Institution: University of Glasgow

Unit of Assessment: Unit 5; Biological Sciences

a. Overview

In RAE2008, the University of Glasgow's submission to UoA14 (Biological Sciences) was from the Faculty of Biomedical & Life Sciences. The reorganisation of the University in 2010 set up the College of Medical, Veterinary & Life Sciences (MVLS) as an integrated biomedical College with research that ranges from molecules to communities and enables the establishment of links between fundamental processes and applied areas including human and animal medicine, biotechnology and the conservation of biodiversity. Research in the College is coordinated through 7 Research Institutes, with staff submitted to this UoA based in two of these Institutes, hence:

- The 62 staff submitted to UoA5 are associated with the Institutes of Biodiversity, Animal Health and Comparative Medicine (BAHCM) or Molecular, Cell and Systems Biology (MCSB). Staff submitted in UoA5 are in **bold,** staff returned in other UoAs are in normal font.
- UoA5 staff are further subdivided into three broad research areas, **Ecology and Evolution** (29 staff), **Plant Sciences** (8 staff) and **Cell and Molecular Biology** (25 staff).

Individual highlights that illustrate the vitality of these research groupings include:

- *Ecology and Evolution:* **Monaghan** and **Metcalfe's** clear demonstration of the relationship between early life telomere length and subsequent lifespan (PNAS); **Hampson's** work on transmission dynamics of canine rabies and a strategy for its elimination (PLoS Biology)
- *Plant Sciences*: **Jenkins** and **Christie's** work showing how plants perceive UVB light (Science, PNAS); **Cogdell's** analysis of energy transfer reactions in photosynthetic light harvesting (Science)
- *Cell and Molecular Biology*: **Milligan's** extensive work, largely on G-protein-coupled receptors (over 70 research papers published 2008-13 with over 1100 citations); **Bulleid's** research into mechanisms of disulfide exchange (EMBO Journal, Molecular Cell); **Dalby's** series of papers on nanoscale materials and their uses (Nature Materials, ACS Nano)

The scope and quality of our research and the international standing of our staff have grown significantly since RAE2008 as evidenced by the:

- recruitment of 23 new PIs, of which 4 are at the level of Professor, and election of 5 individuals to the Fellowship of the Royal Society of Edinburgh, bringing our total to 10
- number of new substantive and long-term grants including two ERC Advanced Grants (**Metcalfe**, **Monaghan**), a Wellcome Trust Programme grant (**Bulleid**), an MRC programme grant (**Milligan**) and a BBSRC strategic LoLa grant (**Stark**, **Rosser**)
- doubling of the value of new grants awarded over the period 2008-13
- establishment of the Scottish Centre for Ecology and the Natural Environment (SCENE), a major new initiative in integrated aquatic resource management (£5.3M) funded by the European Regional Development Fund and the University
- successful renewal of major PhD training grants from the Wellcome Trust, BBSRC and MRC
- award of personal fellowships (over £9M) to **Apfelbeck** (Humboldt Foundation), **Berry** and **Christie (**Royal Society), **Bulleid** and **Tokatlidis** (Scottish Universities Life Science Alliance, SULSA), **Hampson** (Wellcome Trust), **Killen** (NERC), **MacLeod** (Royal Society of Edinburgh), **Nimmo** (Leverhulme Trust), **Noguera** (Marie Curie, AXA) and **Rosser** (EPSRC)
- development of a world class Polyomics facility for metabolomics, genomics, transcriptomics and deep sequencing
- establishment of the **Boyd Orr Centre for Population and Ecosystem Health**, which brings together wide-ranging research projects from population and landscape ecology to

epidemiology, immunology, and population genetics, and the recent award of a Queen's Anniversary Prize for Higher and Further Education to the Centre.

b. Research strategy

University context

The reorganisation of the University in 2010 allowed us to refocus our research efforts in line with both our strategic goal of exploiting the advantages provided by the integrated nature of MVLS and the University's focus for 2010-20 on the promotion of interdisciplinary research. In the life sciences, the University has invested heavily in bottom-up initiatives to bolster research into Solar Fuels (joint with Chemistry, £1.5M) and Synthetic Biology (joint with Chemistry and Engineering, £2.6M), providing research assistant posts and infrastructure support in these areas. UoA5 has also benefitted from the University's Lord Kelvin/Adam Smith (**LKAS**) PhD studentship programme that is specifically aimed at promoting interdisciplinary research (see People below). The University has made a major investment in Freshwater Biology (SCENE, £2.0M) and provided direct support in several areas via its **LKAS** Fellowship recruitment programme. SULSA, the Scottish Funding Council's research pooling partnership in the life sciences (http://www.sulsa.ac.uk/index.html), provided an additional £4.15M to support the appointments of **Bulleid**, Breitling and **Tokatlidis**.

College organisation

Research in the College is mainly carried out by our Research Institutes. The Schools of Medicine, Veterinary Medicine and Life Science manage our undergraduate teaching portfolio in their respective disciplines. Major strategic decisions regarding research are initiated by the Heads of Institute and discussed and prioritised at monthly College management group meetings.

The College structure has created an environment in which interdisciplinary research is encouraged and the focus is on areas in which we have international excellence. The Heads of Institute can ensure that all members of staff are provided with the infrastructure and environment required to achieve their full potential. In addition, the flat management structure reduces the distance between individual staff members and the top management enabling policy to be driven bottom-up as well as top-down. Such an open and transparent system allows strategy to adapt rapidly to changing research landscapes and priorities. The initiatives in Solar Fuels and Synthetic Biology, and the creation of the Boyd Orr Centre, are examples of such bottom-up ideas that developed into University initiatives.

Development of group structure and strategy

In RAE2008, UoA14 identified five groups: **Functional and evolutionary ecology, Plant science, Cell biology**, **Protein science** and **Molecular pharmacology and neuroscience**. The first two themes remain essentially unchanged, the third and fourth have combined, and most staff in the fifth are now submitted in other UoAs. Hence our groups are now **Ecology and Evolution**, **Plant Sciences** and **Cell and Molecular Biology**. There are substantial synergistic overlaps between these groups. Our strategy is to co-locate staff with similar infrastructure requirements irrespective of group, and several successful collaborations have developed as a result. Our overarching objective as stated in RAE2008 was to 'maintain established strengths by ensuring continued access to first class facilities, and inputs of new ideas'. Specific targets for 2008-13, how these have been achieved and current strategic objectives are identified for each of our groups below.

Ecology and Evolution

This group of 29 staff addresses broad research challenges in relation to *environmental change*, *evolutionary analysis, infectious disease ecology* and the conservation of *biodiversity*. Since 2008 staff have been awarded 26 major research grants/contracts and 10 competitive fellowships; 8 of the staff have Early Career Researcher status. Staff have published 11 papers in Science/PNAS/PLoS Biology/Current Biology. The group is renowned particularly for work on life history trade-offs and the ecology of infectious diseases. For example **Monaghan** and **Metcalfe** showed that early life telomere length in zebra finches is a strong predictor of lifespan (PNAS); **Hampson's** uniquely detailed tracing of canine rabies during an outbreak in Tanzania showed a low rate of transmission implying that appropriate vaccination campaigns could eliminate the disease (PLoS Biology). There are close interactions with veterinary medicine, facilitated by formation of MVLS, that have resulted in the emergence of strength in zoonotic diseases in particular, and the development of One Health approaches to the study and control of disease.

Some 20 BAHCM staff are returned in UoA6, illustrating the links between ecological, veterinary and life scientists.

A major objective for 2008-13 was to complete phase 2 of SCENE, located on the shores of Loch Lomond (the largest area of fresh water in Great Britain), and to establish it as a national centre for freshwater and terrestrial ecology. The development of the training facilities has been completed as planned with well-equipped wet and dry laboratory space. These include a genetics laboratory, bird and fish holding facilities, observation tanks and aquarium systems, an artificial stream, field sampling equipment, a weather station, and a variety of craft and boat handlers. Research at the Centre is supported by two full-time technicians. SCENE is a key collaborator in an EU Inter-regional grant that is contributing approximately £3.3M. We also planned to redevelop the aquaria and aviaries to provide controlled environmental facilities; this has been achieved as outlined below. These investments have enabled substantial research programmes in life history and physiological ecology supported by two ERC Advanced Grants (£1.8M, **Monaghan;** £1.73M, **Metcalfe**), two NERC fellowships to **Killen** (£1.1M) and one to Constantini, and £1.6M of further funding to **Metcalfe** and **Monaghan** from Leverhulme, NERC and BBSRC.

A further objective for 2008-13 was to cement links with University strength in infection and immunity to create a world-leading group in the biology and epidemiology of wildlife diseases. This was achieved by the appointments of Cleaveland and Kao (Wellcome Trust Senior Fellow) both of whom now hold Chairs in BAHCM but are returned in UoA6. **Our strategy** now is to expand this close collaboration between ecological, veterinary and life scientists and explicitly target research at the boundaries between UoA1, 4, 5, and 6. This will allow us to address global agendas linking environmental change, food security, infectious diseases, and aging, health and welfare. The appointment of **Selman** (Professor of Biogerontology) is providing synergies with **Monaghan** and **Metcalfe** in the comparative biology of aging, illustrated by a recent short review in Current Biology. Recent investments have strengthened our research capacity in mathematical and spatial ecology (**Matthiopoulos** – Professor of Spatial Ecology, **Hopcraft** - migratory ungulate ecology), chronobiology (**Helm**), and the evolutionary ecology of fishes (**Killen**, **Elmer** and **Parsons**); the latter four appointments illustrate our ability to exploit infrastructure investments at SCENE. Our strength in infectious disease biology (particularly rabies) has been enhanced by the appointment of **Hampson** and **Streicker,** further developing our links with the University of Glasgow/MRC Centre for Virus Research. Likewise, our high profile in parasitology and 'wild immunology' has been increased by the appointments of **Ferguson** and **Babayan** who provide links to the Wellcome Trust Centre for Molecular Parasitology. Our new Fellows are of the highest international calibre; for example **Baldini**, **Hampson**, **Streicker** and **Wakefield** have all published recently in Science or PLoS Biology. In addition **Streicker** has won the 2013 Science & SciLifeLab Prize for Young Scientists. Now we need to further develop the abundant research potential of SCENE through appointment of PIs and Fellows addressing key questions in aquatic biology and fisheries management, and in particular to build on long-term experimental studies of environmental change and its impacts on avian life-histories and emerging diseases. Further investment in aviary and aquaria that can hold wild organisms will advance our research on the ecology, behaviour, and physiology of organisms in their natural context.

Plant Sciences

This is a very interactive group of eight staff that has outstanding strength in the areas of (a) rapid reactions in photosynthesis and (b) the cell and molecular biology of signalling events in model systems. Since 2008 staff have published 20 papers in Science/PNAS/Plant Cell/EMBO J and been awarded 27 project grants. One highlight is the work of **Jenkins** and **Christie** identifying the plant UV-B photoreceptor and defining its mode of action (two papers in Science); this illustrates the essential underpinning provided by our structural biology and physical biochemistry infrastructure with both **Smith** and **Kelly** as co-authors of one of the Science papers. Another is that of **Cogdell** on the energy transfer processes in natural light harvesting systems (two papers in Science).

Our future objectives are to continue our distinctive basic research and to develop its application to challenges in **food security**, **global environmental change** and **synthetic biology**. **Blatt** has already obtained funding from the BBSRC Photosynthesis Ideas Lab Initiative in a collaborative UK/USA partnership to explore novel ways of generating increased CO_2 in the chloroplast.

Amtmann is PI on a multidisciplinary £1M EPSRC programme on biodesalination. We also plan to develop synthetic systems to trap light energy (linked to our **Synthetic Biology** programme) and to exploit our knowledge of stress signalling to address drought and salt tolerance. To achieve these objectives we need to maintain the strength and synergies of this collaborative group as some members approach retirement. We have already recruited one new research fellow (**Kaiserli**) to the Plant Science group on a University-funded **LKAS** Fellowship and will recruit further staff to maintain our excellence in basic science and to extend our interactions with industry. We will develop the contacts made through BBSRC Crop Improvement Research Club and Industrial Partnership Award grants (**Jenkins**, **Amtmann**). We will also expand our growth facilities to allow lab-scale growth of crop species.

Cell and Molecular Biology

This group address a broad range of basic and applied problems from structural biology through intracellular trafficking to cell engineering. It has particular strengths in redox biology, G-protein-coupled receptors, intracellular protein trafficking and cell engineering. Since 2008 staff have published 17 papers in Science/Nature/Cell/Mol Cell/EMBO J/PNAS and been awarded some 60 project grants and 3 programme grants. Highlights include **Dalby's** work resulting from an **LKAS** studentship with Gadegaard (Engineering) on a nanostructured surface suitable for long-term stem cell culture which was published in Nature Materials and led to a patent application, and **Bulleid's** identification of the reductase that catalyses removal of non-native disulfides and correct folding of the LDL receptor (Molecular Cell).

The first objective for 2008-13 was to consolidate and expand our activities in cell engineering. **Dalby** was appointed to lecturer in 2008, from a BBSRC Fellowship, and promoted to Reader in 2010. **Berry** secured a Dorothy Hodgkin Fellowship (2008) and was appointed lecturer in 2012. Substantial grant funding during this period has been secured from BBSRC, EPSRC, MRC, NC3Rs, the EU and several charities. The work is highly inter-disciplinary with joint grants being held with materials scientists and engineers at the University. With NHS surgeon and Honorary Clinical Associate Professor Dominic Meek, **Dalby** is co-founder of the Glasgow Orthopaedics Research Initiative (http://www.gla.ac.uk/researchinstitutes/biology/research/cellengineering/glori/) that aims to use basic materials research and stem cell technology to devise and deliver next-generation orthopaedic care. The University now provides a unique setting for multidisciplinary research into various aspects of manipulation of cell differentiation using novel engineering approaches. **Related objectives for 2008-13** were to provide new research facilities for the Cell Biology and Molecular Pharmacology groupings and to support our recent progress in basic stem cell research with a new appointment (Mountford, submitted in UoA1). Extensive refurbishment including expanded media preparation and cell culture facilities allowed us to develop our cell biology interests on a single site (the Davidson Building). The location here of **Selman** from the Ecology and Evolution group and Mountford illustrates the opportunities for inter-disciplinary collaborations which are already being explored in a cross-Institute interest group. These are further illustrated by the joint venture between **Milligan**, Mountford and Baker (UoA1) on 'synthetic blood'. This developed from the Intermediate Technologies Institutes Scotland programme (£3.2M, 2005-09), is now supported by the SFC Horizon Fund (£3.25M, 2011-16) and has already led to the filing of two patent applications. Another successful outcome from such juxtaposition of groups is a new BBSRC-funded project in which expertise in a nematode model system (Johnstone) and mammalian cell biology (**Bulleid**) will be used to analyse the key players contributing to maintaining the redox balance in the endoplasmic reticulum in a collaborative project with Page (UoA1).

Additional objectives for this group in 2008-13 were to add to our expertise in Systems Biology and to invest further in our Functional Genomics Facility by adding metabolomics to the 'omics' technologies available at the University. We appointed Breitling as SULSA-sponsored Chair of Systems Biology; he enhanced our bioinformatics capacity before moving on to a position at Manchester University. Our ISSF partnership with the Wellcome Trust allowed creation of the world-class Glasgow Polyomics centre which now provides the metabolomics, genomics, transcriptomics and proteomics on which many of our projects depend. Included in this facility are four core staff who provide the dedicated bioinformatics support needed to maximise the return from large datasets. An example of the impact of this enterprise is that **Herzyk**, who runs the genomics service, has made substantial contributions to the acquisition and analysis of data in 20

joint papers published with other members of MVLS since 2008, including papers in Science and PNAS.

Recently a bottom-up initiative led to a significant increase in the group's portfolio in which the University invested £2.6M in the formation of the **Glasgow Synthetic Biology Centre**. This area of science, broadly the design and engineering of novel biologically based parts and devices, is critically dependent on cross-disciplinary collaborations; our strength is illustrated by the current composition of the Centre with five PIs from Engineering and one in Chemistry, as well as five from the life sciences. Investment to develop new, purpose-built laboratory space in the Bower Building allowed the strategic relocation of **Stark** and led him to interact with **Rosser**; this resulted in the award of a £4M BBSRC strategic LoLa grant to develop site-specific recombinases as a platform technology for synthetic biology. **Rosser** also contributed to a recent £5M EPSRC Frontier Engineering grant with Beaumont (VP Research) and Sloan (Engineering). We have strengthened our synthetic biology group with the recent appointment of **Colloms** at lecturer level. Recruitment of a senior Professor in synthetic biology is now the **highest College priority** in the life sciences. Synthetic biology is closely related to much research in the College, for example that of the microbiologists Walker and Penades (both in UoA1) and the plant scientists, particularly **Amtmann**, **Christie** and **Cogdell**, whose interaction with Cronin (Chemistry) and Gadegaard (Engineering) in construction of systems capable of artificial light harvesting and photosynthesis has unlocked further University support for the **Solar and Bioenergy Research Centre**. The **Glasgow Synthetic Biology Centre** is still in the development phase but our capacity for multi-disciplinary research, our strong links with industry (e.g. Proctor & Gamble and Ingenza), and the potential synergies with our strength in cell engineering put us in an excellent position to exploit this emerging area of biology.

Additional future objectives for this group are to develop our emerging and distinctive cross-disciplinary strengths in **chemical biology**, and to invest in **equipment for biomolecule analysis and imaging**. A focus on **chemical biology** has been established with the appointment of **Bulleid** and **Tokatlidis** to MCSB and Liskamp to Chemistry. **Bulleid** and **Tokatlidis** both study aspects of redox biology, in the endoplasmic reticulum and mitochondrion respectively; both groups will collaborate extensively with Liskamp and Hartley (Chemistry), and **Bulleid** already has an **LKAS** studentship with Hartley (Chemistry) on developing methods to measure reactive oxygen species in cells and cellular compartments. **Milligan** also has an **LKAS** studentship with Liskamp employing chemical biology to identify cell surface receptors for microbial toxins. We will focus on building this strength through setting up a cross-College interest group in **chemical biology**, through recruiting PhD students on cross-disciplinary studentships and by further cognate appointments. Already **Hudson** (currently supported by the Canadian Institutes of Health) has been awarded a University Leadership post (see People below) in Chemical Biology.

The Cell and Molecular Biology group rely heavily on the local availability of the excellent support in imaging, physical biochemistry and 'omics' technologies. **We plan to invest** and update our current facilities for biomolecule analysis (CD, SPR, ITC, SEC-MALS), and to develop our current imaging capability by providing technical support for the existing confocal microscopes and capital support for acquisition of new high-resolution microscopes using a combination of Institute, College and external funding.

Collaborations

The unified structure of the College has explicitly facilitated cross-Institute collaborations, which along with cross-College collaborations represent a major route to achievement of the University's strategic goal of increased interdisciplinary research. UoA5's research portfolio ranges from molecules through cells and organisms to the level of communities. As a consequence, UoA5 staff occupy a central position in the life sciences and contribute underpinning expertise to many current funded collaborations with colleagues in clinical medicine and veterinary science returned in UoA1 and UoA6. Examples include **Milligan** as a co-I with several colleagues from UoA1 in a £3M BHF Centre of Excellence award led by Touyz (UoA1), and project grants with both Nicklin (MRC) and Baker (BHF) including the stem cell collaborations with Mountford (see above); these illustrate both success in achieving our RAE2008 objective of increasing the clinical-basic science interface and the opportunities delivered by the formation of MVLS in 2010. In addition **Bulleid** collaborates with Page (UoA1, see above), **Biek** with Palmarini (UoA6) in a Wellcome Trust programme grant on

bluetongue virus, **Hampson** with Haydon and Cleaveland (both UoA6) in an MRC-funded 4-year project grant on rabies control and **Smith** with Morgan on a CRUK grant on human papillomavirus. **Biek** and **Herzyk** contributed to the £5.25M MRC award setting up the University of Glasgow/MRC Centre for Virus Research. Another notable theme of UoA5 is our very strong links with the College of Science & Engineering as equal partners in the development of both **synthetic biology** and **cell engineering**. There are particularly strong links with Cronin and Liskamp (Chemistry) and Gadegaard, Sloan and Cooper (Engineering) that are listed above. This culture of collaboration is also illustrated by outputs; of 154 papers submitted to the REF that are based on work carried out in the University (i.e. excluding papers by recent external appointments), 36% involve intra-College collaborations, 14% collaborations elsewhere in the University, 38% collaborations within the UK and 60% collaborations outside the UK (these categories are non-exclusive). Furthermore, the College structure has facilitated development of several cross-disciplinary interest groups that will provide the basis for new collaborations in the future; for example a group focussed on chronobiology, ageing and metabolic disease involves **Helm**, **Nimmo**, **Selman** and **Wyse** from UoA5 with colleagues from UoA1 (Salt) and UoA4 (Biello).

c. People

I. Staffing strategy and staff development

Our strategy is to recruit a mix of established, internationally recognised staff who can provide leadership in selected areas, innovative and collaborative staff at lecturer level and highly promising early career researchers on University **LKAS** positions or their own funding. Of the 62 staff submitted in UoA5, 23 have been appointed since RAE2008. We have recruited 4 senior staff to strategic Chair appointments – **Bulleid** (SULSA Chair of Cell Biology) **Matthiopoulos** (Spatial & Population Ecology), **Selman** (Biogerontology), **Tokatlidis** (Cathcart Chair of Biochemistry) – and have appointed 7 Lecturers and 12 new Fellows, ensuring that our pool of PIs includes both current leaders and future stars. Just under 70% of our 62 REF-submitted staff are aged 50 years or less, just over 25% are aged 40 years or less; 13 have Early Career Researcher status. These data demonstrate the long-term viability of our research effort.

We aim to provide an environment that promotes the **personal development and productivity** of staff at all levels and a culture of **equality and diversity**.

Mentoring and staff development

New academic staff and independent Fellows
We focus on encouraging young researchers to join us as independent fellows and provide two routes (see http://www.gla.ac.uk/research/fellowships/). The College has its own University-funded **LKAS** fellowship programme that allows us to offer research fellowships to top young scientists. This programme provides salary funding for 3-5 years and up to £50k in additional research support funds; UoA5 currently has three such Fellows (**Hopcraft**, **Kaiserli**, **Wyse**). Potential recruits can also apply for external funding. We use the University-funded Leadership Fellows scheme to bring external candidates here while they write their proposals or to reward them with additional resources if successful; **Baldini**, **Killen**, **Hudson** and **Wakefield** are recent appointments. Independent Fellows are given the same opportunities as new lecturers including access to research students and technical support, and if successful are offered permanent positions.

All new staff are strongly supported by a well-developed mentorship programme. They are assigned a senior academic as a mentor who helps them to establish their research programmes and supports them in writing both grant proposals and scientific papers. They attend training programmes for both new PhD supervisors and new lecturers. Training is reinforced by an annual performance and development review (P&DR) process where the Head of Institute and the member of staff concerned agree targets for the next year's activities. At this point training needs are identified; technical skills can be addressed, for example by secondment to an appropriate laboratory, and personal skills enhanced through the University's extensive Staff Development programme. New lecturers are given a reduced teaching load for the first 2-3 years to allow them time to fully establish their research programmes. To illustrate the success of our training, all of the lecturers appointed before 2013 have already obtained research funding.

The College has started its own Research Crucible programme that identifies our top young post-doctoral scientists, Fellows and new Lecturers and puts them through a leadership and development programme. This aims to encourage participants to become more collaborative and interdisciplinary in their approach to their research, to help them develop skills to make their research more innovative and to develop their understanding of how research can impact on society through the process of Knowledge Exchange.

Research staff

The performance and development of each member of research staff in UoA5 is assessed each year by experienced academic staff who provide advice on wide-ranging aspects of career development, for example specific training courses, publication and presentation strategies, management of research projects, visits to other labs and applications for grants or jobs. The expectation is that our research staff are properly prepared in experimental, communication and teaching skills by the time they move on to an academic or industrial post. In addition to this internal focus on career development, the University's Research Strategy and Innovation Office and Staff Development Service run a tailored suite of training courses for research staff.

Established staff

Career progression is facilitated by an environment that provides both thoughtful personnel management and a stimulating and collaborative intellectual climate. The College operates a workload model that allows the Head of Institute to manage staff time equitably and in the most appropriate way to ensure the promotion of world-class research. This model is supported by the annual P&DR process. Staff are encouraged to apply for independent fellowships and/or for leave of absence to give them periods in which they can concentrate fully on research. For example **Rosser** and **Nimmo** both received Fellowships that relieved them of teaching. All research proposals are read by senior colleagues to ensure that these proposals are optimised. Both the College and the University have well-staffed research offices that help with all aspects of costing of proposals and their subsequent administration.

To ensure that staff are informed about research developments in other fields, we run both College-wide seminars, in which international experts provide an overview of topical areas, and more specialised seminars at the levels of the Institutes and research groups. Themed intra-College and intra-Institute away-days bring together researchers with different perspectives on the same topic, thereby promoting interdisciplinary research. Specific workshops are organised to update staff in particular research techniques (e.g. proteomics, statistical analyses, microarray techniques, image analyses). The large number of cross-disciplinary collaborations evident from the Research Strategy section is an illustration of the success of these programmes.

Equality & Diversity Training

Two training courses run by the University in equality and diversity are compulsory for all staff prior to any involvement in recruitment. *Equality and Diversity Essentials* outlines the key legislation in relation to the Equality Act 2010, the protected characteristics and types of discrimination and harassment. *Managing Diversity* looks at the benefits of managing diverse teams, and how to challenge unacceptable behaviour. The University has embedded equality training into all its management and leadership courses.

The University was awarded an institutional Athena SWAN Bronze Award in April 2013. BAHCM will apply for a departmental award in November 2013 and MCSB plans to apply in 2015. We are fully committed to eliminating gender or other bias; analysis of recruitment by the staff submitted to this UoA highlights the lack of discrimination. Of the 178 research staff appointments made since 2008, the ratio of male:female appointments was almost 1:1. The breakdown of diversity was as follows; white-UK (40%), white-non-UK (37%), Asian-Indian (5%), Black (5%), Chinese (5%), and other ethnic background (8%). Of the 19 staff appointed to lectureships or awarded personal or **LKAS** fellowships, 8 are female including **Hampson** who recently won a L'Oreal UNESCO For Women in Science Award.

In addition to our recruitment policy, staff from UoA5 organise a Scottish Executive Leadership Development Programme (Stellar West) for ethnically diverse University staff. The remit is to develop individual leadership skills and management strategies, and to enhance the deployment of talented ethnically diverse staff including Black, Asian and Minority Ethnic individuals. Stellar West

is similar to the very successful HEFCE-endorsed 'Stellar HE London'. Stellar West will be run by the University in 2014-15, initially for West of Scotland Universities. The project team is led by **Davies** and includes the University Equality and Diversity Unit and Human Resources. The provision of Stellar West for ethnically diverse staff in Scottish Universities is the first such scheme in Scotland, and will provide cutting-edge strategic leadership training for key individuals.

II. Research students

MVLS has a single Graduate School which runs a fully integrated Graduate training programme across the College designed to ensure the viability and quality of the project and both the subject-specific and wider personal skills of the student. All PhD supervisors must attend a tailored training course that deals with all aspects of how to be a successful PhD supervisor, and potential PhD projects are vetted to ensure that they are suitable and that the laboratories involved are well resourced. The progress of students and their acquisition of specific research skills are carefully monitored through an assessor scheme with students being allocated two appropriate academics who act as their assessors throughout their PhD training. Meetings are held twice in the first and final years and once in the second year, or more frequently if necessary; at each meeting a written report is assessed, progress is discussed and potential problems are identified. Students are required to present their work in different formats; they give talks to Institute audiences in their first and third years and present posters in second year. In addition, research groups run their own discussion meetings at which students present regularly so that by graduation all students have presented their work several times. We run specific training courses tailored for the needs of our students, for example microscopy and imaging, biophysical analysis of proteins, molecular modelling, and polyomic approaches to biology. We strongly encourage all PhD students to attend at least one major international scientific conference and provide them all with up to £800 for attendance. The local and tailored delivery of these parts of PhD training is a key element that allows us to achieve excellent satisfaction and completion rates, with 88% of students expressing satisfaction with their supervision in the PRES 2013 survey (http://www.heacademy.ac.uk/pres), above the national average, and 87.4% of students since 2008 submitting within 4 years.

To develop more generic skills there is an extensive portfolio of more than 30 skills training courses for PhD students, who are required to attain a specified number of 'credits' by taking a selection of these during the course of their research. Students on the new BBSRC funded DTP are now required to take a 12-week Professional Internship for PhD Students (PIPS). We have a wide portfolio of these that has been integrated with other Scottish Universities under the umbrella of SULSA. As a result we can offer more than 75 possible placements. Our PIPS programme is co-ordinated by a dedicated administrator who ensures that each placement fulfils the required high level training experience. In addition, over the past 4 years we have developed a successful 2-day enterprise and entrepreneurship course which covers all aspects of research commercialisation, bringing researchers into contact with role models, technical experts (such as patent attorneys) and support organisations, as well as training participants in negotiation, team-working and pitching ideas. We encourage participation from staff and students in both internal and external business planning competitions. The University has recently appointed an Enterprise Manager to support the delivery of enterprise training and support. The University is an active participant in Converge Challenge, which is co-funded by Universities and the Scottish Funding Council and is Scotland's largest business plan competition; an MCSB researcher won second prize in the 2012 competition (see REF3a). Researchers are encouraged and supported to participate in external enterprise programmes such as BBSRC Biotech YES.

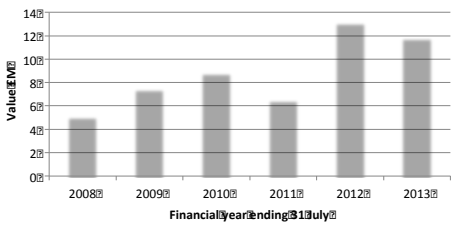
Under the auspices of our Graduate School we have successfully obtained DTP awards from BBSRC (6 students per year) and MRC (3 students per year), and a Wellcome Trust PhD training programme (5 students per year). The College has provided matching funding for the BBSRC and MRC schemes to double the number of studentships (to 12 and 6 per year) and funded an additional place for the Wellcome Trust scheme each year. We also get annual PhD studentship allocations from NERC (£286k) and EPSRC (typically £150-200k). The University's special **LKAS** PhD studentship programme (http://www.gla.ac.uk/services/postgraduateresearch/scholarships/kelvinsmith/staffkelvinsmith/) is specifically aimed at promoting interdisciplinary research. To qualify for one of these studentships, two supervisors from different disciplines who have never worked together before must be

involved. In UoA5 we have had 15 **LKAS** PhD students since 2008. These have proved very successful in germinating new and fruitful research collaborations. For example, **Cogdell** (UoA5 plant science group) and Cronin (Chemistry) were awarded an **LKAS** studentship in the general area of Solar Fuel Research. This led to grants from both EPSRC and BBSRC, as well as a specific initiative funded by the University, to a total value of ~£4M.

d. Income, infrastructure and facilities

Income

We obtain research funding from a wide range of sources: about 50% comes from UK Research Councils and about 15% each from Charities, UK Government and the EU. As shown in the figure, the **value of new grants** awarded to UoA5 staff, adjusted for the percent ownership of each award, has **doubled** between financial years 2008-09 and 2012-13. This illustrates both the sustainability of UoA5 research and the added value arising from the formation of MVLS in 2010.



Columns show the value of new grants awarded (£M) in each financial year; the value for 2007/08 includes 5 months outside the REF period. The data are not the research spend values in REF4.

Infrastructure and facilities

Polyomics

In 2008 we created a fully equipped genomics, transcriptomics and DNA analysis laboratory. In 2011 this Functional Genomics Facility was amalgamated into Glasgow Polyomics which is equipped for the collection, analysis and integration of high-throughput biological ('omics') datasets (www.gla.ac.uk/polyomics). It is increasingly necessary to assess not just the genome but also the epigenome, transcriptome, proteome or metabolome, and Glasgow Polyomics provides us with rapid and convenient access to top-class facilities. It also provides a unique range of experience in network biology, bioinformatics and software development, in particular for the integrated analysis of multi-level 'polyomic' datasets.

Structural biology and physical biochemistry

These facilities provide essential underpinning for much of the molecular work in this and other UoAs. Continued financial support for structural biology has ensured that both crystallography and NMR facilities are maintained and developed. The College of Science and Engineering provides funds for a senior research officer (Roszak) who runs the crystallisation and X-ray detector facility. This investment has proved invaluable as it has led to the solution of 15 structures in the last 5 years including the mannose-binding lectin from *Champedak* and the reaction centre from *Blastochloris viridis* (**Cogdell**) and human peroxiredoxin 4 (**Bulleid**). The facility has allowed non-structural biologists to gain access to valuable structural information.

Our 600 MHz NMR console and cryoprobe has been upgraded at a total cost of £240k, sustaining our capability to determine structures of proteins and peptides in solution with high resolution as well as allowing for small molecule analysis for metabolomics studies. The NMR facility run by **Smith** has been involved in the determination of the structures of 10 proteins including the novel fatty acid binding proteins Na-FAR-1 and ABA-1A (with **Kennedy,** Cooper**,** Corsico) and the natural surfactant proteins Rsn-2 and Latherin (with **Kennedy,** Cooper), and analysed conformational changes upon protein-ligand interactions in ten additional systems (e.g. ypTpx with Roe). **Smith** is part of an international team pioneering *in vivo* NMR which determined the first three dimensional structure of a protein to be solved in living cells, published in Nature. The biomolecular NMR group will shortly move to newly refurbished laboratory space. Other techniques available include CD, SPR, ITC and SEC-MALS.

Animal facilities

Given the high cost of animal experimentation, obtaining funds for pilot *in vivo* experiments or for the import of novel experimental mouse strains is a constant challenge. The College has therefore initiated a scheme whereby members of staff can apply for up to £10k to support such *in vivo* work. The scheme is designed to enhance the scientific content of publications resulting from ongoing research as well as to provide preliminary data to support more substantive external grant

applications. The College has also made a significant financial contribution (£1M) to the overall cost of *in vivo* experimentation with the consequence that animal tariffs have been reduced by over 30%, making it more feasible for external funding agencies to support our *in vivo* experimentation.

The College has maintained and redeveloped large and high-quality aviaries. The facility consists of a range of rooms designated for ASPA work in which photoperiod and temperature are controlled. The facility can hold several hundred breeding pairs and thus allows for studies that require large sample sizes in order to make robust assessments of the effects of biological treatments, which is not possible in many other facilities. The College supports a dedicated NACWO and four technicians who provide animal care and assist with experimental work. The Graham Kerr Building contains eight specialist aquarium rooms designed for long-term holding and experimental work on aquatic invertebrates, fish and amphibians, plus one room for short-term physiological experiments that includes extensive respirometry and swim tunnel facilities. The majority of rooms have been fully refurbished in the last 5 years. All aquarium rooms have full temperature regulation for either temperate (5-25°C) or tropical (15-30°C) species, a compressed air supply and either a fresh or sea water supply. The rooms are equipped with both flow-through and static tanks designed for holding and experimental work on a range of species (in particular sticklebacks, salmon, trout, cichlids and swordtails); facilities include two glass-sided stream channels for behavioural observations, and are designed to complement the fish-holding facilities at SCENE. All animal husbandry is provided by a dedicated team of animal technicians. These facilities have proved invaluable in the recruitment of outstanding Fellows such as **Killen** and **Noguera**, as well as for ongoing projects.

Workshops
Our research often requires the manufacture of bespoke equipment. We therefore operate both mechanical and electronic workshops. During the REF period these workshops have designed and built several unique items of equipment. Examples include control and monitoring of bird flight and fully independent control of the illumination of plant shoots and roots for imaging experiments. These workshops are very important as they allow cutting edge research to be undertaken that involves equipment that is not available commercially.

e. Collaboration or contribution to the discipline or research base

Involvement with Research Councils and Other Grant Giving Agencies
Given the focus on top quality basic science in UoA5, a major area for involvement with external bodies comprises contributions to UK Research Councils and other funding bodies. **Dow** is on the BBSRC Strategy Panel for Integrative and Systems Biology and Exploiting New Ways of Working. He is also the Chair of their grant panel 'Bioinformatics and Biological Resources'. Five members of UoA5 sit as core members of BBSRC grant panels and a further six are on their Panel of Experts; two sit as core members of the NERC Peer Review College and a further two as members; three are on the MRC and two on the EPSRC Panel of Experts. **Byron** is on the STFC Science Board, on their Advisory Panel for Public Engagement and is the Chair of their Large Facilities sub-group. **Bulleid** is on the Wellcome Trust Equipment Panel and was previously on their MGC funding panel. **Cogdell** has sat on German DFG grant panels reviewing their Universities Excellence Programmes (twice) and special research groups (twice). **Bulleid** and **Kennedy** have sat on grant panels for the Finnish Academy of Sciences. **Bryant** sits on the Australian National Health and Medical Research Council grant panel. **Monckton** sits on the Muscular Dystrophy Campaign Scientific Review Panel, the Scientific Advisory Board of the US Muscular Dystrophy Foundation and is a panel member of their Postdoctoral fellowship committee. **Cogdell** was a member of the Royal Society's Research Grant Board E. **Dow** has been a Chair of the ESF Standing Committee for Life, Earth and Environmental Sciences search and interview panel and on the Scientific Advisory Board of ERASysBio, a European funding initiative to support the convergence of life sciences with information technology and systems science. **Monaghan** sits on the Royal Society Research Appointment Panel B, the Royal Society of Edinburgh – Scottish Government Research Fellowship Committee and the Science Advisory Panel of Leverhulme Trust.

Involvement with Scientific Journals
Members of staff in this UOA make major contributions to publications in their disciplines. **Blatt** is

Editor-in-Chief of Plant Physiology, the highest-cited research journal in plant biology. Other members of staff are on the Editorial Boards of 44 different international scientific journals including Biochem J (6 staff), J Biol Chem, Biochim Biophys Acta, FEBS Letters, Plant Physiol, Traffic, J R Soc Interface and Heredity.

Involvement with Learned Societies

Members of staff in UoA5 are very actively involved with a wide range of learned societies. During the assessment period three staff have been on the Executive Committee and four on the Council of the Biochemical Society; two have been Chairs of Biochemical Society Theme Panels. **Monaghan** was President of the International Society for Behavioural Ecology. **Riehle** has been on the Council of SEB and three others on different sectional panels. **Dow** is on the Council of the Physiological Society, and the European Society for Comparative Endocrinology. **Cogdell** is a past President of the International Society for Carotenoid Research and President-Designate of the International Society for Photosynthesis Research. **Helm** is the President of the European Ornitholigists' Union. **Dalby** is on the Committee of the Tissue and Cell Engineering Society. **Milligan** is on the International Union of Pharmacology Nomenclature Committee. **Furness**, **Milligan**, **Monaghan** and **Nimmo** are on sectional panels for election to the Royal Society of Edinburgh. **Bailey** is a member of Marine Environment Policy Advisory Group of the British Ecological Society.

Organisation of International Conferences

Members of this UoA have been very active in organising international conferences and symposia such as Gordon Research Conferences (four staff) and SEB symposia (six staff). **Stark** has organised two Biochemical Society Focussed meetings and a Harden Conference and **Yarwood** has organised two Biochemical Society Focussed meetings. **Cogdell** has organised four International Light-Harvesting Conferences. **Berry** organised a UK Biomaterials Society Conference and **Dalby** organised a Tissue and Cell Engineering Society Conference. Bailey organised the 2013 Annual Symposium of the Fisheries Society of the British Isles on deep sea fish. **Tokatlidis** organised 2 graduate summer Schools in Crete funded by FEBS/EMBO and the ESF. Fourteen others have been on organising Committees for various International Conferences.

International and National Collaborations

Members of staff in UoA5 have numerous and wide ranging international collaborations as shown by the analysis of outputs in the Research Strategy section. **Ferguson** and **Hampson** (with BAHCM colleagues in UoA6) have strong links with Tanzanian research organisations (particularly Ifakara Health Institute) funded through the EU-FP7 project *AvecNet*, BBSRC, MRC, Wellcome and UBS. **Blatt** is part of a joint BBSRC/NSF consortium grant. **Monaghan** holds a Leverhulme International Network grant with US colleagues. **Cogdell** co-ordinates an HSFP grant with groups in Japan, Italy and the US. He also co-ordinates an EUROCORE grant with groups in Poland, Germany and Holland and is a member of a large Energy Frontier Research Center US DOE funded consortium run from St. Louis, USA. He also had a joint BBSRC/DFG grant with colleagues in Germany. **Dalby** has a joint Swiss-funded grant from the AO foundation. **Davies** and **Dow** have a BBSRC UK-Japan partnering award. **Jenkins** is part of a EU Cost Consortium. **Milligan** has a joint grant with Danish colleagues funded by the Danish Agency for Science Technology and Innovation. **Riehle** has two EU grants. **Biek** has a joint NIH grant with colleagues in the US. **Helm** has funding from the DFG and is Co-Chair of a COST action programme. **Monkton** has two EU grants and one funded by the US Muscular Dystrophy Association with colleagues in the US. **Bulleid** held a Royal Society International partnership award with a colleague in IISC, Bangalore. During the reporting period we have had 14 major grants with colleagues in other UK Universities.

Industrial Links

Members of staff in UoA5 interact widely with industry**. Davies** and **Dow** receive funds from BASF and Pfizer, and **Amtmann** funds from Bayer Crop Science, both in the form of BBSRC Industrial Partnership Awards. As part of their BBSRC LoLa grant **Stark** and **Rosser** get £300k support from the SME Ingenza aimed at exploiting their gene technology. **Milligan** sits on the Scientific Advisory Boards of six companies including Johnson and Johnson and Cara Therapeutics. **Milligan** also has a £500k contract with Servier for work on G-protein-coupled receptors. **Dalby** is a member of the Scientific Advisory Board of a local SME, BiogelX. **Dalby** has also had three University-funded First Step Awards with three SMEs, Pharmacells, BiogellX and Giltech; his link with Pharmacells

has now received a KTA of £30k. He has also had £10k from Thermo Fisher to trial one of their products. **Blatt** has received £65k from Zeiss and Plant Bioscience Ltd to support PhD student research projects. **Riehle** has consultancy agreements with two SMEs, Mantis Deposition and Hook Marine. **Bulleid** was awarded a BRIC studentship and an Industrial CASE award with UCB Pharma to develop novel cell lines that produce antibodies.

Other Indicators of Influence

Cogdell chairs the Board of Trustees of the former BBSRC Institute 'The Genome Analysis Centre' and the Scientific Advisory Board of the Max Planck Institute for Renewable Energy in Muelheim, Germany. **Gould**, **Bryant**, **Monkton** and **Tokatlidas** are members of the Lister Institute. **Milligan** is the Section Head of Molecular Pharmacology for the Faculty of 1000. **Monaghan** has been appointed to the Joint Prizes Selection Committee of the Natural Sciences and Engineering Research Council of Canada, and along with **Metcalfe** is a member of Academia Europaea. **Page** has recently been elected as chair of the Science Committee of the Global Biodiversity Information Facility . **Helm** is President of the European Union of Ornitholigists.

Several staff have published review articles in highly regarded journals, including Annual Reviews of Biochemistry (**Bulleid**), Annual Reviews of Plant Biology (**Jenkins**), Ecology Letters (**Monaghan** & **Metcalfe**), Nature Reviews in Molecular & Cellular Biology (**Gould**), Pharmacological Reviews (**Milligan**), PLoS Medicine (**Ferguson**) and Trends in Ecology and Evolution (**Elmer**, **Killen**, **Matthiopoulos**, **Metcalfe** & **Monaghan**, **Page** twice, **Parsons**, **Selman**). The influence of these reviews is illustrated by citation data; the 8 articles published prior to 2012 have accumulated citations at a rate of over 30 per paper per year.

Response to National and International Priorities

The members of UoA5 routinely respond to these priorities following consultation with the College Management Group. Two examples are Synthetic Biology and Solar Fuels. Synthetic Biology is a priority research area for both BBSRC and EPSRC. In response to a bottom-up approach the College and the University decided to promote Synthetic Biology as a cross-College initiative. £2.6M has been invested to fund Fellows and research studentships to build capacity in this area and further funds were provided to support LoLa and IKC bids. A similar cross-College initiative was funded (£1.5M) in the area of Solar Fuels, linking Chemistry and UoA5. This is a priority area for BBSRC, EPSRC and the US DOE, and central funds have been used to help support grant proposals to these bodies. These examples illustrate how our own resources are optimally targeted to respond to national and international priorities when they fit with our own strategic plans.

Promotion of Collaborative Research

BAHCM and MCSB, and their predecessors, have a history of encouraging national and international collaborations, for example through supporting applications for leave of absence. The University has a variety of small research funds that can be used to both initiate and pump prime collaborative research; it has established partnerships with a variety of overseas Universities, such as Columbia University and Nankai University, and has special funds dedicated to promote these interactions. The College also has its own travel fund to promote international collaborations, and three staff in UoA5 have benefitted from this recently. Each month all academic staff receive an e-mail detailing all possible grants for international collaboration. Specifically for the EU, both the College and the University have dedicated staff in their research offices who have expert knowledge about all EU funding programmes, promote them and help with the completion of EU application forms.

Summary

UoA5 staff cover a very broad range of research topics in the life sciences. The two Research Institutes BAHCM and MCSB have clearly defined strategic objectives and pursue these through investing in individuals of the highest quality and supporting areas of international excellence. They share as a common philosophy the view that cross-disciplinary collaborations are particularly fruitful in the progress of biology. The many examples of high quality and collaborative science in this document illustrate the **vitality** of our research environment. The future **sustainability** of our research is evident from the quality of our substantial number of new appointments and our new research fellows, the strong growth of our research grant income and the robustness of this income which comes from a wide range of different funding agencies.