

Institution: Queen Mary University of London

Unit of Assessment: 5 Biological Sciences

1. Unit context and structure, research and impact strategy

a. Unit context and structure

Research in the Biological Sciences at Queen Mary University of London (QMUL) submitted under UoA5 spans human, animal, plant and microbial sciences, and is directed at understanding multiple levels of biological organisation, from molecules and cells through to organisms, populations and ecosystems. Activity is hosted in three departments (Biology, Biochemistry, and Biological and Experimental Psychology) in the School of Biological and Chemical Sciences (SBCS) within the Faculty of Science and Engineering. UoA5 researchers are primarily located in the GE Fogg Building, with smaller teams strategically placed in the Joseph Priestley Building (Chemistry) and Blizard Institute (Medicine and Dentistry) to strengthen interdisciplinary approaches and access to emerging technologies. We also have strong collaborative links with the Schools of Electrical Engineering, Computer Science, and Geography, and with several research institutes (Bioengineering, William Harvey Research, Barts Cancer, and Materials Research). Since 2014 we have:

- Recruited 38 new academic research staff, with strategic appointments in genomics, ecology, cell biology, psychology, and structural biology.
- Improved staff diversity across grades and roles, with a three-fold increase in the proportion of both female and BAME academics between 2012-13 and 2019-20.
- Increased total research income by 71% compared to REF2014 and expanded the diversity of funding sources.
- Produced 1,073 papers, and doubled the proportion published in leading multidisciplinary journals.
- Increased PhD student numbers by 32% (98-129) since 2014, with 93% of PhD submissions in the period being on time.
- Improved research infrastructure by investing in new state-of-the-art laboratories, facilities and equipment (total >£6.5M).

Our submission of 52.7 FTEs includes 30 FTE Early and Middle Career Researchers alongside established staff. Since 2014, these staff members have worked together with an average annual population of 21 technicians, 27 FTE postdoctoral researchers and fellows, and 109 PhD students, forming a cohesive and vibrant community whose quality is reflected in the high percentage of papers published in top-tier journals. Building on our distinctive research strengths highlighted in REF2014, we have focused on developing research vibrancy in three core research themes.

Ecology and Evolution

Sub-themes: *Evolutionary Genetics and Genomics; Microbial and Network Ecology*

In *Evolutionary Genetics and Genomics* we have developed our established track-record in evolutionary genetics to include genomics, with a focus on non-model taxa. *Microbial and Network Ecology* represents a broadening of our long-standing focus on aquatic ecology to encompass terrestrial ecology and microbial processes, reflecting burgeoning major challenges in biology. Overall refurbishment and equipment spend was >£3M.

Cell Dynamics and Structural Biology

Sub-themes: *Cell Dynamics; Structural Biology*

We have built on historical strengths in mechanistic and structural biology and photosynthesis with substantial investment in new staff and in cryo-electron and super resolution microscopes to boost *Structural Biology*. In *Cell Dynamics* we have strategically expanded into medically-relevant areas of eukaryotic cell dynamics. Overall refurbishment and equipment spend was >£2.5M.

Biological and Experimental Psychology

We have extended our capacity in animal cognition and grown critical mass in positive psychology. This research theme includes researchers working on human psychology, and we therefore request cross-referral of those psychologists who work on human subjects to UoA4 (Psychology, Psychiatry and Neuroscience). Overall refurbishment and equipment spend was >£1M.

b. Research strategy

Our overarching aim is to foster sustained originality, creativity, and critical mass in our distinctive world-leading research, while remaining receptive to emerging themes and opportunities. Our areas of excellence encompass fundamental science, as well as research that addresses pressing issues of global significance, including food security, climate change, biodiversity loss, healthy ageing, anti-microbial drug resistance and the environmental impacts of plastic waste. In implementing our research agenda, we are committed to interdisciplinary approaches, including the adoption of emerging technologies. Strategic priorities for research direction, investment and growth are set by the School's Senior Executive, supported by its Research Strategy Group, and are reviewed regularly. Our aims, developing from 2014, have been to:

1. Sustain and build excellence in our areas of research strength through the strategic appointment of new staff, support of existing personnel, and investment in infrastructure and facilities that underpin our expanding research activity.
2. Increase research income and improve the quality of research outputs by building on a culture of success.
3. Grow numbers of PhD students in collaboration with other London-based Russell Group universities, by establishing Centres for Doctoral Training, and by linking with industry.
4. Build new and strengthen our existing research links and collaborations with world-leading UK and overseas institutes.
5. Increase the volume of impact-generating activity and research.

c. Impact strategy

We consider research impact at all stages of academic staff development, from recruitment and probation to promotion. We also emphasise the importance of research impact with our PhD students and postdoctoral researchers, several of whom participate in industry-focused career development events, and/or industrial placements as part of their training. Our impact agenda, formalised in 2015 with the establishment of directors of impact and industrial innovation, sets out several objectives for the enhancement of impact-generating research in the School.

1. Expand interactions and links with commercial enterprises, including large companies, and small and medium-sized businesses.
2. Sustain and strengthen our research links with government agencies and non-governmental organisations. In particular, continue to invest in impact-generating research by funding the River Communities Group, and also by supporting staff to pursue external secondments and joint appointments.
3. Cultivate an entrepreneurial environment by investing in networking and other impact-oriented events for staff and students.
4. Value staff for publishing patents and filing disclosures of discovery.
5. Strengthen and widen educational links with industry and non-academic stakeholders, including through increased numbers of CASE and other co-funded studentships.

d. Approach and mechanisms for promoting and enabling research

Our Research Strategy Group—chaired by a Director of Research and comprising established and early career staff working across our research themes—covers all aspects of research activity, from identifying funding opportunities and developing impact to facilitating grant applications. This group organises internal peer-review of grant applications and impact statements. Top-down

support is provided by the Faculty-level Dean's Research Advisory Group, of which the Chair of Research Strategy Group is a member, while University-level strategic decisions regarding larger-scale investments are made by the Queen Mary Senior Executive Team.

Since REF2014 we have implemented several new initiatives aimed at increasing research vitality. These include holding quarterly grant- and paper-writing workshops, monthly grant-pitching sessions, sessions with invited editors from broad readership journals (Nature Communications, Open Biology and EMBO J), and mock interviews for shortlisted applicants of ERC and other large grants. Additionally, the Faculty has introduced the policy of allocating 10% overhead income to the awardee to use flexibly on research, and 10% to the School's Research Support Fund, which funds PhD students, and equipment on early career researcher bids and large grants (>£750k).

e. Approach and mechanisms for promoting and enabling impact

UoA5 staff who conduct impact-related research are offered support from the University's Research Impact Support Team, led by the Deputy Vice-Principal for Research Impact (position launched 2018), and are allocated time for impact-related activities. Staff wishing to develop industrial links can also obtain support from QMUL's Business Development Office, which matches academics to industrial collaborators, and Queen Mary Innovation, which negotiates commercialisation agreements.

Since 2014, to elevate the School's impact agenda we have launched two new roles, a Director of Impact and a Director of Industrial Innovation, both members of the Research Strategy Group. These staff are responsible for tabling issues and promoting activities that relate to research impact and industrial links, respectively, and both liaise with counterparts from other schools across the University, and report to the Head of School and Director of Research.

The School also enables impact-generating research by allocating funds and releasing staff for part-time secondments. For example, throughout this REF period, we made a strategic commitment to fully fund the River Communities Group at the River Laboratory, which forms part of the *Microbial and Network Ecology* sub-theme and is at the forefront of developing biomonitoring tools for UK waterways. Other School funding has covered overseas research visits for staff conducting conservation biology, and staff time for those either seconded to industry or with large external roles. Further financial support for impact-related research comes from the Faculty, which match-funds projects that have at least 50% industrial funding; and the University, which awards small grants and/or PhD studentship funding via its 'Proof of Concept Fund' 'Innovation Fund', Life Sciences Institute, block grants, EPSRC Impact Acceleration Account, EPSRC Pump-Prime, Global Challenges Research, and multi-institutional DTPs with professional internship placements.

f. Commitment to promoting open and reproducible research

We follow an ethos of being 'as open as possible, as closed as necessary', a recommendation of the European Commission's Guidelines on FAIR Data Management. Data sharing policies are aligned with UKRI regulations, and data, metadata and code are archived for public access on Queen Mary Research Online ('QMRO': <https://qmro.qmul.ac.uk>) and on field-specific repositories (e.g. GenBank, DRYAD, PDB). We promote reproducible research by storing genomic datasets on the QMUL's computer cluster, and code and data on personal GitHub and webpages. Papers are archived on the University's online repository 'Elements' for external access via QMRO, and, for papers funded by QMUL's UKRI block grant, are published full open access ('gold'). There is also a growing culture of submitting to open preprint repositories (e.g. bioRxiv). We list our equipment on the HE national database (equipment.data.ac.uk/) and we share expertise and technologies relating to imaging by following guidelines set out by BioimagingUK and Euro-Bioimaging.

g. Achievement and progress of strategic aims since REF 2014

Steps taken since REF2014 have transformed our research environment. We have made strategic appointments, developed strong impact, and focused on areas where we excel: evolutionary

genomics, microbial and network ecology, structural biology, and biological and experimental psychology. We have also strategically invested in cell dynamics, and have established critical mass in cytoskeletal networks and chromosome segregation biology.

(i) Achievements in publications

We have seen a marked improvement in the number of high-quality outputs, producing ~112 research publications in interdisciplinary journals (Science, Cell, Nature, Nature-banded Journals, PNAS, eLife, Current Biology, and PLoS Biology). Compared with REF2014, our submission for REF2021 contains approximately twice the percentage of articles published in the top 1% of journal percentiles based on the Snowball Metric 'Source Normalized Impact per Paper' (SNIP) (10.7% vs. 20.2%, respectively). Analyses of UK-wide data show that the mean 1% SNIP scores of the sets of outputs submitted under UoA5 are strongly correlated with the REF2014's own published percentages of 4* papers ($R^2 = 0.86$).

(ii) Refurbishment and investment in laboratories and research facilities

Large-scale capital projects include the reconfiguration of two floors (>2000 m²) of the GE Fogg Building, including the installation of two large shared laboratories with ancillary rooms for genomics research, academic offices, and a bioinformatics room (£2.1M). We have also installed new aquaria, aviaries and an insectary (£400k), and, to catalyse collaboration with the School of Medicine and Dentistry, have developed new space and infrastructure for UoA5 structural biologists at the Blizard Institute at Whitechapel (£700k). We have also purchased new equipment for sequencing, genome assembly (£1.2M), mass-spectrometry and NMR, dynamic super-resolution imaging, and cryo-electron microscopy (£2.5M).

(iii) Introduction of new mechanisms for promoting research and impact, with evidence of success

Efforts to invigorate research have contributed to a marked upswing in grant success. Overall, 87% of census staff won grants, with 70% receiving grants of >£100k (93 grants) and 25% receiving grants >£500k (14). Awards include 72 UKRI (1.4 FTE⁻¹) and 23 EU grants, including three ERC-Starting Grants (**Frantz**, **Martín-Durán** and **de Mendoza**), one ERC-Advanced Grant (**Chittka**) and 12 Marie Skłodowska-Curie Fellowships (see Section 3a).

Initiatives to strengthen impact have also seen marked success. The School's funding of 3.5 FTEs at the River Communities Group (~£1M) has led to two impact case studies (see section 1v) and substantial grant success, including a €10M EU award (€2.2M to UoA5) for mitigating plastic pollution, and three Defra-funded projects on pollution and metal contamination (total £408k to UoA5). Other impact case studies that have benefited from internal strategic funding are **Eizaguirre's** research on turtle conservation, and **Osman's** work on decision making, which was developed in conjunction with the Food Standards Agency during a five-year funded (0.5 FTE) secondment.

Research with actual or potential impact has also been supported through the award of several small competitive grants administered by the University, including three EPSRC Impact Acceleration Account grants, three Large Grants from the Centre for Public Engagement, one Proof of Concept Fund grant, one QMUL Innovation Fund grant, one EPSRC Pump-Prime grant, and five Strategic PhD studentships. Overall, engagement with industry and impact is more firmly embedded than in 2014, and we have new partnerships with several large enterprises, including Carl Zeiss (**Draviam**), Oxford Nanopore Technologies (**Martín-Durán**, **de Mendoza** and **Hurd**), Singer Instruments (**Thorpe**) and Syngenta Ltd (**Ruban**), and government organisations, including the Centre for Environment, Fisheries and Aquaculture Science (**Rosberg**), and the Environment Agency (**I Jones**).

(iv) *Major achievements of research themes*

Ecology and Evolution

Sub-theme: *Evolutionary Genetics and Genomics*

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|----------------------------|--|
| Academic staff | 12.2 FTE |
| Professor | Buggs (0.2 FTE), Elphick, Leitch, Nichols and Rossiter |
| Reader | Eizaguirre, Frantz, Stollewerk and Wurm |
| Senior Lecturer | Martín-Durán, Hurd and dos Reis |
| Lecturer | de Mendoza |
| PhD completed | 44 at 3.6 FTE ⁻¹ |
| Grant value awarded | £10.2M at £839k FTE ⁻¹ |

This group has an established track-record in evolutionary genetics. Members focus on the causes and evolutionary consequences of divergence and hybridisation, and the genetic basis of adaptations, covering diverse non-model taxa from trees and arthropods to mammals and marine invertebrates. New appointments (**Frantz**, **Martín-Durán**, **de Mendoza**, and **dos Reis**), alongside investment in emerging technologies, have further extended our expertise in applying -omics approaches in evolutionary and developmental biology. Since 2014, researchers in this theme have produced 20 papers in Science and Nature-branded journals, and generated impact informing conservation policy.

- **Buggs** led the sequencing of the ash tree genome in response to the ash dieback epidemic (Nature), and used this genome with **Nichols** to identify genes underlying resistance to ash dieback (Nature Ecology and Evolution), and with **Rossiter** to pinpoint genes underlying resistance to emerald ash borer (Nature Ecology and Evolution). These findings have been translated to design ash tree recovery breeding programmes, as outlined in our impact case study '*Leading the Fight Against Ash Dieback in the UK and Europe*'.
- **Martín-Durán** and **de Mendoza** both recently won ERC-Starting Grants (EVOCELFAE €1.5M and METHYLEVOL €1.5M, respectively) to work on invertebrate genomics. **Martín-Durán** discovered morphological and molecular convergence in nerve cord development across phyla (Nature), and **de Mendoza** found convergent methylation patterns across mammals and sponges (Nature Ecology and Evolution).
- **Frantz** won an ERC-Starting grant (PALAEOFARM €1.5M, €915k to QMUL) to extend his research on the genomics of domestication. He discovered that dogs were domesticated more than once, and that canine cancers contain a genomic trace of extinct dogs (Science x2). He also uncovered pervasive hybridisation between wild and domestic pigs (Nature Genetics, PNAS).
- **Eizaguirre** was among the first to discover eco-evo feedback loops (PNAS) by showing how fish parasites affect the interactions of their hosts and the environment. His work on nano-tagging turtles (Proc Roy Soc) also informed our impact case study '*Transforming the Conservation Strategy for One of the World's Most Significant Populations of Endangered Sea Turtles*'.
- **Wurm** discovered that convergently-evolved supergene regions determine social organisation across lineages of ants (Current Biology), and that these regions evolve by suppressed recombination (Molecular Biology and Evolution). Also in social insects, **Hurd** reported the first putative caste-specific enhancers in honeybees (Genome Research).

Sub-theme: *Microbial and Network Ecology*

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|----------------------------|--|
| Academic staff | 9 FTE |
| Professor | Trimmer |
| Reader | I. Jones, Knell, and Rossberg |
| Senior Lecturer | Clare, Henry, Hirst* and Le Comber* |
| Lecturer | Eyice-Broadbent, Kratina and Schofield |
| PhD completed | 20 at 2.2 FTE ^{-1**} |
| Grant value awarded | £6.9M at £765k FTE ^{-1**} |

*not included in census. **only includes census staff

This group is concerned with the organisation and function of ecosystems. With strategic new hires, the group has developed larger research programmes in environmental microbiology (**Eyice-Broadbent, Henry**) and network dynamics (**Rossberg**). Key recent discoveries relate to the global nitrous oxide and methane cycles (**Trimmer, Eyice-Broadbent**). Other group members (**Henry, Knell** and **Schofield**) have expertise in evolutionary ecology, and work closely with staff in the *Evolutionary Genetics and Genomics* subtheme.

- **I Jones's** Defra-funded research has produced two impact case studies: '*Informing 'Glastir', a New Sustainable Land Management Scheme delivering Benefits to Public Spending, Welsh Farmers and the Environment*' and '*Counteracting the Damaging Effects of Fine Sediment Pollution in UK Rivers*'. Subsequently, **I Jones**, with **Eyice-Broadbent, Kratina** and **Trimmer**, secured a €10M EU-funded grant (€2.2M to UoA5) to work on plastic pollution in aquatic systems.
- **Trimmer** demonstrated that oceanic nitrous oxide production is driven by ammonium-oxidising *Archaea* (Nature Communications), and that anaerobic ammonium oxidation can dominate the removal of fixed nitrogen in oxic riverbeds (Nature Geoscience). He also showed that long-term warming disrupts the carbon cycle in favour of methane production (Nature Climate Change), and provided the first evidence of rapid microbial cycling of carbon in the tropical North Pacific (Nature Communications).
- **Rossberg** won a £1.1M NERC Highlights Topic grant to investigate mechanisms and prediction of large-scale ecological responses to environmental change.
- **Rossberg** and **Kratina** discovered that top-down trophic cascades are active in most freshwater lakes even without human pressures (Nature Communications). **Rossberg** also showed that prey release can reverse diversity-productivity relations (Nature Communications).
- NERC Fellow **Henry** showed that an insect's life history influences endosymbiotic bacteria (Ecology Letters), and that the functions and transmission modes of these microbes drive irreversible host-symbiont dependencies (Nature Communications).
- Work led by **Knell** has shown that sexual selection predicts the persistence of populations within disturbed tropical environments (Ecology Letters).

Cell Dynamics and Structural BiologySub-theme: *Cell Dynamics*

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|----------------------------|---|
| Academic staff | 12 FTE |
| Professor | Bessant, Draviam, Mullineaux and Ruban |
| Reader | - |
| Senior Lecturer | Duffy, Hanke, Thorpe and Wilkinson |
| Lecturer | Caudron, Engl, Palacios and Subramanian |
| PhD completed | 13 at 1.1 FTE ⁻¹ |
| Grant value awarded | £6.3M at £521k FTE ⁻¹ |

Members focus on diverse biological systems, and are united by common interests in developing and applying state-of-the-art techniques to probe the structure and dynamics of living systems at the cellular scale. Particular strengths cover evolutionarily-conserved chromosome and genome stability (**Draviam, Subramanian, Thorpe** and **Wilkinson**), protein aggregation and transport relevant to ageing and fertility (**Caudron, Palacios**), interaction between host and microbes (**Engl**), '-omics' approaches to reveal novel genome products and their networks (**Bessant** and **Draviam**), DNA and RNA repair mechanisms (**Draviam, Engl** and **Wilkinson**), and photosynthesis and bioenergetics relevant to food security (**Duffy, Hanke, Mullineaux** and **Ruban**). New live-cell deconvolution and super-resolution light microscopes and associated infrastructure, funded by BBSRC 19ALERT, EPSRC and QMUL, has bolstered research capacity.

- **Draviam** discovered PAXX and elucidated its structure-function in human DNA repair (Science) and uncovered master regulators of microtubule interaction at human chromosomes and cortex (Nature Communications and eLife). **Subramanian** showed how histone H3K36 modifications dictate DNA repair pathway choice (Nature Communications).
- **Caudron** reported the first endogenous protein that aggregates during ageing in yeast (Science) and is elucidating the role of aggregating proteins in cellular memory (eLife and Current Biology). **Engl** described novel burst kinetics during bacterial transcription (Nature Communications). **Palacios** described actin and microtubule cytoskeleton-dependent active diffusion and advection of cytoplasmic components in the fly egg (Nature Communications).
- **Hanke** discovered a unique ferredoxin that regulates the low-iron response in plants (PNAS).
- **Mullineaux** demonstrated the basis for directional light perception in a cyanobacterium (eLife) and elucidated the biogenesis and membrane targeting of cyanobacterial photosynthetic machinery (Nature Plants). **Ruban** developed his world-leading research programme on the regulation of photosynthetic light-harvesting (Nature Plants), and formulated a new parameter to quantify the impact of photoprotective energy quenching in plants (Nature Communications).

Sub-theme: **Structural Biology**

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| Academic staff | 8 FTE |
| Professor | Heathcote* and Pickersgill |
| Reader | Viles |
| Senior Lecturer | Janes and Main |
| Lecturer | van Breugel, Darbari, Ilangovan and Stieglitz |
| PhD completed | 18 at 2.25 FTE ^{-1**} |
| Grant value awarded | £2.5M at £307k FTE ^{-1**} |

*not included in census. **only includes census staff

This group has consolidated its strengths in crystallography, and recently-hired members **van Breugel, Darbari, Ilangovan** and **Stieglitz** have extended its expertise in cryo-electron microscopy. With a newly-acquired BBSRC 16ALERT-funded cryo-electron microscope, a cryo-EM pipeline has been established that is anticipated to deliver transformative insights into bacterial secretion systems and molecular machines, and their roles in pathologies. This group is also part of the LonCEM consortium, and benefits from access to high-resolution imaging equipment at the Crick Institute.

- **Darbari** revealed the structural basis of silencing of bacterial transcription by σ_{54} explaining how conserved regulatory domains can have profoundly different effects on the RNA polymerase - RNA complex (Science).
- **Ilangovan** determined the cryo-EM structure of a relaxase elucidating the molecular basis of DNA unwinding during bacterial conjugation (Cell x2).
- **Darbari, Ilangovan** and **Pickersgill** provided structural insights into molecular machines and bacterial secretion systems using cryo-EM, NMR, and crystallography (Cell, EMBO Reports, Nature Communications).

Unit-level environment template (REF5b)

- **Stieglitz** shed insights into ubiquitination mechanisms and their subversion by invading bacteria (Nature Methods).
- **Main** and **Pickersgill** developed and characterised protein cages and nanotubes for industrial biotechnology (Nature Communications, Small, Structure).
- **van Breugel** illuminated the role of protein interactions in the assembly of the structure of the human centriole (eLife, Nature Communications).

Biological and Experimental Psychology

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|----------------------------|---|
| Academic staff | 11.5 FTE |
| Professor | Brennan, Chittka, Clayton and Pluess |
| Reader | Mareschal and Osman |
| Senior Lecturer | Di Bernardi Luft |
| Lecturer | Beyer, Chen, J. Jones, Lachlan*, Malanchini and Versace |
| PhD completed | 27 at 2.3 FTE ^{-1**} |
| Grant value awarded | £10.7M at £890k FTE ^{-1**} |

*not included in census. **only includes census staff

This group of biologically-minded psychologists has grown out of a historical capacity in behavioural neuroscience, exemplified by the work of **Brennan, Chittka, Clayton, Lachlan** and **Versace** on the comparative psychology of various animal models. In expanding the psychology department we capitalised on these existing strengths, recognising that human psychology can only be comprehensively understood by exploring its genetic bases, as epitomised by the work of **Malanchini** and **Pluess**, its neurobiological underpinnings, spearheaded by **Bernardi Luft, Beyer, Chen** and **Mareschal**, and in interaction with researchers from across the School using powerful animal models for neuroscientific, psychological, epigenetic and genetic analyses. As this group grows, we are developing two strong subthemes, 'Behavioural Psychology' and 'Resilience, Health and Wellbeing'.

- **Brennan** was awarded ~\$2M (\$1.1M to QMUL) by the National Institute of Health (USA) to apply zebrafish models to identify addiction genes, and a Human Frontiers grant (\$1.05M, \$368k to QMUL) to explore the neurobiological basis of numerical abilities in fish.
- **Chittka's** team discovered that bumblebees display simple tool-use, which they learn by copying other individuals (PLoS Biology; Science), and also that insects exhibit positive emotion-like states underpinned neuro-hormonal mechanisms (Science). **Chittka** was also awarded £1.1M from the EPSRC and €3.44M (SPACERADARPOLLINATOR €2.1M to QMUL) from the ERC to work on insect cognition.
- **Lachlan** discovered that songbirds categorise sound frequencies according to context (PNAS), and also transit songs to conform with conspecifics (Nature Communications). Also in songbirds, **Clayton** uncovered dramatic effects of social isolation on gene expression and methylation in the zebra finch brain (PNAS).
- **Malanchini** discovered that human spatial abilities are heritable, and that performance over a variety of tasks appears to be controlled by a single genetic factor (PNAS).
- Using imaging to examine cognition, **di Bernardi Luft** has shown that active inhibition in the right temporal lobe is a key component of creativity (PNAS).
- **Mareschal** was awarded £1.14M (770k to QMUL) from the MRC, British Academy and Waterloo Foundation to examine emotion recognition, and **Pluess** won \$2.2M (\$979k to QMUL) from the National Institute of Child Health and Human Development (USA) to work on well-being in refugees.
- **Osman's** research on decision making behaviour has informed government policies on regulating food safety standards, and forms an impact case study '*A New View of Decision-making: Delivering Innovative, Evidence-based Policy across Government Departments via Novel Research Hubs*'.

h. Future strategic aims and goals for research and impact

We aim to consolidate and extend our world-leading research portfolio on evolutionary genomics, climate change, structural biology, cell dynamics, and biological psychology. Our goals, aligned with QMUL's 2030 Strategy [see REF5a, section 2], are as follows:

Future strategy (aims and goals) to sustain and build research

- Continue to attract and support the most talented staff so they can reach their full potential.
- Invest in infrastructure, facilities and equipment to meet changing needs, and horizon scan and invest in emerging new areas within our themes.
- Grow income for research by targeting externally-funded larger and longer grants, significantly increasing industrial income, bidding for internal University funds, and by expanding our portfolio of postgraduate taught programmes and transnational education.
- Continue to build strong multidisciplinary research collaborations within and beyond the University.
- Provide rigorous postgraduate training, including via DTPs, to produce highly skilled and well-rounded researchers for careers within and beyond academia.
- Spearhead equality, diversity and inclusion so we can attract and retain the best researchers and make our School the most supportive, vibrant, and collaborative research space.

Future strategy (aims and goals) to sustain and build impact

- Strengthen and expand links and interactions with industry, government agencies, and non-governmental organisations, through collaborative research and secondments.
- Continue to recognise, promote and reward impact generation through its inclusion in annual appraisals and promotion applications.
- Set up an international industry advisory board to identify and nurture emerging industrial cluster highlights within the School.
- Match-fund PhD studentships with industry, and set up industry-led CDT programmes in the School.

2. People

We are committed to recruiting staff of the highest intrinsic talent and potential, and to providing an environment in which all can thrive and fulfil their potential. By pursuing this policy, we have increased the diversity of our UoA5 staff. Self-assessment of our research environment and culture align with principles of the UK Concordat to Support the Career Development of Researchers, to which the University is a signatory [see REF5a, section 3-I]. This has facilitated the steady improvement of institutional working conditions, and increased the engagement of individuals in supporting the School's performance. We have increased the proportion of female research staff members at all levels, expanded interdisciplinary student training programmes, improved PhD student supervision, training and career development, brought greater awareness among staff to the importance of an inclusive research environment, and enhanced productivity in terms of research outputs, impact and career progression.

a. Staffing strategy

Our strategy to recruit and retain staff members is guided by our vision to create a collaborative environment to solve large and complex problems by combining complementary research expertise. Staff members returned under UoA5 include 29 new appointments: 23 Lecturers, five Senior Lecturers, and one Reader. Internal promotions have seen five staff members promoted to Professor, 10 to Reader, and 12 to Senior Lecturer. All aspects of recruitment (advertising, shortlisting, and interviewing) and promotions take account of our desire to balance diversity, including gender equality. In this REF cycle, the representation of female UoA5 academics has

risen from 10% (2014) to 31% (2020), and four women have been promoted to Reader (**Brennan, Draviam, Mareschal** and **Osman**), and two to Professor (**Brennan** and **Draviam**). We have also introduced support packages for staff on parental leave; to date seven staff have been allocated core-funded research assistants or technicians.

In Ecology and Evolution, new hires extend our position as a world-leading group working on the genomics of non-model species (**Martín-Durán, de Mendoza, Frantz** and **dos Reis**), and critical mass in microbial systems and ecological modelling (**Eyice-Broadbent, Henry** and **Rosberg**). In Cell Dynamics and Structural Biology, the arrival of **van Breugel, Darbari** and **Stieglitz** add vitality to structural biology, while the recruitment of experts in chromosomes and cytoskeletal networks (**Caudron, Draviam, Palacios, Subramaniam** and **Thorpe**) has enriched our research on multi-scale cell dynamics. In Biological and Experimental Psychology, **di Bernardi Luft, Malanchini** and **Versace** strengthen our research on cognition, emotions and well-being.

b. Staff development (newly recruited staff and permanent/probationary staff)

New lecturers typically received ~£50k and a PhD studentship, although start-up packages have exceeded £250k where new infrastructure was needed. New arrivals are allocated reduced teaching loads and protected from significant administrative roles for their first three years, allowing time to establish their research. Early career staff members are assigned a research mentor, who can provide day-to-day advice on research-related matters. On completing the three-year probation, staff members (including academics, technicians and administrative personnel) participate in an annual appraisal process. Those who have reached the requisite milestones are encouraged by Heads of Department and the Head of School to apply for promotion. During appraisals, staff are asked to identify aspirations and opportunities for career development; in this period, five academics were awarded sabbaticals or funded secondments (**Chittka, Mullineaux, Osman, Pluess, Ruban** and **Wurm**), and 10 pursued professional training programmes, including 'Women into Leadership' (Aurora by Advance-HE), 'High Potential Leaders', and 'Pathways to Promotion'. Staff are also able to access ~100 training courses run by the University's 'Researcher Development Team', covering research, teaching, career progression, personal effectiveness, and well-being.

c. Support and promotion of equality, diversity and inclusion

Our self-assessment team (Equality, Diversity and Inclusion Committee, EDIC) has grown from 11 to 22 individuals (10 academics, 5 administrative staff, 2 technicians, 1 PDRA, 1 PhD student and 3 undergraduates), spanning research, teaching and administrative roles. The EDIC has driven the adoption and development of best practice for the benefit of all staff, and has spearheaded positive cultural change across QMUL. As examples, the School introduced menopause guidelines (now adopted University-wide), introduced conference support for carers, established an emergency care network, and revised PhD recruitment guidelines to reflect EDI principles. We also provide research support for staff on maternity and shared parental leave. Women are represented on all committees and panels, and we seek to embed EDI in everything that we do.

In this REF period, we have also substantially increased the number and proportion of female staff. 45% of newly-recruited academics were women, and women now make up 56% of

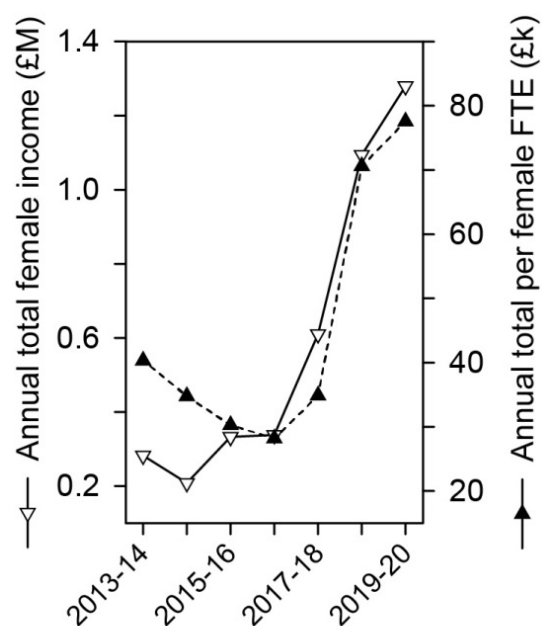


Fig 1. Uplift in grant income for female staff since REF2014

Lecturers (up from 37% in 2014), 17% of Senior Lecturers (from 16%), 33% Readers (from 25%) and 14% Professors (from 0%). Of the 27 promotions awarded since 2014, nine were to women (33%). Over the assessment period, 40% of promotions to Reader and Professor went to women. We have also seen an increase in the number and proportion of BAME UoA5 staff (5% 2014 to 12% 2020). Both our UoA5 female and BAME staff have also seen considerable grant success in this assessment period, with 23% and 24% of grant applications funded, respectively. Since 2014, total and FTE⁻¹ annual research income for women has quadrupled and doubled, respectively (Fig 1). The School holds an Athena Swan Silver Award, which we have held for five of the six years since REF2014.

This transformation has been facilitated by successful implementation of Concordat principles. These include compulsory training in equality and diversity for all staff members, a balanced recruitment and appraisal panel for research and professional staff, investment in professional and career development (including leadership) for research staff members, and annual self-assessments. In the future, we aim to further improve the supportive culture and environment within the School, increase the proportion of women and BAME staff in leadership positions, and roll-out our best practice to the wider University.

d. Mechanisms for recruitment, training and supervision of PhD students

(i) Recruitment

We aim to recruit the best research students, who join a vibrant community of around 129 students from 29 countries. During this REF period, ~£5M was received in PhD studentship funding, and 145 PhDs were awarded, covering the full breadth of topics in UoA5. Our PhD students are financed by diverse and competitive funding programmes, including UK and EU funding schemes (UKRI, Leverhulme Trust, Marie Skłodowska-Curie ITNs, and European Research Council), international scholarship schemes (China Scholarship Council, Conacyt, Pakistan Higher Education Commission and Islamic Development Bank) and internal QMUL schemes (Principal's Postgraduate Research Studentships, Start-up Studentships and Life Sciences Institute studentships).

We are partners in the NERC London Doctoral Training Partnership (DTP) and BBSRC London Interdisciplinary DTP (LIDo), both renewed in 2019, and the ESRC London Interdisciplinary Social Science DTP (LISS). These DTPs provide world-class research training in environmental, biological and social sciences, respectively, and our UoA5 staff have been heavily involved in the management of these DTPs, by contributing to shortlisting and interviewing, by hosting cohorts during training weeks (NERC) and providing rotation projects (BBSRC). In this assessment period, we have acted as supervisors to 25 NERC, nine BBSRC, and one LISS student. Additionally, industrial links have been strengthened through CASE and iCASE awards, with partners including IMSOL™, Isogenica Ltd, Oxford Nanopore, Prozoomix™, Singer Instruments™ (all BBSRC), Scottish Natural Heritage and CEFAS (both NERC), and Entelechy Arts (ESRC).

To attract strong applicants, studentships are advertised on FindAPhD.com alongside discipline-specific websites (e.g. EvolDir or ASCB). Applications are processed by the University's postgraduate office. Shortlisted candidates are interviewed by two or more academic staff, all of whom must have attended training in fair selection. We aim to achieve gender balance on interview panels and among short-listed candidates. Applications to DTPs, including shortlisting and interviewing, are administered by the respective DTP panels.

(ii) Training and supervision

New PhD students and postdoctoral staff complete an induction that introduces procedures and support services, and are allocated to one of several shared doctoral or postdoctoral offices where they can interact with others working in related areas outside of their immediate group. Each student is appointed an Advisory Panel that comprises the supervisors and an independent Chair, and postdoctoral researchers are allocated a mentor. PhD Panels hold a series of progression

meetings, for which students prepare reports for discussion: a literature review (2 months), progression reports for entering the second (7-9 months), third (19 months) and fourth years (30 months), and a thesis completion plan (36-42 months). At all panel meetings, supervisors are asked to leave the room to allow the student to discuss any concerns privately with the Chair. As part of their training, PhD students give three formal presentations to the School: a talk introducing their project (first year), a poster presentation (second year), and a talk reporting their findings (third year). These latter two presentations are delivered at an annual Postgraduate Symposium, to which all staff, supervisors, and CASE partners are invited. Students and postdoctoral staff also give talks annually at departmental meetings.

Students are allocated budgets for consumables and conference attendance from training grants, or, for those not on DTPs, from School funds. Students gain teaching experience as paid Demonstrators for undergraduate and MSc modules, and many also help supervise undergraduate dissertations. They gain further experience by participating in weekly themed journal clubs and seminar series (e.g. ecology and evolution, psychology) and attending School seminars for external speakers, and they are encouraged to engage with external groups, including 'The Women in Science and Engineering Society', 'London Cell Cycle Club' and the 'London Evolutionary Research Network' (LERN). PhD students and postdoctoral staff are also represented in departmental staff meetings, and on the Diversity and Inclusion Committee.

(iii) Professional training and support

All PhD students are expected to complete ~210 hours of professional development activities, which they record on an online PhD Skills Points Database, administered by the Doctoral College. Points are mapped against a Vitae Researcher Development Framework that covers four domains (knowledge and intellectual abilities, personal effectiveness, research governance and organisation, and engagement, influence and impact), and can be accrued by attending courses run by the Research Development Team on the PhD process and professional research skills development (including presenting, publishing, and time management). For our international students, in-session English language courses are run annually. In addition to the DTP and School's allocations, the Doctoral College also administers a Postgraduate Research Fund, to which all PhD students can apply for funds for attending conferences, fieldwork expenses, or access to external training and/or facilities. Funding is also available for student-led initiatives; for example, in 2014, 2015 and 2016, the School hosted and financed the annual LERN conference, a society for PhD students from across London's institutions.

The success of our support mechanisms for PhD students is evidenced by high rates of progression. Of the students who were recruited and submitted their theses in this period, 93% (140/151) did so on time. Many of our students author research papers in multidisciplinary and leading subject-focused journals, including Nature (Sollars), Science (Baciadonna), Current Biology (Hunt, Peng), Nature Plants (Mahbub, McCarthy, Wang), PNAS (Schorsch), eLife (Islam, Gul, Yanez-Guerra), New Phytologist (Day, Guignard, Renny-Byfield), Small (Uddin), Journal of Cell Biology (Hart), Systematic Biology (Álvarez-Carretero, Dodsworth), BMC Biology (Odekunle), and Ecology Letters (Dinner, Parrett). In 2020, BAME PhD student Galpayage Dona co-authored a perspective article in Science on the pioneering African American zoologist Charles Turner, and several PhD students won prizes in this assessment period. Notably, Renny-Byfield and Dodsworth each won the Irene Manton prize (2014 and 2017, respectively) from the Linnean Society of London for the best botany thesis in the UK, and Álvarez-Carretero was awarded the 2019 Ernst Mayr prize Award by the Society of Systematic Biologists.

(iv) Career development and support

PhD students and postdoctoral staff can access a range of courses aimed at enhancing employability and career progression, covering job hunting, interview technique, business development, and grant writing. Advice and events for PhD students and postdoctoral researchers are provided by the School and Faculty, and University's Careers and Enterprise Unit, and include an annual careers networking event, where students meet alumni from diverse sectors, and STEM

and International Careers Fairs. Our Director of Industrial Innovation co-organised a Faculty-wide industry research engagement day (FIRED-Up), attracting >70 industry participants and 110 academics, and launched a new annual event, 'The Peter Mansfield Young Entrepreneur Lecture' (Sept 2019), to showcase successful pathways to impact. Findings from our PhD-alumni survey show that 92.8% of our PhD students leaving in the REF period (up to 2017) went onto highly skilled employment, with 58% remaining in HEIs and 26% with salaries of £30k or above

(v) Pastoral and well-being support

The School's Postgraduate Research Student Officer acts as a point of contact for student support issues. Aside from their supervisors and Panel, PhD students can access the University's Advice and Counselling Service, Disability and Dyslexia Service, and PhD Support Group. The University's Researcher Development team runs workshops for students to help with stress management, resilience and well-being. PhD students can switch to part-time study and, where medical or other personal factors affect progress, may interrupt their studies, or apply for an extension to their submission deadline. During the Covid-19 pandemic, students were offered extensions to report deadlines and guidelines were amended so that affected students were not deregistered for progression-related reasons. The University disbursed 3-month stipend extensions for UKRI students in their final year, as well as unfunded extensions to students ineligible for funded extensions.

3. Income, infrastructure and facilities

Our research strategy implemented since 2014 has led to a near year-on-year increase in both total and FTE⁻¹ annual research income (**Fig 2a**). Across the whole period, income has totalled £31.1M from 260 grants, representing an overall uplift of 71% for total income, and 36% for FTE⁻¹ income, compared to REF2014 (**Fig 2b**). We have also expanded the diversity of income sources, and now have considerably more success from overseas funders, including the EU, and the charity sector (**Fig 3**). Our principal funders are UKRI (55%), Commission of the European Community (17%) and UK charities (11%), totalling £84k FTE⁻¹ year⁻¹. Since 2014, we have held or been awarded four ERC-Starting Grants, one ERC-Advanced Grant, and 18 Marie Skłodowska-Curie Fellowships, and we have led Marie Curie ITN, and partnered on three ITNs. We also received £752k income in-kind for use of NERC maritime equipment and ship-time, NERC Biomolecular Facilities, ESRF and Diamond Light Source. Major grants were awarded to staff across our research themes.

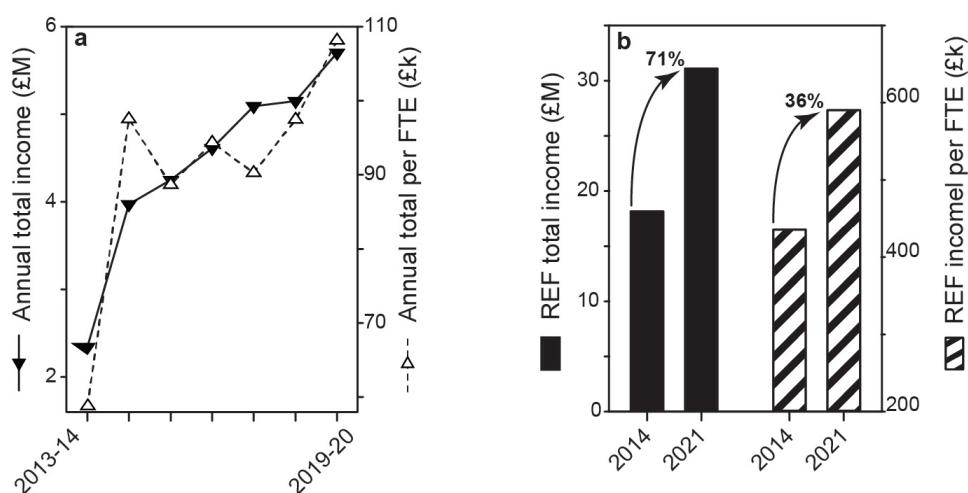


Fig 2. Increases in research grant income per individual and for all staff, shown (a) annually and (b) for the whole REF period.

In Ecology and Evolution, research income for staff in post at the census date (31/07) totalled £11.4M. Grants and fellowships, held or awarded, include a NERC Fellowship (**Henry**), an ERC-

Starting Grant (**Rossiter**, EVOGENO, 2013-2019), 10 Marie Skłodowska-Curie Fellowships, NERC consortia grants held by **Trimmer** (x1) and **Rossiter** (x2), a National Science Foundation (USA) grant (**Rossiter**), and an EU-funded ITN (INTERCROSSING) held by **Nichols** (2012-2015, €3.6M including partners). Additionally, recent awards include ERC-Starting Grants to **Frantz** (PALAEOFARM, €1.5M, €915k to QMUL), **Martín-Durán** (EVOCELFAE, €1.5M) and **de Mendoza** (METHYLEVOL, €1.5M), a European Regional Development Fund grant to **I Jones** (€10M including partners) to lead a project on preventing plastic pollution, and a NERC Highlight Topic grant to **Rossberg** (£1.1M) for investigating ecological responses to environmental change.

In Cell Dynamics and Structural Biology, research income for staff in post totalled £7.1M. Awards held or received include 26 BBSRC research grants (~£6.5M), BBSRC equipment grants to **Pickersgill** (£604k 50%-funded) and **Draviam** (£853k 43%-funded), and a Wellcome Trust consortium award (£3M, **Pickersgill** is Co-I). Additionally, **Ruban** was awarded a Royal Society Wolfson Research Merit Award, **Mullineaux** and **Ruban** were Co-Is of an ITN (€547k to QMUL) on optimisation of light energy conversion in plants and microalgae, and **Pickersgill** was the institutional lead on the successful BBSRC LIDo DTP bid (~£22M consortium award).

In Biological and Experimental Psychology, research income for staff in post totalled £8.5M. During this period, **Chittka** was awarded an ERC-Advanced Grant (SPACERADARPOLLINATOR, €3.4M including partners) and an EPSRC Programme Grant (£1.1M) to work on insect and machine cognition. **Mareschal** was awarded £723k (including partners) from the MRC for work on emotion recognition, **Brennan** was awarded \$2M (including partners) from National Institute of Health to work on non-human animal models, **Pluess** obtained \$2.2M (including partners) from the NICHD for studies on well-being. Other large grants and individual Fellowships awarded or held during this assessment period include a Royal Society Wolfson Research Merit Award, a Fellowship of the Institute of Advanced Study (Wissenschaftskolleg) Berlin, and a Human Frontier Science Programme grant (all to **Chittka**). Members of this group held or were awarded eight Marie Skłodowska-Curie Fellowships in this REF period.

a. Infrastructure

UoA5 activity is hosted in a suite of state-of-the-art laboratories. Investing in research infrastructure was highlighted as a strength in REF2014, and we have sustained this strategy, with a further £4.8M invested to refurbish infrastructure, ~£750k to buy new equipment and maintain shared research facilities, and ~£640k per annum to support core technicians. For genomics research, we have built two new large genomics laboratories with ancillary rooms and a bioinformatics room, co-funded by the University (£1.2M) and a Royal Society Wolfson Laboratory Refurbishment Grant (£150k). For ecological research, we have installed an analytical laboratory (£1.3M) for the high-specification measurement of stable isotopes, greenhouse gases and organic and inorganic molecules. In Cell Dynamics and Structural Biology, researchers have benefitted from a new Centre for Cell Dynamics, equipped with deconvolution and super-resolution live-cell microscopes

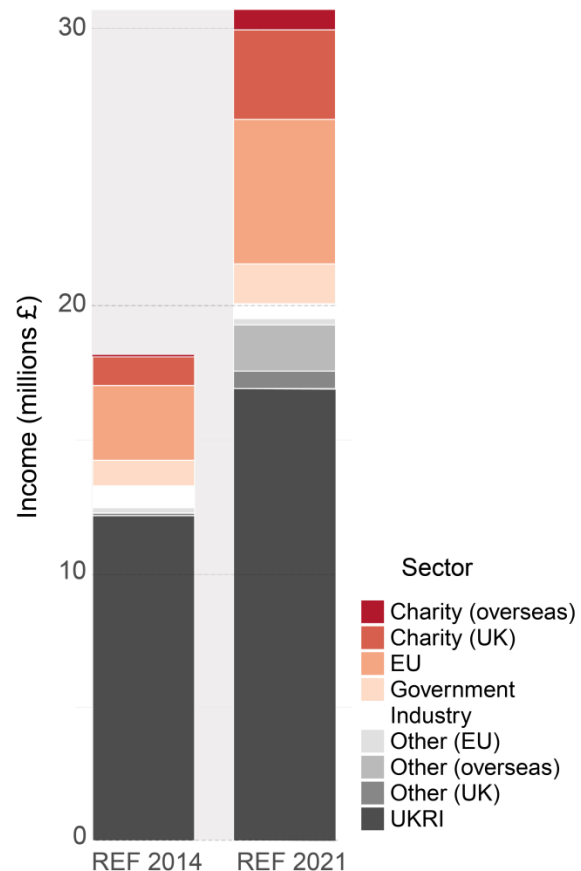


Fig 3. Increase in diversity of funding sources.

(£1M). For biological and experimental psychology, we have refurbished laboratories for studying cognitive neuroscience (behavioural, eye-tracking, EEG, brain stimulation, psychophysiology), and installed purpose-built multi-room facilities for rearing and housing zebra fish and birds in the University's Biological Services Unit (total £300k).

b. Facilities

(i) Computer facilities

Staff across the biological sciences benefit from access to excellent computer resources; following substantial upgrades since 2014, the University's HPC now comprises 260+ nodes totaling over 4200 CPU cores and 1.3PB storage. Our staff also continue to have access to several EPSRC-funded Tier 2 HPC clusters. Additionally, SBCS has invested £50k in an archive solution for longer term storage of research data to supplement the high speed storage on the HP cluster, and large memory nodes for -omics analysis were added with NERC funds (£85k) awarded to **Nichols** and **Wurm**.

(ii) Genomics facilities

To equip two newly-built shared laboratories for genomics research in UoA5, the University provided >£500k for the purchase of platforms for the isolation, quantification, preparation and sequencing of nucleic acids for genomic analyses, including an Agilent Bioanalyzer, an Agilent TapeStation, Mosquito liquid handler, a Covaris M220 Focused-Ultrasonicator, a PromethION (Oxford Nanopore Technologies) for long-read sequencing, and an Illumina NextSeq sequencer (co-purchased with the University's St Barts and the London Genome Centre). During the same period, with two NERC strategic capital equipment grants (2015 and 2019, total >£550k PI **Rossiter**), the School purchased the UK's first Bionano Irys optical mapping platform for the assembly of genomes of non-model taxa, followed by a Bionano Saphyr platform for high throughput optical mapping.

(iii) Facilities for mass spectroscopy and nuclear magnetic resonance

The identification and analysis of proteins and protein complexes has been advanced by the procurement of a Waters Synapt G2Si ESI-qTOF HDMS mass spectrometer with ion-optics and ion-mobility separation and associated equipment (£350k). There has also been investment in a new console for our Bruker AV 600 MHz NMR (£270k) which is used for many purposes including characterising protein folding and protein-protein and protein-ligand interactions.

(iv) Facilities for microscopy

We have invested in cutting-edge equipment to support work at the interface of structural biology and cell biology (~£1.2M). For example, acquiring the UK's first live-cell Super-Resolution OMX-FLEX microscope (BBSRC ALERT19, £369k of £825K, PI **Draviam**) has helped establish a new Centre for Cell Dynamics. Two additional awards for cryo-electron microscopy equipment have positioned us to take full advantage of the emerging cryoEM revolution in structural biology: a 200 KeV cryo-electron microscope (BBSRC 16ALERT, £302k of £600k, PI **Pickersgill**) and a new Titan Krios cryo-electron microscope (Wellcome Trust Co-I **Pickersgill** as part of the LonCEM consortium), housed at the Crick Institute.

(v) Cell growth Facilities

State-of-art facilities are being maintained and upgraded for growing cell lines from a variety of model and non-model species in Class II and Class III containment facilities.

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

a. Collaborations networks and partnerships

(i) *Structures and mechanisms for supporting research collaborations, networks and partnerships*

Our physical infrastructure—in which geneticists, ecologists, biological psychologists, and biochemists share buildings and facilities—encourages a naturally high level of interdisciplinary research. All academics, postdoctoral researchers and PhD students are able to attend our two series of weekly School-wide research seminars for invited speakers, as well as PhD student talks and weekly departmental seminars. Invited speakers in this period include Nobel Laureates (R. Henderson FRS and V. Ramakrishnan FRS) and many world-leading scientists (e.g. D. Bishop FRS, P. Donoghue FRS, A. Grafen FRS, A. Kacelnik FRS, J. Shapiro, C. Stringer FRS, J. Wendel and A. Yoder). Our researchers also belong to several hubs established to foster interdisciplinary collaboration across the University: the Centre for Aquatic and Terrestrial Environment (**I Jones, Kratina, Trimmer**), Centre for Cell Dynamics (led by **Draviam**), Centre for Intelligent Sensing (**Chittka** and **Mareschal**), Epigenetics Hub (**Hurd, Martín-Durán** and **de Mendoza**), Institute of Applied Data Science (**Bessant, Draviam, Versace** and **Wurm**), and Material Sciences Institute (**Palacios**). Collaborations are also promoted via QMUL-funded PhD studentships (19 to UoA5 since 2014) and funding schemes for kick-starting interdisciplinary projects (e.g. Proof of Concept Award and Impact Acceleration Awards). Examples of interdisciplinary collaborations include **Bessant's** work with biomedical scientists on phosphoproteomics, **Chittka's** EPSRC-funded research with engineers on flying robots, **Draviam's** BBSRC-funded research with computer scientists on cell imaging, **Lachlan's** BBSRC-funded research with engineers on machine learning of bird song, **Rosberg's** NERC-funded work with physicists on food webs; and **Trimmer's** NERC-funded collaborations with hydrologists. Research collaborations have also been facilitated by our hosting of >100 visiting researchers in the assessment period, including >45 UK and overseas academics (several on sabbatical), >35 PDRAs, and >30 PhD students.

(ii) *Greater London Region collaborations, networks and partnerships*

We participate in several London-based networks of researchers and institutions: the Centre for Ecology and Evolution, the student-led Evolutionary Research Network, London Cytoskeletal Club, London Cell Cycle Club, London Echinoderm Network, London Structural Biology Club (chaired recently by **Stieglitz**) and Yeast Genetics Club. The School belongs to three UKRI-funded Doctoral Training Programmes (BBSRC LIDo, London NERC, and ESRC LISS), a Leverhulme Doctoral Centre, and a new Wellcome Trust DTP. Both the BBSRC LIDo and NERC-DTPs require that PhD students have supervisors from at least two London institutions. Through these initiatives, we have cultivated existing and new links with research institutions across London (NERC DTP: with UCL, Birkbeck, Brunel, Institute of Zoology, KCL, Natural History Museum, Royal Botanic Gardens Kew and RHUL; BBSRC DTP: with UCL, KCL, Birkbeck, LSHTM, University of Greenwich, and the Royal Veterinary College). Networking is also facilitated by shared equipment; for example, **Pickersgill** was co-applicant on a consortium Wellcome Trust grant (with Imperial, Institute of Cancer Research and KCL) for a Titan Krios cryo-electron microscope, housed at the Crick Institute.

(iii) *UK-wide collaborations, networks and partnerships*

UoA5 researchers derive collaborative opportunities through the University's membership of the EPSRC-funded Alan Turing Institute, of which four staff (**Bessant, Osman, Versace** and **Wurm**) hold affiliate positions as Turing Fellows. Examples of major funded collaborations with other universities and research institutions cover the breadth of our research. For example, **Chittka** holds an EPSRC Programme Grant (2017-2021) with Sussex and Sheffield (QMUL ~£1M of £4.8M); **Draviam** led a pharmacogenomics drug repurposing screen with the European Bioinformatics Institute and Sanger Institute; **Elphick** holds BBSRC and Leverhulme grants with the University of Warwick; **Frantz** collaborates with Liverpool (NERC award) and Oxford (ERC and

NERC); **Mullineaux** holds BBSRC grants with the Imperial, Liverpool and UCL; **Pickersgill** was awarded a £600k BBSRC sLOLA grant with Bristol and Kent for work on bacterial micro-compartments; **Rosberg** holds a £1.2M NERC grant with St Andrews; **Rossiter** and **Frantz** hold a joint NERC grant with Kent and Sheffield, and the Natural History Museum; **Rossiter** also held a NERC grant in this assessment period with Kent, Lancaster and Oxford; **Thorpe** has a Francis Crick Institute Award with Imperial and King's; and **Trimmer** collaborates on NERC-funded research with the National Oceanography Centre, Imperial, Essex, Exeter and Southampton.

(iv) International collaborations, networks and partnerships

Of UoA5 outputs submitted in REF2021, 73% have international co-authorship, representing an increase of 23% on our REF2014 submission. International collaborations develop organically through shared interests, and are also promoted by external funding schemes, and School- and University-led initiatives. For example, to build links with Mexican researchers, UoA5 staff **Chittka** and **Martín-Durán** joined Faculty-led visits to, respectively, the Instituto Politécnico Nacional and Universidad de Las Américas Puebla. We have also partnered with CONACYT to train Mexican PhD students, and have supervised 22 Chinese PhD students awarded via the University's Memorandum of Understanding with the Chinese Scholarship Council. European collaborations have been promoted via staff involvement in Marie Skłodowska-Curie Innovative and Initial Training Networks (ITNs). **Mullineaux** and **Ruban** were members of ITN 'SE2B' (~€550k of €3.8M to QMUL, 2016-2020), and in this REF period, **Nichols** coordinated the ITN 'INTERCROSSING' (2012-2015, ~€800k of €3.6M), which funded 13 PhD students and involved industrial partners from Denmark (CLC bio), Germany (JMU Giessen), Spain (ERA7 Bioinformatics) and the UK (PopGenTech).

Many of our international collaborations have led to high-profile publications, substantial funding, or ODA compliant research. Examples from beyond Europe include Australia: **Clayton** collaborates on neurogenomics with Deakin University (BBSRC, £518k) and the University of the Sunshine Coast (Leverhulme Trust, £312k). China: **Chittka** is a Guest Professor at Fujian Agricultural and Forestry University; **Leitch** collaborates with Fairy Lake Botanic Gardens in Shenzhen on gymnosperm genomics; **Frantz** works with the Chinese Academy of Science on domestication genomics; and **Rossiter** works with East China Normal, Shaanxi Normal, and Wuhan Universities on bat genetics. Ethiopia: **Buggs** and **Nichols** hold a BBSRC/Global Challenges Research Fund (GCRF) grant with Addis Ababa University, Hawassa University and the Ethiopian Biodiversity Institute (£273k of 1.2M) on crop plant genomics. Indonesia: **Rossiter** and **Frantz** have a NERC/Newton grant (£196k of £898k, 2019-2022) with the University of Indonesia to work on mammal genetics. Japan: **Rosberg** holds a NERC grant with Tohoku University (>£1.2M) on environmental change; **Draviam** works with Keio University on systems biology; and **Elphick** has BBSRC grant (£354k) to work with Waseda and Tokyo Gakugei Universities on starfish ovulation. Jordan: **Mareschal** has a British Academy Grant (£339k) to measure psychological outcomes in refugees in Jordan. Lebanon: **Piuess** is leading an NIH-funded project (\$1M of \$2.2M to QMUL) to examine resilience in refugee children. Malaysia: **Rossiter** held a NERC-funded consortium grant with the Universiti Malaysia Sabah (Human Modified Tropical Forests Programme £208k of £2.2M to QMUL) to study forest degradation and biodiversity, and also a Newton travel grant with the Universiti Malaysia Sarawak. USA: **Chittka** had a HFSP programme grant with Universities of Toulouse and Washington (\$303k of >\$1M to QMUL) on insect cognition; **Brennan** leads a HFSP grant (\$368k of \$1.05M to QMUL) with the University of Southern California on neurobiology of numerosity; **Rossiter** was a co-investigator on a five-year National Science Foundation grant (2014-2019, \$75k of \$1.91M to QMUL) with Stony Brook University on sensory adaptations; and **Subramanian** works with the University of Michigan (BBSRC, £470k) on centromere protein architecture. Examples from Europe involve include those with Joseph Fourier University (**Buggs**, **Leitch**, **Nichols**), KTH Royal Institute of Technology (**Eyice-Broadbent**), LMU University, Ludwig Maximilian Universität Regensburg (**Henry**, **Wurm**), Max-Planck Institute, Dresden (**Draviam**), Trinity Dublin (**Frantz**), Swiss Institute of Bioinformatics (**Wurm**), and the Universities of Barcelona (**Elphick**), Copenhagen (**Frantz**), Freiburg (**Mullineaux**), Ghent (**Leitch**), Granada (**Nichols**), Helsinki (**Wurm**), Kiel/GEOMAR (**Elphick**, **Eizaguirre**), Leiden (**Clayton**), Milan (**Elphick**, **Palacios**), Munich (**Buggs**, **Frantz**, **Leitch**, **Nichols**), Münster (**Palacios**), Max Planck Institute for

Evolutionary Biology (**Eizaguirre**), Pierre et Marie Curie (**Wurm**), Southern Denmark (**Trimmer**), Trento (**Brennan**), Tübingen (**Mullineaux**), and Vienna (**Buggs Leitch, Nichols**).

b. Relationships with key users, beneficiaries or audiences

Our work has benefitted a wide range of end-users, spanning UK and overseas government agencies, non-governmental organisations (NGOs), charities, industry, researchers, educators, and the public. Key beneficiaries and stakeholders include agencies and organisations focused on the protection of biodiversity, habitats and ecosystem services, and units working with refugee children and the elderly. Other beneficiaries include commercial companies that sell equipment informed by our research, in areas of disease monitoring, biomarker discovery, and targeted therapeutics. Examples of the application and translation of our research are given below.

(i) Impact covered in impact case studies, with beneficiaries

Our impact case study '*Informing 'Glastir', a New Sustainable Land Management Scheme delivering Benefits to Public Spending, Welsh Farmers and the Environment*', led by **I Jones**, has influenced new environmental policy in Wales, including the design of the Welsh agricultural policy ('Glastir Advanced') that impacts £150M of subsidy payments to Welsh farmers. Our second impact case, '*Counteracting the Damaging Effects of Fine Sediment Pollution in UK Rivers*', also led by **I Jones**, is being used to assess fine sediment pollution by Natural England and the Environment Agency to protect England's Natura 2000 Sites. Our third impact case, '*Leading the Fight against Ash Dieback in the UK and Europe*', is underpinned by **Buggs's** work on the genetic basis of ash tree resistance to ash dieback disease. This disease costs the UK economy ~£15 billion, and **Buggs's** findings are being translated to breeding policies to safeguard this native species. He is a member of the 'Future Proofing Plant Health' Project Management Group, which oversees Defra research on plant health conducted by the Food and Environment Research Agency (FERA), Natural England, Forest Research, Royal Botanic Gardens Kew, and Joint Nature Conservancy Council (JNCC). **Eizaguirre's** work on the conservation of endangered populations of loggerhead turtles in Cape Verde forms our fourth impact case study '*Transforming the Conservation Strategy for One of the World's Most Significant Populations of Endangered Sea Turtles*'. This work is shaping conservation strategies for this endangered species, and beneficiaries include the Turtle foundation, Maio Foundation biodiversity, Project Biodiversity, and Projecto Vito, as well as the Ministries for the Environment and for Maritime Affairs. Finally, **Osman's** research on decision-making under typical conditions of risk forms the basis of our fifth impact case study '*A New View of Decision-making: Delivering Innovative, Evidence-based Policy across Government Departments via Novel Research Hubs*'. Osman was seconded to the Food Standard Agency for three years, to inform new policy on consumer behaviour and business compliance. She has acted as also an advisor to numerous organisations, including the Dutch National Bank, Financial Conduct Authority, DEFRA, and Ipsos Mori.

(ii) Additional impact not captured by impact case studies

In Ecology and Evolution, **I Jones** has conducted research for the Scottish Government, Environment Agency, and Northern Ireland Environment Agency. He also sits on the British Ecological Society Brexit Policy Working Group, which provides Defra with policy advice on request through the Demonstration Test Catchments (since April 2014). **Rossberg's** work on the impact of fishing stocks has influenced policy of the OSPAR Convention, which regulates cooperation among 15 governments and the EU for marine protection. **Frantz** and **Rossiter** serve on IUCN Specialist Groups, for pigs and bats respectively, and have contributed to Red Data listings.

In Cell Dynamics and Structural Biology, **Bessant** launched the spinout company Mebomine Ltd for the collection and analysis of pharmaco-vigilance data, and also developed a web-based platform GIO for integrated analyses of transcriptomic and proteomic data. **Ruban's** discoveries of plant protective mechanisms against excessive light have been utilised in a new kit (PSP32) from Opti-Sciences Inc (USA) for monitoring crop performance. **Ruban** also collaborates on equipment

development with Hansatech (UK), Valoya-Microsoft (Finland) and Walz GmbH (Germany). **Palacios** founded the charity DrosAfrica, which supports *Drosophila* researchers across Africa. Other competitively-funded research projects aimed at commercialisation have focused on biologically-inspired high-speed low-light illumination imaging (**Draviam**, IMSOL and Konica-Minolta™), deep-learning algorithms for image processing (**Draviam**, Carl Zeiss™), high-throughput robotics for functional genomics (**Thorpe**, Singer Instruments™), and drugs for neurodegenerative diseases (**Caudron**, SunRegen Healthcare AG).

In Biological and Experimental Psychology, **Pluess** and **Mareschal** designed positive psychology interventions to improve resilience in Syrian refugee children. This work involved training NGOs, educators and refugee camp staff (incl. PRAKSIS, MedGlobal, Boat Refugee Foundation, and the Greek Ministry of Education). **Pluess** has developed telephone-delivered interventions for Syrian refugees, working with the NGO Médecins du Monde, and the Lebanon-based charity IDRAAC, and supported by an NIH grant (\$1.2M of \$1M to QMUL) and a Research for Health in Humanitarian Context (ELRHA) grant (£383k). He also compiled a guidance document on phone-delivered psychotherapy for children; this was shared directly with the WHO, Ministry of Public Health in Lebanon, UNHCR, and the Inter-Agency Standing Committee (IASC), and included in a Covid-19 toolkit that is used by UNICEF and the BluePrint Group. Also in response to Covid-19, **Pluess** launched *sensitivityresearch.com*, which shares evidence-based knowledge on sensitivity, for use by the public, researchers and practitioners; since its launch (June 2020) it has received >37,000 visits. **J. Jones**' is investigating the effectiveness of community-based arts interventions in promoting health and well-being among older adults, a collaborative project with the arts organisation Duckie, funded by Arts Council England.

c. Wider contribution to the economy and society

(i) Outreach and public engagement

Staff members who have promoted biological sciences to the public and other non-specialist audiences include UoA5 researchers as well as academics on teaching contracts (**Faulkes** and **Hone**). The University encourages these activities by hosting events for the wider community, and by disbursing Public Engagement Awards. Recipients of these awards include **Eizaguirre**, for establishing TurtleProject (£49.7k), a citizen-science project that contributed to an impact case study, and **Chittka**, for launching the citizen-science initiative 'Save London Pollinators' (£18k) to promote pollinator-friendly urban gardening. Staff interviewed about their research on television, radio and podcasts include **Buggs** on ash dieback disease (e.g. BBC Six O'clock News, BBC Radio 4 Today, France24, Planet Earth Podcast, The Economist Podcast), **Chittka** on bee pollination (Sky News), **Mullineaux** on the bacterial eyeball (BBC Radio 4 Today), and **dos Reis** on mammal evolution (The Scientist). Several staff have written media articles, including **Buggs** (The Conversation), **Hone** (Guardian's 'Lost Worlds' online series, >120 articles and ~900,000 visits) and **Knell** (The Conversation). **Hone** also wrote the popular science book 'The Tyrannosaur Chronicles: The Biology of the Tyrant Dinosaurs' (April 2015, > 10,000 copies sold). **Frantz** was Scientific Adviser on the France2 television documentary 'Le Plus Bel Amis de l'Homme' (2019, ~2.6 million viewers) and **Hone** advised on the BBC documentary 'The Real *T. rex*' (2018, ~1.5 million viewers) and Sky's series 'David Attenborough's conquest of the Skies' (2015). Throughout this REF period, research conducted by our researchers has been widely reported in many major newspapers in the UK (Express, Financial Times, Guardian, Mail, Observer, Sunday Telegraph, Telegraph, and Times) and overseas (Le Monde, New York Times, Reuters, and Wall Street Journal). Of relevance to the promotion of diversity, **Chittka's** recent Science article about the African-American scientist Charles Turner—co-authored with BAME student Samadi Galpayage—attracted international media attention.

We have run activities, including talks and public interviews, at several science events, including the Brighton Science Festival (**Trimmer**), Cheltenham Science Festival (**Buggs**, **Hone**, and **Le Comber**), Northern Ireland Science Festival (**Engl**), Pint of Science Festival (**di Bernardi Luft**, **Brennan**, **Mareschal** and **Pluess**), Pisa Internet Festival (**Le Comber**), and UKRI's Cutting Edge Science Event (**Hurd**). Others have contributed to STEM-themed events and platforms for school

children, including the Festival of Communities (**Eizaguirre**, **Trimmer** and **Wurm**) and the 'I'm a Scientist' website (**Elphick**). In the arts, **Brennan** contributed an exhibit ('A Skinner box for zebrafish') to the London Science Museum's permanent collection; **Chittka** released the music album 'Strange Flowers' with profits to the charity 'Buglife', and also worked with playwright Robbie Hudson on a production about moral conflicts, supported by Leverhulme Trust 'Artist in Residence' grant (£13k); and **Osman** works as an Associate Scientist with the theatre company 'Fuel' to promote cross-disciplinary approaches in performance, funded by a Wellcome Trust 'Sustaining Excellence Award'. **Faulkes** developed an experimental art project (RAT.systems) that uses real-time data transmission to educate the public about naked mole-rats. This project, supported by a QMUL Large Public Engagement Award (£18.9k), attracted 21,924 website visits and 1800 phone app downloads, and was showcased at 17 national and international events, including Somerset House's year-long Utopia-themed exhibition (2016), and New Scientist Live (Excel Centre, London, 2017, >84,000 visitors).

(ii) *Journal editorships*

We have held 64 editorship roles (chief editor, associate editor or guest editor) for academic journals. Examples include American Naturalist (**Rosberg**), Biochimica et Biophysica Acta Bioenergetics (**Ruban**), Briefings in Functional Genomics (**Hurd**), Chemical Physics (**Duffy**), Current Opinion in Insect Science (**Chittka**), Ecological Entomology (**Knell**), Ecology and Evolution (**Kratina**), Evolutionary Applications (**Eizaguirre**), Frontiers in (Fi-) Cell and Developmental Biology (**Caudron**), Fi-Cellular and Infection Microbiology (**Wilkinson**), Fi-Ecology and Evolution (**Kratina**), Fi-Endocrinology (**Elphick**), Fi-Genetics-Neurogenomics (**Clayton**), Fi-Marine Science (**Schofield**), Fi-Neurogenomics (**Clayton**), Fi-Microbiology (**Engl**), Fi-Physiology (**Draviam** and **Elphick**), and Fi-Psychology (**Chittka**), Genome Biology and Evolution (**dos Reis**), Journal of Animal Ecology (**Eizaguirre**); Journal of Bacteriology (**Mullineaux**), Journal of Biological Research-Thessaloniki (**Schofield**), Journal of Zoology (**Knell**), Marine and Freshwater Research (**I Jones**); Marine Biology (**Eizaguirre**); Nature Scientific Data (**Knell**), Neurobiology of Learning and Memory (**Clayton**), PeerJ (**Palacios** and **Draviam**), Plant Physiology (**Ruban**), Plants, People, Planet (**Buggs**); PLoS Biology (**Chittka**); PLoS Genetics (**Clayton**); PNAS (**Clayton**); and Royal Society Open Science (**Mareschal**).

(iii) *Other external recognition (prizes, committee membership, advisory roles)*

Our researchers have won several prestigious prizes, including an Early Career Researcher Prize from the British Crystallographic Association 2018 (**Darbari**); MRC Suffrage Science Award 2019 (**Palacios**); and Royal Society Wolfson Research Merit Awards (**Chittka**, **Ruban**). We have also served on numerous UK and overseas funding evaluation panels. UK examples include the BBSRC (**Bessant**, **Pickersgill**); British Ecological Society (**Eizaguirre**); NERC Biomolecular Analysis Facility (**Nichols** is Chair); NERC Peer Review College (**Buggs**, **Henry**, **I Jones**, **Trimmer**, **Knell**); Royal Society (**Rositer**); and Science and Technology Facilities Council (**Pickersgill**). Overseas examples include the Bulgarian Research Council (**Chittka**); CEITEC Evaluation of Scientific Excellence, Czech Republic (**Leitch**); Czech Academy of Sciences (**Leitch**, **dos Reis**); Deutsch Forschungsgemeinschaft (**Rosberg**); ERC Synergy Panel (**Chittka**); Finland Academy of Science (**Eizaguirre**); French National Research Agency (**Draviam**); and INRA, France (**Leitch**). Our staff have also contributed to the activities of numerous academic bodies and learned societies, with examples including the Applied Vision Association (**Mareschal** is the elected chair); Darwin Tree of Life Project (**Elphick**); European Society for Comparative Endocrinology (**Elphick** is a council member); IUCN Species Survival Commission Specialist Groups (**Frantz** and **Rositer** are members) and Muséum National d'Histoire Naturelle (**Elphick** was a member of the evaluation committee for Laboratory of Physiology, 2012-2017). Examples of advisory and consultancy roles for commercial organisations and government agencies include the All Party Parliamentary Group on Biodiversity (**I Jones**, 2014); British Ecological Society Brexit Policy Working Group (**I Jones**); Cytel (**Wurm**); Defra (**Buggs** is a member 'Future Proofing Plant Health Project Management Group', **Clare**, **Rosberg**); Dutch National Bank (**Osman**); Environment Agency (**I Jones**); Intergovernmental Platform on Biodiversity and Ecosystem Services (**Rosberg** was a Lead Author of Regional Assessment for Europe and Central Asia,

2015-2018); Ipsos Mori (**Osman**, 2017-2020); JNCC (**Rossberg**); MEDASSET (**Schofield**); Marine Stewardship Council (**Eizaguirre**); OSPAR (**Rossberg** was a UK delegate to the expert group on Food Webs); Seven Bridges Genomics (**Wurm**); South Korea Ministry of the Environment (**I Jones**); and US Environmental Protection Agency (**I Jones**, 2018).

(iv) Conferences

During this period, we have organised ~40 conferences or scientific meetings and >50 conference sessions, and have delivered >580 conference presentations and >260 university seminars. Named-lectures given include the 2020 Baerends Lecture, Netherlands Society for Behavioural Biology (**Chittka**); 2017 Ganken Seminar, Tokyo, Japan (**Draviam**); 2017 Heller Lecture, Hebrew University of Jerusalem, Israel (**Chittka**); 2015 John Emlen Lecture, University of Wisconsin, USA (**Chittka**); 2016 Tupper Lecture, Smithsonian Tropical Institute, Panama (**Chittka**); and 2020 Tinbergen Lecture, ASAB Winter Meeting, London, UK (**Chittka**). Plenaries were given at the Behaviour Adaptations Conference, Toulouse, France, 2016 (**Chittka**), BOMBUSS Conference, Logan, Utah, USA, 2017 (**Chittka**); 3rd BritBat Meeting, Bristol, 2019 (**Rossiter**); Conference of European Comparative Endocrinologists, Leuven, Belgium, 2016, and Glasgow, UK, 2018 (**Elphick**); CSHA Genomics and Phenomics meeting, Shuzou, China 2014 (**Brennan**); Entomological Networks: Ecology, Behaviour and Evolution, Newcastle, UK, 2017 (**Chittka**); IDEEV, Gif-sur-Yvette (annual conference, plenary evening lecture), France, 2015 (**Chittka**); International Congress of the Polish Pharmacology Society, Lublin, Poland, 2019 (**Brennan**); International Symposium on Phototrophic Prokaryotes, Vancouver, 2016 (**Mullineaux**); IUSSI Conference, York, UK, 2017 (**Chittka**); Italian Society for Evolutionary Biology Congress, 2015, Bologna, Italy, 2015 (**Versace**); and Phylogenomics Workshop, Czech Republic, 2019 (**dos Reis**); and Symposium on Ecological Networks Molecular Analysis of Trophic Interactions, Uppsala, Sweden (**Clare**).

Conferences organised include three Royal Society-sponsored Theo Murphy International Scientific Meetings, run by **Elphick**, **Knell** and **Leitch** on, respectively, neuropeptide signaling, sexual selection, and nutrients and genomes. We have organised sessions at diverse international meetings, including Avian Model Systems (**Clayton**); Conference of European Comparative Endocrinologists (**Elphick**); Congress of the European Society for Evolutionary Biology (**Buggs**, **Frantz**); EuroEvoDevo conference (**Martín-Durán**); International Botanical Congress (**Leitch**); International Cell Cycle Meeting (**Thorpe**); International Conference on the Evolution of Language (**Versace**); International Congress of Comparative Endocrinology (**Elphick**); International Sea Turtle Symposium (**Schofield**); International Symposium on Phototrophic Prokaryotes (**Mullineaux**); Joint Congress on Evolutionary Biology (**Eizaguirre**); Plant and Animal Genome Conference (**Buggs**, **Leitch**); Society of Molecular Biology and Evolution Conference (**de Mendoza**, **Frantz**); Southeast Asian Gateway Evolution Meeting (**Frantz**). **Mareschal** organised three annual conferences for the Applied Vision Association.