Unit-level environment template (REF5b)

Institution: Durham University

Unit of assessment: Biological Sciences (UOA5)

Section 1. Unit context and structure, research and impact strategy

Plans are accurate at the time of writing, contingent on impacts of the pandemic falling within current expectations. Further details are in the 'Institutional-level statement on COVID-19'.

1.1 Executive summary and context

The vision for biosciences research at Durham is to focus on fundamental and cross-disciplinary science underpinning global challenges in climate change, food security, global health, sustainable bio-manufacturing, biodiversity and replacing animal models in research. The cohesive and distinctive theme across our research portfolio is that of 'sustainability'. This strategy has been strengthened through investment in 21 outstanding new staff appointments in priority sub-disciplines, new research equipment and geographical consolidation of research in Durham City. This submission represents 49.2 FTE staff from the Department of Biosciences (formerly the School of Biological and Biomedical Sciences), located either in a Biosciences building, or embedded in the nearby Chemistry Department to promote a key objective of interdisciplinary innovation. Our research informs undergraduate Biological Sciences B.Sc. and M.Biol. degrees that enjoy entrants with a minimum of AAA grades (without clearing). The co-delivery of research-led teaching, aligned to the aspirations of exceptional students, promotes a broad-based, sustainability-centred research strategy, informed by scientific advances and national and international priorities.

Our environment promotes cross-disciplinary working (e.g., via Durham's Research Institutes and Centres; https://www.dur.ac.uk/research/institutes/ and co-location of some staff with Chemistry), and underpins economic and social impact in ecosystems management, biotechnology, agritechnology and health.

In 2014 the Department reorganised its research into four groupings to promote staff interactions and the strategy summarised above:

- Ecology, Evolution & Environment (EEE)
- Molecular Plant Sciences (MPS)
- Animal Cells & Systems (ACS)
- Biomolecular Interactions (BMI)

Discoveries include:

- that global climate change has driven population change in birds;
- the connectors between the cytoskeleton and other plant structures;
- a novel signalling pathway for skin wound healing;
- the mechanism for correct metalation of ~half of the reactions of life.

Summary of impact

Our staff:

- co-formed two companies and enabled the sale for merger of one other;
- were granted >50 patents;
- helped to maintain and to restore biodiversity in aquatic and terrestrial ecosystems;
- influenced policy in 194 nations preventing millions of cases of vector-borne disease.

1.2 Research structures

To promote cross-disciplinary research, the Department engages with discussion groups, research centres, institutes, networks and initiatives via the Bio-X network (where X is any discipline other than biology: https://www.dur.ac.uk/research/bioeconomy/; **Section 1.2.5**).

Research is overseen by a Director of Research (DoR) via a Research Management Committee (RMC), which includes a Director of Facilities and Infrastructure (DoF), the Director of Postgraduate Studies (DoP), Director of Impact (DoI) and a representative from each of the Research Groupings (RG; **Section 2.1**). The RMC reports to an Executive led by the Head of Department (HoD), which in turn answers to a Board of Studies (BoS) where all academic, teaching, postgraduate, undergraduate and research staff are represented. A contract researcher and a research staff coordinator (RSC) report to meetings of a Research Staff Forum, which allows PDRAs to discuss any concerns with academic staff and report to the BoS.

Individuals with delegated responsibilities for equality and diversity, ethics, outreach, health and safety also report to the BoS. The Executive and BoS coordinate the planning of research and teaching and include representation from all relevant committees. The Department receives strategic advice on research, education and appointments from an External Advisory Board with representatives from academia (Profs. Rob Freckleton, Alison Smith FRS, Martin Warren, Fiona Watt FRS (recently stepped down)), and from industry (Prof. Mark Carver). Each member of staff has a primary home in one of four RGs (**Table 2**), which organise seminar series, run research away-days, manage joint research facilities, provide staff and PhD student mentoring, identify strategic priorities for staff recruitment, oversee internal peer review of funding applications and nucleate larger research programs.

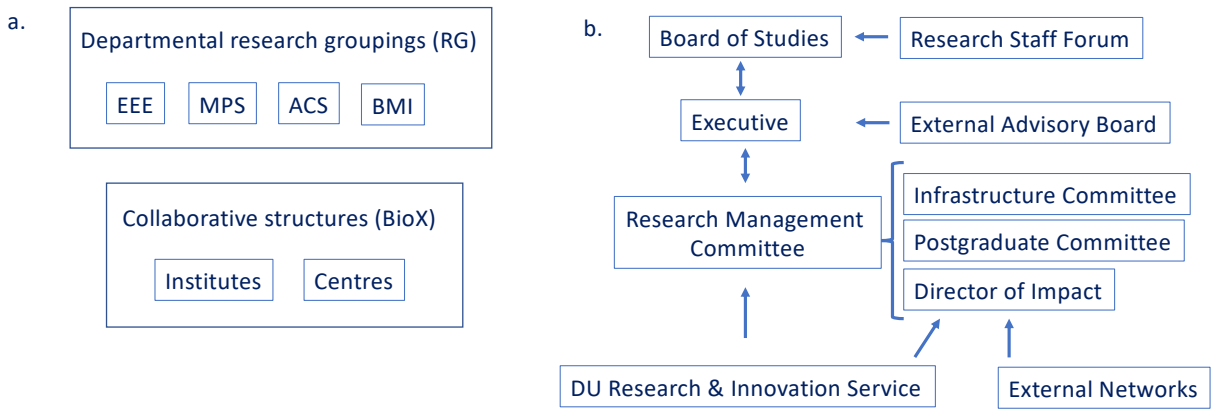

Figure 1. Research organisation (a) and management (b).

1.2.1 Ecology, Evolution and Environment (EEE)

This grouping is uncovering relationships between organisms and their changing environment, at scales from global (range changes) to sub-cellular (genetic traits), whilst considering behavioural and evolutionary plasticity. The purpose is to understand the drivers of biodiversity and hence the ecological impacts of human activity. The EEE grouping has helped to improve the management of aquatic and terrestrial ecosystems to benefit biodiversity and/or human health (**REF 3**).

EEE works with Non-governmental Organisations (NGOs) (Birdlife International, Kew, RSPB), governmental, and supranational organisations (eUNEP, Environment Agency, DEFRA) (**Section 4**). Staff explore:

- the impact of environmental change, particularly global climatic change and anthropogenic factors, on populations (**Willis**, **Stephens**, **Baxter**, **Dawson, Lucas**);

- the role of evolution in shaping species' relationships with their environment (**Hoelzel**, **Drury**, **Welch**);
- the role of behaviour in modifying individual variation (**Twiss**, **Drury**);
- the impacts of manipulating ecological systems for human benefit (biofuels, **Bothwell**; disease, **Lindsay**).

Since 2014, **Dawson** and **Drury** joined the group as Assistant Professors, **Chomicki** and **Welch** as Fellows. Core research hubs within the group include the Conservation Ecology Group (**Willis, Stephens, Dawson, Drury**) and the Molecular Ecology Group (**Hoelzel, Welch, Bothwell).** Both groups make extensive use of Durham's high-performance computing cluster, while the Molecular Ecology Group is an intensive user of the Department's genomic sequencing facilities (**Section 3.2**).

Predicting scenarios by modelling

A major focus is modelling natural systems to predict future scenarios. For example, **Willis** used contemporary models of species-climate interactions to infer future threats (*PNAS* 2019 **52** 13294-23299). To inform new conservation strategies resilient to a changing world, the group applies simulation models to predict impacts on biodiversity. **Dawson** identified global hotspots of alien species' richness across multiple taxonomic groups (*Nat. Eco. Evol.* 2017 **1** e0186) and has explored global exchanges of non-native plants (*Nature* 2015 **525** 100-103). Statistical and mechanistic models, especially spatially and/or temporally explicit models of ecological and evolutionary processes, are being developed and applied to predict the responses of species and ecosystems to environmental change. **Stephens** and **Willis** demonstrated a widespread response of common bird species across two sub-continents to recent climate change (*Science* 2016 **352** 84-87). **Lindsay** demonstrated the impact of house design, changing housing conditions in Africa and the utility of bed nets in limiting the *Anopheles* mosquito-borne spread of malaria (*Lancet* 2015 **385** 1436-46; *Lancet* 2018 **392** 569-580; *Nature* 2019 **568**:391-394).

Evolution research

Relationships between genetic diversity, drift, fitness and local adaptation are used to investigate evolutionary process and define evolutionarily significant units for conservation. For example, **Hoelzel** used genomic data to demonstrate ongoing selection across the mesopelagic/bathypelagic boundary in a deep-sea fish (*Nat. Ecol. Evol*. 2018 **2** 680-87). At the interface with the MPS grouping, **Bothwell** has used genomic approaches to uncover the genetic basis of multicellularity in the *Ulva* lineage (*Curr. Biol.* 2018 **28** 2921-2933), filling large omissions in the tree of life.

EEE group impact

The research has wide-ranging impact, including:

- influencing waterway management (**Lucas**: *Nature* 2020 **588**, 436-441);
- deployment of insecticide-impregnated bed nets in Africa (**Lindsay**);
- producing biodiversity indices for global use by, for example, the Convention on Biological Diversity (CDB) and Sustainable Development Goals (SDGs) (**Willis, Stephens)** (**Section 4.2**);

1.2.2 Molecular Plant Sciences (MPS)

The MPS grouping is housed in laboratories next to extensive plant growth facilities, and works to understand plant development, evolution and responses to the environment. Durham has a long-standing record of research in plant sciences leading to agritechnology impact and innovation - for example, the transgenic cotton line SGK 321 expressing the cowpea trypsin inhibitor (CpTI), developed in Durham in the 1980s, was approved for commercial use in China (a case study in REF2014) and *Bt/CpTI* cotton continues to be cultivated on a commercial scale. Ongoing MPS research similarly underpins agritechnology, including cotton research with

partners in China (**Lindsey**: *Nat. Gen.* 2017 **49**, 579-587; *Nat. Gen.* 2018 51, 224-229; **Sections 1.2.5, 4.1**).

New appointments

There has been a significant injection of new staff into MPS in the form of five-year research fellowships (**Fitches**, **De Lucas, Etchells, Chivasa** and **Brennan**), all gaining permanent positions (**Section 2.6**). **H Knight** was also recruited to Assistant Professor (then promoted to Associate Professor) from a Senior Demonstrator position. Rapidly establishing her own group, she has determined the role of specific Mediator subunits in regulating genes required for freezing tolerance in plants (*Plant Cell* 2014 **26** 465-484).

Tackling global food security

To accelerate impact, DCCIT (**Section 1.2.5**) joined a five-year Agrifood Resilience Programme, co-funded by HEFCE (£8M) and the N8 Universities (£8M), to tackle the challenge of global food security through three themes (**Section 4.1**). Durham MPS forms part of the "Sustainable Food Production" theme, providing opportunity for collaborative research between Durham and other N8 University and industrial partners.

Plant development research

Work on the molecular and cellular basis of plant development (**Lindsey**, **Etchells**, **de Lucas** and **Liu**) has provided insights into the regulation of embryogenesis and root development through hormonal control (**Lindsey** and **Liu**), vascular differentiation and development (**Etchells**) (*Curr. Biol.* 2015 **25** 1050-1055, *Plant Cell* 2020 **32**: 319–335 cover article) and epigenetic regulation of cell-specific gene expression in cellular differentiation (**de Lucas**) (*Plant Cell* 2016 **28** 2616-2631). **Hussey** visualises the dynamics of plant cell structures in exquisite detail (**Section 3.2**). Multiple MPS staff study plant tolerance to abiotic and biotic stresses and help to develop crop protection technologies: This includes research on signalling via second messengers, posttranslational modification and control of gene expression in abiotic stress (**H Knight**, **Sadanandom** and **M Knight**) (*Plant Cell* 2014 **26** 465-484, *Science* 2018 **362** 1407-1410), responses to microbial pathogens (**Sadanandom**) and crop protection against invertebrate pests (**Fitches**) (*The Plant Cell* 2018 **30**: 2099-2115).

1.2.3 Animal Cells and Systems (ACS)

The ACS grouping studies diverse cellular models with emphasis on *in vitro* cultures and non-mammalian systems. A series of strategic appointments (**Clark**, **Doupé**, **Riabinina, Davies, Croset and Bazopoulou**) has, with **Weinkove,** created critical mass in invertebrate systems and especially *Caenorhabditis elegans* and *Drosophila melanogaster*. This new grouping interacts, and/or shares facilities, including a recently extended insectary (**Section 2.5**), with others working on plant-insect interactions (**Fitches**, MPS), insects as disease vectors (**Lindsay**, EEE), and vector-borne parasites (**Denny**, BMI). ACS has created two spin out companies and sold on a third as part of a merger to create a new company, furthering animal-free research (**Section 4.2; REF 3**). As examples of ACS research:

- **Doupé** studies epithelial stem cell regulation in the *Drosophila* intestine. He combines genetic screens, bioimaging and genomics, revealing coordinated cell migration from seemingly chaotic movement (*Nat. Comms.* 2017 **8**: 14905, *PNAS* 2018 **115** 12218-12223).
- **Clark** studies host-microbe interactions during ageing in the *Drosophila* intestine. She has a particular interest in the impact of the intestinal microbial population on physiology and age-related decline in epithelial permeability at three-way cell junctions (*Nat. Cell Biol.* 2017 **19** 52-59).

- **Weinkove** combines *C. elegans* host genetics with that of its *E. coli* microflora and has developed automated techniques, leading to a spinout company (**Section 4.2**).
- **Riabinina** is exploring sensory processing in *Drosophila* via genetics, behavioural assays, neuroanatomy, electrophysiology, functional imaging and computation. The discovery of an intestinal zinc sensor that modulates *Drosophila* growth and development (*Nature* 2020 **580**: 263-268), has tantalising implications for the notion that zinc acts as a master regulator. Her work offers new approaches to malaria control by complementing the epidemiological work of **Lindsay** (EEE) on the ecology of flies and the control of vector-borne disease (**Table 5**).
- The most recent recruits, **Davies**, **Croset** and **Bazopoulou,** joined in 2020 (**Section 2.5**).

Exemplary imaging facilities are a mainstay of the ACS group (**Section 3.2**), enabling **Goldberg** to visualise, for example, detailed interactions between the cytoskeleton and vesicles during endocytosis (*Curr. Biol.* 2015 **25** 868-878). **Quinlan** (**Section 4.3**) uses a multiplicity of imaging modalities to characterise structures within the eye, with emphasis on the cytoskeleton and chaperones.

ACS has an additional focus on cell and tissue biotechnology incorporating tissue engineering and the application of *in vitro* models and biomarkers of health and disease. A feature is new *ex vivo* skin models (**Jahoda, Przyborski**, **Benham**, **Karakesisoglou** and **Maatta**), especially for use in conjunction with Procter and Gamble (P&G; **Sections 1.4, 4.2**), with the over-arching purpose of replacing animal testing. **Ambler** has uncovered how signals between basal epithelial and dermal layers reorganise the composition of skin in wound healing (*Nat. Comms.* 2016 **7** 11394).

1.2.4 Biomolecular Interactions (BMI)

The BMI group work at the Biology-Chemistry interface, aided by location within the Department of Chemistry, and use chemical, biochemical, and biophysical methods to understand:

- pathogen-host interactions, with protozoan parasites, bacteria and viruses;
- the handling of metals in biology, including enzyme metalation and nutritional immunity;
- other types of post translational protein modification, especially carbamylation.

Djoko is one of a group of BMI academics, including **Robinson, Young** and **Chivers**, specialising in Metals in Biology research (*Nat. Chem. Biol.***,** 2017 **13** 409-414; *Nature*, 2018 **543** 78-82; *Nat. Chem. Biol.*, 2019 **15** 241–249), that benefit from interactions with bio-inorganic chemists and that direct a BBSRC Network in Industrial Biotechnology and Bioenergy (NIBB) driving impact in sustainable biomanufacturing (**Sections 4.1, 4.2**). Organisms sense change in carbon dioxide concentrations but the primary sensors and extent of detection through protein carbamylation have largely remained enigmatic due to its ephemeral nature. Working with Hodgson and O'Donnoghue (Chemistry), **Cann** used triethyloxonium tetrafluoroborate to covalently trap CO_2 for proteomic detection (*Nat. Comms.*, 2018 **9** 3092). **Cann** also led the *Journal of Biological Chemistry* plant biology paper of the year (http://www.jbc.org/site/vi/2018/) by establishing how a transcription factor allows an otherwise nonspecific DNA-binding protein to specifically confer viral resistance. The previous identification of the DNA-binding protein by **Cann** (*J. Biol. Chem.*, 2015 **290** 24945-24960) also featured in a special issue devoted to the best plant biology in this journal from 2015-2017.

A common focus of several programmes at the Biology-Chemistry interface (**Sharples**, **Djoko**, **Blower**, **Denny**, Pohl plus collaborators Cobb, Sandford, Steel, Badyal, McGonigal, Walton, Whiting and Williams from the Department of Chemistry) is to identify targets for antimicrobial (including antiviral) compounds. New recruits **Blower** and **Djoko** are working towards the development of bio-active compounds to tackle antimicrobial resistance. Back-to-back articles by **Blower** reported the visualization of fluoroquinolone antibiotics locking bacterial topoisomerases into partly inactive states, a molecular interaction that is impaired in enzymes from antibiotic-resistant strains of *Mycobacterium tuberculosis* (*PNAS* 2016 **113** 1706-1713; *PNAS* 2016 **113**

E839-E846). A fluoroquinolone was discovered with increased complex stability against antibiotic-resistant topoisomerases, and related moxifloxacin is already part of a promising three-drug trial. **Blower** swiftly took advantage of co-location with Walton (Department of Chemistry) to jointly discover modes of action of bioactive ruthenium-complexes that inhibit histone deacetylases (*ChemPlusChem* 2016 **81** 1276-1280). **Djoko** has developed metal-related antimicrobials and has advanced understanding of the interplay between copper fluxes and pH fluxes in response to host nutritional immunity (*PNAS* 2017 **114** 6818-6823). **Denny** has been instrumental in securing an £8M MRC-GCRF award to tackle the scourge of parasitic vector-borne ill-health (**Section 4.1**).

BMI research underpins impact in;

- the development of bioactive antimicrobial compounds;
- sustainable biomanufacturing (clean growth).

1.2.5 Structures promoting interdisciplinary research

The nature of Durham University, with its college system, location within a compact city, its scale and internal structure is suited to fostering collaboration across traditional discipline boundaries. Seven Research Institutes bring together staff from Departments in the Faculties of Science, Social Sciences and Arts & Humanities, either virtually or in shared space, with commitments to common research questions (**REF5a/2.2**). Institutes most relevant to biosciences are: the *Biophysical Sciences Institute*; *Durham Energy Institute*; *Institute for Hazard, Risk and Resilience*; and the *Wolfson Institute for Health and Wellbeing*. Institutes provide small scale funding to support bursaries, meetings and project seed-corn.

As noted earlier, most of the BMI grouping is embedded in laboratory space within Durham's Department of Chemistry (**Section 2.1**); this initiative actively promotes collaboration at the Chemistry-Biology interface while retaining close links to the Department of Biosciences for line-management, teaching and administration. There are particularly close interactions with a Bioactive Chemistry and Synthesis grouping. BMI staff direct three networks driving the exploitation of this research in biotechnology (**Sections 4.1, 4.2**).

Table 1. Major engagement with University Institutes and Centres

Biophysical Sciences Institute (BSI) *With Physics, Chemistry, Mathematics, Engineering, Computer Science* *BMI, ACS*	**Institute of Hazard Risk and Resilience (IHR^2)** *With Geography, Applied Social Sciences, Earth Sciences* *EEE*	**Durham Energy Institute (DEI)** *With Earth Sciences, Geography, Chemistry, Physics, Engineering, Computer Science, Business School* *MPS, EEE*	**Wolfson Research Institute for Health & Wellbeing (WRI)** *With Anthropology, Psychology, Chemistry, Law, Philosophy, Geography* *ACS, BMI*
Durham Centre for Crop Improvement Technology (DCCIT) *MPS, EEE, BMI*	**Durham Centre for Bioimaging Technology (DCBIT)** *ACS, MPS*	**Behavioural Ecology and Evolution Research Centre (BEER)** *EEE*	**Centre for Global and Infectious Disease (CGID)** *BMI*

BMI, ACS, EEE, MPS represent the dominant Departmental groups involved (**Section 2.1**)

The University supports Centres (more focused than Institutes) that traverse Departmental boundaries and four are closely aligned with Biosciences (**Table 1**). DCBIT is a designated European Plant Cell Imaging Hub and provides exemplary imaging facilities adjacent to the Integrative Cell Biology Laboratories (ICBL) (**Section 3.2.1**). DCCIT has been described in

Section 1.2.2. CGID coordinates research in Biological Chemistry with relevance to combatting infections and is involved in steering the MRC global network to combat neglected tropical diseases (**Section 4.1**). BEER integrates EEE research in Biosciences predominantly with Earth Sciences, Anthropology and Geography.

1.3 REF 2014 plans

As planned in REF 2014, the Department has sustained a vigorous campaign to recruit, support and retain staff of the highest quality in priority areas, developing multi-skilled teams focused on questions related to adaptation and environment, biomolecular interactions, crop improvement, cell structure, development and regeneration, all of which map closely to the new research groups and centres (**Sections 1.2, 2.1**). It has been possible to exceed expectations in realising the DCCIT strategy to establish collaborative research programs with end-users in agricultural biotechnology and seed industries, through the N8-AgriFood program (**Section 4.1**) and plans to develop a multidisciplinary research hub focused around industrial biotechnology was realised through the Durham-led phase 1 and phase 2 BBSRC NIBB (**Section 4.2**).

1.4 Mechanisms promoting impact and responsible research and innovation (RRI)

A central *Research and Innovation Services* (RIS) promotes research commercialisation, supports engagement with stakeholders and provides advice in relation to research ethics (**REF5a/4.4**). Through RIS, staff within this submission established more than 80 funded links with industrial partners during this REF cycle, sustained existing spin out companies, for example via mergers and acquisitions, and initiated further spinout companies (**Section 4.2**). A facilities coordinator and business liaison manager within the Department of Biosciences promote interactions with RIS and with external stakeholders, for example via workshops.

The Department has an industrialist on its external advisory board (Mark Carver, former Chief Scientific Officer of Avecia Biologics, Senior Vice-President Research, Development and Innovation for Fujifilm Diasynth Biotechnologies), and has appointed two Professors in Practice (Elena Lurie-Luke, former Head of Global Life Sciences Open Innovation at Procter and Gamble (P&G); and Adriana Botes, former Senior Manager at the *Centre for Process Innovation* and entrepreneur), fostering industry interactions. Funded networks (EPSRC Physics of Life, BBSRC NIBB) drive collaboration with industry to advance research along the technology readiness levels and (MRC NTD and BOVA) promote engagement with policy makers and other stakeholders (**Table 5**). Durham University has an extensive strategic partnership with P&G (**Section 4.2**), enabling the swift execution of collaboration agreements, non-disclosure arrangements and memoranda of understanding.

The Department of Biosciences takes advantage of Institution-level training and support for RRI, ethics, integrity, open access and open data (**REF5a/2.4**). PhD training programmes (**Table 3**), and networks (**Table 5**) also provide bespoke RRI training. In addition, the Department has bioethics and safety committees, and mentors are assigned to all staff, including postdoctoral research assistants and PhD students. Mentors are independent of supervisors to provide a conduit for confidential reporting of any concerns relating to ethics, safety, open research or research integrity; the bioethics and safety committees provide a second such route. The emergence of post-publication peer review platforms has brought research integrity into focus and this is an issue that Biosciences monitors closely. Staff are encouraged to make all background data available online and to use pre-publication platforms, such as BioRχiv.

1.5 Impact strategy

Durham Biosciences is committed to the translation of fundamental science into impact and has support structures to promote this (**Section 1.6)**, including a designated academic Director of

Impact (**Lindsay**) to develop strategy, the strategic use of research leave and institutional support, including funding (**REF5a/2.5**).

Impact is recognised and valued in the staff promotion process. The selected case studies (**REF3**) exemplify our impact in internationally important areas that include ecosystems management (climate change, aquatic animals), biotechnology, and health and wellbeing at interfaces with Ecology (vector control) and Chemistry (tissue engineering; **Section 1.6**). A series of potential impact studies are in the pipeline for future development. In REF 2014 a case study exemplified agritechnology, and of the 18 nascent case studies (which form our future impact strategy) several in agritechnology are swiftly moving along the technology readiness levels guided by DCCIT and the N8 AgriFood programme. For example, in 2018 **Sadanandom** was awarded patent PCT/EP2017/057333 jointly with KWS Plant Breeders Ltd to optimise plant immunity allied to nitrogen uptake. Under a licensing agreement, KWS are collaborating in field trials of winter wheat varieties screened in Durham. In 2019, these trials attracted funding from the Bill & Melinda Gates Foundation for a pilot study to enhance nitrogen use efficiency in wheat, in support of increased yield in low to middle-income countries. **Fitches** and **Sadanandom** lead a £10M Innovate UK project in insect biotechnology.

1.6 Development of impact case studies

Mechanisms to support impact are apparent in the development of the case studies:

Tissue Engineering

RIS (**REF5a/4.4**) supported initial IP protection, formation of spin-out *Reinnervate* and its merger with *Biopta* to form *Reprocell Europe* in 2016 and negotiated finance from NorthStar Equity and Park Walk Investors. A commercial terms agreement enabled **Przyborski** to buy-out his time 40-60%, 5 years, to develop the business. Durham's strategic partnership with P&G fostered multiple, funded collaborations and leveraged RCUK funds.

Vector control

Workload management provided **Lindsay** with six months' research leave to draft the global vector control policy with the WHO, RIS supported the acquisition of VC funding and negotiated IP for forthcoming commercialisation.

Climate change

Workload management granted six months' research leave for **Willis** to liaise with organisations using outputs of climate impact modelling. Seedcorn funding was awarded to test the application of models at scale.

Aquatic animals

University Research Impact Funding supported a consultant to assist negotiations with water management authorities and businesses, while workload management agreed 12 months' research leave for **Lucas**.

1.7 Summary of future impact strategy

Our strategy to drive future impact:

- Aligns with our basic research strengths;
- Is related to priority areas in Ecosystems, Agritechnology, Biotechnology and Health (**Figure 2**);
- Exploits our extensive networks **(Section 4.1**) and engagement with industry and society **(Section 4.2**);
- Will be supported by new staff appointments, infrastructure and facilities through the departmental and institutional mechanisms described **(Sections 1.5, 1.6, 3.3**).

Section 2. People

2.1 Staff affiliations to research groupings

Table 2. Departmental groupings

Ecology, Evolution and Environment EEE	Molecular Plant Sciences MPS	Animal Cells and Systems ACS	Biomolecular Interactions BMI
Robert Baxter MPS	Adrian Brennan* EEE	Carrie Ambler	Tim Blower* C
John Bothwell MPS	Stephen Chivasa*	Adam Benham BMI	Martin Cann MPS C
Guillaume Chomicki*	Peter Etchells*	Paul Chazot	Peter Chivers C
Wayne Dawson*	Elaine Fitches*	Rebecca Clark*	Paul Denny C
Jonathan Drury*	Patrick Hussey BMI	Tim Davies*	Karrera Djoko* C
A Rus Hoelzel	Heather Knight	David Doupé*	Sushma Grellscheid
Steve Lindsay ACS	Marc Knight EEE	Martin Goldberg BMI	(Ehmke Pohl) C
Martyn Lucas	Keith Lindsey BMI	Colin Jahoda	Nigel Robinson MPS C
Philip Stephens	Junli Liu	Akis Karakesisoglou	Martin Schröder
Sean Twiss	Miguel de Lucas*	Arto Maatta	Gary Sharples C
Andreanna Welch*	Ari Sadanandom	Stefan Przyborski	Tessa Young* C
Stephen Willis		Susan Pyner	Brian Suarez-Mantilla* C
		Roy Quinlan BMI	
		Olena Riabinina*	
		David Weinkove	
		Vincent Croset*	
		Daphne Bazopoulou*	

EEE MPS ACS BMI Secondary affiliations: *ECR when appointed since 2013: Name in parenthesis submitted to UOA8: C Housed in laboratories embedded within the Department of Chemistry.

2.2 Staffing strategy and staff development

Since the last REF submission, there has been a net increase in the number of FTEs from 39 to 49.2, to build research strength and generate critical mass in specific areas. The focus has been on ECR appointments (Assistant Professor-level; 41% female and ten nationalities in the REF period), to build careers, and sustained vitality is evidenced by a similar mean staff age (48.7 in 2020; 48.4 in 2013) despite the passage of seven years.

Appointments

Newly appointed academic staff include **Blower, Clark, Davies, Dawson, Djoko, Doupé, Drury, Fitches, Riabinina, Croset** and **Bazopoulou**; plus, **Brennan, Chivasa, Etchells** and **Grellscheid** who were submitted to REF 2014 as Fellows, along with Heather **Knight** who was submitted as Senior Demonstrator; most are now appointed to open-ended academic contracts. **Chomicki**, **De Lucas, Welch** and **Young** joined as Fellows (**De Lucas** now permanent), while the research of six staff (**Ambler**, **Lucas**, **Schröder**, **Sharples, Pyner**, **Twiss**) who were not submitted for REF 2014 has benefited from newly introduced research structures and systems of mentoring (setting of clearly defined targets; five have had research leave). Ten staff left (nine were submitted in REF 2014) and one individual with a joint appointment in Chemistry (Pohl) is submitted to UOA8.

Drivers for recruitment

Academic staff recruitment strategy is by fit to research areas, the quality of past performance and future promise. Recruitment also recognises the need to sustain a spectrum of sub-disciplines that match student interests and needs, including for undergraduate and masters-level projects. Since 2013, ~90% of the Department's graduates entered employment (including in biosciences-related jobs) or further study within 12 months, with ~30 % graduating to bioscience-related masters and PhD programmes.

Probation, progression, promotion

A University-wide shortened (12 months) probation period was introduced during this REF period for all newly appointed academic staff, reflecting our emphasis on the quality of the initial recruitment process. All staff complete annual written progression and promotion reviews with feedback, to support career development (**REF5a/3.2**). Promotion criteria are transparent, and staff are actively encouraged to seek promotion. Twenty-one academic staff have been promoted in the census period.

Mentoring and training operate at the Departmental level through individual mentors and workshops focusing on new developments, and at the Institutional level via courses on, for example, grant writing, research management, open access and data management (**REF5a/2.4**). A credit-based workload model, managed by the Head of Department, recognises and rewards staff for carrying out research and for achieving impact, and provides balance in research, teaching and administrative duties.

2.2.1 Fixed-term postdoctoral researchers

Relevant Concordats guide supervision of postdoctoral researchers, for example, *Support the Career Development of Researchers*, in which staff are trained. Postdoctoral researchers are affiliated to the Departmental RGs, through which they organise seminar series. Postdoctoral researchers deliver presentations to the entire Department at annual research away-days and become members of research centres and research institutes, facilitating the delivery of seminars to multidisciplinary audiences. Postdoctoral staff are offered staff development courses, given opportunities to engage in (modest amounts of) teaching. They are assigned mentors to assist with career development in addition to advice provided by supervisors. After two years postdoctoral contract, researchers are enrolled in the same departmental promotion and progression annual review as academic staff. Representation is provided via the Research Staff Forum (**Section 1.2**).

For all staff, the Department has a weekly seminar series with external speakers. Research Institutes and Centres also host speakers.

2.3 Postgraduate environment

Postgraduate study by research in Biosciences is supported by a robust infrastructure and established programmes of training and assessment. There are typically about 100 students

enrolled, financed by a range of funding sources with 27% non-UK, 62% female. A factor in recruitment is international visibility, attracting students who contact staff directly and often bring support grants (such as from the *CONACYT* programme in Mexico and Chile, *Science Without Borders* in Brazil, and the *FCT* foreign studentship programme in Portugal). Funding is available through the Durham University Doctoral Studentship programme, and University matched grant schemes, for example with the Chinese Studentship Council. The Department has generous levels of support from a series of externally funded Doctoral Training Partnerships (DTP) and Centres for Doctoral Training (CDT) (**Table 3**), reflecting the spectrum of sub-disciplines with which the Department engages.

BBSRC and NERC DTPs were both renewed in 2019/20 and each supports *ca*. six students per year in Durham. The soft matter CDT includes a sub-group of students working at the interface between Biosciences and Chemistry (about three each year). IAPETUS NERC DTP is led by Durham as is the Leverhulme Trust Durham-Arctic CDT with a cohort of 15 PhD students, while the Durham GCRF CDT funds 20 international studentships in support of GCRF-related initiatives. In collaboration with Newcastle University, a centre for Doctoral Training (CDT) was established in 2019 with funding from EPSRC, to train 60 PhD students over nine years in Molecular Sciences for Medicine (MoSMED). This CDT harnesses Durham's expertise across the natural sciences and especially those of Biosciences staff embedded within Chemistry. Biotechnology, pharmaceuticals and related sector partners from the UK and Europe provide co-supervision and industrial placements. Another source of studentships has been matched grants from industry (e.g. Procter & Gamble).

Table 3. Funded PhD training partnerships with Durham Biosciences

NLD DTP (BBSRC) *With Newcastle and Liverpool Universities*	**IAPETUS environmental science DTP (NERC)** *Academic partners in Scotland and the North East of England*	**MosMED molecular sciences CDT (EPSRC)** *With Newcastle University*
SOFI soft matter CDT (EPSRC) *With Edinburgh and Leeds Universities*	**Durham Arctic (Leverhulme Trust)** *Durham only*	**Durham UN sustainable goals CDT (GCRF)** *Durham only*

Student progression

Student progression is assessed and monitored regardless of funding source. All students complete a training needs analysis, updated annually, and attend a series of induction workshops, providing training in generic skills and concepts relevant to the Biosciences. Students take at least four of an additional 12 workshops on bioscience skills. DTPs and CDTs provide further training. Thesis committees of at least two staff, excluding the supervisor, meet with students each year with written and oral reports. The Department makes decisions about progression at eight months. Second-year PhD students present a poster at an annual Durham Biosciences Postgraduate Conference. In the third year, PhD students give an oral presentation at an annual conference. The NLD DTP students organize a yearly conference held in Durham.

The student environment is overseen by a Graduate Studies Committee, which includes a PG student representative, further informed by the Graduate Liaison Committee, which comprises the Director of Postgraduate Studies, the Postgraduate Secretary, and ten postgraduate students from across the Departmental RGs and from different stages of study. One seminar series is attended and managed by PG students as is an annual careers fair.

Prizes and wider activities

An annual prize is given to a postdoctoral researcher or PhD student in recognition of a published paper: for example, Stuart Nelis' discovery, reported in *Developmental Cell* 2014 **28** 102-110, that plants can control growth via 20S proteasome-targeted degradation of specific second

messenger proteins. Posters from PG students at all levels are presented each year in lively poster-sessions at the Departmental Research Away Day, with bursaries to support conference attendance awarded for the best ten presentations. During the REF cycle, more than 198 papers have been co-authored by PhD students including 15 in discovery journals. PhD students and postdoctoral researchers regularly win prizes for poster and oral presentations at international conferences. They have also chaired international meetings for early-stage researchers such as the 2019 Gordon Research Seminar on the Cell Biology of Metals in Barcelona. At least 87% of PhD students enter research posts in academia, industry or the third sector.

Postgraduate students are supported in wider activities such as the Biotechnology YES competition (NLD DTP students were winners in 2018) and outreach (e.g. events at the Durham Botanic Garden; the BBC Good Food Show, Birmingham NEC; https://www.dur.ac.uk/dccit/outreach/).

2.4 Equality and diversity

The Department of Biosciences includes seven teaching-only positions, and 25% of all staff are female (41% female appointments since 2014). The numbers of RAE/REF-eligible female staff have grown from 2 in 2008, 4 in 2014 (versus 37 and 39 males) and now 11 (22%). The majority of eligible staff (92% of males and 100% of females in RAE2008 and 92% of males and 75% of females in REF2014), were submitted previously. The Department benefits from a diverse and multicultural staff profile; this submission contains all eligible staff and includes 14 holders of non-UK passports and five BAME staff. The Department renewed its Bronze Athena SWAN Award in 2019 and will be applying for Silver in 2022. Two female staff, including one ECR, are currently on the departmental Executive Committee (eight members).

Meetings and seminars are scheduled to enable attendance by staff with family or caring commitments. The Department maintains an equal gender balance amongst invited speakers coming from a range of backgrounds, providing diverse exemplars to PGs and PDRAs. The vibrant postgraduate community has an even gender balance. The *Research Staff Forum* promotes mentoring and disseminates information regarding career opportunities. Fixed-term contract staff enrol in a redeployment pool for six months before their contract ends, giving preferential opportunity to apply to internal positions before external advertising.

Research leave and flexible working

All academic staff are entitled to research leave, accumulating one term's leave for every seven terms worked. The Executive arranges cover for teaching and administrative duties. Over the past five years, the relative number of males and females applying for leave has reflected the numbers of eligible male and female staff. The Department is committed to supporting requests for flexible or part-time working arrangements. Trial periods of up to 12 months may be agreed to ensure plans are suitable. Several members of research support and academic staff currently work part-time due to personal commitments. The University IT system facilitates flexible remote staff working.

Before parental leave, needs are discussed with the Departmental Manager, HoD and Human Resources. The Department offers bespoke support beyond the statutory policy, for example arranging and funding technical support during leave. The Department has attracted and hosted two Daphne Jackson Fellows, returning to science after long career breaks. The University sponsors this scheme.

Diversity

Shortlisting for academic, research and support staff positions uses a scoring matrix based on criteria in the job description. The 'Disability Confident' scheme guarantees an interview to all disabled applicants meeting the essential criteria. For positions at Assistant Professor and above, shortlisting requires Faculty-level approval. Interview panels have at least two male and two

female members. All staff involved in shortlisting or interviewing are given 'Equality Diversity Inclusivity' and 'Unconscious Bias' training.

The selection and inclusion of papers and impact case studies for REF have followed the institutional code of practice (**REF5a/3.6**), based firstly on merit and then considering protected characteristics where this increases diversity while retaining quality.

2.5 Early career researchers (ECRs)

Supporting the development and progression of early-career staff (at the time of appointment) is a priority. In addition to the mentoring mechanisms already described (**Section 2.2, REF5a/3.3**), ECR support includes a reduction in teaching or administrative workload (approaching 90% reduction in most cases) for the first two years with some ongoing reduction for at least three years. Use of facilities (**Section 3.2**) and associated technical support is provided free of charge to ECRs. Access to facilities is also open for individuals bridging between sources of funding, but otherwise paid-per-use at cost. Support for at least one, and often more, PhD student(s) is provided to ECRs.

Laboratory and office space refurbishment for ECRs is a priority, exemplified by a £350k conversion of 98.5 m^2 of former teaching laboratory into research space for the nascent invertebrate research sub-grouping (**Clark**, **Croset**, **Doupé**, **Weinkove, Bazopoulou, Davies, Riabinina**) to include category two containment of genetically modified flying insects (*Drosophila* and mosquitos) and *C. elegans*.

Among recent recruits, **Davies** has exploited *C. elegans* to understand how cytokinesis is influenced by cellular context (*eLIFE 7* 2018), **Croset** has discerned cell diversity in *Drosophila* from gene expression in single cells (*eLIFE* 7, 2018), and **Bazopoulou** has uncovered the connections between ROS, histone methylation, lifespan and stress in *C. elegans* (*Nature*, 2019 **576** 301-305).

ECR start-up packages have exceeded £100k for consumables and equipment costs, according to strategic need. Examples include an ACTA Protein Purification System and crystal trials robot (**Blower**), containment level 2 cabinet and newly constructed office space (**Djoko**) and Chromium Single Cell Sequencing (**Croset**).

RIS, DoR, HoD, RGs and mentors all work with ECRs to identify sources of funding, to help prepare bids, draft responses to referees and conduct mock interviews. Institution-wide, funder-specific liaison groups (MRC, NERC, BBSRC) offer pitch-to-peer sessions and provide feedback to ECRs on developing plans for grant applications.

2.6 Independent research fellowships

A set of five–year University-funded fellows were recruited in this REF period to strengthen Molecular Ecology (**Section 1.2.1**), and MPS (**Section 1.2.2**). The opportunity for these researchers to establish their groups led, for instance, to **Fitches** co-discovering a novel molecular mechanism for jasmonate signalling in response to stress (*Plant Cell* 2018 **30** 2099-2115) and **De Lucas** obtaining insights into the regulation of gene expression in plant development at both transcriptional and epigenetic levels (*Nature* 2015 **517** 571-575 and *Plant Cell* 2016 **28** 2616-2631). **Powell** joined EEE on a COFUND fellowship and **Chomicki** on a NERC fellowship. Recent work of **Chomicki** on farming-ant behaviour (*PNAS* 2020 **117** 2535-2543) featured in a commentary in the same issue because it presents a Darwinian solution to the problem of managing the conflicting demands of crop plants for light, nutrients and protection.

Two Daphne Jackson Fellows, Helen Thompson and Victoria Maltman, re-entered research careers in MPS and ACS, the former having since obtained a BBSRC-funded position with **Lindsey**. Arthur Glasfeld joined the BMI group on a one-year Fulbright award, Tessa **Young** initially joined for 18 months on a COFUND Fellowship, then for three years on a Royal

Commission 1851 Fellowship. **Blower** was awarded a Lister Prize Fellowship in 2019. A third of Fellows obtained more secure positions in Durham Biosciences, and it is intended to (at least) sustain this.

2.7 Plans for future staffing

The University is committed to sustaining Biosciences staff FTE numbers in the region of 50 (the current number) by replacing an anticipated ten retirements during the next REF cycle, and additionally making 10 to 15 more appointments (to *ca* 60 FTEs) to further increase research quality and critical mass in perceived areas of strength and to create more links between RGs (**Section 2.2**). All RGs have positions approved for advertising at the census date with eight posts authorised (in November 2020) for recruitment in the current fiscal year. Outstanding staff will be recruited to priority areas as follows:

2.7.1 Ongoing plans for EEE

Appointments post-2020 will focus on "Ecosystems Modelling" and "Molecular Ecology and Evolution", plus especially the interconnections between these sub-disciplines, to underpin impact concerning "Climate Change", "Biodiversity" and "Ecosystem services".

2.7.2 Ongoing plans for MPS

Appointments post-2020 will focus on "Integrative Cell Biology" (**Section 3.2.1**) including plant signalling (transduction and integration), to deliver impact in "Food Security" and "Plant Biotechnology". With effective structures in place to support the development of early-career research staff (**Section 2.5**), the cohort of MPS Fellows (**Section 2.6**) will exert a growing influence on the MPS research culture as they advance through permanent academic positions.

2.7.3 Ongoing plans for ACS

Appointments post-2020 will focus on "Integrative Cell Biology" (**Section 3.2.1**) including invertebrate molecular cell biology and "*In vitro* Tissue Biology" with the strategic aim of delivering impact in "Replacement of Animals in Research" and in "Global Health". Mentoring the career development of staff in the nascent invertebrate cell biology group (**Sections 2.5, 1.2.3**) will remain an ongoing priority.

2.7.4 Ongoing plans for BMI

Appointments post 2020 will focus on "Biological Chemistry of Molecular Interactions", underpinning impact in "Next Generation Antimicrobials" and "Sustainable Biomanufacturing (clean growth)". Via the Global network to combat neglected tropical diseases (**Section 4.1**), chemists such as Sandford, with a track record in bringing to market fluorinated compounds to treat eukaryotic microbial infections, will work with **Denny** to identify targets for combatting leishmaniasis and Chagas disease.

2.8 Promoting exchange with business and the third sector

The University supports the preparation of non-disclosure agreements, initial costs of patent filing to facilitate industry collaboration, and back-filling of teaching while individuals develop spin-out companies such as *Magnitude Biosciences*, *Reprocell Europe* and *LightOx* (**Section 4.2**). Impact activity is recognised in the Departmental workload model (**Section 2.2**) and is supported by University seedcorn grants (**Section 1.6**). Extensive networks provide routes to engage with non-academic partners and schemes to encourage interactions are funded by, e.g. the BBSRC NIBB and N8 AgriFood (**Sections 4.1, 4.2**).

Section 3. Income, infrastructure and facilities

3.1 Income

Larger scale awards have been provided by UKRI, with BBSRC as the major contributor (totalling >£10M), while an ~£8M MRC GCRF network that involved Biosciences staff located in Chemistry is mostly recorded on the Chemistry (UoA8) return. In fiscal year 2018/2019, the Department of Biosciences won £5.8M in new awards (the highest to date), representing significant progress towards a forecast of £200kFTE⁻p.a. by the end of the next REF cycle.

Industrial funding came from numerous start-ups and SMEs, plus major multinationals and nationals, including Total, Procter & Gamble, Unilever, Syngenta and Northumbrian Water. Income from industry exceeded £5.1M with P&G being the largest single industrial funder (£3.1M to Biosciences staff since 2013). A >£1M European Research Council starter grant to **Sadanandom** commenced during this REF cycle; he also leads a BBSRC sLoLa with **de Lucas** (£4.5M, announced July 2020) and partners in Cambridge, Nottingham and Liverpool universities. Large scale funding for multiple collaborative networks is described in **Section 4** and recent growth in new awards is described in **Section 3.3**.

Priority areas such as applied ecology, conservation biology and mathematical modelling are supported by a wide diversity of agencies, including NERC (>£1.5M and the IAPETUS DTP) and a total of 26 other bodies, including:

- BirdLife International
- British Trust for Ornithology
- Sir Halley Stewart Trust
- British Deer Society
- Natural England
- RSPB
- British Trust for Ornithology
- Heritage Lottery Fund
- Charities Aid Foundation
- Bill & Melinda Gates Foundation
- The Environment Agency
- National Geographic Society
- Marine Management Organisation
- Leverhulme Trust
- UNEP World Conservation Monitoring Centre

Willis and **Stephens** have pioneered the use of Citizen Science to increase data collection to a scale well beyond that possible with solely grant-funded staff, identifying the hallmarks of environmental change in biodiversity pushing ecosystems towards tipping points and extinctions (*Science* 2016 **352** 84-87; *Remote Sens. Ecol. Conserv.* 2018 **4** 361-374).

Since 2014, internal and external funding has injected about £4M into equipment managed by the Department of Biosciences. These funds include:

- £900,000 for a super-resolution microscope and £480,000 for electron microscopy;
- £500,000 for a light sheet microscope for biological imaging;
- £600,000 for Illumina sequencers for genomics;
- £375,000 for a triple ToF mass spec for proteomics;
- £310,000 for a Qtrap chromatography system for bioanalytics.

The DoF and DoR maintain a ‘pipeline’ document of new equipment needs and of ageing equipment approaching renewal, which informs the priority order for internal and external funding bids. The University maintains a reserve to match external equipment-funding, an annual round

of bidding for new equipment and an emergency fund to replace ageing equipment. Funding for impact activities is considered elsewhere (**Sections 1.6, 2.8, 4.1**).

3.2 Infrastructure and facilities

The Department of Biosciences has outstanding core facilities, supported by excellent Experimental Officers, strengthening grant applications and promoting strong research outputs. These are augmented by facilities held by other departments and also accessible to UoA5 staff, including biophysical techniques, such as high field NMR, EPR, CD- and IR-spectroscopy plus diffractometers for small molecule crystallography. Skilled facility managers, overseen by specific academics, operate the Departmental facilities and report to an infrastructure committee, chaired by the DoF which in turn reports to the DoR via the Research Management committee and to the Executive. The DoF coordinates the capture of funding from internal and external sources to maintain and extend these facilities.

Research facilities

There are 10 research facilities in the Department of Biosciences (**Table 4**). These have been used, not only by Durham researchers, but also by external collaborators from institutions in the UK, Germany, Poland, Russia, Switzerland, USA, Austria, China, Czech Republic, Belgium, Brazil and Spain. The facilities are also used by companies such as BioToolomics, Cambridge Research Biochemicals, P&G, and public institutions such as Public Health England.

Table 4. Departmental core facilities

Advanced light imaging and microscopy	Electron microscopy	Genomics	Bioinformatics laboratory	Bioanalytics
Proteomics	Crystallography and biophysical methods	Specialised plant growth environments	Advanced animal cell culture facility	Cell technology suite

Bioimaging

Advanced light imaging microscopies include: Super-Resolution, Structured Illumination (3D-SIM), localisation (PALM/STORM), Airyscan Confocal Laser Scanning (CLSM), Spinning Disk Confocal Laser (SDCLM), Multiphoton, Total Internal Reflection Fluorescence (TIRFM), Deconvolution, Fluorescence Lifetime Imaging (FLIM) and Fluorescence Cross-Correlation Spectroscopy (FCCS). Electron microscopy includes scanning and transmission electron microscopes (with the highest resolution SEM that is unique to a biology Department in the UK), advanced sample preparation, 3D imaging and high-sensitivity imaging.

More than half (58%) of the academics in this submission use the Bioimaging core facility (with its team of technical support staff and microscopy specialists) which is central to the *Durham Centre for Bioimaging Technology* (**Table 1**). It is one of the leading facilities in the UK in terms of the breadth of imaging modalities, especially for Plant Science research, and is a member of the UK-Bioimaging network of microscopy facilities. All microscopes are located in purpose-designed space. The facility is recommended as a European node for plant and crop imaging by an independent international evaluation board for the Eurobioimaging infrastructure programme (ESRIC). The imaging laboratories are licensed by the Food and Environment Research Agency to work with plant pathogens.

Since 2014 the facility has provided images for more than 70 publications. Such exceptional facilities have made it possible, for instance, for **Hussey** to visualise how the Networked (NET) superfamily of actin-binding proteins connect the cytoskeleton to other structures, for example NET3C to the plasma membrane and endoplasmic reticulum (*Curr. Biol.* 2014 **24** 1397-1405); how actin polymerizes to regulate autophagy in plants (*Curr. Biol.* 2016 **26** 2060-2069, highlighted in *Curr, Biol.* Dispatch, R703-705); and how the plant immune response triggers cytoskeletal-

plasma membrane connections to invaginate, strengthening the cell wall to inhibit pathogen ingress (*Curr. Biol.* 2018 **28** 2136-2144).

Genomics, bioanalytics and proteomics

Genomics capabilities include an Applied Biosystems 3730 capillary instrument for Sanger sequencing, an Illumina HiSeq 2500 and MiSeq for a broad range of Next Generation Sequencing applications, allied to a Bioinformatics lab with 7 Linux workstations boasting high RAM capacity. Bioanalytics includes Sciex 6500 hybrid triple-quad MS with Shimadzu UHPLC system, Waters H-Class UPLC system with diode-array, fluorescence and single-quad MS (QDa) detectors, Waters UPC2 system with diode array and single-quad MS (QDa) detectors, Shimadzu GC-MS with single-quad mass detector, AKTA Purifier LC system with UV detector, plus preparative and standard HPLC. Proteomics facilities include a Sciex TripleTOF 6600 mass spectrometer and Sciex 4800 MALDI TOF/TOF mass spectrometer. A cell technology suite provides a specialised environment for isolation and analysis of single cells, including laser capture micro-dissection, flow cytometry and microinjection equipment and Chromium single cell sequencing technology.

Structural analysis

For the determination and analysis of molecular structures, assorted methods complement crystallography, including techniques to study protein-ligand interactions, such as Isothermal Titration Calorimetry, Thermal Shift Assay and Surface Plasmon Resonance. Allied to these facilities operated by Bioscience staff embedded within Chemistry is a dedicated ICP-MS used exclusively for elemental analyses of biological samples, plus an anaerobic chamber and associated spectrophotometers for following metal-protein interactions.

Plant and animal growth facilities

Specialised plant growth environments include 13 walk-in growth chambers, six arctic/tropical cabinets with humidity and carbon dioxide control, tissue culture cabinets, and 12 freestanding cabinets. An advanced animal cell culture facility contains Ruskin flow hoods with precisely controlled environmental conditions, vital for tissue engineering as used in one of the impact case studies (**Przyborski**). These facilities have enabled impact, including from spin-out companies *LightOx*, *Magnitude Biosciences* and *Reprocell Europe* (**Figure 2**).

Environmental field research facilities

The Department has excellent facilities to support environmental field research, delivering impact though the citizen science initiative *MammalWeb* (**Figure 2**) and exemplified by two impact case studies (**REF3**). Specialist equipment includes high precision, real-time, kinetic GPS and high-resolution field spectroscopy, Eddy covariance measurements of methane, carbon dioxide and energy fluxes using a tuneable diode laser instrument coupled with an open-path infrared gas analyser and sonic anemometer, automatic weather and soil stations for ecosystem modelling, mass spectroscopy that enables the use of rare elements and stable isotopes as environmental tracers. At the heart of this important hub of research activity is the University High-Performance Computing Facility (**REF5a/4.3**) which allows large-scale simulations and modelling of ecological and other systems-based biological processes.

3.2.1 Buildings

The total floor area of the Biosciences building is 6343 m^2 (including 676 m^2 dedicated to teaching laboratories), plus 224.5 m^2 of greenhouse space, and 595.84 m^2 of embedded laboratories in the Department of Chemistry. All research laboratories are serviced by facilities expected of well-found laboratories, such as central autoclaves, centrifuges, incubators, warm- and cold-rooms, gel-documentation systems, general biochemistry and molecular biology facilities. EEE-staff have wet and dry labs plus storage and infrastructure for fieldwork and computing.

The Department recognises the value of research at interfaces between its RGs, for example, commonality and specialism in animal versus plant cell biology. Several ACS and MPS staff are

housed in the Integrative Cell Biology Laboratories (ICBL) extension to the Biosciences building, which was added to encourage shared working and information-exchange and contains many of the core facilities (**Table 4)**.

3.3 Strategy for future infrastructure, income and facilities

The University has priority plans (next REF cycle) for a new-build, cross-departmental, teaching facility that will provide state-of-the-art space for digital learning and laboratory learning. In turn, this will vacate existing teaching laboratory space - currently housed in multiple Natural Science Departments - which will be refurbished as research laboratory space for new staff.

Re-alignment of research to deliver impact in global priority areas (**Section 1.1**) is central to the strategy to enhance future income. Expenditure (**REF4b**) lags behind awards and both will grow as recently appointed ECRs establish their funding portfolios. Evidence of the success of this strategy is the relatively higher level of grant funding in 2018/2019 (£5.8M in new awards).

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

4.1 Summary of networks supporting engagement and impact

Local, national and international networking has led to multidisciplinary collaborations which have, in turn, led to 43 Durham-based co-investigators on funded grants plus 23 co-investigators from outside Durham, during the census period. Outputs have been co-authored with collaborators from over 820 institutions across 71 countries, equating to 77% of outputs having international co-authors. Through exchange visits with partners in China, **Lindsey** and collaborators acquired genomic sequences of more than 300 varieties of cotton *(Nat. Gen.* 2017 **49** 579-587), subsequently discovering at least a dozen loci linked to superior fiber quality for use in breeding programmes (*Nat. Gen.* 2019 **5**: 224-229). **Baxter** and others in EEE were the second UK group to become members of the "University of the Arctic". Researchers at MIT and Harvard selected Alvetex® Scaffold technology developed by **Przyborski** to test the effects of gravity on the density of bone tissue models cultured on the International space station.

Departmental structures also promote collaboration within and between groups (**Table 2**), and Institutional structures work across the natural and social sciences (**Table 1**; **Section 1.2.5**) to benefit the economy and society.

Table 5. Formal external networks directed (or co-directed) by staff in this submission

Physics of Life Networks (EPSRC) *National and International (USA, EU, China) academic partners, Biotechnology industrial partners* **Cann**	**N8 AgriFood Program (HEFCE)** *Academic partners in the N8 Universities, Agribusiness industrial partners* **Sadanandom**	**Global network to combat neglected tropical diseases (MRC NTD)** *International academic partners especially in LMICs* **Denny**
Metals in Biology: Elements of Biotechnology & Bioenergy (BBSRC NIBB I and II) *National and International academic partners UK-based industrial biotechnology business partners* **Robinson**	**Building out vector-borne diseases in sub-Saharan Africa BOVA (NERC, BBSRC, MRC)** *Academic, building sector, industry, development agencies, advocates and policymakers in the UK and sub-Saharan Africa* **Lindsay**	**Strategic and coordinated business partnership with:** *Procter & Gamble* **Lindsey**

Two externally funded networks exemplify collaboration supporting the Department's approach to research for health and wellbeing (Table 5): both are multidisciplinary exploiting, respectively, research strengths at the Chemistry-Biology interface and in insect ecology. **Denny**, with Pohl and co-investigators in the Department of Chemistry and the University of York, lead the UK HUB of the Global network to combat neglected tropical diseases, supported by £8M from GCRF. Combinations of chemical and genetic approaches are being used to discover new targets for drugs to combat leishmaniasis and Chagas disease. Over 350M people worldwide are at risk from leishmaniasis, while 7M people suffer from Chagas disease in Latin America alone. The network includes a dozen partner institutions from at-risk countries. Funded by multiple UKRI councils, **Lindsay** leads an interdisciplinary network in sub-Saharan Africa to prevent the transmission of malaria, dengue and zika by developing built environments hostile to mosquitos. This requires collaboration between experts in vector-borne disease and epidemiology, with architects, urban planners, industry, local stakeholders and decision-makers in endemic countries.

Sadanandom was appointed to an N8 AgriFood Programme chair in 2015 to develop capacity in the North of England to tackle global challenges of sustainable food production, resilient supply chains and improved nutrition and public health. This programme, involving researchers from eight HEIs in the North of England (Durham, Lancaster, Leeds, Liverpool, Manchester, Newcastle, Sheffield, York), has forged alliances across disciplines and with non-academic organisations.

Across the partnership, three patents have been filed, £26M of external funds won, 29 externally funded projects have been instigated with agri-industry partners and >147 projects have been primed with Programme funding. Dissemination activities have included a meeting at the House of Commons ('From Farm to Fork') and a presentation to the US Environment Protection Agency. Pump priming funds have led to UKRI grants, including a BBSRC award to **Sadanandom** in collaboration with Newcastle University investigating the effect of nitrate upon *Septoria* resistance via WRKY transcription factors. **Sadanandom** identified a key step between pathogen recognition and plant defence responses with implications for developing resistant crops (*Nat. Comms.* 2018 **9** 5185). **Lindsey** was Co-I with Kepinski at Leeds for a successful BBSRC ALERT award for plant bioimaging.

Cann directs the renewed (2019) phase 3 Physics of Life network+ with McLeish (York), which in 2018 supported a £15M UKRI (EPSRC, BBSRC, MRC) Physics of Life Strategic Priority Fund for collaborative projects.

4.2 Overview of engagement with industry, investors and society

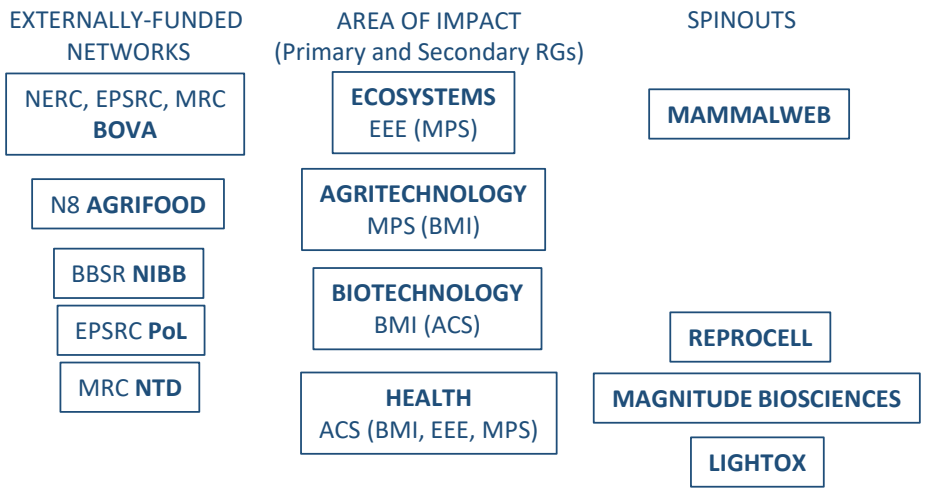

Figure 2. The wider impacts of research.

The research commercialisation team (**REF5a/4.4**) liaises with early-stage investors to establish companies, assisted in Biosciences by a Director of Impact (**Lindsay**). A third of staff have been awarded patents since 2014. New spinouts during this REF cycle include *Magnitude Biosciences Limited,* a collaborative venture between **Weinkove** and academics in Physics, to test the impact of metabolites and drugs on ageing in *C. elegans*. The company's *Healthspan Machine* uses bespoke image analysis to monitor large numbers of nematodes under multiple conditions. *Magnitude* has received investment from Saker Capital, the North East Innovation Fund, the European Regional Development Fund and is managed by Northstar Ventures. The spinout was highlighted in the BBSRC Impact Showcase 2020.
Founded in 2018 by **Stephens**, *MammalWeb* is a non-profit partnership between Durham University and Durham Wildlife Trust that has developed a platform to engage volunteers in the routine monitoring of mammals. *Lightox* was founded in 2016 in a collaboration between **Ambler** and academics in Durham's Department of Chemistry, the University of York and High Force Research Ltd. *Lightox* has coupled photosensitizers and light exposures to specifically target primary and secondary tumours. *Lightox* won the 2018 *Bionow* Start-up of the Year Award.

Reprocell Europe was formed via merger, in 2016, with *Reinnervate* (founded by **Przyborski**). Scotland's First Minister opened the Company's Contract Research Facility in 2017. The wider *Reprocell* corporation continues to market and develop the Alvetex® family of 3D cell culture products, including in collaborative ventures with P&G to generate skin- and other tissue-models to minimise the use of live animals in product testing.

The P&G strategic partnership (**Table 5, REF5a/2.5.3**) includes 40 biosciences-led projects, valued at £10.3M, and has led to the development of products (see **Przyborski** case study, **REF3**) and seven joint publications. Biosciences links with P&G have mostly revolved around *ex vivo* skin models (**Przyborski**, **Määttä**, **Benham**, **Karakesisoglou**) and metal-related antimicrobials (**Robinson**, **Sharples**, **Schröder**). Both of these areas secured matched funding from BBSRC (LINK and IPA awards), leveraging at least £2.6M.

The Durham-led (**Robinson**) phase I, BBSRC-funded, Metals in Biology NIBB (**Table 5**) instigated 43 collaborations between UK academics with expertise in this sub-discipline, and a diversity of industrial partners, to create or secure at least 86 jobs, leverage more than £12.8M of additional funding, file patents; and one business has already launched metalloenzyme-generated products in Europe and Asia. A second phase was awarded £1.3M in the first instance in 2019, to sustain the network for a further five years to advance Metals-in-Biology-related projects along the technology readiness levels towards more products. In a series of publications led by **Robinson**, the monumental task of measuring the dynamic ranges of each of a set of DNA-binding metal sensors has been completed, defining metal availabilities inside a cell (*Nat. Chem. Biol.***,** 2017 **13** 409-414; *Nat. Comms.*, 2017 **8** 1884 1-12; *Nat. Chem. Biol.*, 2019 **15** 241–249), highlighted in *Nat. Rev. Chem.* 2019 **3** 130, with all three articles recommended one or more times by F1000 prime. Since approximately half of the reactions of life are catalysed by metals (*Nature*, 2009, **460** 823-830), this has broad implications by rendering protein metalation predictable and open to manipulation, which underpins the Durham-led phase I and II BBSRC NIBB. **Chivers** engineered Ni(II)-handling by *E. coli* to create cells capable of metalating cofactor F430, allowing collaborators to recreate the pathway in a heterologous bacterium (*Nature*, 2018 **543** 78-82).

Outreach

Two-way communication with the public is encouraged via an outreach coordinator reporting to the BoS (**Hawkins**, https://www.dur.ac.uk/biosciences/publicoutreach/). In the last 12 months, staff delivered more than a dozen outreach lectures (including engagement with the local community through *Cafe Scientifique*, *Saturday Morning Science* and *Pint of Science)* and contributed to six large scale outreach events. Media appearances include five with BBC Country file, interviews on Radio 4, BBC World-service, BBC Good Food Show, articles in the Washington

Post, BBC online, national newspapers, and expert advice was given to the BBC Natural History Unit. Steve **Lindsay's** recent work to repurpose malaria-detection by trained dogs to SARS-CoV-2 detection has attracted considerable media attention.

4.3 Citizenship, leadership and esteem

Examples of national and international roles since 2014 (additional to those noted previously) include:

- **Lindsay**: World Health Organisation's Vector Control Advisory Group;
- **Przyborski:** Chair of BBSRC Appointments Board, Chair of BBSRC Responsive Mode Panel C, Chair of NC3Rs grant panel, Board of Directors NC3Rs, President of the Anatomical Society.
- **Lindsey**: BBSRC Council, Chair BBSRC Appointments Board, Advisory Committee on Releases to the Environment (UK Government), BBSRC Expert Panel on Germplasm Collections, Royal Society Newton Fund Advanced Fellowship Panel, Chair of the New Phytologist Trust;
- **Stephens**: Science Panel to Quality Assure the UK and England Biodiversity Indicators;
- **Baxter**: Marie Skłodowska-Curie Research and Innovation Staff Exchange Scheme for Horizon 2020, International Arctic Science Committee;
- **Willis**: Deputy panel chair (and UK Chair) of NERC Latin American Biodiversity Panel;
- **Denny**: review panel for Museum d'Histoire Naturelle in Paris, Treasurer British Society for Parasitology;
- **Lucas**: British Standards Institute, Ecological Methods panel;
- **Sadanandom**: UK-US Plant Health Committee for UK government white paper on crop protection research;
- **Quinlan**: Scientific trustee for Fight for Sight UK;
- **Cann:** Induction panel chair for new BBSRC panel members;
- **Lindsey** and **Hussey**: Presidents of the Society for Experimental Biology, and Chairs of SEB Council.

Multiple staff assess appointments and promotions at institutions in the UK and overseas (including USA, France, Germany, Italy, Australia, New Zealand, Canada, Malaysia, South Africa, Russia, Oman, Pakistan).

Staff served on more than 39 funding panels for organisations including:

- NERC (multiple members of the peer review college, frequent funding panels, Independent Research Fellowships sift and interviews panels, Large Grants Moderating Panel, case studentships panels);
- BBSRC (responsive mode committees B, C and D, Fellowships panel, CASE studentships panel, Strategic LOLA panel, future leaders programme panel, Newton Fund);
- Portuguese Fundação para a Ciência e a Tecnologia;
- Assessment Board of the Government of Ireland Postdoctoral Fellowship Scheme;
- Fight for Sight;
- The Royal Society Research Grant Panel.

Editorial boards

Staff served on more than 42 editorial boards (or advisory boards), including:

- *Current Biology*, **Hussey**;
- *Journal of Applied Ecology*, **Stephens** and **Willis**;
- *New Phytologist*, **Lindsey**;
- *Parasitology*, **Denny**;
- *Behavioural Ecology and Sociobiology*, **Twiss**;
- Editor of *Conservation Genetics*, **Hoelzel**;
- *Antioxidants and Redox Signalling*, **Benham**;
- *Journal of Biological Chemistry*, **Quinlan**.

- **Dawson**, founding Editor-in-Chief of *Plant-Environment Interactions*.

Staff wrote 15 invited commentaries/News-and-views items for *Nature* and *Nature-family* journals, *Science* and *PNAS*.

Conferences and lectures

Since 2014 staff hosted more than 44 conferences, chaired sessions and delivered more than 219 lectures, including at diverse Gordon Research Conferences, and invited named lectures such as:

- The Norwood Lecture, San Francisco, **Jahoda**;
- The Wills Lecture Queen Mary University of London, the 2020 West Riding Lecture Sheffield University, Pioneer Lecture at the 2020 (rescheduled to 2022) Nobel Symposium in Chemistry, Swedish Academy of Sciences, Stockholm, **Robinson**;
- Chair of the 2020 (rescheduled to 2022) Gordon conference on Intermediate filaments, **Quinlan**.

Prizes

Prizes won include:

- Innovative Technology Award 2016, **Przyborski;**
- Fellow of the Linnean Society of London, **Lindsey;**
- Fellow of the Association for Research in Vision and Ophthalmology, and 2018 Special Recognition Award from the International Society for Eye Research, **Quinlan;**
- 2016 FESPB award for a young member of the European Federation of Plant Biologists, **de Lucas;**
- Lister Prize 2019, **Blower;**
- 2020 Institute of Physics Rosalind Franklin Medal, **Cann** (co-awardee).