Institution: University of East Anglia

Unit of Assessment: 5 – Biological Sciences

a. Overview

In 1963, Biological Sciences (BIO) was one of the two founding Schools of UEA, at a time when integrated biology departments were very unusual. We stay true to an original vision of excellence and vitality through broad integration: our research-led teaching always puts us in the UK's top 5 biology departments in the National Student Survey, and our research has received excellent scores and clear commendations from every previous Research Assessment Exercise.

Although interdisciplinary by nature, BIO's research programmes are placed in four overlapping Themes: 1. **Molecular Microbiology**, 2. **Cell and Tissues**, 3. **Organisms and Environment**, and 4. **Plant Science**, which also features research from the Sainsbury Laboratory whose researchers are full-time UEA staff. Each Theme's Leader sits on BIO's senior management team. Research activities are housed across our three main sites: the UEA walkway building, the Sainsbury Laboratory, and the Biomedical Research Centre which, together, dedicate >80% of their floor space to research, currently accommodating a total of 334 researchers - faculty, research assistants, PhD students and technicians. We have our own BIO Café, serving the best coffee on campus, which promotes interaction, engagement, and a collegiate research environment.

BIO's research base is much-strengthened by the interactions widely available to staff through collaboration across (1) the six science schools at UEA, all housed in one continuous building, (2) UEA's Faculty of Medicine and Health, with which we share the Biomedical Research Centre building, and (3) the outstanding opportunities presented across the Norwich Research Park (NRP). This is one of the largest Life Science research campuses in Europe, housing three internationally renowned government-funded Research Institutes, the John Innes Centre, the Genome Analysis Centre and the Institute for Food Research, as well as the Norfolk and Norwich University Hospital (NNUH), the 6th largest hospital in Britain, and ~30 science and IT businesses. Among these different biosciences organisations, which recently attracted considerable (£26M) government infrastructure investment, BIO sits as the academic anchor of this "Bio-Campus", formalised via three strategic Alliances, for: "*Earth & Life Systems", Food and Health*" and "*Industrial Biotechnology & Bioenergy*. Through these, and other initiatives, we have invested greatly since RAE2008 into developing and exploiting our favourable position on the NRP by the sharing of staff appointments, skills, know-how, symposia and infrastructure.

b. Research strategy

BIO during the REF period

Throughout the REF period, our strategy has been to sustain and promote our vision of 3* and 4* research excellence and leadership. To achieve this, we rigorously recruit, mentor and manage staff and here we return 44 research leaders who contribute what we believe to be the excellence and impact demanded by REF. This selectivity means non-inclusion of 8 staff who conduct international impact research, but not all of which surpasses our assessment of 3* work. This focus on excellence has allowed BIO's research to flourish across the REF period, with £56.6M total income and 1109 peer-reviewed publications (50% involving international collaborations) attracting 16,973 citations, with an *H*' index of 61 (ISI Web of Science Nov '13).

Significant changes in BIO during the REF period

Since 2008, 8 staff departed BIO to retirements or new jobs (Bass, Costa, Emerson, Lipka, Rathjen, Roberts, Ryder, Sesma), but we gained 16 new researchers, from independent Fellows to senior Chairs. We delivered on every appointment planned in RAE2008, and our new staff, from across the biosciences, allow us to maintain breadth through our four Themes while sustaining 3* to 4* research quality.

Research Themes: rationales and achievements

Our Themes span a continuum and have their own particular research strengths; each has a Leader and deputy who coordinate strategy, as well as managing local infrastructure and space.

1) The **Molecular Microbiology Theme** carries out research encompassing environmental microbiology and microbial community analysis, through to bioenergetics and the discovery of new antibiotics. Research in environmental microbiology used genetics to demonstrate the unexpected diversity of bacterial enzymes that break down dimethylsulfoniopropionate to form the climate-changing gas dimethyl sulfide, an essential part of the global sulfur cycle. We also conduct extensive research into the global nitrogen cycle, particularly denitrification and generation of the important greenhouse gas, nitrous oxide (N_2O). We showed that bacterial N_2O emission is regulated by copper availability, possibly informing emissions mitigation strategies. We also found that nitric oxide detoxification by the enteric pathogen *Salmonella* generates high levels of N_2O. In bacterial physiology, we gained structural insights into a "molecular wire" comprising a porin:cytochrome complex that supports electron transfer between metal-degrading *Shewanella* bacteria and extra-cellular iron minerals. This electron transfer system is widely applicable for generating bioenergy, attracting considerable media attention, and major research funding. Our research advanced understanding of the biosynthesis of bacterial lipoproteins, an unusual class of extracellular proteins with essential cell envelope functions, including electron transfer and cell envelope homeostasis, and which may be targets for new antibiotics. Our work on host microbe interactions includes the leafcutter ant *Acromyrmex,* which forms a tripartite symbiosis with fungi (for food) and antibiotic-producing bacteria (for protection), so far yielding novel antifungal antibiotics and some antimycins that inhibit anti-apoptotic machineries and have pharmaceutical potential in several important human diseases. This ant system also lets us unravel the ecology of an unusual adaptive microbiome.

2) Research in the **Cells and Tissues Theme** focuses on biomedical sciences, from cell biology to human health and disease, using whole animal and cell-based platforms. We benefit from close interactions with the Schools of Medicine, Pharmacy, Chemistry and Computing Sciences, as well as with the Food and Health Alliance, across the NRP. Our work in cancer biology provides an exemplar of our ability to exploit basic work in animal models to generate translational impact for human health. We developed an *in vivo* screening protocol in *Xenopus* to identify small molecules that inhibit neural crest cell migration and, in collaboration with Harvard Medical School, we showed that some of the identified "hits" are effective against melanoma xenografts in mice. This has already led to clinical trials in the US. Investigations of tumour angiogenesis have dissected the roles of integrins, especially β3, in signalling via vascular endothelial growth factor receptor and its co-receptor, neuropilin-1. Work on prostate cancer involved senior roles in the International Cancer Genome Consortium effort, and the identification of novel prostate cancer susceptibility genes and biomarkers of disease.

In Developmental biology we use chick, *Xenopus* and mouse models to understand the molecular basis of cell fates in early embryo development and postnatal neurogenesis, focussing on FGF and Wnt signalling. We identified a new neurogenic niche in the adult hypothalamus, with Fgf10-expressing tanycytes acting as the resident stem cells and supplying new neurons to nearby brain circuits that control appetite and energy expenditure; modulating the behaviour of tanycytes (through FGF signalling or otherwise) offers a new route for tackling eating disorders and obesity. We also identified roles for Wnt signalling in progenitor migration and cell fate during cardiac and skeletal muscle development and advanced understanding of post-transcriptional regulation of myogenic commitment by microRNAs, in collaboration with biologists in the Plant Science Theme. Analyses of microtubule dynamics and reorganisation made major contributions to revealing how epithelial cell differentiation works in mammals.

In musculoskeletal research we study development, maintenance and repair of skeletal muscle and joints. In mouse models, we uncovered a β1 integrin-PKB/Akt signalling axis, important during mechanical stress in skeletal muscle. Cell-based and *ex vivo* approaches, as well as human tissue, allowed pioneering studies of microRNAs in osteoarthritis, revealing miR-140 and miR-455 as key to cartilage homeostasis *in vivo*. An important recent discovery was the ability of dietary glucosinolates such as sulforaphane to attenuate the progress of osteoarthritis, a good example of the benefits of complementary skills in the NRP's *Food and Health Alliance*.

3) The **Organisms and Environment Theme** addresses questions that improve understanding, management and conservation of biodiversity. Our work helped UEA to be 3rd in Europe for scientific impact in ecology and the environment between 2000 and 2010 (*THES July* 2010). In

reproductive evolution, we used *Drosophila* mutants to show how males detect rivals using combinations of sight, smell, hearing and touch to accurately determine their competitive sexual environment, thus providing a strong selective advantage which we directly quantified. Working with *Oxitec Ltd*, we applied our understanding of insect behaviour to improve biocontrol using GM insects. In experimentally evolved populations of *Tribolium* (flour beetle), we demonstrated rapid evolution of female resistance to sexual conflict, unveiling clear costs to females of polyandry, which can be offset through mate choice to avoid genetic incompatibilities. Under these bottleneck conditions, we also measured the evolution of female promiscuity in the lab. Using outbreeding (hybridisation between salmon and trout), we discovered how eggs avoid incompatible sperm through ovarian fluid that chemoattracts conspecific sperm after changing their swimming paths. In wild birds, we showed that female infidelity maximises variation within offspring MHC genes, critical for acquired immunity, improving survival in the wild. This work reveals that mate choice maintains genetic variation in the wild, and is directly relevant to our use of translocations in conservation management of the Seychelles warbler, once the most critically endangered bird in the world with ~30 individuals, all on just one island; now, thousands of birds exist on five islands, and it is no longer endangered. Using the same bird population, we showed that individual differences in rates of telomere shortening, a measure of biological ageing, predict future survival in the wild.

Strengths in social evolution build on our recent authorship of an acclaimed book '*Principles of Social Evolution*' outlining how inclusive fitness theory can explain the organisation of all life. Using theoretical and empirical approaches, we advanced understanding of the evolution and maintenance of cooperation in systems as diverse as ant-plant mutualisms, cooperative breeding birds, eusocial insects, and even cancer-forming tumour cells. Across a species-rich group of Neotropical catfish, we showed that partitioning across trophic levels combines with phylogeny to allow stable existence of Müllerian mimicry rings.

In applied ecology, our work led to key insights for habitat conservation, including biodiversity measurement in agricultural landscapes, validation of historical biological collections for application to climate change studies, and work on restoring and managing wetlands and salt marshes. We successfully applied 'alternative' biodiversity metrics such as functional diversity or endemism to better understand the contributions of species to communities, and used genetic markers to map North Sea cod spawning grounds and identify stock provenance to monitor illegal fishing. At the species level, we improved understanding of European migratory birds, hawksbill turtle breeding sustainability, management of island species, and created influential theoretical frameworks to assess the sustainability of hunting.

4) The **Plant Science** Theme continued to deliver key insights into several aspects of plant biology. Exploiting new technologies, our emphases were on two topics in which we already excel: (i) small, non-coding RNAs and (ii) molecular plant pathology. Our Theme was involved in the discovery of non-coding sRNAs, and further development of techniques for deep sequencing opened up ways to obtain comprehensive census data on sRNA populations. In plants, these affected traits ranging from fruit-ripening in tomato to sulfur stress responses in *Arabidopsis;* in this latter case, we showed that sRNA and its target gene were, unexpectedly, in different, neighbouring cells. The ubiquitous nature of sRNAs and the analytical power of our approaches were vividly shown in other target species; for example, we showed, with colleagues in the **Cells and Tissues** Theme, that particular sRNAs were associated with the onset of arthritis, and of a particular form of familial deafness. Our bioinformatic analyses also found wide application, with important inputs into *Nature* papers on the genomes of such disparate systems as fleshy fruit evolution in tomatoes, and butterfly wing pattern mimicry.

Research in Molecular Plant-Microbe interactions also benefited by genomic approaches. Thus, the REF period saw publications in *Science* and *Nature* on the whole genome sequences of the oomycetes *Hyaloperonospora arabidopsidis*, an obligate biotrophic pathogen of *Arabidopsis* (demonstrating evolutionary signatures to biotrophy), and of *Phytophthora infestans,* which causes blight, hence leading to the Irish Potato famine. Very recently, and rapidly, ash dieback fungus *Fraxinus excelsior* was also sequenced. Functional gene studies were also fruitful, as in the functional analysis of avirulence genes and effector proteins in the "secretome" in *Phytophthora.* Our data not only throw light on genes for pathogenicity, but also caught the public imagination, notably with ash dieback, where Facebookers from ~120 countries were enlisted to seek patterns

in DNA sequences by downloading the gaming app "*Fraxinus*".

Our work has allowed major gains in understanding how and why plants succumb to particular pathogens. Using genetics and advanced imaging techniques, we have a clearer picture of how Pathogen-Associated Molecular Patterns are perceived, and how the downstream signalling events lead to plant immunity. Analogous work on important pathogens, such as *Albugo,* the agent causing white rusts, revealed the basis by which its effector molecules interact with the host plant's immune system. We also extended our understanding of how host resistance genes work. For example, the *RPW8* gene that we had shown to confer resistance to fungal powdery mildew was found to be regulated by the plant's *14-3-3* gene, and we showed that the *COII gene* for jasmonate synthesis (and hence a major determinant of disease resistance) was important for the synthesis of octadecanoid aphid chemoattractants. Our work on *Arabidopsis* showed that the FeS protein INDH has a role in assembling Complex I, mediated by differential effects on the translation of mitochondrial polypeptides, with implications on the roles of INDH-like proteins in other organisms, from yeasts to man. The identification and introgression of newly found blight-resistance genes in potato was not just of scientific significance, but formed a platform for a series of TV appearances, radio interviews and lectures to allay public anxiety about GM food and crops.

Mechanisms for the development, promotion and dissemination of research

We nurture research excellence through mentoring, training, management, communication, admin support and strategic funding (more in **c. people**). Focused development occurs at personal levels through specific training / advice on management, technical skills, grant writing and paper publishing, proceeding either through the mentoring system, in Themes, or *ad hoc*. We run regular Grant Seminars, where approaches for successful grant applications (and those under development) are described. During the REF period, BIO established formal 'sifts' for all BBSRC, NERC and MRC applications. Each has a review committee comprising senior researchers, especially those with formal experience on RCUK funding panels. Applications are reviewed through an authentic process, with detailed feedback and final decisions on whether applications can be submitted. Notably, our success rates for BBSRC and NERC grants now surpass national averages: 39% for NERC and 35% for BBSRC grants. The Vice Chancellor writes a personal letter of congratulations to each researcher who wins a grant.

UEA runs a study-leave system, allowing researchers up to 6 months away from teaching and administrative duties to concentrate on tangible research deliveries. In the REF period, this allowed the development of new programmes and collaborations, large grants from BBSRC, NERC and Leverhulme, and major outputs in top-ranking journals. Study leave to Yu, for example, allowed him to form, then lead, the *Ecology, Conservation, and Environment Center*, a joint venture with the Kunming Institute of Zoology and the Chinese Academy of Sciences.

Open communication is key to sustaining a vital research environment. BIO sits at the heart of a large and vibrant life sciences campus, with several well-resourced weekly seminar programmes in almost constant operation, so a wide choice exists for engagement with emerging research by international leaders, from applied ecology (Sir John Lawton) to molecular biology (Sir Paul Nurse). BIO has a weekly, cross-Theme Open Seminar series, and an annual research Colloquium. Themes also have their own weekly research and postgraduate seminar slots. We actively support participation of junior staff at scientific conferences through a travel fund, typically ~£20K pa across the Science Faculty. BIO also provides strategic funds (typically £200K available p.a.) for agile investment in particularly promising or urgent projects, emergency staffing or resource to complete experiments, coverage of publication charges, or pump-priming for research activity and grants.

Multi- and inter-disciplinary interactions

All BIO Themes carry out inter-disciplinary research with other UEA Schools and NRP institutes. Three Alliances involving UEA, the Institutes and the NNU Hospital were initiated in the past 6 years, and BIO plays key roles in each. The research themes of ELSA, the *Earth & Life Systems Alliance* (*Biodiversity and Adaptation*; *Agricultural Transitions*; *Elemental Cycles*) map directly onto BIO's Organisms & Environment, Plant Science, and Molecular Microbiology Themes, now involving 4 joint pilot projects and 5 PhD studentships with BIO; the Head of ELSA (**Colin Murrell**, returned to UoA 7) houses his research group in BIO. The Food & Health Alliance (FAHA), focusing on biology of the gut and the role of diet in health, ageing and disease, has active involvement from our Cells & Tissues and Molecular Microbiology Themes. The Industrial

Biotechnology & Bioenergy Alliance was founded this year, and will build on Molecular Microbiology Theme, including discovery of novel natural product antibiotics in fungus-growing ant nests and development of bio-batteries using electricity-generating *Shewanella* bacteria. These Alliances are built on strengths in fundamental bioscience, and they fund small pilot projects, collaborations and PhD studentships, but their core remit is to achieve both academic and societal impact. H.M. Treasury invested £26M into the NRP in the March 2011 Budget which, together with funds from UEA, the EU Regional Development Fund and the Department of Business, Innovation and Skills, is creating new infrastructure for commercial development in the Life Sciences. We will soon see the completion of a 'Centrum Building' to house SME's on the Research Park, and a new £14M Enterprise Centre on UEA's campus, to facilitate commercial interactions by combining business activities in five major Themes: (i) encouraging innovation, (ii) stimulating enterprise, (iii) enhancing skills, (iv) promoting employment, and (v) supporting business.

Within BIO, we foster interactions by housing researchers in related disciplines close to each other; for example, the School of Environmental Sciences ecology researchers are adjacent to our organismal biologists, allowing productive collaborations in conservation. We share space with the Medical School in the Biomedical Research Centre which, for example, has encouraged our arthritis researchers to join with nutrition experts in a study showing the protective effects of diet on osteoarthritis development. Bioinformatics growth is fostered by siting molecular biologists close to colleagues from Computing Sciences, a link that was further cemented by appointing a research facilitator who was pivotal in the development of our widely used "small RNA workbench" suite of RNA seq analysis tools (http://srna-workbench.cmp.uea.ac.uk/).

Objectives and activities in BIO research over the next 5 years

The main objectives for BIO are targeted, selective growth in each Theme by; appointing high-calibre researchers and post-graduate PhD students, and by contributing to Norwich Research Park strategy in five areas covering biodiversity, food security, synthetic biology, industrial biotechnology / bioenergy, and gut health. Over the REF period, appointments were made in each Theme, surpassing our plans in RAE2008 (see **c. People**). Our research staff and PhD student recruitment was robust, enhanced by the recent £4M BBSRC Doctoral Training Partnership award held jointly with the NRP institutes, and the funding of our UEA-led £5M NERC DTP. We invest substantially in studentships, to the tune of £1M since 2009. We plan to grow our funding for studentships from national and international programmes (targeting MRC and Marie Curie initiatives) and charities (Arthritis Research-UK and British Heart Foundation in particular) as well as our growing links with China.

In terms of strategy that plays to our strengths and opportunities, we have six clear objectives:

1. Appoint new researchers in an initiative that combines strengths across the NRP with those at the nearby Easton College, and which exploits our position as 5th in UK for Agritech research (Witty review, Oct 2013), we will establish research leaders in the areas of food security, agri-intensification, ecosystem services and conservation biology.
2. Develop our expertise in molecular ecology and marine microbiology for understanding sustainability in the oceans, in collaboration with nearby CEFAS in fisheries research,.
3. Create a base for translational medical research in the new Medical Research Building, in collaboration with the Norwich Medical School and the NNUH.
4. Contribute in areas of diet and health, gut biology and microbiology, involving creation of a new Norwich Research Park Institute, *The Centre of Food, Health and the Gut*.
5. Participate with other UEA Schools (Mathematics, Environmental Science, Computing, Chemistry) in the formation of the research platform of the new School of Engineering, whose portfolio of research will embrace microbial systems for energy capture.
6. Recruit a synthetic biologist to metabolically engineer cells to yield useful products, such as biofuels and anti-infective agents, as part of a new Eastern Academic Research Consortium (ARC) involving UEA and the Universities of Essex and Kent.

c. People, including:

i. Staffing strategy and staff development

In RAE2008, we targeted six new Faculty positions in plant science, molecular ecology, microbial evolution, biology and biochemistry, and an expert in mouse models. We have greatly surpassed

these targets and, in 2010, exploited our close links with the John Innes Centre, via the "Synergy Lecturer Scheme". Here, UEA pays the salary of a Faculty member who is predominantly based in an NRP institute; s/he benefits directly from low teaching loads, and the resources and infrastructure within research-only institutes, while BIO benefits from formal interactions created by this sharing. Thus, we appointed **Janneke Balk** and **Jacob Malone** to plant and microbial sciences respectively. **Philip Gilmartin** was appointed Chair in Plant Molecular Genetics, and we appointed **Silke Robatzek,** working on cellular adaption in plant immunity, and **Dan Maclean** as bioinformatics team leaders in the Sainsbury Laboratory. We also expanded our mission to translational plant pathology with the creation of a group collaborating with the *Two Blades Foundation*, so **Peter Van Esse** and **Matthew Moscou** were appointed to develop fungus-resistant soybean and wheat, respectively. The Organisms and Environment Theme attracted **Martin Taylor,** a molecular ecologist with fisheries expertise, and two new NERC Fellows in ecology and evolution, **Simon Butler** (returned in UOA 7) and **Marco Archetti**, who were both offered permanent Faculty posts. The Molecular Microbiology Theme welcomed **Jonathan Todd** and **Andy Gates** who work on bacterial biotransformations of sulfur- and nitrogen-containing compounds. **Colin Cooper** was a joint appointment with the Medical School as Chair of Cancer Genetics. **Stephen Robinson** joined the Cells and Tissue Theme, as a mouse expert investigating mechanisms responsible for tumour angiogenesis. The Theme also hosts the Fight for Sight Fellow, **Tim Grocott**, working on eye development, and BBSRC David Phillips Fellow **Sam Fountain** who studies nucleotide signalling in the cardiovascular system.

Implementation of the Concordat to support career development of researchers

Recognising the importance of Research Staff in so much of what we do, UEA set up a Research Staff Working Group, chaired by the pro-Vice Chancellor for Research, and comprising senior staff and researchers from across UEA and the NRP. This Group steers career development strategies and monitors implementation. In 2012, UEA was awarded the European Commission's, HR Excellence in Research Award, recognising its commitment to professional, personal, and career developments of research staff, through alignment with the European Charter for Researchers, Code of Conduct for Recruitment and the UK Concordat to Support Career Development of Researchers. All twelve of the independent Research Fellows hosted in BIO in the past 10 years have been promoted to permanent Faculty positions, a testament to the efficacy of our approach.

Support for equality and diversity

In 2013, BIO was one of the first UEA School's to be awarded Athena Swan Bronze status, and we will apply for the Silver award in 2014. UEA's *Single Equality Action Plan* is proactively delivered by the Equality and Diversity Committee. A core of information on staff and student populations, developed by an Equality and Diversity Officer, maintains awareness and allows decisions to be sensitive to an equality perspective.

Arrangements for the effective development and support of the research work of staff

In addition to annual appraisals for all staff, BIO Faculty complete an annual Research Plan, discussed with senior management. BIO is especially attentive to early career researcher development. Mentoring is available for staff at any level, but a formal system applies for new staff who are mentored by a senior Faculty member, supporting their integration into BIO and the NRP. New Faculty must complete a 2 year course in the Centre for Staff and Educational Development after writing, with their mentor, a Personal Development Plan. Researcher management is achieved by balancing teaching and admin load against research and impact priorities. We concentrate individual teaching duties into one of two semesters, so that staff can focus wholly on research in the other. Our new staff are protected from significant teaching or admin while they establish their research programmes, and we prioritise strategic start-up funding and facilities to them, as well as a PhD studentship. Established staff who underperform in research are reviewed, and may decide (if exhibiting sufficient talent) to move to teaching-facing roles, allowing us to reduce teaching loads of more active researchers. Postdoctoral researchers participate in the Research Staff Forum, which aims to enhance career development, a goal shared by ResNet, a university-wide network of women researchers of all ranks and disciplines.

ii. Research students

Our vibrant research culture provides an excellent PhD student environment, over 200 of whom have graduated during the REF period. Our students have been first author on over 250 papers,

including influential outputs in *Science* and *PNAS*. Currently, 93 PhD students are in programme, of which ~15% are overseas. Important funders are: BBSRC (21%) and NERC (16%) DTP and CASE awards, with the remainder being funded by the University, NRP, EU, foreign governments and charities e.g. British Heart Foundation, Arthritis Research-UK, Anatomical Society, Humane Research Trust. Over the REF period, all of our returned Faculty have been PhD supervisors. PhD completion rates are well above the threshold stipulated by funding bodies. BIO is integral to current £4M BBSRC and £5M NERC doctoral training partnerships.

Doctoral training arrangements

BIO prioritises quality supervision and training of PhD students to equip them for future careers in research or other high-value positions. Evidence of our ability to nurture excellent postgraduates is demonstrated by BIO students taking up Lectureships / Fellowship during the REF period at the Universities of Groningen, Iceland, Imperial, Krakow, Sheffield, and UEA, as well as academically-related career paths such as: senior PR officer at the Society for General Microbiology, project management at the British Trust for Ornithology, programme manager at the pharmaceutical giant, *Schlumberger*.

Supervisors undertake training to comply with UEA's Code of Practice and we adhere to RCUK guidelines on PhD student supervision and training. Studentship distribution is contingent upon suitable resources in supervisors' labs, and projects that address strategic priority areas. On starting, all students attend induction (safety, administration, technical and IT) and must have a formal meeting with their supervisory team within two weeks, when the student's Personal Development Plan is mapped out. Subsequently, the team must hold a minimum of three formal meetings per annum to monitor progress. Written reports and presentations are delivered at each main meeting, and outcomes formally logged, centrally reported and evaluated by the Director of Postgraduate Research. All students receive generic training through the Faculty of Science Graduate School, fully endorsed by both BBSRC and NERC who have given us large DTPs to manage and deliver. Training programmes fit the guidelines of the Quality Assurance Agency for Higher Education and the Research Councils' Joint Skills Statement, consisting of a Science Faculty "Advanced Skills for PhD Students" programme, complemented by centrally-run units from the Centre for Staff and Educational Development. For the Personal Development Plan, each student selects at least two weeks of training per year from a choice of modules, including oral and written communication, statistics, enterprise, engagement and impact, career development and social dimensions of science. And, of course, all requisite project-specific skills are taught and developed in the research groups themselves. PhD students give at least 2 talks per year via a diverse set of seminar programmes, and funding exists for travel to international conferences.

Research student culture

To create a strong and integrated culture, BIO holds a lively annual PhD Colloquium where all students participate in talks or discussions, providing opportunities to disseminate to peers, and hone presentation and networking skills. Each Theme has its own PhD seminars; for example the Centre for Ecology, Evolution and Conservation (combining BIO and Environmental Sciences) runs an annual "Rebellion" organised by PhD students, where junior researchers speak alongside invited external plenaries. We fund PhD students to host lunches for external Open Seminar speakers, which have led to post-doctoral opportunities. BIO also supports research students to participate in national / international competitions such as the Biotechnology YES and iGEM. In addition to PhDs, we encourage undergrad summer students to our labs, many of whom go on to research careers. Last summer, for example, we hosted studentships funded by the Society of Biology, the Company of Biologists, the Association for the Study of Animal Behaviour, the Society for General Microbiology and the Biochemical Society.

Evidence of CASE awards and application of technology generated by students

Thirty-six CASE PhD studentships were awarded over the REF period to BIO, sponsored by 25 different companies, including *Inspiralis*, *Celltech*, *Pfizer*, *Schlumberger*, RSPB, Birdlife International, Institute of Zoology. For example, two CASE-funded BIO students worked in conjunction with *Oxitec Ltd*. to develop and test molecular constructs for "Release of Insects Carrying a Dominant Lethal", in medflies, running the first proof-of-principle trials to eliminate wild medfly populations. The project allows *Oxitec* to advance ambitions to bring this technology to the open market, while providing students with a rich training experience.

d. Income, infrastructure and facilities

Research income and financial management

UEA has recently overhauled its administrative structure through an Integration Project, resulting in an aligned, dedicated support for grant-funding, with individual grants being given coherent oversight, from preparation through to pre and post award administration for seamless support across each grant's life. BIO has generated £56.6M income through the REF period, 65% of which came from RCUK funders: for 147 BBSRC and NERC major project applications we achieved a 31% success rate, well above the national averages. Since 2008, our four Themes have applied for a total of 535 research grants over £10K, so far winning 160 of these (30%).

Quality of the research infrastructure and evidence of collaborative use

80% of our overall space is dedicated to research. At UEA, BIO is housed in 7,500m^2 space, over half of which is research-dedicated, highly serviced, CL2-standard space. A rolling programme of refurbishment exists, with almost all labs having been modernised in recent years, along with the 2005 build of the Biomedical Research Centre, with 2,200m^2 of high-grade research space. The Sainsbury Laboratory has another 2,000m^2 top-quality research accommodation. All recently built or refurbished space is open-plan, to facilitate active sharing of both space and equipment, and we designate lab space as multi-user for specific methodologies rather than being under the control of individual groups. For example, the Hewitt Molecular Ecology Lab and the Microbial Biochemistry Lab each house researchers from at least six different groups. A Central Support Services Laboratory provides generic technical support, including media prep, wash up, glassware and sterilisation, and there is a central Science stores carrying a wide range of routine consumables.

A distinct new feature of the NRP, which exemplifies the power of Research Park sharing, is our "Virtual Technology Centre" http://www.norwichresearchpark.com/researchfacilities/home.aspx). Here large equipment and facilities (including technical support) are accessible via one portal to all NRP staff. This unique resource brings together a huge range of up-to-date platforms including equipment for nuclear magnetic resonance and X-ray crystallisation robotics, fluorescence activated cell sorting, and proteomics and metabolomics facilities with state-of-the-art mass spectrometers. Within BIO itself, the Henry Wellcome Laboratory for Biomedical Cell Imaging provides imaging technology via conventional and multi-photon confocal microscopes, and image-processing facilities. Next generation sequencing and bioinformatics core services are provided by The Genome Analysis Centre. The Sainsbury Laboratory has in-house proteomics and its own next generation sequencing capability and a plant-specific high throughput confocal imaging system (OPERA). The Disease Modelling Unit, a 4000 cage, individually ventilated, transgenic mouse facility, occupies the top floor of the Biomedical Research Centre. This Unit also contains multi-photon intra-vital imaging and germ-free capabilities (both resourced by BBSRC) and the Wolfson Foundation-funded Emerging Pathogens Containment Level 3 suite. These are used extensively by researchers from the Institute of Food Research as well as our own microbiologists.

Within BIO, the £1M+ Controlled Environment Facility for insect, amphibian and fish research was completed in 2010, which has enabled new NERC and BBSRC funded research projects and high-impact papers in e.g. *Science* and *Current Biology*. Also in BIO is the Wolfson Bioenergy Laboratory, refurbished and extended in 2008 and equipped with a suite of advanced fermenters up to 90L capacity, that are intensively used by microbiologists both in BIO and in the School of Environmental Sciences. Significant contributions for new builds (e.g. Biomedical Research Centre) and refurbishments have come from sources including the Wellcome Trust, the Wolfson Foundation, the Humane Research Trust and Big C (a regional cancer charity); core equipment is renewed through on-going UEA central infrastructure and Science Faculty equipment funding, often matching competitive external bids.

e. Collaboration or contribution to the discipline or research base

Contributions to the discipline and research base

BIO staff play leading roles in a range of decision-making bodies, from society officers to government advisors, as the following examples show. **DJ Richardson** is a member of BBSRC Council. **Jones** sat on the BBSRC Technology Strategy Board, the Royal Society SC7 Election panel, and is a Board member of the European Plant Science Organisation. **Hutchings** and

Rowley were both on the Council of the Society for General Microbiology, and **Hutchings** edited SGM's *Microbiology Today*. **Gage** is Council member and Treasurer of the Association for the Study of Animal Behaviour. **Clark** served on Arthritis Research-UK grants committees, and is on the British Society for Rheumatology Heberden committee. **DS Richardson** is Advisor to the Seychelles Government. **Bourke** was president of the International Union for the Study of Social Insects and part of the UK Government's Science and Innovation Network on insect pollinators. **Gill** is president of the British Ornithologists' Union, a member of NERC Biodiversity and Ecosystem Services Sustainability Advisory Group, and on the All-party Parliamentary Group on Biodiversity. **Cooper** is a member of the Government's Prostate Cancer Advisory Group. **Kamoun** is a member of Plant Science and Environmental advisory boards in Holland, France and Germany, and the *Two Blades Foundation,* and President of the International Society for Molecular Plant-Microbe Interactions. **Wheeler** is Secretary of the British Society for Cell Biology. **Munsterberg** was on the Executive Committee of the British Society for Developmental Biology.

All our staff typically deliver at least 2 external research talks per year. We have also been busy as organisers of meetings. **Jones**: the 2010 Gordon Research Conference in Plant Molecular Biology. **Kamoun**: the 22nd and 30th New Phytologist Symposia in California and Paris, and Plant Pathogenomics Conference, Shenzhen, China. **Zipfel** and other Sainsbury Laboratory scientists organised an EMBO practical course on Plant-Microbe Interactions. **Hutchings** ran a *Streptomyces* meeting at the SGM this year. **Clark** regularly organised the basic science sessions in the British Society for Rheumatology annual conferences. **Munsterberg** organised a meeting of different Societies for Developmental Biology in France. **Gill** ran the European Ornithologist's Union annual conference this year, attracting 360 delegates from more than 30 countries to UEA.

Participation in the peer-review process and journal editorships

BIO staff have an above-average participation rate as external reviewers for RCUK grant applications. Many BIO staff have been members of grant committees including **Munsterberg, Kamoun, Edwards, Jones, Gilmartin**, **Hutchings** (BBSRC grant panels); **Gill, Bourke, Gage, Johnston, Davies, Chapman**, **DS Richardson** (NERC Peer Review College, four as Core Panel members); **Chapman** (Leverhulme Advisory Panel); **Edwards** (Scientific Advisory Board of Breast Cancer Campaign); **Cooper** (Chair of Tenovus); **Clark** (AR-UK Scientific Committee and Fellowships Committee); **Taylor** (EU Marie Curie panel); **Gilmartin** (DFG Excellence Initiative and ERA CAPS EU panels); **Kamoun** (BASF and INRA science panels); **Jones** (ERC junior investigator and Royal Society Dorothy Hodgkin panels).

All our staff have been active in peer review for journals, and most BIO staff are also board members of international journals including **Bourke** *Ecology Letter*s; **Davy** *J Ecology*; **Taylor** *Marine Biology*; **Gage** *Proceedings of the Royal Society B*; **Chapman** *Evolution, J Evolutionary Biology*; **Gill** *J Applied Ecology*; **Yu** *Methods in Ecology & Evolution*; **Hutchings** *Peer J;* **Todd** *Frontiers Microbial Physiology & Metabolism*; **Clarke** *Biochemical J.*; **Kamoun** *Plant Physiology, Molecular Plant Pathology*; **Robatzek** *Molecular Plant-Microbe Interactions, New Phytologist*; **Dalmay** *FEBS Letters, Planta,* **Gilmartin** *Nature Scientific Reports*; **Zipfel** *Molecular Plant Pathology, PLoS Pathogens;* **Jones** *Current Opinion Plant Biology;* **Hajihosseini** *Developmental Biology*; **Mayer** *Frontiers Vascular Physiology*; **Munsterberg** *Molecular Biology of the Cell*; **Edwards** *International J. Cancer*; **Chantry** *Molecular and Cellular Proteomics*; **Clark** *Arthritis Research & Therapy*; **Cooper** *British Cancer*.

Fellowships and other awards

Since 2008, BIO members won the following Fellowships: **Zipfel**, **Robatzek** (ERC), **Jones** (ERC Senior); **Archetti**, **Butler** (NERC); **Moscou** (Human Frontier Science Program); **Grocott** (Fight for Sight); **Fountain** (BBSRC David Phillips); **Gage** (Leverhulme). Also, **Gill** received the Marsh Award for Ornithology; **DJ Richardson** won a Wolfson Foundation award; **Kamoun** was elected to the Academia Europaea, and won the American Phytopathological Society Noel Keen Award, and the Royal Society Daiwa Adrian prize. **Kamoun** also became a fellow of the American Association for Advancement of Science, as did **Jones,** who also received the Stakman award from Minnesota, and was the Storer Lecturer at UC Davis and the Pirie memorial lecturer at Rothamsted.

External academic collaborations

Our research staff have extensive collaborative networks, with half of our 1000+ outputs over the

REF period co-authored with overseas groups, institutes, government bodies and NGOs.

In plant sciences and molecular microbiology: **Kamoun** has a productive collaboration with Ryohei Terauchi in Iwate, Japan, which has resulted in a series of influential papers including Abe et al. (2012) *Nature Biotechnology*, and the award of the Royal Society Daiwa Adrian Prize for collaboration between Japanese and British teams. **Dalmay** led a BBSRC-funded collaboration with Nottingham on tomato short RNAs and fruit development, leading to a key output by the Tomato Genome Consortium on fleshy fruit evolution in *Nature* (2012). **Dalmay** also worked with Cambridge to generate high impact papers in *BMC Genomics* and *Nature* on the genomics of butterfly wing patterning. **DJ Richardson**, **Rowley** and **Gates** are partners in the Nitrous Oxide Research Alliance Marie Curie Training Network (NORA) aiming to understand microbial influences on atmospheric nitrous oxide, and mitigation strategies.

In biomedicine: **Munsterberg**, through her FP6 initiative, joined workers from the Max Planck and Weizmann Institutes to produce outputs in *PNAS* and *Developmental Biology*, and further grant funding on skeletal muscle development. **Wheeler** combined his abilities in *Xenopus* development with Harvard Medical School to show that the drug Leflunomide affects neural crest development and inhibits melanoma tumour growth (White et al (2011) *Nature*), now being further developed by a multi-national.

In organismal biology: **DS Richardson** leads the Seychelles Warbler Study Group, combining 15+ researchers from Groningen and Sheffield Universities with Birdlife International and Nature Seychelles into a long-term natural study system that has produced outputs in top tier journals, as well as rescuing this species from near extinction. **Gill** collaborates with Cambridge and Iceland, plus a large force of volunteer birdwatchers, to understand how avian population regulation occurs across entire migratory ranges, and outputs published in *Nature*. **Taylor**, under the Brazilian "Science without Borders" scheme, joined with the Universidade Estadual Paulista to produce an influential *Nature* output on mimicry evolution using *Corydoras* catfish system. **Davies** worked with macro-ecologists at Aarhus, Cambridge and Exeter to show, in *Science,* that vertebrate species endemism is concentrated in areas where velocity of past climate change was mitigated by topoclimatic gradients.

Responsiveness to national and international priorities and initiatives

Jones co-authored the influential Royal Society "*Reaping the Benefits"* report on global food security and agricultural intensification (http://royalsociety.org/policy/publications/2009/reaping-benefits/. **Bourke** won funding from the Insect Pollinators Initiative (BBSRC, Defra, NERC, Scottish Government, Wellcome Trust) to measure habitat structure in relation to bumblebee distributions, an important factor in decline of pollinators. **Chapman** and **Gage** were part of the NERC AGRIFOOD initiative, combining knowledge of insect behaviour and ecology with *Oxitec*'s GM technology for sterile insect release.

Under the auspices of "European Union FP6" **Edwards** led a €10.4M programme in cancer (*Cancerdegradome*), **Dalmay** a €12M programme in Small RNAs (*Sirocco*), and **Munsterberg** was a member of the €12M MYORES project on muscle development, function and repair. **Taylor** is PI on two EU FP7 initiatives (FishPopTrace and AquaTrace, total €7M) to apply molecular techniques to fisheries sustainability and traceability. **Dalmay** was also in two ERA-NET projects, one with German and Portuguese colleagues on the role of sRNA in stress responses and one with Finnish and Dutch labs on this class of molecules in an important timber tree, the Poplar. **Jones** runs an ERA-CAPS project on "Downy mildew effectoromics" with Warwick, Utrecht and Köln, and was integral to a large, collaborative Human Frontier Science Program on plant sciences. **Davy's** ongoing work on salt marsh and coastal realignment, and the economic need to respond to sea-level rise, responding to the EU Habitats Directive, and published in leading applied ecology journals.

DJ Richardson and **Clarke** receive long-term funding from the US Department of Energy in collaboration with the Pacific Northwest National Laboratory to research microbial energy transfer. **Yu's** leadership of the Ecology, Conservation, and Environment Centre, a joint venture with the Kunming Institute of Zoology and the Chinese Academy of Sciences, has attracted £1M+ of overseas funding to allow molecular barcoding of biodiversity in unexplored systems and areas.