Institution: Durham University
Unit of Assessment: UoA5 – Biological Sciences

a. Overview

The vision for bioscience at Durham is to exploit multidisciplinary research to solve challenges in cell biology and biological chemistry, plant molecular science, ecology and adaptation. This is delivered through research groupings in: *Adaptation and Environment*, *Biomolecular Interactions*, *Cell Structure*, *Development & Regeneration*, and *Crop Improvement Technologies*, each with flexible membership (**Table 1**). Durham University delivers its research and teaching through discipline-based Schools and Departments, and its bioscience research in this UoA is coordinated by the School of Biological and Biomedical Sciences (SBBS).

Durham University strongly encourages multidisciplinary research. The University's nine Research Institutes bring together staff from different disciplinary Departments, either virtually or in shared space, but with overarching research questions that all are committed to address. The three University Research Institutes that are most relevant to the biosciences are the *Biophysical Sciences Institute* (involving, in addition to SBBS, staff from Physics, Chemistry, Mathematics and Engineering & Computer Science); the *Durham Energy Institute* (also involving Earth Sciences, Geography, Chemistry, Physics, Engineering & Computer Science and Business School); and the *Institute for Hazard, Risk and Resilience* (also involving Geography, Applied Social Sciences and Earth Sciences). Thus the School shares joint laboratory space and infrastructure with groups in Chemistry, Physics, Mathematics, Earth Sciences, Geography and Engineering & Computer Science. The high quality of all of Durham's departments fosters an ideal environment for discovery across discipline boundaries.

Our five Research Groupings (**Table 1**) bring together investigators to tackle common problems working across traditional methodological boundaries and studying a range of organisms. The research in these five groupings is supported by state-of-the-art infrastructure in bioimaging, plant and animal growth facilities, genomics and proteomics, and a new plant pathology suite, each supported by Experimental Officers and technicians, facilitating staff access to the latest experimental approaches.

Ensuring our research makes a difference to people's lives and the economy (has impact) is an important component of our research strategy, either through award-winning spinout companies (such as *ReInnervate Ltd*, developing and selling products for three-dimensional animal cell culture) or via strategic relationships with multinationals such as Procter & Gamble, from whom Durham won its 2012 *Global Business Partner of the Year Award* (this partnership was presented to the US congress in February 2012 as the exemplar for industrial engagement with academia). Our research informs policy at national and international level, particularly in the environmental and conservation sciences (see Impact Case Studies). SBBS's oversubscribed undergraduate degree programmes (minimum entry requirement AAA) are research-led, and provide quality postgraduate students to Universities around the world.

Our research strategy is embodied in a 5-year rolling plan, led by the Head of School, Director of Research, Director of Education and Director of Infrastructure, and is approved by the Faculty and the University Research Committees as contributing to and consistent with the overall University research strategy. This plan guides our academic appointments strategy, grant applications, PhD student recruitment and bids for necessary equipment and infrastructure.

Delivery of the research strategy is coordinated by the School's *Research Management Committee*, which manages the allocation of PhD studentships, promotes applications for research leave and allocates resources for research equipment and seedcorn funding. The Research Management Committee is chaired by the Director of Research, and includes the Director of Postgraduate Studies; Director of Infrastructure; the leaders of each of the five Research Groupings (**Table 1**); the Facilities and Business Manager, who is responsible for managing research facilities and interacting with companies who may wish to establish collaborative links or require services; the Senior Technician ('School Superintendent') who is line manager for SBBS technical staff; and a postdoctoral representative. Postgraduate students express their views on research and other issues via the Postgraduate Committee (see below).

b. Research Strategy

Our bioscience strategy has been to **deliver the vision** for our research by building critical mass and infrastructure in five specific areas of strength, targeted to major national challenges, a number of which coincide with those laid out in RCUK strategy documents - *Adaptation and Environment*, *Biomolecular Interactions*, *Cell Structure*, *Development & Regeneration* and *Crop Improvement Technology* (**Table 1**). These are essentially as laid out in RAE 2008. In four of the Research Groupings, *Biomolecular Interactions*, *Cell Structure*, *Development & Regeneration* and *Crop Improvement Technology*, emphasis has been placed on the use of model systems, including Arabidopsis, mouse, *C. elegans*, zebrafish and yeast, but increasingly we are translating the basic findings into application and impact. In the fifth theme, *Adaptation and Environment*, we have used a variety of methodological approaches, from genomics to computational modelling. These developments have been underpinned by new infrastructure, new staffing and studentships (see below). We have a further ten academic staff to appoint from 2014 to further develop our research strategy, building on current strengths and our strong industrial links. As part of this strategy, we will develop a cross-cutting *Centre in Industrial Biotechnology* to ensure delivery of impact from each of our five themes, with a new physical building established in partnership with industry, including Procter & Gamble.

Table 1	
Research Groupings	**Research Interests**
Adaptation and Environment (Baxter, Hoelzel, Huntley, H Knight, M Knight, Lindsay, Richards, Stephens, Willis)	Adaptation in response to environmental change, particularly global climatic change and anthropogenic habitat alteration; role of evolution in shaping species relationships with their environment; the role of behaviour in modifying individual variation; environmental policy development.
Biomolecular Interactions (Benham, Cann, Chazot, Chivers, Denny, Gatehouse, Goldberg, Grellscheid, Lindsey, Liu, Pohl, Robinson, Schroeder, Walmsley, Weinkove, Yeo)	Nature and role of interactions between biological macromolecules (protein/protein or protein/nucleic acids) and protein-ligand interactions.
Cell Structure (Bashir, Goldberg, Hussey, Hutchison, Karakesisoglou, Maatta, Quinlan, Yeo)	Analysis of animal, plant and yeast cytoskeletal, nuclear and cell membrane dynamics in normal or pathological conditions; use of sophisticated microscopy to analyse cellular architecture of diverse organisms at the ultrastructural level and examine fundamental processes such as cellular asymmetry, cell migration, cell division and cellular signalling.
Development & Regeneration (Bashir, Goldberg, Hole, Jahoda, Karakesisoglou, Maatta, Przyborski, Weinkove)	Analysis of embryo tissue development and adult tissue repair and regeneration, to understand basic cellular mechanisms and develop applications in tissue engineering.
Durham Centre for Crop Improvement Technology (Bothwell, Brennan, Cann, Chivasa, Etchells, Gatehouse, Hussey, H Knight, M Knight, Lindsey, Liu, Pohl, Robinson, Sadanandom, Slabas; Beeby, Steel, *Chemistry Dept.*)	Application of fundamental plant molecular and cell science to understanding the genetic basis of important traits in crop plants, and development of new traits through links with end users.

While most of the research effort is on long-term basic research, we do also carry out some shorter-term research projects. This shorter-term research is typically in collaboration with industry, with examples in bioimaging - ***Maatta, Goldberg and Hawkins*** with Procter & Gamble; effects of potassium minerals on plant growth and development - ***Lindsey*** with Sirius Minerals; control of crop seed germination - ***Sadanandom*** with Tozer Seeds. Shorter-term science supports part of our strategy for industrial engagement and impact in the wider community, by offering research expertise to companies that may lack particular skills, research facilities or insights into biological problems. Our longer-term research is supported principally by RCUK, the major biomedical

charities, UK Government and the EU, but also often in collaboration with industry, through LINK and IPA funding (see 'income', below).

Infrastructure has been put in place over several years to support the research strategy, encompassing programmes from molecules to landscapes – such as in bioimaging, proteomics, Next Generation Sequencing and bioinformatics (supporting cell and molecular biology, population genetics and molecular ecology), high-performance computing and environmental monitoring technologies (supporting climatic change research). These technologies are cross-disciplinary, and since RAE 2008 the emphasis of our research strategy has been increasingly across traditional boundaries.

Each *Research Grouping* is led by a relatively early career staff member, to provide opportunities for engagement in research strategy at all levels of academic staff. The role of these groupings is many-fold - they act as peer review bodies for early stage grant ideas, hold regular research discussion meetings or journal clubs, and suggest seminar speakers. They have led to a number of collaborative grant applications between PIs - e.g. ***Cann*** and ***McLeish (Physics)***, ***Pohl*** and ***Edwards (now York)***, ***Pohl*** and ***Denny***, ***Denny*** and ***Steel*** (***Chemistry***), ***Goldberg*** and ***Hutchison***, ***Hussey*** and ***Lindsey***, ***Slabas*** and ***Lindsey***, ***Lindsey*** and ***Liu***, ***Slabas*** and ***Schroeder***, ***Knight*** and ***Knight***, ***Baxter*** and ***Knight***, ***Baxter*** and ***Huntley***, ***Hoelzel*** and ***Huntley***, ***Robinson, Pohl and Hess (Chemistry)***, ***Robinson, Chakrabarti (Mathematics)*** and ***Liu***.

It is recognized that there are enormous gains to be achieved by establishing a culture of multidisciplinary science, whether across laboratories within SBBS (via the *Research Grouping* structure), across departments at Durham via the Institutes and Centres, or with external academic or industrial partners (illustrated in **Fig. 1** and discussed in more detail in section (e) below). Support for developing multidisciplinary research programmes is through the provision of studentships and seedcorn grants, for example, for which any PI can apply.

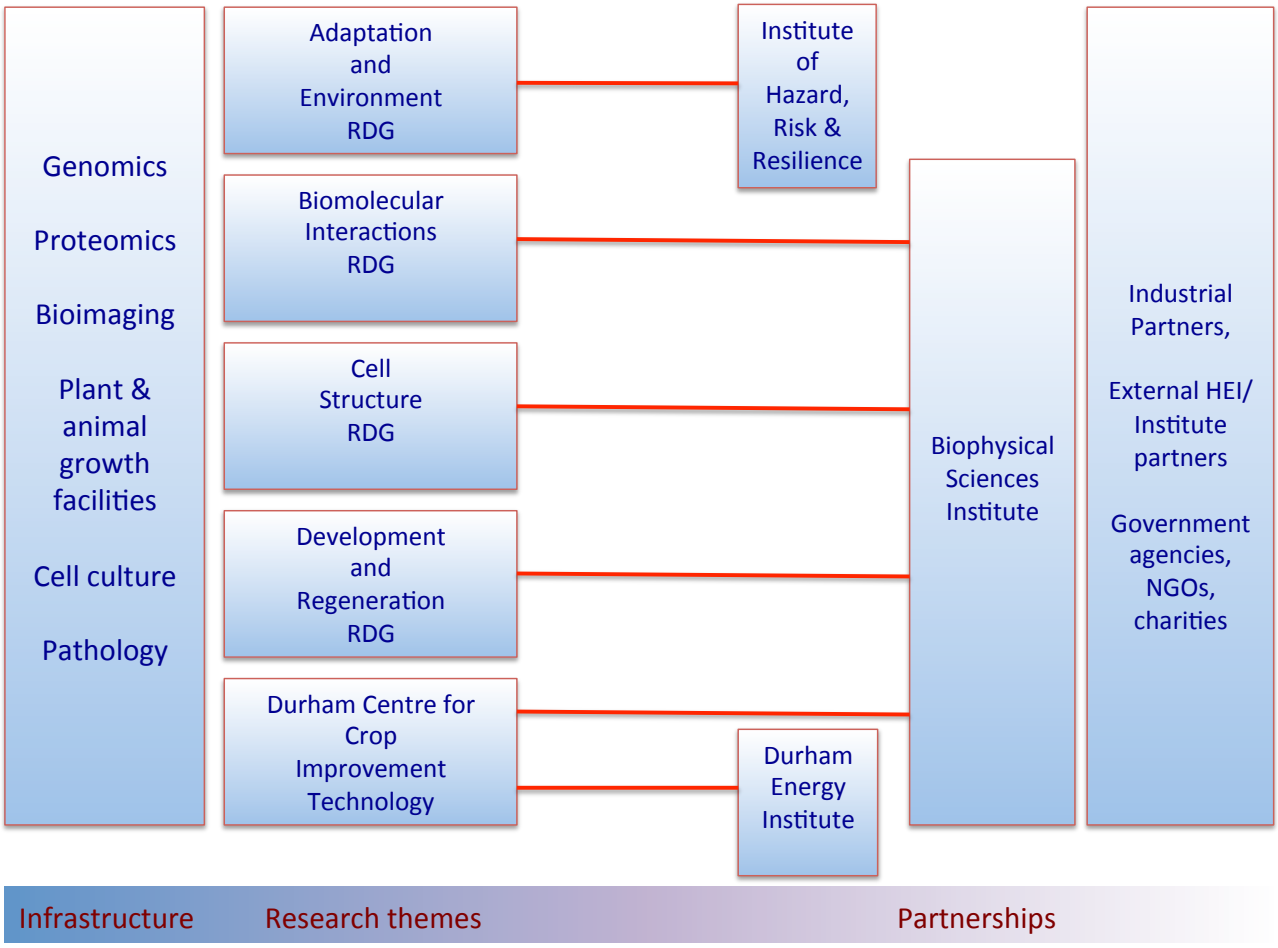

Fig. 1. Research structure organization - links between SBBS Research Themes and partners internal and external to Durham

The Durham Centre for Crop Improvement Technology (DCCIT) was founded in 2010 in order to direct the School's research strength in plant science towards major challenges, especially food

security and industrial plant biotechnology. DCCIT integrates plant genetics, cell biology, microbiology and biochemistry with Durham's expertise in chemistry, physics, mathematics and engineering to develop new technologies for crop improvement. DCCIT is evaluating the factors that limit crop production and coordinating research that targets the foremost challenges. Current DCCIT research emphasises 2 main areas: (1) crop protection/yield-improvement and (2) industrial plant biotechnology. DCCIT is coordinated by a Director and Deputy Director, and activities are managed collaboratively by 17 member PIs. A key part of the DCCIT strategy is to establish collaborative research programmes with the agricultural biotechnology and seed industry, detailed in Section (e) below.

DCCIT has some particular highlights from the REF period, which build on the strategy articulated in our RAE 2008 Environment document. Integrative plant science is an established and increasingly flourishing area of research emphasis at Durham, contributing 188 of the 582 papers published by SBBS staff, with 16 outputs in *The Plant Cell* and *The Plant Journal* during this census period. For example, collaborating with bio-mathematicians and exploiting our superb facilities for imaging living plant cells (in the multidisciplinary *Durham Centre for Bioimaging Technology*), ***Hussey*** has described how plants assemble their unusual cytoskeletal scaffold for cell division, the phragmoplast (*Current Biology* 2011 **21**:1924-30), and discovered the connectors which attach the plant cytoskeleton to cell membranes (*Current Biology* 2012 **22:** 1595-1600).

The Biophysical Sciences Institute (BSI) was created in response to the ever-increasing need to carry out research that crosses the boundaries between biology and the physical and mathematical sciences. Its members are drawn from University Departments across the Science Faculty, as described above. Many of today's major biological challenges, such as unraveling the molecular basis of cell function and crop productivity, and understanding the effects of climatic change, demand this multidisciplinary approach.

A track record in directing multidisciplinary research is also a major factor for new staff recruitment. For example, appointed in 2011 to work in our *Bioactive Chemistry* suite of laboratories embedded within the Department of Chemistry and supporting our initiative in industrial biotechnology, ***Robinson*** has described in research articles and reviews how cells help proteins to acquire the correct metal cofactors and (perhaps an even greater challenge) to avoid the wrong metals (*PNAS* 2012 **109** 95-100, Faculty1000 recommended; *Nature* 2008 **455** 1138-42, Faculty1000 recommended; *Nature* 2009 **460** 823-30, plus linked *Nature*-podcast, *Nature* 2011 **475** 41-42). The appointment of ***Chivers*** further supports this initiative.

The Durham Energy Institute (DEI) also involves many Departments across the Faculties of Science and Social Science, and brings together research in energy, from photovoltaics and fusion energy to social aspects. The contribution from SBBS is in the area of developing new plants and algae for biofuels and industrial biotechnology, in part in collaboration with the Departments of Earth Sciences (***Lindsey and Greenwell***) and Chemistry (***Lindsey and Whiting***), and also with industry (***Slabas*** and the Plymouth Marine Laboratory with Harvest Energy). Two new appointees (***Bothwell***, ***Etchells***) work in areas of plant science directly relevant to the bioenergy area (algal biofuels and cell wall biology, respectively).

Ecological and environmental research has developed new links with Durham's *Institute for Hazard, Risk and Resilience* (IHR^2), which is home to the *Durham Climate Change Network*. Highlights include, for example, ***Baxter's*** discovery of a dramatic switch in carbon capture by the Arctic tundra due to changes in the rates of infection by a fungal pathogen, because certain plants become more susceptible under snow (*Nature Climate Change* 2011 **1** 220-23). Virulent versus avirulent molecular interactions between plants and fungal pathogens are also a focus of research within *DCCIT*, for example by ***Sadanandom*** (*Nature* 2009 **461** 393-98; *PNAS* 2010 107 9909-14).

A new build is planned to house a multidisciplinary research hub focused around our research effort in industrial biotechnology, representing a further step towards realizing the aspirations of the BSI and DEI. Through the activities of all of the Institutes and Centres, Durham is assembling multi-skilled teams equipped to develop technologies and methodologies to solve outstanding questions in cell biology, plant and microbial science and ecosystems biology.

A lively research culture is promoted by School and Research Institute (BSI, DEI etc.) seminar programmes. Recent seminar speakers include Professors Rico Coen FRS (John Innes Centre), Prof. Jonathan Jones FRS (Sainsbury Laboratory, Norwich), Prof. Paul Birch (Dundee), Prof. Thomas von Zglenicki (Newcastle), Prof. Martin Warren (Kent), Prof. Alistair Hetherington (Bristol), Prof. Kathryn Ayscough (Sheffield), Prof. Pat Monaghan (Glasgow), Prof. Chris Thomas FRS (York),

Prof. Rory Wilson (Swansea). The postdocs and postgrads organize their own weekly seminar programme, with financial support from external sponsors. A one-day Annual Research Review is held – this is an AwayDay for academic, research and technical staff and research students, during which research strategy is discussed, and examples of current excellent research are presented. This helps consolidate our research culture.

The School has attracted sabbatical and short-term visitors from a range of countries, including India, China, Spain, Brazil, Austria, Belgium, Germany, Czech Republic, South Africa, Mauritius, Sri Lanka. Sabbatical visitors are provided with office space, and IT and laboratory access and contribute enormously to the research diversity and life of the School. They form the basis of new joint research projects and publications, such as between Lindsey and Escobar (Spain), Yang (China), Gheysen (Belgium); and Hussey and Coupland (Germany), Zarsky (Czech Republic).

c. People, including:

I. Staffing strategy and staff development

Staffing Strategy: School staffing policy aims to promote our research strategy by ensuring that we appoint, support and retain staff of the highest quality; and also to develop staff to support the UK and international science base. Since 2008 we have made targeted appointments in areas of strategic importance, notably in plant and microbial molecular sciences (***Robinson***, ***Sadanandom, Bothwell, Chivers, Brennan, Chivasa, Etchells***), in *C. elegans* (***Weinkove***), and in systems and computational biology (***Liu, Grellscheid***). Appointments that support multidisciplinary research with Chemistry, Mathematics and Physics are becoming increasingly important for us, exemplified by the appointments in molecular biochemistry and systems biology. We have also appointed two new Experimental Officers to support our Bioimaging and Protein Biochemistry facilities respectively, and a PhD-level Facilities Manager to oversee the successful management and cost-recovery mechanism for a sustainable core infrastructure. We see as essential the establishment of more Experimental Officer-level support staff, to provide continuity of research expertise within the School and to provide an improved career structure for post-doctoral researchers. Research support staff have undertaken specialist training in: aspects of molecular biology and proteomics; automated DNA sequencing; cDNA microarray technology; and EM gold and *in situ* hybridization.

New academic staff members are mentored by an experienced colleague during their probationary period, and given relatively light teaching and administrative loads. Two RCUK Research Fellows have moved to permanent scientific positions during the REF period (***Ohlemuller*** to a Lectureship, first at Durham, then at Otago, ***Liu*** to a Senior Research Fellowship at Durham), and some Academic staff have moved to senior positions elsewhere (***S Lindsay*** - Chair, London School of Tropical Medicine and Hygiene, though has since returned to Durham; ***P Gilmartin*** - Dean of Science at UEA; ***R Edwards*** - Chief Scientist, Fera).

All Academic staff and independent fellows develop Personal Research Plans (PRPs) that are reviewed annually with a designated senior colleague (a 'mentor') to discuss goals on current projects, and ambitions and opportunities for the future. All junior staff are required to attend the PG-CAP course on training to teach. They are also provided with training modules on student supervision, running research projects and a mentored programme on raising research funds. Durham University has won national awards (2009 *Outstanding Support for Early Career Researchers* award from Times Higher Education) for these activities, modules that are also made available to PDRAs and other early career researchers. Applications to new appointments are encouraged from all backgrounds and races, and from women in particular. We are committed to equality and diversity issues and support this via e.g. family-friendly flexible working hours. The Department has Athena Swan Bronze, and is applying for Silver, status. We have 5 female members of academic staff and a further 18 permanent female research support staff. We have an internationally diverse staff (both fixed term and permanent). Our permanent staff originate from: the UK, Australia, China, Finland, Germany, Greece, Poland, Singapore, Ukraine, Canada and the USA. Our current postgraduate population originates from 12 countries and we regularly host summer research students through the IAESTE scheme. Our 5-year rolling strategic plan provides the opportunity to identify new staff requirements, ensuring a sustainable development programme.
PDRAs and Research Fellows: A *Research Staff Forum* exists to help PDRAs and other RAs and allow them to engage with the School Management. We implement the **Concordat for post-doctoral researchers**, who are supported in their career development through a mentoring system underpinned by an Annual Staff Review (ASR), during which their aspirations are discussed and

advice given. They are encouraged to participate in career development courses laid on by Durham University (these include courses on 'How to Write Research Papers', 'How to Write Successful Grant Applications', 'How to Manage a Research Group', 'Research Ethics', IT training and presentational skills amongst several others), with needs identified in their ASRs. They are also encouraged and assisted to apply for prestigious Fellowships, Lectureships or similar positions. For example, ***Dr. Andrei Smertenko*** has moved to a joint Assistant Professorship at Washington State University (Pullman) and Senior Lectureship at Queen's University, Belfast; ***Dr. Mike Deeks*** to a Lectureship at Exeter University; ***Dr. Stuart Casson*** has been awarded a Lectureship at Sheffield University, following postdocs at Bristol; ***Dr. Steve Chivasa*** has been awarded a 5 year independent Fellowship at Durham; ***Dr. Steve Chivasa*** has been awarded a 5 year independent Fellowship at Durham; and ***Dr. Danielle Battle*** has won an Australian Endeavour Fellowship Award to work at the Garvan Institute of Medical Research, Sydney (2012-13).

Research Fellows are appointed on a 'Tenure-track' model, in areas that support existing research strengths in the School. Promising candidates for Fellowships are identified and their applications are encouraged and supported (e.g. ***Liu, Ohlemuller*** – RCUK Fellows; ***Brennan, Chivasa, Etchells, Grellscheid*** – Durham University Fellows). Fellows are provided with every assistance in becoming established as independent PIs, in preparation for appointment to an academic position (at Durham or elsewhere), and are set clear targets at the beginning of their fellowship – a mentor (a Professor) provides advice on research progress/strategy, and assistance with grant applications and publications. Previous Fellows have taken permanent positions either in academia or Industry - e.g. Simon Warner (BBSRC David Phillips Fellow), group leader at Diversa, San Diego; Federica Brandizzi (BBSRC David Phillips Fellow), PI at Michigan State University; Paul Emerson (MRC Fellow), Technical Director of the Trachoma Program, Carter Center, Atlanta; Sean Twiss (NERC Fellow), Lectureship at Durham; Junli Liu (RCUK Fellow), Senior Research Fellow at Durham and Ralf Ohlemuller (RCUK Fellow), Lectureship at Otago.

c. II. Research students

We have an active Masters (MSc) by Research programme, in which students spend a year working towards a dissertation through a research project. Masters students have more than tripled during the REF period, from 5 (2008-09) to 17 (2012-13), and more than 90% go on to study for a PhD, either in Durham or elsewhere. During the REF period we were awarded a BBSRC DTP (2012-2015, 15 PhDs plus 5 Research Experience Placements per year), in partnership with Newcastle and Liverpool Universities. The number of studentships was matched by the participating Universities, making a total of 30 per year, shared across the institutions. BBSRC students take a 1+3 programme, in which they undertake a MRes programme in the first year, which includes taught modules and a research project, followed by the 3 year PhD programme. We have also been awarded a NERC DTP (12 students, from 2014).

Management of training at School level is carried out by the Postgraduate Committee, chaired by the Director of Postgraduate Research. The School provides specific skills training in state-of-the-art research techniques, delivered through a combination of techniques workshops and the interaction of students with their supervisors, peers and co-workers in the laboratory or field environment. Therefore research students are trained in a lively environment with a strong research culture, and are exposed to many of the latest research technologies. Throughout the first 20 weeks of study, cell and molecular biology students gain expertise in the most exciting and powerful modern research techniques. They attend a series of half- to one-day training sessions on 'Post-genomic Technologies', covering: experimental design and data analysis; animal and plant cell culture; protein preparation and proteomic analysis; RNA preparation, microarray analysis and RT-PCR; cloning and sequencing; transgenesis; confocal and deconvolution microscopy; electron microscopy; structural biology; and bioinformatics. Informal training (delivered by trained support staff) is provided as required for more advanced technologies, such as bioimaging. Whole organism biology PG students attend training in relevant research technologies, including GIS, GPS and environmental monitoring, as well as in identification skills, statistics and research methods, with the option also of attending molecular biology courses.

Durham University Graduate School provides training in more generic research skills for all PG students (preparing for doctoral studies, presentational skills, project management, IP, bioethics), and also manages and monitors student performance, using feedback obtained from students as a result of the University annual progress report system. All PG students make regular presentations of

their work to their research group and to a School audience, which provide critical forums for discussion. This combination of formal and informal training is used to ensure that the student has understanding of relevant research methodologies and techniques and their appropriate application.

The programmes of research seminars (typically 2 per week), with visiting speakers of international standing (see examples in section (b) above), form the basis for maintaining the students' knowledge of recent advances in their area of research – attendance is compulsory for postgraduates. Students present their work to as wide a forum as possible, through publications (ca. 72% of publications in the REF period have students as co-authors) and poster or oral presentations at national and international scientific meetings.

Students are encouraged and supported to attend international conferences and workshops (examples include Gordon Conferences, SEB meetings in Marseilles, Prague, Salzburg, Valencia) and many present talks and posters, to promote their thesis work. Recent students have won meetings prizes and awards, including the for example 1st poster prize at the SET for Britain event at the Houses of Parliament 2008 (Saher Mehdi), FESPB Young Scientist Award 2008 (Stuart Casson), SEB Plant Section Poster Prize, *Valencia 2013* meeting (Stephanie Johnson) and Fairfield Prize for most innovative student research presentation at the *Biennial Conference on the Biology of Marine Mammals*, Tampa Florida, 2011 (Ross Culloch).

d. Income, infrastructure and facilities

Research income: Our strategy for income generation has been to diversify our target funding agencies. Research grant spend during the REF period has totalled more than £21 M, with the majority (>£11 M) from UK Research Councils, but also from the EU, charities, UK Government. This amounts to an average of more than £500,000 per FTE research active staff member. We have also engaged industry, both directly (over £2M) and in collaborative RCUK projects - during the REF period we have secured two BBSRC LINK grants (£2M, ***Slabas*** with Harvest Energy and the Plymouth Marine Laboratory, £1.2M ***Hutchison, Maatta, Karakesisoglou, Przyborski*** and ***von Zglinicki*** (Newcastle) with Procter & Gamble), and two IPAs (***Robinson***, with Procter & Gamble, and with Syngenta). This supports a current cohort of 45 research assistants. There are also significant levels of non-HESA income, through industrial collaborations and consultancies. Examples during the REF period include projects with Sirius Minerals (***Lindsey***, £60,000), Procter & Gamble (***Maatta***, ***Goldberg*** and ***Hawkins***, £80,000); Cambridge Research Biochemicals, £40,000; and Syngenta (***Sadanandom***, £80,000). There has also been substantial investment in our three spinout companies, totally ca. £9.5 M, supporting the development and exploitation of our basic research (see *Section e* below and our *Impact Template*). The appointment of new academic staff and Fellows has been strategically targeted to areas of research focus, and these new staff have generated over £4M of external grant income during the REF period.

Infrastructure and Facilities: The School of Biological & Biomedical Sciences (SBBS), where most biological research is carried out at Durham, occupies purpose-built accommodation, opened in 1994, with *The Integrative Cell Biology Laboratory* (ICBL), housing state-of-the-art cell biology laboratory facilities, added in 2002. SBBS therefore contains modern and high quality research facilities supporting a wide range of research projects, enabling our strategy of working across scales from molecules to landscapes. A team of 13 permanent research technicians, 3 Senior Demonstrators, 3 Experimental Officers and a Facilities Manager provide direct support for research and ensure the facilities are accessible to all. Some staff (***Cann, Chivers, Denny, Przyborski, Robinson, Yeo, Pohl***) occupy space in the *Centre for Bioactive Chemistry*, part of the multidisciplinary BSI and physically located in SBBS "*Embedded-Laboratories*" within the Chemistry Department (5 minutes from SBBS). This supports our strategy of promoting productive interaction at the interface between biology and chemistry and has served as a test-bed for the Embedded-Laboratory model, which we have found to be an effective mechanism to match the challenges of multidisciplinary research. For example, new recruit ***Chivers*** has worked at the Bioinorganic Chemistry interface to discover nickel sensing RcnR (founder member of a new family of metal-sensors), and to define its native metal-coordination site by spectroscopic methods including EXAFS (*J Am Chem Soc*. 2008 130: 7592-606, *J Am Chem* 2012 134: 7081-93). He is now ideally placed to collaborate with chemists (including ***Parker, Hess*** and ***Williams***) and biologists (such as ***Robinson, Pohl*** and ***Walmsley***) with complementary interests in the cell

biology of metals and hence with matching infrastructure needs (for example in ICP-MS, anaerobic protein handling and spectroscopic methods for advanced protein characterization).

The ICBL houses genomics and proteomics infrastructure, and success in project grant funding has been supplemented by successful infrastructure bids totalling more than £4M since 2008, underpinning research strengths in plant and animal cell biology and environmental science. Our *BioImaging Centre* includes TIRF and spinning disc confocal microscopy, live cell imaging, digital TEM and field emission SEM, recently upgraded through £1.2M investment. These facilities are supported by a suite of preparative equipment for traditional and cryopreservation techniques. A cDNA microarray workstation with laser-capture microdissection allows transcriptome studies at single cell resolution, supported by in-house automated DNA sequencing and real-time PCR. We have recently been awarded £580,000 to develop Next Generation Sequencing, to support new genomics and transcriptomics programmes (installation end of 2013). MALDI-TOF, LC-MS-MS, and SELDI protein chip mass spectrometers, BIACORE and FlexChip surface plasmon resonance, isothermal titration calorimetry, dual polarization interferometry and 2D-DIGE underpin efforts to address important biological questions in protein structure-function relationships and animal, plant and microbial cell biology, with plans to install a 750 MHz biological nmr facility (2014). Ca. £2.8M of infrastructure funding has supported new protein chemistry, cell biology and metabolomics facilities in the current REF period. Metabolomics research is supported by HPLC-MS, part of the *Centre for Bioactive Chemistry*. We have new transgenic growth facilities for plants and animals, and a new plant pathology suite. The new *Institute for Advanced Computing* and the associated *University High Performance Computing Facility* allows large-scale simulations and modelling of ecological and other systems-based biological processes.

Antibody production and other animal work is supported through a *Life Sciences Support Unit* (LSSU), fitted with very high quality animal facilities, and recently subject to a ca. £5M refurbishment programme. Antibody production supports research in cell biology, but is also in partnership with a leading manufacturer, *Cambridge Research Biochemicals*, who are on site in SBBS and co-develop products with our research teams.

Environmental field research is supported by high precision real-time kinetic GPS and high-resolution field spectroscopy to enable spatially precise collection of data, allowing ground measurements to be up-scaled using earth observation data. Eddy covariance measurements of methane, carbon dioxide and energy fluxes are possible using a tunable-diode laser instrument coupled with an open-path infrared gas analyser and sonic anemometer. Automatic weather and soil stations enable the collection of environmental data for ecosystem modelling. Mass spectroscopy enables the use of rare elements and stable isotopes as environmental tracers. Ancient DNA facilities and robotics facilitate work in molecular and evolutionary ecology.

e. Collaboration and contribution to the discipline or research base

As described above, collaborative and multidisciplinary approaches to biological research are central to Durham's activities, and are strongly linked to specific technologies and expertise available in SBBS (strengths in for example bioimaging, proteomics and laser-capture have led to multiple joint projects with members of other institutions, including industry - see *section b* above, and below). These occur between PIs within SBBS, between Departments within Durham, and with external partners including other HEIs, research institutes and industry.

The School is in a strong position to exploit research at the interface between animal and plant cell biology and molecular ecology. In recent years, the use of modelling and systems approaches has been an activity that cuts across disciplines within the School, and this has influenced our staffing policy, such as through the appointment of ***Liu, Ohlemuller*** and ***Stephens***. The *ICBL* (£6M) opened in 2002 to house research facilities in genomics, proteomics, imaging and bioinformatics, to capitalize on research initiatives in functional genomics research. This underpins programmes across all disciplines, and attracts and supports numerous collaborative projects, as described above.

Research groupings, led by individual academics, interact through joint projects/grants, and have developed common seminar programmes. For example, there have been recent joint BBSRC grants between ***Slabas*** and ***Lindsey***, ***Hussey*** and ***Slabas***, ***Lindsey*** and ***Hussey***, ***Knight M*** and ***Knight H***; ***Schroeder*** and ***Slabas***; ***Huntley*** and ***Baxter*** have joint NERC funding and ***Huntley*** and ***Willis*** joint Leverhulme funding. These bring together staff with complementary expertise that can be brought to bear on new problems. In the REF period 12 staff have taken sabbaticals abroad and

more have visited overseas institutions, to promote new joint research programmes. Notable examples include ***Benham*** (Visiting Associate Professor at Osaka University), ***Chazot*** (joint grant with the University of Jordan), ***Gatehouse*** (BBSRC collaborative grant with China), ***Huntley*** (joint projects with the South African National Biodiversity Institute, Kirstenbosch Research Centre, Cape Town, and with LandCare Research, New Zealand), ***Hussey*** (a joint project with the Max Planck Institute for Plant Breeding, Cologne), ***M Knight*** (a collaborative project with SCION, New Zealand), ***Weinkove*** (a BBSRC funded partnership award with Shanghai Jiao Tong University, China), ***Lindsey*** (joint projects with the Universities of Gent and Toledo, Huazhong Agricultural University, Universidade Estadual do Norte Fluminense Darcy Ribeiro) and ***Walmsley*** (University of Sao Paolo), and ***Quinlan*** is Visiting Professor to the Guangzhou Ophthalmic Center at the Sunyet Sen University, Guangzhou, China and Affiliate Faculty member of the Department of Biological Structure at the University of Washington, Seattle.

These and other collaborations have led to joint high impact papers (e.g. *Barcala et al. Plant J. 2010; Bos et al. PNAS 2010; Chen et al Science 2011; Chivasa et al., Plant J 2009; Fenyk et al. J Biol Chem 2012; Haas et al. Nature 2009; Higgins et al. PNAS 2013; Huntley et al., Global Ecol Biogeogr 2012, 2013; Huntley & Barnard, Divers Distrib 2012; Ikawa et al. J Biol Chem 2011; Smaczynska-de Rooij et al. J Cell Sci 2011; Stoffel et al. EMBO J 2008; Tokuhiro et al. PNAS 2012; Topal et al. J Molec Biol 2012*). Ca. 23% of papers published during the REF period (133/582) are collaborative with national or international partners.

As described above, Durham University has developed a strategy to maximize impact at the interfaces between biology and other science disciplines. The *Biophysical Sciences Institute* was established with £1.5M funding from The Wolfson Foundation, which incorporates the *Centre for Bioactive Chemistry*, a purpose built £2.5M suite of laboratories in the Chemistry Department. The focus of the *BSI* is in *Bioimaging*, *Bioactive Chemistry, Biological Modelling* and *Biological Soft Matter*, supported by 12 new academic appointments. Multidisciplinary collaborations with Chemists, Physicists and Mathematicians are leading to successful joint grant applications and high impact publications (e.g. ***Cann*** with ***MacLeish***, ***Hussey*** with ***Piette***, ***Przyborski*** with ***Cameron***, ***Quinlan*** with ***Girkin***, ***Lindsey*** and ***Liu*** with ***Goldstein*** and ***Vernon***). Not only are biologists located in the *Centre for Bioactive Chemistry* labs, to promote daily interactions, but physicists interested in developing new imaging systems have also co-located to the School's *Integrative Cell Biology Laboratory*. New staff appointments have supported this initiative (***Robinson***, ***Chivers***), and the proposed new *Centre for Industrial Biotechnology* will build on this.

The *Durham Centre for Crop Improvement Technology* involves not only biologists but also members of the Departments of Chemistry (e.g. ***Beeby***, ***Steel***). Individual PIs also have links with staff in Mathematics (e.g. ***Goldstein***, ***Piette***, ***Vernon***), supporting mathematical modelling work and with Physics (***Girkin),*** developing new imaging technologies. A key aim of DCCIT is to develop links with endusers, including companies in the biotechnology and agricultural biotechnology, and seed industries. Examples of links established during the REF period include Bayer Plant Science, Monsanto, Procter and Gamble, Tozer Seeds, Syngenta, Sirius Minerals, Harvest Energy and NIAB Innovation Farm.

The *Institute for Hazard, Risk and Resilience (IHR^2)* and the *Climate Impacts Research Centre* involve biologists and earth scientists, as well as members of Durham's very highly rated Geography (e.g. ***Bentley, Long***) and other Social Science Departments. IHR^2 hosts the current major Leverhulme-funded multi-disciplinary 'Tipping Points' research project in which members of SBBS collaborate with colleagues from Geography (***Long***, ***Woodroffe***) and Mathematical Sciences (***Goldstein***, ***Straughan***) as well as from a wide range of other disciplines. During the REF period the *Institute of Advanced Study* has supported visiting Fellows hosted by SBBS staff (e.g. ***Leemans*** – Prof. of Environmental Systems Analysis, Wageningen), sponsored joint seminar programmes by invited national and international speakers (e.g. ***Huntley***, ***Goldstein*** – Quantifying Output Uncertainty in Models used for Climate Change Research) and supported international workshops (e.g. ***Huntley*** – Sustaining Ecosystem Service Delivery in a Changing World).

Industry and government policy initiatives: To ensure relevance and impact of our research, members of the School have responded successfully to government, EC and Research Council initiatives, including BBSRC LINK, BBSRC IPA, BBSRC Networks in Industrial Biotechnology and Bioenergy, TSB, NERC thematic programmes and to EC Framework VII. Fifty two new company links have been established as part of these and other activities. Technology transfer is facilitated

by Durham's Business Innovation Service (DBIS), which supports the development of new links with industry and assists in the establishment and running of spinout companies. Durham was awarded a BBSRC 'Sparking Impact Award' (£100k, 2013) to further develop its impact agenda. Three spin-out companies have raised significant funding over the RAE and REF periods, namely *ReInnervate Ltd.* (***Przyborski*;** ca. £8M), which is developing stem cell-based technologies for the healthcare market; *ClarinnisBio Ltd*., which is developing biotechnology products for skin (***Jahoda***; ca. £1M); and *Creative Gene Technology Ltd.* (***Slabas*** and ***Lindsey***; ca. £1.5M), which is developing an IP portfolio in the AgriBiotech area (oils and starch for biofuels, plant protection).

Conference organization and wider scientific engagement: The organization of scientific meetings by Durham staff members advances our research strategy by providing opportunities for raising the profile of our research activities, networking for developing new collaborations, and student and ECR training. Since 2008, Durham biologists have organized/hosted more than 25 major conferences and workshops or sessions, including: the 2010 International Arabidopsis Conference in Yokohama (***Lindsey***, member of the International Organizing Committee); European Cytoskeletal Forum - The Cytoskeleton in Cell Morphogenesis, 2009 (***Hussey***); Gordon Research Conference on cell biology of metals, Rhode Island USA (a conference series co-instigated and co-chaired in 2005 by ***Robinson***, who has subsequently been invited to advise on scientific programmes in 2007, 2009, 2011 and 2013); and 19th Biennial Conference on the Biology of Marine Mammals, Tampa, Florida, 2011 (***Twiss***, Workshop organizer); 12th and 13th Pan-African Ornithological Congresses, Rawsonville, South Africa (2008) and Arusha, Tanzania (2012) (***Huntley***, Symposium co-convenor). ***Hussey*** was the 2013 *Loomis Distinguished Lecturer* at Iowa State University and ***Robinson*** delivered the *Luigi Sacconi Memorial Lecture* in chemistry at the University of Florence in 2011.

Members of SBBS are encouraged to engage with scientific advisory boards, RCUK panels government committees, journal editorial boards and learned societies, to provide expertise and advice that contributes to a wider impact agenda, at national and international levels. Specific examples of membership of major UK agencies include: the UK government *Advisory Committee on Releases to the Environment,* which advises Ministers on GM and related issues as a basis for policy development (***Lindsey***); *the UK Research Councils* – BBSRC: *Council*, *Appointments Board*, *Sustainable Bioenergy Centre Science and Impact Advisory Board* (***Lindsey***), *Sustainable Agriculture Strategy Panel, Bioenergy Initiative Panel* (***Slabas***), grant panels/pools of experts (***Gatehouse, M Knight, Przyborski, Sadanandom, Schroeder***); *NERC* Peer Review College and Panels (***Baxter, Huntley, Willis***); *MRC Studentships Panel, Review Panel for Cambridge Stem Cell Centre* (***Jahoda, Quinlan***), *Scientific Advisory Panel to the Yorkshire Agricultural Society* (***M Knight***), *Stem Cells and Translational Medicine* Associate Board (***Hutchison***); *Royal Society* reviewing panel for *International Joint Projects Scheme* (***Huntley***) and *International Exchanges Scheme* (***Stephens***).

Examples of overseas advisory panel memberships include: *NIH Center for Scientific Review* (***Robinson***); *Commonwealth Fellowships and Scholarships* Expert Adviser and *FP7 Health Call Expert Adviser* (***Hutchison***); the *International Whaling Commission* (***Hoelzel***); the *Multinational Arabidopsis Steering Committee* (Chair, ***Lindsey***); *Centre for Plant Molecular Biology, University of Tuebingen* International Scientific Advisory Board, and *Canada Research Chairs* College of Reviewers (***Hussey***); *Academia Sinica (Taiwan) Institute of Plant and Microbial Sciences* Advisory Board (***Lindsey***); *Portuguese Foundation for Science and Technology* and *National Science and Engineering Research Council* review panel, Canada (***Stephens***); and *Royal Swedish Academy of Sciences Arctic Research Station* Review Board (***Baxter***).

Staff are involved in 32 different journal Editorial Boards, including *Current Biology, Proteomics*, *The Plant Journal, New Phytologist*, *PLoS ONE, British Journal of Pharmacology* and *Antioxidants and Ageing*. We also play significant roles in learned societies - *Society for Experimental Biology* (President, ***Lindsey***; Cell Section Committee Chair, ***Hussey***; Cell Section Committee member, ***Benham***); *European Histamine Research Society* (President, ***Chazot***); *Biochemical Society* and *British Society of Cell Biology* (***Hussey***); *British Neuroscience Association* (***Przyborski, Chazot***); *British Society for Immunology* (***Benham***); *Anatomical Society of Great Britain & Ireland* (***Przyborski***).