2.9 Chilworth Manor Experimental plots designed for long- and short-term ecology projects are in the Victorian Walled Gardens at Chilworth, 3 miles from campus, and supported by a horticultural technician. The garden has four large quadrants surrounded by wide margins, providing the potential for over 3,500 1-m^2, experimental plots.

3.2.10 Other shared facilities. SoBS has also been involved in the development of other shared facilities across the University e.g., Supercomputing (Computational Modelling Group), Lipidomics (Medicine), Biomedical Imaging Unit (Medicine) and Mass Spectrometry (Chemistry), including through direct financial contributions e.g., Category-3 Microbiology Suite (Medicine) and Biomedical Research Facility (Medicine), where **Teeling** and **Andrews** also served on the Scientific Strategy and Management Committee.

At the National level **Williamson** has contributed to the development of the Biomolecular NMR Centre (Crick Institute), the Dynamic Nuclear Polarisation MAS NMR Facility (University of Nottingham) and the National High-Field NMR (University of Warwick). **Tews** has been a member of the user working group for the KMX upgrade to Beamline I24 at Diamond Light Source.

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

Overview Our highly collaborative activity is reflected in our outputs. From 2014 to 2020 we have produced 1,170 research publications (Web of Science), of which 479 are co-authored with one or more of 41 other Schools and Institutes at the University of Southampton, distributed across the Faculty of Environmental and Life Sciences (353 publications), Faculty of Medicine (215), Faculty of Engineering and Physical Sciences (99), and Faculty of Social Sciences (8). These strong internal collaborations (Fig. 8) add power to our research themes (§1.3.1) and our capacity to deliver impact to external academic and non-academic beneficiaries.

Evidence of our advances in academic and non-academic impact since 2014 is provided by:

- Volume of original research outputs increased, from 659 for REF2014 to 1,170 for REF2021 (Web of Science).
- Citations increased, from 7,235 and H-index 36 for REF2014 to 23,254 and H-index 57 for REF2021 (REF2014 submission and Web of Science census end-2020).
- Field-weighted citation impact increased from 1.55 to 1.99 times the world average (Scopus 2014-2019).
- Proportion of publications in the top 10% of all worldwide field-weighted publications increased, from 19.7% to 28.2% (Scopus 2014-2019).
- Proportion of international collaborations increased, from 55.3% to 67.6% of outputs (Scopus 2014-2019).
- Filing of 16 patents with 5 granted, §4.3.1.1.

Our publications from 2014 to 2020 averaged 19.9 citations each (21/1/2021 census), within the top 10% quantile for worldwide publications in biosciences over the same period (Web of Science). These include 34 in the top 1% of field-weighted citations (collecting 9,439 citations across General Science, Ecology, Neuroscience, Evolution, Cell Biology, Microbiology, Plant Sciences), and 104 reviews (including nine in the top 1% of field-weighted citations: **Tumbarello**, **Teeling**, **Gomez-Nicola**, **Morris**, and others).

We have published in 594 source titles covered by Web of Science (i.e., with rigorous peer review and editorial standards), including most frequently *Scientific Reports* (40 outputs), *PLoS ONE* (21), *Nature Communications* (19), *Glia* (16), *PNAS* (16), *Ecology and Evolution* (15), *Global Change Biology Bioenergy* (13). Of the total of 123 science categories covered by these outputs, the most frequent are biochemistry and molecular biology (170 outputs), ecology (157), multidisciplinary (118), neuroscience (113), cell biology (84), environmental science (80), microbiology (62), plant sciences (60). Of the total of 1,686 funding agencies supporting the outputs, funding is most frequently obtained from BBSRC (212 outputs), European Union (209), NERC (181), MRC (145), Wellcome Trust (96), NIHR (88). Our publications are co-authored with 3,096 other organisations in 121 countries, including most frequently University of Oxford (111 outputs), University of Cambridge (76), Kings College London (43), University of Melbourne (37), UCL (34), University of Leeds (34), and Imperial College London (33). Our School has international collaborations that include 84 of the top 100 universities for Biosciences (2020 QS World University Rankings).

We have funded collaborations with more than 50 companies and government organisations spanning food retail, global pharma (including five from the global top-10 listing in 2020), agri-tech and biotech companies, conservation organisations (including UN Environmental Programme) and government agencies. Collaborations with commercial partners linked to 23 of our Category-A staff from across our research themes indicating a strong enterprise and engagement culture.

In the following sections we describe how we support the route for delivering impact (§4.1), how we engage with external academic and non-academic partners to realise benefit from our research (§4.2), and our wider contributions to the economy and society (§4.3).

4.1. Support for delivering impact

Our impact strategy is introduced in §1.3.3.4. The Director of Enterprise (**Teeling**) coordinates our activity providing an immediate point of contact for all external enquiries matching industrial partners and engagement opportunities with academics. She promotes research activities of interest to the business community through *i*) networking events *ii*) establishing introductory meetings and *iii*) integrating our activity with the wider University strategy. This resulted in close links with industry (49% of staff; 15M, 7F), government (20% of staff: 7M, 2F) and with supranational organisations (7% of staff; 3M). **Teeling** explores options for developing IP and links staff to RIS (REF5a§1.5), an Entrepreneur in Residence and a dedicated Collaboration Manager with industry/sector experience who guides exploitation and licence negotiation and a Faculty Patent Panel which evaluates requests to file patents and covers costs of filing for those approved. The value of this support in delivering impact is evidenced by SoBS entering into 112 Confidentially Agreements, 15 Material Transfer Agreements and generating patents, §4.3.1.1.

4.2 Influence that delivers impact

We are advisory-board members of multiple national and international institutes and professional societies and have participated in exchanges and networks as indicated below.

4.2.1 International funding bodies

Lillycrop is influential as a member of the USA National Institute of Health Childhood Cancer Board and Epigenetics Steering Committee, contributing to the NIH strategic funding priorities; **Poppy** is the sole UK representative for EU COST action programmes. Other examples include contributions to the Paris Peace Forum on Global Governance, the Portuguese Governamento Fundação para a Ciência e a Tecnologia, the UNESCO/UNITWIN Network on PhD Education and Research and the Swedish NMR centre. We have also served on grant and advisory panels for charities e.g., Alzheimer's Society, Fight for Sight, Progressive supranuclear palsy Association, Hannah's Willberry Wonder Pony, and international funding organisations, Agence Nationale de la Recherche, Finnish Environment Agency and Genome Canada.

4.2.2 National funding bodies

49% of submitted staff (13M, 9F) have contributed in advisory roles and panel memberships to the work of research councils and charities. The breadth of our expertise is reflected in 5 of the 8 UKRI councils being represented below, along with a wide range of other funding bodies in the UK and overseas. Significant examples include **Poppy** who contributed to establishing, and now leads as Director, a new £47.5 million Strategic Priorities Fund research programme focused on transforming the UK food system; **Teeling** as Deputy chair of MRC iCASE panel (2014-2019) and member of the BBSRC follow-on Fund panel, which make final decisions on industrial studentships and commercialization of research. We are extensively represented on UKRI and other major funding panels with 6 on the BBSRC pool of experts; 2 on the BBSRC/MRC Collaborative Computing Project for NMR Executive Committee; a panel member on each of the following; MRC Neuroscience and Mental Health Board; MRC Covid rapid response panel; MRC Doctoral Training Partnership interview pane; MRC/Crick NMR centre; MRC/Global Challenges research Fund; Antimicrobial resistance (AMR) committee; NERC panel; NC3Rs panel; Wellcome Trust Grant Interview panel; Neuroimmunology Strategic Advisory Group; Royal Society Newton Advanced Fellowship; and 5 members on the International Exchange Scheme panel.

4.2.3 Learned Societies, Other Professional Organizations and Journal Editorship

Examples of organizations where we have significant roles e.g., steering group member, provide an indication of the breadth of our activity: British Neuroscience Association; Wessex Immunology group; British Society of Proteome Research; Genetics Society; Biochemistry Society; Society of Experimental Biology; Microbiome Expert Working Group of the Microbiology Society. We further contribute to the field through journal editorship. A total of 16 staff (8M, 8F) serve(d) as Editors, Associate Editors, or are on the Editorial Boards, of 33 major journals.

4.2.4 Conferences and seminar series

Since 2014, we organised conference sessions e.g., for the British Society for Immunology, British Neuroscience Association, British Pharmacology Society, Biochemical Society, Society of Experimental Biology. We presented at least 121 invited/keynote lectures at major conferences in Universities, Governmental and Non-Governmental Organisations, in the UK and overseas (>19 countries). **Siddle** received the Julia Bodmer Young Scientist Award from the European Federation of Immunogenetics in 2016 and was invited to deliver a keynote lecture at the annual European federation of immunogenetics to receive the award. **Lillycrop** won the prestigious Boyd Orr Trust Fund Medal from the Nutrition Society and gave the keynote Lecture at the 2018 annual meeting of the British Society of Nutrition, which was attended by 400 delegates. **Lillycrop** delivered a keynote at the world congress of the International Society for Developmental origins of Health and Disease, reaching >1000 delegates. **Birts** received a fellowship from the European Society for Clinical Nutrition and Metabolism Research (2017-2018) and was invited speaker at the 41st ESPEN Congress on Clinical Nutrition and Metabolism in Krakow, Poland (2019). During the assessment period we delivered more than 32 sessions at major meetings and delivered conferences e.g., Jacques-Monod conference (vice-Chair, **Terry**), Euro Tau (**Mudher**). **Williamson**, **Tews** and **Werner** chaired national meetings for CCP (Collaborative Computing Programmes) and CCPN (Collaborative Computing for NMR) with >1500 delegates in 2021, making us key players in the structural biology community. We also hosted 9 meetings at Southampton including for the British Society for Proteomic Research (2019), Biofilms (2020), British Society of Immunology (2014-2019), UK EvoDevo (2019), International Young Microbiologists (2020).

4.2.5 Networks and Partnerships

These activities provide exemplars of our extensive influence on agenda setting and activity in biosciences and routes to impact. Our expertise on microbial communities led to the formation of the UKRI-funded National Biofilms Innovation Centre (NBIC) with a wider consortium of 41 additional research organisations and more than 100 companies. Directed by **Webb**, NBIC represents a £26M commitment that brings the best of UK biofilm research together with industrial sectors to accelerate the adoption of new technologies into live products and services. Expertise in multi-omics technologies from **Skipp**, **Schofield**, **Crispin**, **Rackham**, **Ewing,** combined with world-leading clinical partners, is transforming precision medicine across the diseases spectrum from cancer immunology to respiratory conditions, attracting substantial funding and investment from key industry partners, including Unilever and GlaxoSmithKline. **Lillycrop** is co-founder of EpiGen, a collaborative global research consortium focussing on developmental plasticity, nutrition, epigenetics, and human health, with substantial and productive relationships and investment from the private sector (£35M). Other key contributions to major international programmes, include WATBIO, a £9M EU consortium of 22 partners on drought tolerance in bioenergy crops, and EPSRC/NERC core funding for future energy scenarios and ecosystem service impact led by **Taylor** (UKERC phase III and IV) and the public-private funded £5M Wellcome Trust Consortium for Neuroimmunology of Mood Disorders and Alzheimer's Disease which involves researchers from 7 HEI's and 4 pharmaceutical companies.

Poppy championed food security in his role as Chief Scientific Adviser, and co-developed the bid that secured almost £50M of Strategic Priorities Funding now under his directorship.

4.2.6 People exchange

National and international visitors have strengthened our research portfolio and impact as evidenced by the following examples: we hosted 6 (3M, 3F) visiting academics from 4 countries, including 2 visiting University of Southampton Diamond Jubilee Fellows (Dr Zhou Wu, Kyushu-u University, Japan, 2016-2019; Dr Douglas Allan, University of British Columbia, Canada, 2015-2018), and 4 visiting research fellows, including Dr Wei Zhang, The Central Hospital of Wuhan, Wuhan, P.R. China; 2017; Dr Meihong Chen, Jiangxi Maternal and Child Health Hospital, Nanchang, P.R. China; 2018; Dr Sumei Yao, The Second Affiliated Hospital of Nantong University, Nantong, P.R. China; 2019; and Dr Ayodeji Asuni, Lundbeck, Copenhagen, Denmark, 2015-present. We also held Visiting Professorships at other institutions, including **Teeling** (Southern Danish University, Denmark, 2018), and **Webb** (Sydney, Australia, 2017). **Gostling** is visiting researcher at the Charles Darwin Research Station, Charles Darwin Foundation, Galapagos. **Wang** is visiting professor at the Tongji Hospital, Tongji Medical School, Huazhong University of Science and Technology since 2016 and a visiting professor at the Central Hospital of Wuhan since 2019.

4.3 Wider contributions to the economy and society

We have made significant contributions to the economy and to society through our extensive interactions with commerce and policy making bodies. This has generated enterprise and spin-out activity and patents as detailed below.

4.3.1 Contributions to the commercial sector

Our impact strategy has supported the commercial sector and governmental organisations (> 50 companies linked to 49% of staff) and ensures we are responsive to national and international priorities. Examples of our funded collaborations are listed below against research theme:

- *Molecular and Cellular Bioscience.* Our collaborations further technology development in the Biotech sector: Boerhinger Ingelheim (**Wang**, **Skipp**), Femtogenix (**Fox**), Microsoft (**Werner**).
- *Computational and Systems Biology.* Our interactions provide innovation in precision medicine and diagnostics: GlaxoSmithKline, Novartis, Unilever, Waters and Wickham (**Skipp**).
- *Development Biology.* Our broad ranging industry links address global priorities in health care e.g., healthy aging: Abbott (**Lillycrop**), Benevolent (**Lillycrop**), EpiGen (**Lillycrop**), Ministry of Defence (**Clarkin**, **Keevil**), Roche (**Teeling**, **Clarkin**).
- *Neuroscience.* Treatment of dementia is a high societal priority and we are translating our research to deliver advances through the following collaborations: Abbvie (**Gomez-Nicola**), AstraZeneca (**Teeling**, **Mudher**), BioInvent (**Teeling**), Biogen (**Deinhardt**), Chronos (**O'Connor**), Cortexyme (**Teeling**), Defence and Science Technology DSTL (**Holden-Dye**, **O'Connor**, **Smith**), Eli Lilly (**Gomez-Nicola**, **Teeling**, **Deinhardt**, **O'Connor**), Johnson and Johnson (**Gomez-Nicola**), Lundbeck (**Teeling**, **O'Connor**, **Deinhardt**), Medimmune/AstraZeneca (Teeling), MRC-T (**Gomez-Nicola**), Nutritious (**Teeling**), Nestle (**Lillycrop**), UCB (**Teeling**, **Clarkin**, **Ewing**), A*STAR (**Wijnen**), Novartis (**Teeling**).
- *Microbiology.* Antimicrobial resistance and infection present a major challenge for the 21st century. We are working with external partners to provide solutions: Antabio Pharma (**Webb**), Innovate UK (**Terry**, **Webb**, **Keevil**), Morrison's (**Keevil**), Public Health England (**O'Connor**, **Keevil**), Unilever (**Webb**). Through this activity we developed **ICS 05-07**.

- *Plants and Food Security.* '*Zero Hunger*' is the second UN Sustainability Goal. We are working with the commercial sector to improve the production of safe food: Adama (**Terry**, **Holden-Dye**, **O'Connor**), Acidophil (**Holden-Dye**), Algenuity (**Terry**), Amcor (**Terry**), Bayer (**Holden-Dye**, **O'Connor**), Branston (**Terry**), Dupont (**Holden-Dye**, **O'Connor**), Syngenta (**Holden-Dye**, **O'Connor**), Tesco (**Terry**), Vitacress (**Taylor**, **Peh**), Waitrose (**Terry**). Expertise in this area (**Poppy**) has provided leadership in national policy making §4.3.2, **ICS 05-09**.
- *Ecology and Evolution.* Biodiversity and conservation, especially in the context of global climate change, are key international priorities. Our collaborations with the following organisations underpin progress in this arena: BirdLife International, Environment agency, Royal Society for the protection of Birds (RSPB), Tropical Biology Association and UNEP-World Conservation Monitoring Centre (**Peh**), British Antarctic Survey, Government of South Georgia and Sandwich Islands, Government of Bhutan, Operation Wallacea, Panthera, WWF-Canada, and Wildfowl and Wetlands Trust (**Doncaster**). Through these interactions we developed **ICS 05-01** and **05-03**.

4.3.1.1 Patents, spinouts and clinical trials

Extensive links to the commercial sector have facilitated impact, with filing of 16 patents since 2014, some joint with external partners e.g., **Lillycrop** with Benevolent, **Webb** with NewSouth Innovations Pty Ltd (Australia) and **Holden-Dye**, **O'Connor** with Leeds University. RIS advises, guides and funds our patents through all stages pre- and post- granting of the patent. The following patents progressed to publication or have been granted within the REF period:

- '*Phenotype prediction by determining the methylation status of genes*' (**Lillycrop**), published 2015
- '*Méthode de prédiction de la presence d'un ou plusiers phénotypes*' (**Lillycrop**), published 2015
- '*Plant or seed coating*' (**Holden-Dye**, **O'Connor**), published 29/4/2020
- *'Cleaning liquid*' (**Keevil**), published 2015
- '*P38 MapK inhibitors for the treatment of sarcopenia*' (**Lillycrop**), published 25/6/2020
- '*Compositions et leurs utilisations*' (**Lillycrop**), published 25/6/2020
- '*Super-oscillatory lens apparatus and methods*' (**Chad**), granted 2015
- '*Methods and compositions for regulating biofilm development*' (**Webb**), granted 2016
- '*Polarisation microscope*' (**Smith**), granted 2019
- '*Phenotype prediction*' (**Lillycrop**), granted 2016
- '*Predictive use of methylation'* (**Lillycrop**), granted 2016

We have engaged with 6 spinout/enterprise activities across our research themes. **Holden-Dye** and **O'Connor** launched an enterprise unit 'Neur*ivo*' (2015) supported by a BBSRC Follow-on-Fund to facilitate contract research in anti-parasitic drugs. A flagship example of our recent success in enterprise is TopMD Precision Medicine Ltd (**Skipp**, **Schofield**). This developed through pre-seed funding (£37k, 2018) from the Solent Local Enterprise Partnership and SETsquared ICURe (£55k, 2019) and secured a SMART Innovate UK grant (£205k; July 2020), attracting angel investment of £100k, to extend and commercialise their pathway biomarker catalogue. TopMD is the main industrial partner for the biomarker discovery work package in H2020 DRAGON (€14.3M, Covid-19 response, June 2020) and the Health Holland respiratory programme, P402. TopMD has taken their product (worldwide patent filed) to market and is gaining strong market traction, working in partnership with major pharmaceutical and biotech companies (Chiesi, Smith & Nephew, Astra Zeneca; 2019).

Expertise in neuroinflammation (**Gomez-Nicola**) has underpinned phase 1 clinical trials (2019) of JNJ-40346527, a CSF-1 receptor antagonist, as a novel treatment for Alzheimer's disease. Further research (**Holden-Dye**, **O'Connor**) with Bayer AG on the selective toxicity of the anthelmintic emodepside was a key part of the decision making by the Drugs for Neglected Diseases Initiative to work with Bayer to launch clinical trials for the treatment of human filarial disease: phase 1 completed successfully in 2017 with phase 2 planned in Ghana for 2020 (delayed by Covid).

4.3.2 Contributions to policy making

In his role as CSA of the Food standard Agency, London (2014-2020), **Poppy**, influenced >50 policies in food security. He was appointed to the Assured Food Standards (AFS) Board, dealing with issues such as allergies and covering antimicrobial resistance as Red Tractor's new scientific adviser for agricultural and food science.

Keevil is a member of the Food Standards Agency London and Scotland and Chairs the Advisory Committee on the Microbiological Safety of Food. **Keevil** also serves as member of the Department of Health Decontamination working group, and he is a committee member of the Ministry of Defence Independent Science and Technical Advice (ISTA), the British Standards Institute EH/5 Wastewater Treatment and British Standards Institute CH-214 Antimicrobial Surfaces. We advised the Environment Agency on local river water management plan to control the levels of the River Itchen at its tidal confluence within Riverside Park in Southampton.

Further examples of advice to policy makers include provision of written and oral evidence to the Agricultural Bill committee on the use of chlorinated chicken and food security (**Poppy**), providing policy input to UK Energy Research Centre in the area of bioenergy developments (**Taylor**) and involvement with USA-EU twinning activities on Life Cycle Assessments for bioenergy (**Taylor**).

Contributions to the commercial sector include work on anti-microbial surfaces using copper (**Keevil**, **ICS 05-07**), preclinical testing of biologics for dementia (**Teeling**), consultancy on neuroimmunology for pharma (e.g., Eli Lilly, Abbvie, AstraZeneca, Lundbeck, **Gomez-Nicola**), consultancy on pest control agents with low environmental impact (**Holden-Dye**). **Nobrega** is co-founder of the Dutch Phage bank.

Crispin contributed to a Royal Society of Chemistry report submitted to the House of Lords Science & Technology Select Committee, June 2020 entitled '*The Science of Covid-19*'.

4.3.3 Contributions to Community and Public Engagement

The significant extent to which the public engage with our work is evidenced by Altmetrics data on online engagement. Notable examples of top-1% attention scores compared to same-age outputs include work from **Peh** on carbon sink saturation, covered by 139 news outlets and 1,133 tweeters, with an Altmetric of 2,008 (within the top 2,000 of all articles ever published with Altmetrics data across all disciplines by end-2020); **Gostling** on the early evolution of mammals, covered by 136 news outlets, with Altmetric of 1,251; **Teeling** on periodontitis in Alzheimer's Disease, covered by 121 outlets, with Altmetrics of 1,044; work by **Siddle** on the origins of transmissible cancers in Tasmanian Devils, covered by 92 news outlets, with Altmetric of 987; also on immunotherapy resistance, covered by 88 news outlets, with Altmetric of 828; **Lillycrop** on dietary supplementation with seed oil, covered by 99 news outlets, with Altmetric of 797; **Crispin** on identifying site-specific glycans of the SARS-CoV-2 spike protein, covered by 32 news outlets and 907 tweeters, with Altmetric of 737. Research outputs from SoBS during the assessment period have been referenced by 2,758 news outlets (top 5% quantile for biological sciences worldwide: Altmetric Explorer); 437 blogs (top 8%); 61 Wikipedia entries (top 3%); 68 policy citations (top 2%), 43 patent citations (top 2%); 30,478 tweets from 164 countries (top

8%). UoA5 staff have published influential commentary/perspective/ideas publications, including **Poppy** in *Nature Food*, and *Nature*, and **Doncaster** in *Conservation Letters*. **Gostling**'s Facebook page '*The Dinosaur on your Windowsill*' has more than 3,900 members from 43 countries. **Doncaster**'s '*Timeline of the Human Condition*' averages over 500 daily page views from over 160 countries.

Notable examples of engagement include the display of a diamond as part of Against Breast Cancer campaign '*The world's most valuable diamond*' by **Birts**, **Skipp** and **Crispin**. This was an international fundraising campaign during Breast Cancer Awareness month in October 2019 and included both TV and newspaper coverage, as well as coverage in Times Square New York. **Taylor** and **Chapman** participated in the Chelsea Flower show in 2018, raising awareness of the health benefits of watercress, being involved in a professional cooking session, reaching 157,000 people attending the show. We took part in **Marwell Wildlife's 'Zany Zebras'** sculpture trail, taking biodiversity and conservation research into Southampton city centre, attracting thousands of visitors. This engagement event was complemented by **BioBlitz** ecology walks for the general public (>500 participants). **Holden-Dye** led '*The Beautiful Mind'* project, a collaboration with the Winchester School of Art, involving undergraduates and early career researchers, to raise awareness of Mental health amongst the general public, this included a Wellcome Trust-funded fashion show at the British Neuroscience Festival in London's Barbican Centre in 2014, attracting >1000 visitors. At the University's Science and Engineering Festival (2016), **Doncaster** worked with artist Chris Cudlip, who created a sculpture to raise awareness on the impact of pollution in Chinese lakes on biodiversity, reaching >4000 members of the public. **Chapman** participated in Countryfile Live, communicating NERC-funded work on crop domestication and genetics. During this event 600 school-age children extracted DNA from strawberries at the display. We lead exhibits in the annual 3-day New Forest show to communicate Research Council funded research, reaching 20,000 members of the public per day and won '*Best Local Stand*' in 2016.

Our early career researchers are also highly active public engagers, with PhD work by Rachel Owen on 'Cancer in Tasmanian Devils' supervised by **Siddle** one of six national finalists in the 2019 UK 3-minute thesis competition, and microscopy images from PhD work supervised by **Deinhardt** being displayed at OXO gallery, London, as part of a dementia awareness campaign by Alzheimer's Research UK.

Our public engagement activities are presented in national and international news media. Examples include, **Keevil** (with postdoctoral fellow Callum Highmore) presenting a BBC R4 programme on Chlorinated Chicken and antimicrobial resistance (2019), resulting in invitations to give evidence at the House of Commons. **Keevil** also wrote an article in '*The Conversation*' describing the anti-microbial effects of copper, which has been read by 273,000 people, and reported in 11 news outlets and 857 tweets.

4.4 Future impact

We have developed networks, partnerships and commercial opportunities and a breadth of influence that spans the environment to the clinic and engages with diverse communities. We have an embedded strategy that will serve to develop and deliver future impact, e.g. TopMD Precision Medicine Ltd. Moreover, NBIC provides an opportunity for a legacy that will stimulate exciting new opportunities for translating biofilms research to economic and societal benefit. We will continue to pump-prime new enterprise activity through IfLS funding, half-studentships to facilitate new industry collaborations, and traction from SoCoBio for commercial partnerships. All told, we have developed an excellent environment for revenue generation to sustain growth and future impact.