Institution: University of Liverpool

Unit of Assessment: 6 – Agriculture, Veterinary and Food Science

a. Overview

University of Liverpool staff returned in UoA6 are based within the **Faculty of Health and Life Science**. Formed in 2010, it consolidates all health and life sciences research into a single Faculty consisting of five research institutes. UoA6 staff are drawn from three of these Institutes, with primary expertise spanning the disciplines of veterinary science (basic and clinical) and basic biological sciences with relevance to the areas of animal health, food and agriculture. The relevant research institutes comprise:

The Institute of Infection and Global Health (IGH) (contributing 25 staff to UoA6) aims to improve the health and well-being of animals and humans by tackling infectious diseases of economic and social importance; its "One Health" vision unifies the majority of the Faculty's expertise in veterinary and human infectious disease. IGH has 55 academic staff, 11 externally funded research fellows, 49 academic-related research staff and 97 postgraduate students. It currently holds £36M of external funding.

The Institute of Ageing and Chronic Disease (IACD) (contributing 13 staff to UoA6) brings together basic scientists, clinical and veterinary staff with the aim of addressing issues of ageing and age-related disorders, musculoskeletal biology, eye and vision sciences, obesity and endocrinology. IACD typifies the close association of veterinary and human medicine in the Faculty. It has 56 academic staff, 10 externally funded fellows, 44 academic-related research staff and 91 postgraduate students. It currently holds £20M of external funding.

The Institute of Integrative Biology (IIB) (contributing 18 staff to UoA6) focuses on fundamental biological research in ecology, evolution and behaviour, microbiology, genomics, the molecular and cellular biosciences, structural and synthetic biology, bioinformatics and systems biology. These map onto University themes such as food security, infection, diagnostics and climate change. The Institute has 71 academic staff, five externally funded fellows, 86 academic-related research staff and 144 postgraduate research students. It currently holds £33M of external research funding.

Staff from these Institutes not returned in UoA6 are returned either in UoA1 or UoA5. Staff in UoA6 are integral to a number of important cross-Institute facilities and Centres. These include:

- The Leahurst campus, with two working farms providing excellent clinical facilities for large and small animals and incorporating the Tesco Dairy Centre of Excellence
- The *National Consortium for Zoonosis Research* (NCZR) led by **O'Brien** (UoA6)
- The *Technology Directorate* led by **Beynon** (UoA6), which includes the *Centre for Genomic Research* (lead, **Hall N**, **Cossins** UoA6) and other major technology platforms
- *MRC-Arthritis Research UK Centre for Integrated research into Musculoskeletal Ageing* (CIMA) (lead, **Clegg**, UoA6)

Staff returned in UoA6 from the above Institutes and Centres are identified with one, or more, of the following research themes; some are cognate groups within single Institutes, whilst others are linked across Institutes by collaborations such as joint research funding, joint PhD studentships, seminar series and mentoring programmes:

i) Foodborne Zoonoses (seven returned staff, including four chairs)
ii) Infectious diseases of livestock (18 returned staff, including seven chairs)
iii) Spatiotemporal epidemiology of infectious diseases (seven returned staff, including three chairs)
iv) Animal welfare and productivity (13 returned staff, including five chairs)
v) Animal Molecular Sciences (three chairs)
vi) Plant and microbial genomics and molecular biology (seven staff, including three chairs).

b. Research strategy

Faculty reorganisation: Research strategy since 2008 has been underpinned by a reorganisation of Faculty structure aimed at providing the focus, impetus and infrastructure for improved research performance. The Faculty is now better placed to initiate and sustain the cross-disciplinary research required for the research topics covered in UoA6. Notably, there has been substantial growth in new collaborations between clinical and basic researchers and we are better able to address related issues in human and animal health.

Reorganisation has been accompanied by considerable institutional investment. UoA6 has benefited directly with six new chairs, a new Biomedical Services Unit located in the £23M Ronald Ross Building, and new laboratories for veterinary research as part of a £10M refurbishment of Veterinary Science facilities at the Liverpool and Leahurst campuses. This strategy has led to significant changes since RAE2008. For example, in 2009/10 relative national performance in BBSRC funding (the primary funder for UoA6) stood at 24th in the UK, rising to ninth place in 2011/12. Other significant changes involve a doubling of the number of major externally funded research centres, a prime example being the UoA6/UoA1 joint-led £2.5M *Centre for Integrated research into Musculoskeletal Ageing* (CIMA). Faculty PGR research numbers have also grown, with 552 doctoral degrees awarded in 2011/12 compared to 112 in 2008/09, reflecting greater global reach through newly established international PGR programmes. This vibrant Faculty context is one in which UoA6 research has flourished. The total number of research outputs in the UoA6 area has almost doubled in the period 2008-2012 (655) compared to the previous five years (354) and citations for returned UoA6 staff are more than double the sector average (11% of publications attracting the top 5% of citations for Veterinary Science papers worldwide, INCITES analysis). Publications in high profile journals have increased including four *Nature*, three *Science*, two *Lancet*, one *Cell*, seven *PNAS*, 16 *PLoS sister journal* and 11 in *Nature sister journal* papers. Our strategic strengths cluster around the following six research themes:

(i) Foodborne Zoonoses (lead Institutes IGH; IIB): This group focuses on understanding and controlling food safety risks; its vision to develop a holistic, inter-disciplinary approach which responds to national concerns over zoonotic disease and food safety. **Changes since RAE2008:** This newly formed group is built on Liverpool's historical strengths within the *National Consortium for Zoonosis Research* (*NCZR*) and underpinned by new appointments of medical epidemiologist (**O'Brien**, Chair), veterinary microbiologist (**Humphrey**, Chair) and geneticist (**Chaudhuri**).

Achievements against strategy and responsiveness to national and international priorities: Combined funding in excess of £16M has been secured for research to help protect people from infections such as *Salmonella*, *Campylobacter* (**Humphrey**, **O'Brien**, **Williams N**, **Wigley**) and Shiga toxin-producing *E. coli* (O157) (**Allison**, **McCarthy**) and ensure the health and welfare of food producing animals. **Chaudhuri** has developed novel genetics approaches for microbial pathogens (*PLoS Genet* Chaudhuri #1). Work by **Humphrey** and **O'Brien** (*Gut* O'Brien #1) has fed directly into the Food Standard Agency's Science and Evidence Strategy 2010-15 and its Strategic Plan (2010-2015). The group, which has close connections with the food industry (BPEX, food retailers), has successfully competed for new interdisciplinary, inter-institutional awards such as BBSRC EMIDA; FP7 CamCon; FSA; Environmental and Social Ecology of Human Infectious Diseases (£3.5M) and the Health Innovation Challenge Fund (£4.2M) which address zoonotic disease in society and influence the way we farm.

Future strategy: Our objectives are to establish an internationally leading research centre in holistic, interdisciplinary food chain research and to integrate existing strengths in zoonoses, food safety and infectious diseases of livestock. The proposed centre will be based at the Leahurst campus, where there are close links with industry and the Tesco Dairy Centre of Excellence. This initiative (led by **O'Brien**, **Williams D** and **Wastling**) will bring together existing groups and develop new collaborations in sociology, economics and animal welfare.

(ii) Infectious diseases of livestock (lead Institutes, IGH; IIB): This group targets endemic, emerging and exotic infectious diseases of food production animals, with research on pathogen genomics and evolution, host-pathogen interactions, host response, diagnosis and vaccination. **Changes since RAE2008:** This group has grown into a substantial and closely integrated body of 17 staff, benefitting from seven new appointments (**Makepeace**, **Darby**, **Hertz-Fowler**, **Evans**, **Coombes**, **Jackson** and **Hiscox**, chair) that bring additional expertise in genomics, proteomics,

imaging and systems biology. New facilities have enabled staff to be based in one of two cognate research units in IGH and IIB.

Achievements against strategy and responsiveness to national and international priorities: Staff in the area of ***genomics and proteomics of animal pathogens and host-response*** have individually led international efforts to sequence the genomes of major animal pathogens, facilitated by access to UoL's world-class sequencing and proteomics infrastructure (combined funding >£8M). For protozoan diseases of livestock (**Hall N, Wastling**, **Hertz-Fowler**, **Jackson**), these comprise *Toxoplasma gondii* and *Neospora caninum* and animal Trypanosomatids (*PLoS Pathog* Wastling #1; *mBio* Hall N #1; *Genome Res* Hertz-Fowler #2*; PNAS* Jackson #1). UoL hosts the international *Fasciola hepatica* genome mapping consortium (**Hodgkinson**, BBSRC £0.7M) and an innovative RCVS Trust award (**Radford**) supports sequencing of "neglected" veterinary pathogens. **Makepeace** and **Darby** have demonstrated the role of bacterial endosymbionts in parasitism with implications for novel therapies (*Genome Res* Makepeace #1; *ISMEJ* Darby #*2*). **Wastling** has been at the forefront of developing proteomics for animal pathogens (*Genome Biol* Wastling #2) and along with **Jones**, **Hall N** and **Hertz-Fowler**, has helped standardise and disseminate pathogen genomics and proteomics data through international consortia such as *EuPathDB* (www.EuPathDB.org), establishing Liverpool as an international hub for genomics and proteomics of animal eukaryotic pathogens. New tenure-track Fellow **Coombes** has undertaken pioneering work on host-pathogen interactions using live-cell and two-photon microscopy (*Cell Reports* Coombes #1*; PNAS* Coombes #*2*).

We have been responsive to UK and international concern in the area of ***anthelmintic resistance*** by responding to BBSRC strategic priorities (£2.2M) via development of field tests to measure drug failure (**Hodgkinson**, **Williams D**). We participate in three EU funded consortia (DELIVER; PARAVAC; GLOWORM, €9M) (**Williams D**) to understand how climate change and livestock management systems affect disease prevalence, working closely with industry, supermarkets, levy boards and farmers' groups (see impact case on bovine neoposrosis). **Carter** and **Evans** have responded to industry priorities with work on ***treponemal disease of dairy cattle***, being the first to isolate and classify the causative agent of digital dermatitis and determine the routes of transmission in cows and sheep (£2M, BBSRC, DEFRA, BVA and industry). ***Viral infections of food producing animals*** are supported by BBSRC/MRC and industry (**Stewart**, **Hiscox**, £3.7M) with work on the pathogenesis of respiratory virus infection (*PLoS Pathog* Stewart #1). **Naylor** uses reverse genetics to define the functions of avian metapneumovirus proteins in the host response, leading to improvements in vaccination formulation (see impact case on AMPV).

Future Strategy: We will continue to lead in pathogen genomics and proteomics, but will broaden our focus into functional and translational work, in particular vaccination, playing a full part in BBSRC's recently formed Veterinary Vaccinology Research Network. Systems biology approaches to understanding host response will be key, exemplified by a recent £1M BBSRC industry partnership award with Zoetis to study host-parasite interactions in coccidian parasites (**Wastling**) and by **Carter** who is commencing development of a vaccine for digital dermatitis (Industry, £0.5M).

(iii) Spatiotemporal epidemiology of infectious diseases (lead Institute, IGH): This group is focused on understanding and predicting the nature of infectious disease outbreaks in order to develop the tools and expertise in quantitative veterinary and medical epidemiology that can be applied, responsively, to nationally and internationally important disease outbreaks. **Changes since RAE2008**: Recent strategic appointments of a leading statistician (**Diggle**, Chair) and a One Health Epidemiologist (**Fèvre**, Chair) have complemented the existing team of veterinary epidemiologists (**Archer**, **Baylis**, **Christley**, **Pinchbeck**, **Williams N**), a mathematical modeller (Read, UoA1) and a social epidemiologist (**Latham**, a recent independent AXA Fellow).

Main achievements against strategy in the REF period and responsiveness to national and international priorities: We have responded to priority areas in environmental, demographic and societal drivers of disease spread, attracting funding from BBSRC, MRC, NERC and ESRC as well as non-RCUK funders. The group works on food-borne zoonoses, avian and pandemic influenza, and vector-borne diseases such as bluetongue, Schmallenberg and mosquito vectors of flaviviruses. Recent discoveries include important insights into the epidemiology and diagnosis of bovine tuberculosis (*Nature Coms*, Williams D #1). Research is underpinned by spatio-temporal

statistical modelling and inference provided by **Diggle**. The group contributes to international and national efforts to monitor or control infections, also addressing disease in the societal context of human behaviour and decision-making (**Christley**, **Fèvre**, **Latham**). We are responsive to emerging threats posed by the spread of antimicrobial resistance (**Pinchbeck**, **Williams N**), and African horse sickness (**Archer**, **Baylis**) and have successfully responded to new funding initiatives, including combating infectious diseases of livestock for international development (CIDLID**; Christley**, £1M); urbanization as a risk factor for the emergence and transmission of zoonoses in Africa (ESEI; **Fèvre**, £2.5M); developing new models of future bluetongue transmission in the UK under scenarios of global climate change (BBSRC; **Baylis** & **Diggle**, £1.3M). The CIDLID and ESEI funds are multi-funder initiatives and success is indicative of a growing programme of multi- and interdisciplinary research.

Future strategy: The team will be further strengthened by the appointment of a new lecturer in Statistics (early 2014) and will further develop vector-borne disease research in collaboration with LSTM (£4M *Emerging Infections* Health Protection Research Unit, awaiting outcome). Research capability in developing countries will be strengthened by new field laboratories initiated in this REF period (Ethiopia, **Christley** and Western Kenya, **Fèvre**), and by plans to extend the Malawi-Liverpool-Wellcome Centre to include zoonosis and veterinary research.

(iv) Animal welfare and productivity (lead Institute, IACD): This combines two related research groupings *Comparative Musculoskeletal Sciences* and *Evolutionary Morphology and Biomechanics,* who undertake research contributing to health and quality of life relating to musculoskeletal disorders, with an emphasis on older people and animals.

Changes since RAE2008: Research in *Comparative Musculoskeletal Sciences* has developed from a small number of veterinary orthopaedic clinicians (£1M active grants in 2007 and 5 PhD students, funded mainly from veterinary charities and industry), to a 15-strong multidisciplinary research group with substantive external funding (£5M active grants in 2013, 17 PhD students, funded by BBSRC, MRC, Wellcome Trust and Arthritis Research UK). We cover veterinary, human and basic science musculoskeletal biology, including structure-function studies of tendon and ligament mechanics, cell and matrix biology of musculoskeletal diseases, and translational studies in clinical veterinary orthopaedics with industry partners. Strategic appointments of **Canty-Laird** and Tew (UoA1) have developed specific musculoskeletal cell and matrix biology expertise and **Peffers** was awarded a Wellcome Trust Clinical Veterinary Fellowship. The group is supported by recently appointed (2012) veterinary pathologists **Ricci** and **Ressel**. The *Evolutionary Morphology and Biomechanics* group develops novel techniques to model locomotory issues relating to musculoskeletal ageing, with two new appointments to support multi-scale computational modelling (**D'Aout**, **Bates**), and a move to fully refurbished laboratories in 2013.

Main achievements against strategy in the REF period and responsiveness to national and international priorities: The *Comparative Musculoskeletal Sciences* group has responded to musculoskeletal ageing priorities, in line with RCUK and research charities emphasis on "lifelong health and well-being". This has resulted in the recent award (**Clegg**) of the £2.5M MRC-Arthritis Research UK *Centre for Integrated Research into Musculoskeletal Ageing* (CIMA), a joint development between the Universities of Liverpool, Newcastle and Sheffield attracting a further £0.9M in external funding (**Clegg**; BBSRC, HBLB and Arthritis Research UK). Work on tendon/ligament extracellular matrix in ageing laid the foundation for **Comerford's** Wellcome Trust funded clinical leave fellowship investigating ligament structure/function relationships, in conjunction with Engineering. **Canty-Laird** has developed research in collagen fibrillogenesis in musculoskeletal disorders and stem cell biology, which has led to MRC new investigator funding on collagen heterogeneity as a stem cell marker. The *Evolutionary Morphology and Biomechanics* group applies a comparative evolutionary approach to understanding musculoskeletal function in both human and veterinary contexts, bringing a unique breadth of experimental and modelling expertise integral to CIMA (*Nature* Bates #1). For example, the development of novel techniques in contrast enhanced microCT imaging is now widely adopted across several disciplines. Success has been recognized by a capital award (£0.5M) from the MRC for a biplanar radiography system, unique for human/veterinary use in the UK.

Future strategy: We aim to exploit the demand for ageing and chronic disease research by developing new approaches to integrate musculoskeletal ageing research. CIMA will deliver a

translational pipeline for our basic science, through clinical trials and into practice.

(v) Animal Molecular Sciences*:* (lead Institute IIB) This group applies molecular and 'omics approaches to address whole animal responses to environmental, behavioural and nutritional factors as they relate to BBSRC priority areas such as *Food Security, Basic Biosciences underpinning Health, New Ways of Working* and the *3Rs/welfare* objectives of the NC3Rs.

Changes since RAE2008: Faculty reorganisation has brought together this new grouping which combines basic and molecular animal science with veterinary applications.

Main achievements against strategy in the REF period and responsiveness to national and international priorities: Shirazi-Beechey has pioneered work on nutrient sensing in the gut with consequences for dietary formulation and palatability, and the control of satiety and obesity. With industry support (Pancosma SA, £1.0M) her work has led to rational formulation of feed for early-weaned animals (see impact case on maintenance of gut health in domestic animals) and an EU-FP7 project (€7.8M total, €0.8M to UoL) has identified natural dietary ingredients that induce satiety hormone release, currently under clinical evaluation. **Cossins** investigates predictive gene biomarkers for pathogen-resistance phenotypes to support selective breeding of farmed fish and uses a zebrafish embryo model for regulatory chemicals testing (£0.5M NC3Rs). He has also pioneered a new stress biology of myoglobin (Mb) (*Circulation* Cossins #1) and discovered a key Mb sequence signature in breathhold-diving mammals (*Science* Cossins #2). **Beynon** applies advanced proteomics to veterinary and applied problems. His techniques for measuring protein turnover in intact animals and his patented approach to multiplexed markers based on *de novo* gene design for protein quantification have been applied in diverse areas such as systems modelling (*Mol Syst Biol* Beynon #3), global proteome profiling (BBSRC sLOLA £5M+, PI), bovine mastitis, equine scar tissue (with Aarhus) and bovine sperm quality (KTP with Genus plc, top-scoring 'A' KTP assessment). Collaboration with Hurst (UoA5, UoL) in rodent semiochemistry has led to the first discovery of a protein pheromone (*Science* Beynon #1) and a BBSRC sLOLA award (£4.8M, Hurst PI) to translate their findings to rodent control, of relevance to the ~20% food wastage due to rodents, and imminent bans on anticoagulant rodenticides.

Future Strategy: We will expand the *Nutrition & Health*, *Obesity*, and *Food Security* themes with turnover and additions to academic staff, postdocs and postgrads. **Beynon**, will extend work on translational rodent control to a worldwide context, initially through ERC and Horizon 2020, linking with specialists in the built-environment and epidemiologists. We plan to integrate our interests in fish biology and to focus on welfare and intensive re-circulation (urban) aquaculture (**Young** - £1.6M EC grants; **Sneddon**, **Cossins**, **Berenbrink**), linking with vets, engineers and water chemists (see Impact Template Ref3a).

(vi) Plant and microbial genomics and molecular biology (lead institute, IIB): Research is focussed on fundamental biology underpinning agriculture and biotechnology, with impacts on sustainable intensification of agriculture, climate change, novel biotechnological solutions and biofuels. The group promotes the translation of research from model species to commercial plants and fungi and contributes to gene discovery programmes crucial to the production of second-generation biofuels from energy crops and agricultural residues.

Changes since RAE2008: This group has benefitted from four new appointments (**Hasnain** chair**, Liu**, **Parry** & **Savage**), gaining significant research support (£8.5M), with 50% coming from the BBSRC and NERC.

Main achievements against strategy and responsiveness to national and international priorities: In response to BBSRC priority areas of *Food Security* (crop science), *Industrial Biotechnology & Bioenergy* and *Systems Approaches to the Biosciences*, **Hall A** and **Hall N** (BBSRC £1.9M) have extended 2nd generation DNA sequencing to characterise the hexaploid genome of *Triticum aestivum* (breadwheat) (*Nature* Hall A #1), clarifying its relationships to ancestral grass genomes. **Hall A** and **Hartwell** research both fundamental and applied aspects of circadian rhythms, photosynthesis and metabolism, working with Arabidopsis (*Mol Syst Biol* Hall A #2), wheat (BBSRC Research Development Fellowship) and the CAM plant *Kalanchoe fedtschenkoi* (BBSRC £798K). **Liu** (Royal Society University Research Fellow) extends our expertise into photosynthesis and bioenergetics, investigating the molecular basis of protein distribution and assembly of light-harvesting complexes, and the physiological regulation of

bioenergetics machinery (*PNAS* Liu #1, #2). **Parry** works on mechanisms that regulate plant development (*PNAS* Parry #1; *Nature Cell Biol* Parry #2). **Caddick** exploits the biotechnological potential of filamentous fungi through work on gene expression, focussing on mechanisms determining RNA stability and translation (*Mol Cell Biol*, 2012). **Hasnain** and **Eady** have made key contributions to our understanding of denitrifying enzymes, including the crystal structure of a bacterial nitrite reductase (*Nature* Hasnain #1; *PNAS* Hasnain #2; *Nature* Hasnain #4), which provides new insights into electron transfer by protein-protein complexes. **Savage**, a mathematical biologist, interacts widely within the group, integrating post-genomic data and molecular analysis using mathematical modelling, an approach successfully applied to the developmental mechanisms defining cellular polarity (*Cell* Savage #1; *PLoS Biol* Savage #2).

Future strategy: A key focus will be translation of fundamental work to applied areas, addressing major cross-council priorities (Global Food Security, Climate Change and Bioenergy) as well as areas highlighted by BBSRC and EU Horizon 2020 (Industrial Biotechnology and Synthetic Biology). New initiatives include: development of bioinformatics tools to aid SNP discovery in cereal crops for abiotic stress tolerance and also mapping gene networks (**Hall A** & **Savage**); a five-year collaboration with the US Department of Energy ($2M) on genetic engineering of photosynthetic mechanisms in poplar for biofuel production (**Hartwell**); overcoming biophysical constraints in photosynthetic mechanisms (**Liu**); development of fungal gene expression systems for industrial biotechnology (**Caddick**); using environmental metagenomics to discover catalytic agents for polysaccharide deconstruction, enabling sustainable biomass utilisation (**McCarthy**).

c. People, including:

i. Staffing strategy and staff development

Strategic appointment of staff: Appointment of staff within UoA6 is determined by a policy to recruit against strategic objectives and develop critical mass. 21 new staff have been appointed in UoA6 since 2008, with six new chairs aimed at bringing leadership to priority areas (**Humphrey** & **O'Brien** – *foodborne zoonoses/bridging the gap with human health*; **Hiscox** - *viral infections of food production animals/systems biology;* **Diggle** - *biostatistics;* **Fevre** – *'One Health'/epidemiology;* **Hasnain**- *structural biology*). Each has played a leading role in large interdisciplinary funding initiatives with significant success (ESEI; EMIDA; FP7 CamCon; Health Innovation Challenge Fund; HPRU [pending]). More junior appointments have been recruited with a view to career development and succession planning; these appointments have brought new vibrancy and skills to UoA6. They have been complemented by a number of independent Fellows: **Liu** (Royal Society Research Fellow); **Peffers (**Wellcome Trust Veterinary Integrated Research Fellowship); **Latham** (*AXA* Research Fellow); **Westgarth** (MRC Fellowship); **Imrie** (Daphne Jackson Trust). There has been relatively little staff turnover in UoA6 since 2008 with most of the new posts deriving from new investment. When required, staff turnover is approached on the same strategic basis. For example, the retirement of **Humphrey** and departure of **Chaudhuri** are anticipated shortly and we are seeking replacement staff to ensure that vitality and competitiveness are sustained in Food Safety, to support the development of the *Centre for Food Chain Research*.

Investment in new staff has been greatly assisted by a **Wellcome Trust award** of £750,000 per annum to the University as an Institutional Strategic Support Fund (ISSF) to assist its biomedical research strategy and to support the separate needs of veterinary clinical and basic scientists.

Support for basic scientists: We have used the ISSF to support five UoA6 Research Fellows (**Darby**, **Savage**, **Liu**, **Coombes**, **Jackson**) in **five-year tenure track fellowships** positions intended to lead to established University posts. This scheme is now the standard route of recruitment for new academic staff, with tightly defined expectations and a fixed maximum teaching commitment in the first three years of appointment, to favour the development of independent research capability. Financial research support is also offered in Years 1-3, with an expectation that fellows will soon become successful in seeking independent external funding.

Support for clinical veterinary research: We have used the ISSF to support pre-PhD clinical veterinary staff in **Veterinary Academic Clinical Fellowships** to develop competitive PhD fellowship proposals (Gill). At intermediate post-PhD level we provide a **Wellcome Trust Clinical Leave** scheme for up to 24 months for relief from clinical duties to pursue research; three clinical veterinary research leave fellows are currently are on this scheme in UoA6: **Senior**, **Comerford** and **Milner**.

Early Career Researcher (ECR) development programmes: ECRs are central our strategy and we have an active support policy for all UoA6 ECR staff that has proved highly effective in fostering the talent of young staff. This is demonstrated by the success of UoA6 ECRs in consistently winning external grant income in their own right and establishing themselves as independent researchers. So far, five ECRs have reached their three-year review stage (**Hertz-Fowler**, **Darby**, **Makepeace**, **Evans, Canty-Laird**): all five have achieved independent grant success (>£5M between them: BBSRC, EUFP7, Gates, WT, MRC) and each has now been confirmed in tenured posts. Of those yet to reach the review stage, **Liu** has recently been commended in the ECR category of the UoL 'Celebrating Success' awards for research excellence. ECRs in UoA6 publish in high-ranking journals (*Nature*, *Cell*, *PNAS*, *Genome Res*) attracting some of the highest citations in the UoA6 return (e.g. Coombes #3**;** Jackson #2; Savage #1).

We attribute the consistent success of our ECRs not just to our recruitment policies, but to subsequent mentoring and personal development programmes, including initiatives such as the *Fostering Liverpool and IGH Talent* (FLIGHT) programme. This programme operates a regular series of seminars and training workshops, using high profile external speakers in areas such as grant writing and publication strategy. FLIGHT has also supported 19 fellowship applications since 2010, with 10 successful awards made so far; three of which were to UoA6 female researchers (**Latham**, **Westgarth**, **Imrie**). IIB runs a similarly successful 'Fellows Club'. Annual Research Institute Days and Away Days provide opportunities for ECRs to integrate into the research structure, develop new collaborative links, and identify opportunities and support. We support ECRs with preferential access to pump-priming funds such as the Faculty-funded **Technology Directorate (TD) Voucher** scheme, which provides subsidised access to core technology facilities. Over the first nine months of operation the TD has supported seven UoA6 staff (£19K), all of whom were independent ECRs. The University also runs an **Early Career Research Staff Programme**, which offers personal and professional development opportunities in grant writing, time management and leadership.

Staff development, reward and recognition: The **University's Leadership Framework Programme**, which is validated by the *Institute of Leadership and Management*, supports the development of leadership capability amongst all staff, and further training courses and workshops are available through the University's **Centre for Lifelong Learning.** Promotions are awarded on defined criteria clearly communicated to all staff, on a non-quota basis. Since 2008 UoA6 has benefitted from the promotion of key staff into positions of greater responsibility (**McGowan, Caddick** to Chair **Wigley**, **Radford**, **Christley, Jones, Hall A** to Reader; **Hodgkinson** to Senior Lecturer). All staff benefit from the University's Professional Development Review (PDR) process, which provides an annual opportunity to discuss goals for the coming year, personal and professional development, and workload balance of research with other duties. **Athena SWAN:** The University became a member of the Athena SWAN Charter in 2010 and two research institutes have been awarded Bronze status. Athena SWAN Champions have been appointed in all Institutes to submit further award bids. We are committed to ensuring that our family-friendly working environment supports part-time and job share working; UoA6 examples include **Pinchbeck** and **Latham**. **Fixed term contracts:** The University's management of fixed term contracts complies with the Protection of Employment (Less Favourable Treatment of Fixed-Term Staff) legislation and the UoL is a signatory to the *Concordat to Support the Career Development of Researchers*. Compliance with this commitment has been recognised by the award of the European Commission's **'HR Excellence in Research'** badge. **Evaluation:** The University participates in both the **CROS** and **PIRLS** surveys and an analysis of the outcomes informs the action plan associated with the HR Excellence Badge.

ii. Research students

Staff in UoA6 have facilitated 120 doctoral degrees since 2008 with an average of 2.23 degrees per staff FTE. For doctorates included in REF4a, 98 individuals contributed to supervision of the students. High quality supervision of PGR students is an expectation of staff in UoA6. All supervisors, irrespective of experience and status, participate in training workshops from the Training and Development Division in our Human Resources department, and only research active academic staff may be appointed as a primary supervisor. All newly appointed staff must undertake the Certificate in Professional Development that includes 'Good Practice Supervisor Workshops' and new staff are not allowed as the primary supervisor of a PGR student until they

have gained experience as part of a supervisory team, with a senior member of staff acting as a mentor for the length of their probationary period.

Offers to PGR candidates are only made after an interview by a Panel chaired by a senior academic, with the primary and secondary supervisors, together with two other academics to provide a broad perspective on ability, fit to project and candidate motivation. This enables us to treat applicants equally, allows objective assessment and enables us to reassure research sponsors that research potential is central. The quality of our approach is demonstrated by our timely PhD completion rates, with **89% full time students submitting their thesis in less than four years** (average 3.8 years, with 5.9 years for part-time students).

Students are integrated fully into the research landscape; they attend Institute Away Days, which provides an opportunity to present their work to the wider research community, and exceptional achievement is recognised with student prizes. Examples of PGR success include: **Maddox** (ECR; supervisor **Clegg**) and **Vermont** (supervisor **Wastling**) received the N.E. Roberts Memorial Prize for outstanding work whilst PhD students in IGH; Rowland completed a PhD, supervised by **Speed,** which in 2008 won the Thomas Henry Huxley Award and Marsh Prize for best Zoological doctoral thesis produced in Great Britain and Northern Ireland. She has since completed a NERC post-doctoral position, a Junior Research fellowship at the University of Cambridge, and is at present a Research Fellow at the Zoological society of London; Al-Rammahi, supervised by **Shirazi-Beechey**, graduated from his PhD in 2011, and is now Head of the Faculty of Veterinary Medicine, Al-Qadisyah University, Iraq.

Faculty investment has been used to supplement and leverage external funding to create a vibrant PGR community. Faculty direct investment has been substantial, with £300K invested in 2011-2012, £600K in 2012-2013 and £900K in 2013-2014, expanding PGR training in strategically important areas, including those relevant to UoA6. External funding for studentships in UoA6 comes from a variety of sources, including a **BBSRC DTP** joint with Newcastle and Durham awarded in 2012, which currently delivers 14 students to Liverpool p.a. with projects in the BBSRC strategic priority area of Food Security. The DTP includes the **Professional Internships for PhD Students** (PIPS) programme aimed at encouraging doctoral students to take a more proactive approach to their career development by offering them the opportunity to experience a work environment outside the home laboratory in areas of work such as the private, commercial and public sectors and in society more broadly.

Between them, CIMA and the Wellcome Trust four year and clinical PhD programme bring in 10 fully funded four year PhD students p.a. Additional funding comes directly from Government (DEFRA), Research Institutes (Pirbright and PHE), industry (Zoetis, MSD-AH, Novartis Animal Health, DairyCo), charities and fully funded overseas students. UoA6 has hosted **23 CASE studentships** over this REF period, spanning research interests from applying 'omics technologies through to modelling the control of farm infections. CASE sponsors include large Pharmaceutical companies such as Pfizer (Zoetis), Schering-Plough and Merial; biological reagent and software companies such as Badrilla Ltd, Waters Corporation and Genus Breeding Ltd; antimicrobial and nutritional product development with Unilever and CocaCola; through to government sponsorship by the Republic of Iraq Ministry of Education. An example of the success of this scheme is **Batchelor**, a BBSRC CASE student supported by Pfizer who graduated in 2011, and is now a Senior Lecturer based at the Small Animal Teaching Hospital in Leahurst. He is a Diplomate of the European College of Veterinary Internal Medicine, and chairs the Committee of the European College of Veterinary Internal Medicine. Overseas partnership schemes are well-established with A*Star Singapore, RIKEN (Japan), CIC Bio/BiomaGUNE (Spain), Science without Borders (Brazil), Chulalongkorn University (Thailand), India, and China. IACD and IGH jointly run an MRes programme in Clinical Sciences and offer bursary funding for potential MRes students resulting in an increase in cohort numbers from 12 (2011/12) to 29 (2012/13).

The University's Skills Programme is compulsory for all research students and encourages the formation of PGR communities within and across subject boundaries. The Skills Team offers a choice of fifteen intensive three-day themed workshops to first year PGRs. There is a **University-wide Poster Day** and a range of activities to develop employability skills covering enterprise and business awareness, career management, communication skills, and work and volunteer experience. Online equivalents cater for part–time and research students abroad. A personal

development planning tool (the PGR Toolbox) is allied to a supervisor meetings record and provides information on training and development opportunities. Students have formed their own PostGrad society and run social, employability, and skills development events. This vibrancy was key to our award in BBSRCs Excellence with Impact competition in 2011. **Research Council YES programmes, Enterprise Schools, Vitae Grad Schools and leadership programmes** are supported by the UoL Skills Team. In the last three years teams from IIB have reached the national finals of Biotech YES, and in 2011 won the national prize for best IP strategy. Our PGR have engaged in three residential Enterprise Schools joint with Lancaster each year since 2010, promoting entrepreneurial teamwork activity. The current Joint Enterprise School now extends from a four-day residential through a six-week online phase and a weekend residential. In 2012 the PGR Development Team invested HEIF funding to encourage and stimulate KE activities in the PGR community and offer PGRs opportunities to develop their transferable skills (PRACTICE awards). In UoA6 **Coyne** (supervisors **Pinchbeck; Latham**) received funding to work-shadow in the Veterinary Medicines Directorate, to observe a quarterly Defra Antimicrobial Resistance Coordination (DARC) meeting, and to attend a monthly Scientific Secretariat (SciSec) meeting as an observer. This aided her understanding of drug licensing and monitoring, the workings of the VMD, and career prospects for veterinary surgeons outside of practice and academia.

d. Income, infrastructure and facilities

The external research *expenditure* for UoA6 was £40.4M over the REF period, with overall yearly research expenditure increasing from £8M in 2008/9 to £8.5M in 2012/13. BBSRC expenditure was £16.6M, representing 40% of all UoA6 research expenditure since 2008. Looking forward at *new awards* in the REF period the picture is exceptional: for UoA6 staff, total awards for the last six years have **almost doubled to £60M**, from £31M in the previous six year period. This has included particular success in large awards, with **21 funded over £0.5M**, compared to seven in the previous period. The diversity of funders has grown (141 to 151 different funding sources), and **growth in new awards has been seen in all major categories** (see table):

Awards to UoA6 staff (£M)	2001/02 to 2006/07	2007/08 to 2012/13
Research Councils	13.4	28.1
UK Government and health bodies	3.9	5.0
UK Charities	8.6	12.6
UK Industry	2.4	4.9
EU bodies	1.8	4.1
Non-EU overseas bodies	1.2	4.9

The growth in new awards reflects success in the research strategy of UoA6 and is partly attributable to investment in new staff, but also increased productivity of existing staff. Most of this growth has been achieved in the last two years and will be reflected in corresponding increases in research expenditure over the coming years. Of particular note are two strategic LOLAs: Hurst (PI)/**Beynon** (Co-I) on rodent semiochemistry and pest control (£3.1M to UoL) and **Beynon** (PI) on quantitative proteomics (£1.6M to UoL). Other significant BBSRC funding includes **Hall N /Hall A** on the wheat genome (£1.3M); **Baylis**; **Diggle** (£0.9M) on models of bluetongue transmission; **Williams D** (£1.3M) on control of liver fluke and **Wastling** (£1M) on systems biology of parasites. Other Research Council funding comes from MRC (£2.5M) to **Clegg**; MRC CGR hub to **Hall N** (£2.7M) and NERC to **Cossins** (£1.7M). Liverpool was successful in two out of the three awarded *Environmental and Social Ecology of Human Infectious Diseases* grants (**O'Brien**, £3.5M and **Fevre**, £2.5M). The latter has a substantial overseas component, as does an award to **Christly** (£1M) under the BBSRC/DFID CICLD scheme. **O'Brien** won a Wellcome Trust "*Health Innovation Challenge Fund*" award (£4.2M). Research expenditure by UoA6 staff from industry amounted to £6.4M during the REF period, with recent new awards including to **Hartwell** (£2M from US Department of Energy for work on genetic engineering of drought tolerance in marginal trees). EU expenditure was £3M for work on vaccines against livestock disease and anthelmintic resistance.

Provision of core research facilities: Research activity in UoA6 has been enhanced by outstanding core research facilities. The establishment in 2010 of an academically driven *Technology Directorate* (TD) (headed by **Beynon**, UoA6) has ensured cost-effective utilisation and open access to core platforms. The TD oversees all Shared Research Facilities (SRFs) with a combined capital value exceeding £18M, including genomics (£3.5M), proteomics (£5.2M), cell imaging (£1.8M), NMR for structural biology/metabolomics (£2.5M), fluorescence-activated cell

sorting and analysis (£0.4M), laser capture micro-dissection (£0.1M) and magnetic resonance imaging (£2.5M). A Faculty funded TD Voucher scheme provides subsidised access to staff, but all facilities are run on sustainable business plans to ensure that investment is maintained and equipment remains state-of-the-art. The TD incorporates the *Centre for Genome Research* (**Hall N**, **Cossins**, UoA6) which alone has contributed >£25M income to UoL since 2008. Other Faculty core facilities not currently in the TD include the *Centre for Computational Biology & Modelling* (CCBM), a Bruker atomic force microscope (>£100K; **Liu** UoA6), the Barkla X-Ray facility (~£400K; **Hasnain** UoA6) and plant growth facilities. There are outstanding clinical research facilities for musculoskeletal biology including MRI (0.2-3T), CT, microCT and a clinical veterinary gait analysis lab. In the next phase of development the TD plans for a significant increase technical specialist staff at graduate or postgraduate level and will create a career route for such specialists. The TD will provide part funding for new capabilities in Liverpool, and also in other N8 group members (e.g. TD supported the Lancaster bid to BBSRC for a £1M solid state NMR). This strategic Wakeham-inspired approach was the basis of extraordinary success in the recent BBSRC ALERT13 equipment infrastructure bid in which the Faculty won 4 of the 20 UK-wide awards (3-D electron microscopy, mass-imaging, single molecule sequencing and light sheet microscopy). The total value of these infrastructure developments is £2.4M (University matched funding of £0.6M).

Library and Research Computing Infrastructure: The University is one of very few Russell Group members that subscribe to *all* of the national NESLi2 'big deal' site licences for journals. In 2009 the University began a five year £5M investment in its data network that includes a £1M HPC. The University continues to work closely with Net North West which manages our wide area network connections and in particular our high-speed resilient links to the JANET network linking to Daresbury and N8 Leeds. These links operate at 10Gbps with an upgrade to 20Gbps due shortly. The CGR with core funding, has invested heavily in ~£450K clusters and storage (540 cores of compute @ >8 cores, 64Gb memory, 968Tb of storage, connected both by gigabit and infiniband; it is about to invest a further £650K (MRC) & £130K (NERC) in another 1400 cores, 1.4Pb storage, data transfer accelerators and two large machines each with 1 Tb memory and 330Tb storage.

Buildings infrastructure: New infrastructure that specifically benefits UoA6 includes (a) bespoke new veterinary research laboratories in Liverpool and laboratory refurbishments at Leahurst which has enabled co-location of staff with closely aligned research priorities; (b) a CL3 infection system for testing mosquitoes for viruses (linkage of the Class 3 virus facilities of the UoL Ronald Ross Building with the Class 3 entomological facilities in the Liverpool School for Tropical Medicine has put Liverpool at the forefront of such work in the UK, and attracted new investment by BBSRC); (c) a new (2014) £1M research facility for the Liverpool arm of Manchester-led *MRC Health eResearch Centre* (led by **Diggle**, UoA6) to support new ways of harnessing electronic health data to improve care for patients and communities (d) a £0.5M refurbishment of lab spaces for large proteomics and genomics instruments, and (e) two field diagnostic laboratories in Africa: a CIDLID-funded laboratory in Ethiopia currently used to support poultry research (**Christley**); and a research facility in rural western Kenya that supports research on zoonoses in smallholder production systems (**Fèvre**).

Research Governance: The RGF Toolkit (implemented in July 2011) facilitates the research governance approval process for staff and is overseen a University Research Governance Committee (RGC), chaired by an Academic Lead for Research Governance. **Ethics:** The University research ethics process and Committee on Research Ethics (CORE) comprises two new Sub-Committees and covers work both on human and animal subjects.

e. Collaboration and contribution to the discipline or research base

Policy on collaboration: We have an active strategy of encouraging staff at all stages of their career to be collaborative and to contribute to the wider discipline and research base. Such activity is formally recognised in the Portfolio of Activity and encouraged via the University-wide Research Themes, which bring together diverse academic communities within UoL to focus on global challenges. **Christley** (UoA6) is a champion for the University's **Global Health theme** and **Baylis** (UoA6) is a champion for the **Living with Environmental Change theme**. These pan-University themes foster interdisciplinary collaboration across the institution and beyond, providing pump-priming to facilitate networking events and to leverage substantive funding. All Institutes and Centres within UoA6 that offer pump-priming awards are encouraged to focus these on ECRs. For example **Peffers** (ECR) has received grants from CIMA (£40K and £26K), both for proof of concept

work with Newcastle University on biomarker discovery in musculoskeletal disorders and from the TD for work with Maastricht University. **Seniors's** Wellcome Trust Clinical Leave to work on avian mucins is with the University of Manchester. UoA6 research outputs are evidence of the extensive network of research collaborations across the unit, with an increase in papers involving international collaboration (57% in 2012 - Web of Science). Research centres such as CIMA represent formal collaborations between the Universities of Liverpool, Sheffield and Newcastle; similarly the *Health eResearch Centre* with Manchester. UoA6 staff have close ties with laboratories in Ethiopia, Kenya and Malawi, and UoA6 researchers play an important role in the recently funded *Wellcome Trust Centre for Global Health Research (£0.8M)* with Glasgow and LSTM. UoA6 staff hold prominent positions at other Universities: **Diggle** is Yale University, Adjunct Professor in the School of Public Health; **Hiscox** is visiting Professor at Northwest A&F University, China; **Carter** is visiting professor at the University of Lasi, Romania; **Stewart** is an Adjunct Professor at University of Georgia, USA; **Hasnain** is a UK observer on the Council of the Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME).

Contribution to UK and international science policy: UoA6 staff make substantive contributions to research policy. **O'Brien** chairs the Advisory Committee on Microbiological Safety of Food (a Nolan appointment) and is a resource advisor for WHO's Foodborne Disease Epidemiology Reference Group. **Beynon** is Chair of the BBSRC Bioscience Skills and Careers Strategy Group. **Baylis** was co-opted onto the Science Advisory Council on Bluetongue and sits on the European Food Safety Authority's Schmallenberg Epidemiology group. **Wastling** was appointed to the BBSRC Food Security Strategic Advisory Panel. **Christley** advises the Welsh Assembly Government on cattle movement in relation to bovine TB control. **Fèvre** is a WHO Member of the Expert Committee on Human African Trypanosomiasis, a WHO Invited International Expert on control of neglected zoonotic diseases in Africa and advisor to the Kenyan National Zoonotic Disease Unit. **Hall A** is on the GARNET-UK Arabidopsis Steering Group Advisory Committee. **Diggle** sits on the MRC Population and Systems Medicine Research Board.

Contribution to training and skills policy: Diggle chairs the MRC Strategic Skills Fellowships Panel and the BBSRC Biosciences Careers and Skills Strategy Panel. **Beynon** chairs the Biochemical Society Education Committee and is an Executive Council Member. **Wastling** is Chair of the Academic Policy Committee of the Commonwealth Scholarship and Fellowship Programme. **Cossins** sits on the Board of Directors for the Company of Biologists, which provides charitable support for young scientists.

Contribution to the disciplines: Hall N chairs the ELIXIR-uk node for genomics. **Stewart** is Chair of the Herpesvirus working group and a member of the Biochemical Society International Committee for the Taxonomy of Viruses. **Carter** is vice-chair of the European Veterinary Immunology Group. **Comerford** was BVOA Scientific Chair, 2007-2010. **Cossins** sat on the Board of Reviewing Editors for *Science* and other UoA6 members hold senior editorial positions in 17 discipline-specific journals. We encourage ECRs to gain manuscript reviewing/editorial experience, examples include: **Peffers** *BMC Genomics;* **Noyes** *Parasitology*; **Canty-Laird** *PLoS ONE*; **Maddox** Review editor for *Frontiers in Antimicrobials, Resistance and Chemotherapy*. UoA6 staff are widely represented on BBSRC Research Committees (**Hall A, Crompton**, **Stewart**, **Wastling**, **Wigley**, **Humphrey**, **Hiscox, Caddick)** and the NERC Peer Review College (**Crompton, McCarthy)**. We value our ECRs gaining experience of external grant reviewing, including: **Peffers** *Alessandro Liberati* call for Young Investigators (2013)*;* **Noyes** *Wellcome Trust*; **Evans** *NIHR & Alberta Livestock and Meat Agency*, Canada; and **Westgarth** *Dogs for the Blind Association*.

External Awards won since 2008: D'Aout (ECR), the 2009 Nike Research Award; **Radford**, BSAVA *Amoroso Award* for outstanding contributions to small animal studies; **Shirazi-Beechey**, an Honorary Associateship of the Royal College of Veterinary Surgeons for outstanding contributions to basic veterinary research and education (2011); **Beynon**, the International Forum for Proteomics Golden Globe Award (2012).

External Fellowships won since 2008: Beynon, Royal Society Industry Fellowship. **Imrie**, Daphne Jackson Trust Fellowship; **Latham**, AXA Research Fellowship; **Liu** (ECR), Royal Society Research Fellowship; **Westgarth** (ECR) MRC Fellowship; **Peffers** (ECR) Wellcome Veterinary Integrated Research Fellowship**.**