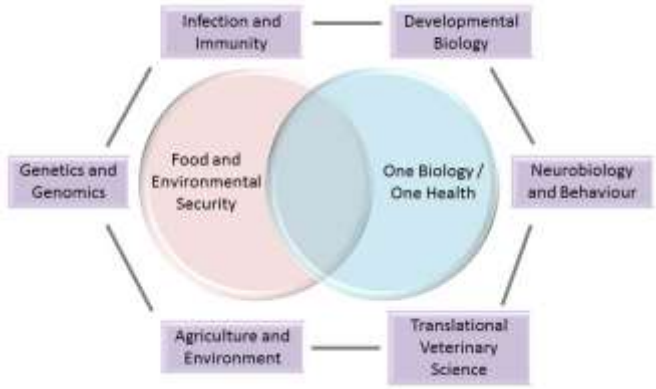
Institution: University of Edinburgh and Scotland's Rural College

Unit of Assessment: 6

a. Overview

The University of Edinburgh (UoE) and Scotland's Rural College (SRUC; formerly Scottish Agricultural College, an HEI and REF returnable since 2008) have collaborated in agricultural research for over a century. This joint submission reflects a well-established strategic partnership developed to address critical challenges in agriculture, food and veterinary sciences. Our Vision brings together a co-ordinated commitment to research and research training that improves the health and welfare of animals and humans, protects the environment and supports safer and more secure food supplies and more resilient rural communities. Our research focuses on ***Food and Environmental Security*** **and** ***One Biology/One Health*****,** two of the greatest challenges facing humanity. These themes are underpinned by our combined strengths in six major research disciplines (see fig).



The Easter Bush Research Consortium (EBRC), comprising UoE, SRUC and the nearby Moredun Research Institute (not REF returnable) was formed in 2008. Our research is leveraged into agricultural practice through 54 strategic industry partnerships. We are well placed to help the UK meet its goal to "become a world leader in agricultural science and technology following the launch of the UK government's strategy to deliver sustainable, healthy and affordable food for future generations" (*UK Agri-tech Strategy, 2013*).

Since RAE2008, the relationship between the UoE and SRUC has grown even further through investment in infrastructure and people. Highlights of the vitality of the partnership include:

Infrastructure Investment. New shared £60M state-of-the-art research facility, the Roslin Institute (opened 2011), at the Easter Bush Campus now accommodating 580 research staff and postgraduate students, located alongside the new £50M Veterinary School. Further investments include the Veterinary Oncology and Imaging Centre (£3M, 2009), Avian Research Facilities (£14M, 2013-2014), GreenCow Facility (£2.5M, 2012), funded Innovation Centre (£25M, completion 2016)

Research Growth. We have recruited a total of 48 new Cat A staff (20 Group Leaders and 28 Career Track Fellows) and 11 new research-active veterinary clinicians. Combined competitive research income has grown from £33.8M in 2008 to a current combined total of £51.8m per annum. In 2011, we renewed the five-year BBSRC Strategic Programme (£40M) to The Roslin Institute as a National Institute of Bioscience, and in 2012 the £40M award to SRUC for five years as a Main Research Provider to the Scottish Government.

Academic Success. The output of peer-reviewed publications has grown each year since RAE2008 from 337 in 2008 to 504 in 2013, including major contributions to sequence and functional annotation of livestock genomes. We have graduated 157 PhD students, more than doubled postgraduate numbers c.f. RAE2008 to 237 currently and introduced new postgraduate research programmes. Our graduate programmes were ranked above the Russell Group average in all categories in the Postgraduate Research Experience Survey (PRES2013).

Industry Impact. We have grown industry funding including strategic partnerships with the large animal health company, Zoetis (£1.5M) and major breeding companies Genus (£1.5M) and Cobb-Vantress (£1M), with land users through SAC Consulting and EGENES, with policy makers through our Rural Policy Centre and with the public through an enhanced programme of engagement. Independent consultants estimated in 2012 that each £1 spent in our research has produced £12.7 annual GVA in the UK economy (edin.ac/1bLvFNr).

b. Research strategy
Strategic developments since RAE 2008 are described here:

Easter Bush Research Consortium (EBRC)
An important initiative foreshadowed in RAE2008 was the creation of the EBRC, which links the partners in this submission with the Moredun Research Institute (MRI) (www.ebrc.ac.uk). The EBRC is supported by a programme partnership agreement with Pfizer Animal Health (now Zoetis), initially £1.5M over 5 years. Many collaborative projects are funded or part-funded across the EBRC from this pool and from joint applications to other sources. An executive of the four Directors of the EBRC organisations, Professors **Hume** (Roslin Institute, UoE), **Fitzpatrick** (MRI), **Argyle** (Royal (Dick) School of Veterinary Studies, R(D)SVS, UoE) and **Webb** (SRUC), meets quarterly to overview this strategic relationship. Scientific direction, coordination and mentoring for the research programmes described in this submission is achieved through a weekly joint Science Management Group comprising Division Heads of Roslin (Archibald, Whitelaw, Kaiser and Manson), the Clinical Research Director of R(D)SVS (Mellanby) and Head of Animal and Veterinary Science at SRUC (Lawrence-A, joint appointment with UoE/Roslin).

Genetics and Genomics
Our capability in this core area has been substantially enhanced. In 2011, the MRC Human Genetics Unit joined the University of Edinburgh to become part of the Institute for Genetics and Molecular Medicine (IGMM). Exploiting this, we have made reciprocal joint appointments with IGMM (Tenesa, Haley, Jackson, Hohenstein) in the area of quantitative genetics and functional genomics and undertaken many joint initiatives. Genomics and bioinformatics is a strategic focus of our submission. The two large sequencing centres in Edinburgh, ARK Genomics (BBSRC) and Edinburgh GenePool (MRC), merged in 2013 to form **Edinburgh Genomics** with >£2.5M investment in equipment and refurbished space, forming the UK's second largest next generation sequencing centre by output. Edinburgh Genomics provides crucial underpinning to our research in livestock genetics and genomics, epidemiology and diagnostics, and also links to major investment and shared initiatives with EPCC, the University's Advanced Computing Facility (www.epcc.ed.ac.uk/), also located physically at Easter Bush. EPCC provides access to the large-scale computing resources offered by massive parallel supercomputing clusters such as HECToR (£13.9m) and its forthcoming successor, ARCHER (£13m); the UK National Supercomputing Facility funded by RCUK.

Edinburgh Genomics also retains a leading capacity in dense SNP genotyping and expression profiling and forms the centre of the large Edinburgh Bioinformatics community (www.bioinformatics.ed.ac.uk). Informatics and mathematical biology has also been a focus of recruitment, with 16 of the new group leaders and career track fellows (CTFs) over the period within that area (submitted within UoA6). This expanding expertise underpins Edinburgh Genetic Evaluation Services (EGENES), which provides genetic evaluations for UK dairy cattle breeders on behalf of DairyCo and sheep and beef breeders on behalf of EBLEX. EGENES creates a very short route to market for genetic and genome-based research outcomes. The concentration of quantitative genetics and genomics expertise has also attracted strategic partnerships with the cattle/pig genetics company Genus worth £1.5M, another worth £1M with Cobb-Vantress, the poultry breeding company, and large co-funded projects with many other livestock companies (notably Aviagen and Hendrix) and levy bodies including DairyCo, BPEX, EBLEX and QMS.

Avian research
We (UoE and SRUC) have a long history in avian research, from basic developmental biology and quantitative genetics to production systems. In 2013, we launched the National Avian Research Facility (NARF) (www.narf.ac.uk/). NARF is a joint venture with The Pirbright Institute, currently supported by UoE, BBSRC, Roslin Foundation and a biological resource grant from Wellcome Trust. It provides the UK with a national resource for the study of avian biology, genetics, infection and disease. A conventional facility was opened in September 2013, and a unique specified pathogen free (SPF) facility is under construction (opening Q4 2014).

Neuroscience and welfare
In Edinburgh, neuroscience is coordinated by the virtual institute *Edinburgh Neuroscience* (www.edinburghneuroscience.ed.ac.uk). In UoA6 we have focused on (i) dissecting mechanisms of neurodegeneration, due to prions and other pathogenic processes, linking with human clinical neuroscientists (returned UoA4), and (ii) we have developed a particular strength in animal behaviour and welfare and an expanded strategic focus in livestock neurobiology, through recruitment in the area of neuroendocrinology and stress research (Brunton, Rutherford), together with a £2M philanthropic investment in the Jeanne Marchig International Centre for Animal Welfare Education in 2011.

Food and environmental security
Interdisciplinary research in food and environmental security across the natural and social sciences has been strengthened with a chair in Future Farming Systems (Stott). The Rural Policy Centre (www.sruc.ac.uk/info/120069/rural_policy_centre) adds further strength to interdisciplinary research across social and natural sciences and provides a mechanism for promoting associations with policy makers (for example it provides the secretariat for the cross-party group on rural affairs in the Scottish Parliament). The Carbon Management Centre in SRUC (£3M) links closely to the newly formed Centre for Carbon Innovation in UoE (www.edinburghcentre.org/), enhancing critical mass and capability in interdisciplinary working at various levels of aggregation. Major recent infrastructure investments in the 'GreenCow' facility (£2.5M) have strengthened the underpinning capacity for work on emissions.

Infectious disease
The investment by Zoetis is a reflection of the depth of our infectious disease research and expertise. We lead EPIC, the Scottish Government Centre for Expertise on Animal Disease Outbreaks (www.sruc.ac.uk/epic/). The virtual organisation, Edinburgh Infectious Diseases (www.eid.ed.ac.uk/) was formed in 2012, to provide an organisational hub for the massive concentration of infectious disease research in the Edinburgh area, notably within the EBRC. We have made appointments to boost our strength in endemic diseases and pathogen discovery (Kaiser, Stevens, Hope, Morrison-L, Simmonds, Sharp, Digard, Opriessnig). Our Centre for Tropical Veterinary Medicine formed the nucleus of a new Global Health Academy, (www.ed.ac.uk/schools-departments/global-health) headed by Welburn. The academy is now a focus for One Health research and international postgraduate education. Several of our PIs work with the Division of Pathway Medicine, which links UoA6-based infection research to clinically-focussed human infectious disease research and the MRC Centre for Inflammation Research (both centres returned UoA1) reinforcing the added value gained from our One Medicine approach to common biomedical pathogenesis.

Translational Veterinary Science
The co-location of Roslin Institute and SRUC staff on the Easter Bush campus in 2011 alongside the R(D)SVS hospitals has underpinned a vigorous clinical research strategy. All research-active veterinary clinicians have Clinical Research Associate (CRA) positions within the Institute and external appointments have been made to underpin a strong clinical research programme (e.g. Schoenebeck to support canine genetics). The research focus takes advantage of this co-location, notably expanding research in the areas of epidemiology, companion animal genetics and stem cell biology (e.g. development of induced pluripotent stem cell technology in dogs through a BBSRC-Industrial link grant with Merck (£0.6M)). In addition, our strategic siting within the College of Medicine and Veterinary Medicine, affords the opportunity to exploit the concept of "One Health" (e.g. the development of canine lymphoma as a model for human disease (Translational Medicine Research Initiative (TMRI) with Wyeth/Pfizer (£0.3M)); Optical imaging in chronic lung disease (MRC £0.8M, PI Haslett, UoA1) and the use of sheep as a model for gene therapy in Cystic Fibrosis (Cystic Fibrosis Trust £3.6M, PI Porteous UoA1). Central to translational research is pathology and The Centre for Comparative Pathology (CCP) is a new initiative that transcends the traditional college boundaries, supported by four new chairs, Arends (UoA1; Systems Pathology), Cheeseman (Experimental and Comparative Pathology), Opriessnig (Infectious Disease Pathology), and junior appointments (del Pozo, Philbey). The structure supports clinical and diagnostic services (Easter Bush Pathology), research (Experimental Pathology), surveillance

(SRUC Veterinary Services) a partnership with MRC Harwell and conclusion of a Strategic Partnership Agreement with AHVLA. In addition to the £1.5M strategic partnership noted above, we have recently attracted support from Zoetis plc, through the EBRC, to be their reference centre for Emerging Infectious Diseases in Europe (£150K p.a.).

Future Investments and Initiatives (2014-2019)

A vital and sustainable research community such as the UoE and SRUC partnership has a substantial momentum for future development. Our vision for the next five years is to build the definitive European centre of excellence in animal bioscience and to create alongside it a pre-eminent capability for interdisciplinary research on farming systems and rural structures To achieve this over the next five years we intend to build upon the £120M invested since RAE2008 with the following initiatives:

- The relocation of the **SRUC Headquarters** and Edinburgh-based SRUC research and teaching to the Easter Bush Campus. As well as strengthening research collaboration, this will maximise the integration of our research and commercialisation, consulting, knowledge exchange and education activities. It will grow critical mass by continuing to attract government, charity and industry investment in infrastructure and joint research.
- A £25M **Research Incubator Building** (funded by BBSRC, Scottish Government and UoE) to enable co-location of industry partners, spin-out companies and new research centres, with projected completion in early 2016.
- The **Centre for Comparative Pathology**, integrating diagnostic, training and imaging resources for Human, Experimental Animal, Companion Animal and Livestock. This will involve a £5M extension to post-mortem and laboratory infrastructure of R(D)SVS and investment of around £2M in image capture technology and other equipment.
- Further expansion following recent investment of £14M in the **National Avian Research Facility**, comprising conventional (open September 2013) and pathogen-free facilities (end 2014), to consolidate our joint capacity in poultry sciences.
- An **Experimental Intensive Care Facility** for mini-pigs and sheep. £1.5M funding is being sought from the Wellcome Trust to expand the current unit to eight beds. This will enable the development of informative alternatives to rodent models for preclinical evaluation of therapies for both veterinary and human medicine.
- Investment of £25M in a **Large Animal Research and Imaging Complex** to underpin both livestock/veterinary research and the development and application of large animal models for biomedical research. This will include surgery, intensive care, and imaging capabilities to include PET-CT, MRI and ultrasound. It will also support further development of world-leading capacity in large animal transgenics and development of gene and cell-based therapies using large animal models. The new unit will include a Research **Centre for Health, Welfare and Rehabilitation of Racehorses** for which we are currently seeking philanthropic support.
- IMPACT, a strategic initiative between Engineering, Medicine and Veterinary Medicine to develop **Implantable Microsystems** for monitoring tumour microenvironment during therapy (£5.2M awarded by EPSRC, 2013).
- A new **Clinical Research Unit** to be embedded within the hospitals' infrastructure to promote clinical translation. This will link into our referring practice networks to expand our capability to examine large patient datasets in both companion and livestock veterinary medicine.
- Major roles in the **Agricultural Innovation Centres** e.g. we are partners in the newly-awarded **Aquaculture Innovation Centre** (circa £11M).
- The continued expansion of **Edinburgh Genomics** and coordination with the **Edinburgh Parallel Computer Centre** to enable the use of large data in all aspects of Agriculture Research, especially diagnostics, quantitative genetics and epidemiology/modelling.
- Consolidation, enhancement and shared management of our **farm assets** to support field research, translation and research-led teaching of veterinary and agricultural undergraduates.

Research Achievements and Future Directions.

The strategic investments outlined above will enable us to sustain world-leading research in ***Food and Environmental Security*** and ***One Biology/One Health*****.** These themes place translation at the heart of our research programme, addressing the needs of humans and animals for health, safe and secure food supplies and a healthy environment and are aligned with national and

international funding strategies. Our research will continue to be focussed within the six broad discipline areas that underpin our two major themes as summarised below. The research highlights since RAE2008 are selected from >2,500 refereed publications from this submission. These examples illustrate the clear synergies within this joint submission, the multidisciplinary reach of our research and the applied focus. We calculate that 42% of our total publications involve collaborators elsewhere in the UK and 31% involve international collaborators.

Genetics and Genomics

Research Focus

The intellectual and practical challenge in both livestock production and animal and human health is to generate a predictive biology that links genetic and epigenetic variation with phenotype. The essential skill base required for that objective is the ability to analyse genetic variation on a genome-wide scale and the development of theoretical and statistical frameworks for analysis of very large datasets. The programme is based upon recruitment and training of early career scientists with quantitative and informatics skills (see below) and a commitment to the iterative cycle of systems biology. We aim to produce testable models at all possible scales of bioscience: molecular, cellular, organism, population as well as environmental interactions. Progress depends upon technology development. We will make major contributions to functional annotation of livestock and human genomes, sustainable breeding programmes and new breeding tools, capitalising on new technologies such as Genotyping by Sequencing (GBS). Implementation of the outcomes is achieved through multiple strategic partnerships with major breeding companies and other industry partners.

Recruitment

This area is the core of much of our research programme, especially with the completion of livestock genome sequences, high-density genotyping and the formation of Edinburgh Genomics. To reinforce the focus on genetics, informatics and quantitative biology, we have made **five appointments or promotions to professorships** (Freeman, Summers, Coffey, Glass, Banos), plus **three senior** (Michoel, Tenesa, Watson-M) and **eight career-track** (Houston-R, Joshi, Vernimmen, Prendergast, Baillie, Doeschl-Wilson, Schoenebeck, Hickey) academic research appointments. A further highlight was appointment of Andreas Kranis, formerly a research geneticist at Aviagen, to a **Royal Society Industrial Fellowship**.

Publication Highlights 2008-2013

- Led the completion and annotation of numerous livestock and other genome assemblies including chicken, pig, sheep, cattle, duck, zebrafinch and turkey (*Archibald, Nature 2012; Burt, Nature Genetics 2013; Smith, PLOS Biol 2010; Glass, Science 2009*).
- Utilised deep CAGE sequencing to support functional annotation and comparative genomics in mouse and human as part of the FANTOM Consortium (*Hume, Cell 2010; PNAS 2012; also Nature Genetics, 2009, 2010).*
- Developed a new microarray platform for the pig and produced a gene expression atlas (*Freeman, BMC Biology 2012*).
- Multiple publications on the genetic evaluation of production traits in UK Dairy Cattle notably the existence of heritable resistance to tuberculosis (e.g. *Coffey, Journal of Dairy Science 2010*).
- Developed and applied a new high density SNP genotyping resource for chickens (*Burt, BMC Genomics 2013*).
- Combined quantitative genetics with infectious disease epidemiology to enable application of marker-assisted selection in salmon (*Houston-R, BMC Genomics, 2012 and Heredity, 2010*).
- Developed a new statistical approach that combines the effects of rare alleles to enable detection of some of the missing heritability of complex traits (*Haley, PLOS Genetics 2013*).
- Identified the genetic association between energy balance during lactation and fertility in dairy cattle (*Coffey, Animal, 2009*).
- Produced new insights into the genetic control of body weight (*Bunger, Current Biology 2012*).
- Developed new technology (repeat capture sequencing) to identify somatic retrotransposition events and demonstrated their occurrence in aged brain (*Baillie; Nature 2011*).

Developmental Biology

Research Focus

We investigate fundamental processes such as stem cell biology, control of somatic growth,

embryonic patterning, organogenesis, musculoskeletal development, haemopoiesis, gonad function and sex determination that ultimately determine both reproductive success and productivity in livestock and humans. We exploit our ability to analyse and manipulate the genomes of mice, rats, chickens, pigs, sheep and cattle alongside detailed knowledge of human genetics and functional genomics and to analyse the genetic variation in both farmed and companion animals to gain insight into the function of individual genes. We employ systems biology approaches to understand how environmental signals interact with the genetic programme to produce phenotypic outcomes, and how this knowledge can be exploited to improve productivity and welfare. We study domesticated animals as unique model organisms that are important in their own right, and are also more closely related to and predictive of, normal human biology.

Recruitment
This research area is critical to the connection of genotype to phenotype, and emerging animal biotechnology, and has been an area of significant strength and focus. To expand our skills in this area, we have created **three new professorships** (Farquharson, Sang, Whitelaw), **two joint appointments with the MRC Human Genetics Unit** (Hohenstein, Jackson (UoA1)), **one senior appointment** (Headon) and **three career-track appointments** (Davey, MacRae-V, McGrew).

Publication Highlights 2008-2013
- Demonstrated the absence of dosage compensation on avian sex chromosomes and consequent cell-autonomous sex identity (*Clinton, Nature 2010*).
- Developed efficient culture and genetic modification of primordial germ cells and germline transmission using Tol2 and PiggyBac transposons (*McGrew, PNAS 2012*; *PLOS One 2010*).
- Generated embryonic stem cells in the rat that can produce germline transmission and characterised the role of beta-catenin in their self-renewal (*Burdon, Stem Cells 2013; PLOS One 2010*).
- Demonstrated the non-redundant roles of two phosphatases, PHOSPHO1 and bone alkaline phosphatase in skeletal mineralisation (*Farquharson, Journal of Bone and Mineral Research, 2011 MacRae-V, Journal of Bone and Mineral Research 2013*).
- Identified the molecular basis of the naked neck phenotype in chick and developed models of feather patterning (*Headon, PLOS Biol 2011*).
- Identified the gene involved in the talpid3 mutation in chick, a key centrosomal protein that controls primary cilia formation (*Davey, Development 2009*).
- Developed transgenic and gene-editing technologies using lentiviral vectors in sheep and pigs (*Whitelaw, PNAS 2012, Cell Reprogramming 2012*).

Infection and Immunity
Research Focus
Infectious disease is the greatest single constraint on livestock production, especially with increasing intensification. Our aim is to reduce the economic burden of diseases of livestock and to mitigate impacts on food safety and transmission to humans. The research will continue to be based on the genetics, genomics and cell biology of innate immunity in livestock, and includes research on livestock responses, host susceptibility, host-biome interactions and vaccine development to important bacterial zoonoses and emerging diseases. We address gaps in fundamental knowledge or in specific diseases and translate the outputs into control strategies including animal breeding, transgenics and vaccine strategies. The research will deal mainly with endemic pathogens of economic importance to food production in their natural hosts, some of them with significant potential as vaccine vectors. It also includes an expanded focus on pathogen genomics and discovery in livestock species. Alongside studies on host-pathogen interactions and pathogenesis, we continue to expand our ability to utilise molecular diagnostic and mathematical tools to develop predictive epidemiology models.

Recruitment
With the change in research focus of the Institute for Animal Health (now The Pirbright Institute), we made a strategic decision to further expand our capacity to address economically-important endemic and neglected tropical diseases. This is also an area of significant interactions with the Moredun Research Institute within EBRC, and Entrican was appointed a visiting professor. This decision also underpins an emerging interest in the genetics of infectious disease resistance and the basic biology of innate immune systems in livestock. **Five senior appointments** in infectious

diseases to build depth included Digard (influenza), Morrison-L (Trypanosomes), Kaiser (avian immunology), Stevens-M (Salmonella) and Hope (Mycobacteria), alongside **nine career-track appointments** (Vervelde, Sharp, Lengeling, Stevens-J, Handel, Muwonge, Grey, Pridans, Athanasiadou) and appointments in pathology (see below).

Publication Highlights 2008-2013

- Created transgenic chicken lines that do not transmit avian influenza (*Sang, Science 2011*).
- Identified AIM2 as the cytoplasmic detector for DNA that initiates caspase activation in macrophages (*Hume, Science 2009).*
- Demonstrated the role of shigatoxin-encoding bacteriophages in the ability of enterohemorrhagic *E. coli 0157* to colonise the bovine gastrointestinal tract (*Gally, PLOS Pathogens, 2012*).
- Used genome analysis to demonstrate a human to poultry host jump by *Staphylococcus aureus* and also evidence of transmission patterns in humans (*Fitzgerald, PNAS 2009*).
- Demonstrated that *Salmonella* can promote the formation of M cells in the wall of the gut (*Lengeling, Cell Hosts and Microbes 2012*).
- Produced a comprehensive assignment of the roles for *Salmonella typhimurium* genes in intestinal colonization of food-producing animals (*Stevens-M, PLOS Genetics 2013*).
- Identified IRG1 as a candidate regulator of susceptibility to Marek's disease in chickens (*Kaiser, Journal of Virology 2011*).
- Identified the major route of uptake and initial site of replication of ingested prion proteins (*Mabbott, PLOS Pathogens 2011*).
- Demonstrated that TSEs can be efficiently transmitted between sheep by blood transfusion and that passage through sheep increases the pathogenicity of BSE (*McCutcheon, PLOS One 2011; Barron, Journal of Virology 2011*).
- Determined the interactive effects of protein nutrition and growth potential on resilience of animals to gastro-intestinal parasitic infection (*Houdijk, Parasitology 2011*).
- Determined likely modes of transmission of tuberculosis amongst badgers and between badgers and livestock (*Hutchings, PLOS One 2009; Journal of Animal Ecology 2008*).
- Identified a novel protein product of influenza A virus that modulates the host response (*Digard, Science 2012*).

Neurobiology and Behaviour

Research Focus

Animal behaviour and welfare are major areas of public concern as production systems change and intensify. Underpinning this theme, we will continue to expand our focus on fundamental biology of the cells of the CNS of large animals, in part through investment in imaging infrastructure. Part of that focus builds upon our commitment to studying the biology of transmissible spongiform encephalopathies (TSEs). Alongside that focus, we aim to develop large animal models of other forms of neuro-degeneration and enhance our multidisciplinary links with Edinburgh Neuroscience and the MRC Centre for Cognitive Ageing and Cognitive Epidemiology (UoA4). One of the challenges here is to develop a better understanding of the importance of behavioural expressions to farm animal welfare. We intend to continue work on understanding 'negative' aspects of welfare such as expressions of pain, fear, stress and aggression; in addition there will be a growing focus on 'positive' behaviours such as play and non-aggressive social behaviour. There will be a substantial increase in the interlinking between behavioural and genetic, epigenetic and neurobiological studies in order to make a step change in our ability to assess and improve welfare in the field. We also envisage an increasing involvement of complex systems modelling to help us simulate the multi-dimensional control of behaviour. The challenge of this area is the continued development of objective and quantitative measure of temperament and aggression, pain and stress in animals, to identify genetic and epigenetic control pathways that underlie behavioural traits, and to use the information to improve animal welfare and productivity.

Recruitment

This area has been reinforced with the **appointment of four professorships** in the area of animal welfare (Ashworth, Dwyer, Mitchell, Waran) and **five career-track appointments** in neurobiology (Wishart, McColl, Brunton, Baxter, Rutherford). In addition Lawrence-A now has holds a joint appointment between UoE and SRUC to coordinate research in animal behaviour.

Publication Highlights 2008-2013

- Discovered an intrinsic vasopressin system in the olfactory bulb that helps animals recognise each other by smell (*Meddle, Nature 2010*).
- Identified the role of dopamine in a novel pathway of spinal motor neuron generation and regeneration (*Becker, Developmental Cell 2013).*
- Used a combined proteomic and molecular genetic approach to identify regulators that control synaptic and axonal stability *in vivo* (*Wishart, PLOS Genetics 2012*).
- Demonstrated the link between expression of the satiety signal receptor CCKAR and growth and body weight in chickens (*Dunn, American Journal of Physiology 2013*).
- Identified genetic parameters for fitness and neonatal behaviour traits in sheep (*Dwyer, Behavioural Genetics 2012*).
- Demonstrated the impact of stress in pregnancy on the stress reactivity of offspring in pigs (*Rutherford, Biology Letters 2009*; *Ashworth, Reproduction 2011*).
- Demonstrated that puberty onset, stress response, cognitive function and glucose homeostasis in offspring are modulated by maternal stress in rats (*Brunton, Journal of Endocrinology 2013*).
- Identified the role of genetic variation in neuroendocrine systems underlying aggression in pigs (*D'Eath, Animal 2009*).
- Developed and assessed free-farrowing systems for pigs that allow expression of natural behaviours (*Baxter, Animal 2011*).
- Identified transcriptional circuits in the par tuberalis organ and the function of substance P in the seasonal response to changes in day length (*Burt, Current Biology 2010*).

Translational Veterinary Science

Research Focus

The pathophysiology and management of disease are major aspects of our translational clinical research and capitalize on the co-location of veterinary hospitals with the research institute. The strategy to enhance clinical research will continue to revolve around providing access and support for clinical researchers to research infrastructure, a vibrant research culture within the small animal and large animal clinics, investment in pathology (formation of the centre for comparative pathology) and imaging (large animal research and imaging complex), and encouraging veterinary graduates to undertake PhD training (e.g. £6.2M Wellcome Trust Edinburgh Clinical Academic Track (ECAT) encompassing ECAT-V for veterinarians). Strategic areas include infectious diseases (including antibiotic and anthelmintic resistance), genetic basis of disease in companion animals, healthy ageing (e.g. longitudinal "Dogs Life" project: http://www.dogslife.ac.uk), inflammation, cancer and stem cell biology. Collaborative research between veterinary and human medicine has benefits for all species. On this basis, we will continue to enhance our research in the area of "one medicine" through our strong collaborations, particularly focusing on genetics, infectious diseases and large animal models of human disease (e.g. cancer, lung disease). As 60-70% of infectious diseases in animals have zoonotic potential we have also exploited the opportunities to map between animal and human traits and diseases. For example, many single gene defects of interest in companion animals have counterparts in humans and pets share many of the diseases of human ageing. Our shared activities in surveillance and epidemiology combined with an emphasis on genetics, nutrition, vaccinology and economics are directed towards the development of integrated strategies for disease control in the UK and extending internationally through our many partnerships. Translation is greatly enhanced by the relationship of our researchers with the veterinary surveillance service operated by SRUC, and with our teaching hospitals.

Recruitment

We established the position of Clinical Research Associate to encourage the development of research-active clinicians. To expand our veterinary clinical research we have made **three professorial appointments in pathology** (Opriessnig, Cheeseman, Thomson), and **one Professor of Livestock Medicine** (Sargison) as well as **eleven key junior and senior clinical appointments** in pathology (Philbey, del Pozo, Beard, Houston-F), dermatology (Nutall), oncology (Lawrence), internal medicine (Mellanby), orthopaedics (Clements, Labens, Reardon), and cardiology (Culshaw).

Publication Highlights 2008-2013

- Identified a canine homolog of hepatitis C virus (*Simmonds, PNAS 2011) and a* new non-primate hepaciviruses in domestic horses (*McGorum, Emerging Infectious Diseases, 2013*).
- Modelled the impact of incursion of blue tongue virus into Scotland (*Gunn, Epidemics 2010*).
- Identified *Calicophorn daubneyi* and the major rumen fluke in GB livestock, and exploited the implications for liver fluke diagnosis (*Sargison, Veterinary Parasitology 2013*).
- Developed and evaluated a web-based longitudinal study of Labrador retriever health (*Clements, BMC Veterinary Research. 2013*).
- Evaluated non-viral gene transfer agents for the treatment of cystic fibrosis using a sheep model and aerosol delivery (*McLachlan, Gene Therapy 2011*).
- Identified and characterized canine and feline cancer stem cells, including aberrant DNA damage response mechanisms. (*Argyle-DJ, The Veterinary Journal 2013, Bergkvist, The Veterinary Journal, 2012*).
- Used transcriptional profiling to support the use of the dog as a model for human lymphoma (*Argyle-DJ, PLOS-One, 2013*)
- Confirmed the molecular basis of bovine neonatal pancytopenia and association with the BVD vaccine (*Bell-Ch, Veterinary Immunology and Immunopathology 2013*).
- Demonstrated introgression of invermectin resistance onto the genomic background of *Haemonchus contortus* as a first step in genetic dissection of the mechanism (*Sargison, PLOS Pathogens 2012*).
- Demonstrated the impact of cow lameness on the technical efficiency of dairy herds (*Barnes, Journal of Dairy Science 2011*).

Agriculture and Environment

Research Focus

The overall objective of this research is to support the economic, environmental and social sustainability of rural areas. Research related to rural policy combines economic and socioeconomic approaches with research on biological systems (both crop and animal). This provides an evidence base to inform future policy making in addition to the conventional goals of future research benefits. Socioeconomic research is based around locations and sectors. We address actor behaviours in relation to innovation and the attitudes of the public to technology and welfare. Specific targets are the suboptimal uptake of technologies and/or systems that are expected to be highly cost effective in greenhouse gas (GHG) mitigation or in improving animal health and welfare. Farming systems research emphasises efficiency and resource use and is a vehicle to integrate the outcomes of disciplinary-based research strands. We continue to develop systems of crop production that minimise the use of agrochemicals and maximise the efficiency of plants' natural defence mechanisms. Barley continues to be a major target because of its importance in northern Britain. Nutrient cycling and use provides the point of interaction with the SRUC Carbon Management Centre and external collaborators both nationally and internationally. On-going work aims to improve the accuracy of methods used in national and international greenhouse gas inventories and with developing cropping and livestock systems that reduce emissions whilst maintaining soil functionality. The implementation of livestock improvement programmes is, increasingly, linked with farming systems level research activity, especially developing sustainable, efficient, carbon-efficient farming systems. There are close interactions with SAC Consulting that provide front line services to around 12,000 agribusinesses, especially in Scotland and northern England.

Recruitment

This is an area of substantial growth directed towards effective translation and integration. We have made **ten professorial appointments** to build critical mass in ruminant nutrition (Dewhurst), international development (Peters) and soil science (Griffiths, Edwards), created chairs in carbon management (Rees), agricultural systems (Stott, Watson-C), agricultural ecology (McCracken), avian science (Sparks) and disease ecology (Hutchings), and made **eight early career appointments** (Kaichi, Auty, Baxter, Bell, Hoebe, Huntly, Prichard, Smith)

Publication Highlights 2008-2013

- Developed spatial models using soil, climate and land-use information to improve estimates of

nitrous oxide at national scale (*Ball, Global Change Biology 2009*).
- Developed rapid in-line assessment of meat quality in beef carcasses (*Roehe, Meat Science 2009*).
- Demonstrated the ability of intercrops to modify nitrous oxide emissions and N leaching in arable rotations (*Watson-C, Agriculture, Ecosystems and Environment 2011*).
- Quantified the potential to reduce global warming emissions from dairy herds by improving reproductive performance (*Stott, Journal of Dairy Science 2011*).
- Developed greenhouse gas marginal abatement cost curves for agricultural emissions from crops and soils and applied to policy development at UK level (*Macleod, Climatic Change 2010; Moran, Journal of Agricultural Economics 2010)*.
- Developed global estimates of the value of ecosystems and their services in monetary units (*McVittie, Ecosystem Services 2012*).
- Identified yield-enhancing effects of fungicides in the absence of visible disease control in spring barley crops and strategies for rational fungicide use (*Bingham, Field Crops Research 2012*).
- Quantified effects of plant breeding on the nitrogen use efficiency of spring barley and identified possible routes to further improvements (*Bingham, European Journal of Agronomy 2011*).
- Demonstrated the impact of aquatic pathways in the carbon and greenhouse gas budgets of peatlands (*Rees, Global Change Biology 2010*).
- Critically analysed inconsistencies between contrasting methods used for consumer preference studies (Akaichi*, American Journal of Agricultural Economics* 2013).

Effective Mechanisms for the Development, Promotion and Dissemination of Research

As described in REF3a, our strategy for knowledge exchange, enterprise and commercialisation and other impact from our research addresses five distinct KEC target audiences:

- *Animal health/biosciences/agri-food companies/veterinary professionals* – the primary means of engagement is through collaborative research, including through research co-funding schemes such as BBSRC industry clubs, TSB and EU projects. Aside from the relationship with Zoetis, we have established strategic partnerships worth £2.5M over five years with Cobb-Vantress and Genus and have ongoing research interactions with at least 70 other companies across the pharmaceutical, animal health livestock breeding and biotechnology sectors. In 2012-2013 we attracted research funding from industry of £3.8M, which in turn, leveraged £14.1m, including twenty five BBSRC CASE studentships, five TSB grants, four BBSRC Link, five BBSRC IPA awards and nine EU FP7 collaborative projects. We were also supported in 2013 through five grants from the BBSRC Animal Health Research Club (£2.4m).
- *Farm and land-based industries* – links are through co-funded research, training and consulting including via our network of eight veterinary surveillance centres and thirty farm and rural business support services across Scotland and northern England in SAC Consulting (http://www.sruc.ac.uk/info/20005/sac_consulting). Research is often carried out on-farm, with farmers, and knowledge exchange is a key part of the participatory research process. In livestock genetics, our EGENES genetic evaluation unit provides a direct avenue to industry exploitation of our joint research endeavours.
- *Policy-makers* – links are via membership of key government committees and dedicated policy-relevant communications (e.g. Knowledge Scotland). The Rural Policy Centre (http://www.sruc.ac.uk/info/120069/rural_policy_centre) issues regular reports and briefings and provides the secretariat for the Scottish Government Cross-Party Group on Rural Affairs. Importantly, researchers are in regular contact with colleagues in Scottish, UK and EU Governments to feed research findings into policy processes as well as to maintain familiarity with policy direction and research needs.
- *The public* – via website and media strategies, open days including the Edinburgh International Science Festival, ESRC Festival of Social Science, Edinburgh Medical Detectives Lecture Programme and Midlothian Doors Open day and displays at the Royal Highland Show and other UK agricultural shows. Many public lectures can also be accessed through YouTube or via our websites and we will continue to develop Massive Open On-Line Courses (MOOCs), the first of which, in equine nutrition, attracted 28,000 students. We plan to develop further MOOCs in areas of public interest. Our new Innovation Building will provide a home to the Midlothian Science Centre, which will provide a resource for teaching high school teachers and students.
- *Other scientific users* — the main route of communication is though publication of high quality

research studies in appropriate journals and presentation of findings at key international conferences. In line with the majority of our funding streams, much of what is published is open access to the scientific community. For genomic resources, we are increasingly involved in the generation of databases, and development of improved analytical tools to enable their access and utility.

c. People, including:

Mechanisms and Practices for Promoting Research, and Sustaining and Developing an Active and Vital Research Culture.

Our commitment to our staff exceeds the requirements of the University of Edinburgh's Code of Practice for the Management of Research Staff and the national Concordat to Support the Career Development of Researchers. Our submission of 186 independent researchers includes 69 women (37%) of whom 15 are appointed at professorial level (26%, compared to 36% for men), compared to UK-wide statistics (www.hesa.ac.uk/) where 45% of appointees are women and <20% hold professorial positions. We will continue to move towards greater equity. Like most research organisations, especially in veterinary and animal sciences, we have a much larger percentage of women as postgraduate students (63%) and postdoctoral scientists (65%). To promote career development and opportunity for all of our younger scientists our on-going strategies include:

- A research-mentoring scheme for clinical academics. This will build upon a recent award of £6.2M from the Wellcome Trust to extend the ECAT scheme to Vets (ECAT-V) (see below).
- Continued recruitment of early career researchers under the University of Edinburgh Scientific Academic Track (ESAT) scheme (value ~£2M).
- An open plan physical research environment that promotes interaction amongst staff members.
- Instigation of strategies for achievement of Athena Swan Silver status in 2014 (Roslin and R(D)SVS already have Bronze status; Roslin was the first BBSRC National Institute of Bioscience to achieve this status and R(D)SVS the first veterinary school).
- A joint weekly EBRC seminar series with invited external speakers.
- A separate weekly post-doc-led seminar programme for PhD students and post-doctoral scientists to share their research and weekly seminars by video across SRUC's geographically distinct campuses.
- Annual postgraduate research days that are devoted to posters and oral presentations for all postgraduate students, including clinical residents. An annual shared UoE/SRUC event concludes with the Charnock Bradley lecture. Roslin Institute students also present at the BBSRC National Institutes of Bioscience Conference. The SRUC postgraduate students also take part in an inter-institute competition among Scottish Government Main Research Providers, culminating in the Science for Life lecture.
- Internal funding to support academic members of staff to enrol for a part-time PhD.
- Regular "group leader retreats" to develop research strategy and ideas.
- Strong formal mentoring programmes to support new members of academic staff and early career post-doctoral scientists. Early Career and Contract Researchers (ECCRs) are an integral part of our research community and culture.

i. Staffing strategy and staff development

The building of world-class research infrastructure has provided both the capacity and the drive to recruit additional full-time researchers. Since RAE2008 (when SRUC was not included) UoE alone has almost doubled the full-time research base in UoA6 with 30 new research posts (16 group leaders and 14 career track fellows) recruited along with 11 new research-active clinicians. SRUC has recruited 18 new staff in the same period. Staff recruitment has been focussed on our core strengths, and directed towards a clear vision of translation of basic studies into practical applications. The strategic recruitment of early career researchers provides a younger cohort to take the organisations forward over the next 10-15 years and ensure effective succession.

Both the University of Edinburgh and SRUC have instituted a formal process of career progression. The first stage of independent appointment is a research associate (UoE) / researcher (SRUC). These are research positions, funded from our core budget, rather than external research grants, and are individuals who have significant previous postdoctoral experience. These people are mentored by more senior researchers, and encouraged to develop proposals for fellowships and grants. Career progression depends on achievement in research as measured by outputs, impact,

grant generation, team and institutional responsibilities. The staff reporting system allows reporting officers to recommend progression at any time depending on reviewed progress. In SRUC, Baxter, Rutherford, Pritchard, Bell, Duthie, and Smith have been appointed to these positions since 2008.

The Edinburgh Scientific Academic Track (ESAT) is built upon the award of RCUK-like tenure track positions for early career scientific researchers, targeted to areas of strategic priority or "discipline-hopping" that promote innovation. Selection is on the basis of potential and likely success, and hence the expectation is of appointment to the permanent staff after a review at four years. Three CTFs, Vernimmen, Schoenebeck and Joshi, were recruited as ESAT Fellows in 2012/13, and we aim to use the scheme to attract further appointments in 2014. This has represented a massive investment of £30M across the University under the aegis of the Chancellor's Fellowship scheme and Scottish Funding Council's (SFC) International Excellence Initiative.

With the ESAT scheme, research associates may be promoted to become career track fellows (CTF), at which stage they receive additional support from the Institute for an initial period of five years. CTFs may also be directly appointed on an initial 5-year contract. Researchers who have made the transition from research associate to CTF include McGrew, Grey and MacRae-V. At the end of four years, CTFs are formally reviewed and either confirmed as group leaders, given feedback and reassessed after a further year or (and this has not yet occurred), advised to seek a position elsewhere. Those who have been promoted since 2008 include MacRae-V, Doeschl-Wilson, McGrew and Lengeling as well as former staff members Faulkner and Kohl who have taken senior positions elsewhere. SRUC stimulates and recognises similar career progression through the award of Readerships. Since 2008, these have been awarded to Barnes, Bingham, Bunger, Coffey, Chagunda, D'Eath, Dwyer, Haskell, Houdijk, McCracken, Moran, Mrode, Rees, Stott, Wall, Wemelsfelder. Several of these staff have since been awarded personal professorships.

A special subset of this training path is directed towards clinician researchers. The Wellcome Trust-funded Edinburgh Clinical Academic Track (ECAT) (www.ecat.ed.ac.uk) scheme has already attracted medically-qualified researchers towards unconventional PhD paths. Dr. Ken Baillie has graduated from this scheme to a CTF position in The Roslin Institute, and another ECAT fellow, Alistair Jubb, is currently undertaking a joint PhD between Roslin and MRC-HGU. The extension of this scheme, ECAT-V, is a unique UK venture. For the best veterinary graduates, appointments will be made to a clinical lectureship and candidates will then be mentored through a Wellcome Trust-funded PhD and post-doctoral training, alongside further clinical experience (underpinned by the recent £6.2M Welcome Trust award).

The mentoring and guidance of new researchers in UoE is reinforced by the >30FTE resources of the UoE Institute for Academic Development (IAD) (http://www.ed.ac.uk/schools-departments/institute-academic-development). To mentor career progression, we have a formal internal mentoring scheme for research assistants, postdoctoral fellows, career-track fellows and clinical academics that link these junior staff to a mentor outside their immediate groupings. We have also implemented a universal and simplified performance appraisal system with full compliance. Supplementing the formal appraisal, every group leader and CTF also has an annual informal meeting with their Director to discuss their science in addition to their formal performance appraisal. This process is used especially to encourage connections within and outside the organisation. SRUC has a formal internal mentoring scheme with similar aims and structure, open to research staff at all levels. We also have a longstanding, compulsory performance appraisal/personal development system.

ii. Research students

Since 2008, we have exceeded our strategic goal to double postgraduate student numbers. This has been achieved in a number of ways including DTG awards from BBSRC and a large increase in industrial CASE studentships and internal schemes. SRUC registers the large majority of its PhD students with the UoE. The number of PhD students has almost tripled since 2008 to a current registration of 237 students across this UoE/SRUC submission. This rapid increase and the transition to four-year programmes means this has not yet translated into the corresponding increase in graduate numbers, which we anticipate will reach 60-65 per annum by 2015. The international reach of our programmes is evident from the fact that 42% of postgraduate students

are from outside the UK and 18% are full-fee paying overseas students. Future growth in graduate student numbers will focus partly upon international non EU/UK students, notably through growing relationships and new funding streams from India, Africa and Brazil that are linked to joint research activities. An example is the Brazilian Science without Borders scheme where we have developed a joint funding scheme involving EBRC, Zoetis plc and BBSRC. We also aim to develop new ways of attracting veterinary graduates into both PhD programmes and residencies with a strong research focus.

Many PhD studentships have supervisory teams from across the EBRC. Each PhD student has a primary and secondary supervisor, and all supervisors are required to attend regular training sessions. All PhD students receive induction-briefing sessions during which they are given guidance about internal training events and courses and skills training events offered by the IAD. The IAD integrate transferrable and scientific skills as outlined in the Vitae Researcher Development framework. Postgraduate programmes are overseen by a campus postgraduate dean and supported by the campus postgraduate hub. Since 2008 we have introduced initiatives into the postgraduate training programme to support development of individuals at this early stage of their career. These include:

- Uniform induction process for all postgraduates.
- An active thesis committee, with formal reports from students at 10 weeks, 9 months and then annually until completion. The 10-week report articulates the aims of their project and provides evidence that a realistic and achievable project plan has been agreed with the student and supervisors. The 9-month and annual reports, in line with University policy, are to assess student progress and include an independent chairperson.
- Annual postgraduate research day with opportunities for presentation in a supportive environment.

Research students remain a high priority. Some of the ongoing recruitment initiatives include:

- Promoting research careers to veterinary students. There is an active summer research student programme for around thirty 3rd year veterinary students each year. This is in addition to accommodation of 15-20 science honours students each year across the partners.
- All clinical residents are postgraduate students and conduct a research project as part of their clinical speciality training. Such students can also undertake a masters degree by research (MRes).
- Students awarded “Principal’s Career Development Scholarships” from the University also have the opportunity to spend a period of time on activities aimed at promoting career development. Opportunities include training in undergraduate teaching, entrepreneurship and public engagement activities.
- Pro-active promotion and nomination of our students and early career researchers for awards and encouragement and funding through a dedicated allocation to present their work at national and international meetings.
- Engagement with international partners, notably the Brazil Science without Borders programme, and the National Institute for Animal Biotechnology in India, to attract research students with a focus on scientific areas of impact in their own countries as well as the UK.

Comparative Performance of our students in Postgraduate Research Experience Survey 2013.

Primary Theme	This Submission	Russell Group
Assessment and feedback	85%	79%
Academic support	89%	80%
Learning resources	88%	80%
Personal development	83%	75%
Overall Satisfaction	93%	82%

In addition to our large PhD programme we have developed 13 taught and research-based masters programmes, which have proven a valuable foundation to the development of high quality PhD proposals, create links with industry and are essential to the vitality of our research.

The success and vibrancy of our programmes and student support is evident from the most recent

Postgraduate Research Experience Survey (PRES2013) (table above). The survey of postgraduate taught courses placed this submission top in the University of Edinburgh and ahead of the Russell Group average in every category, with a 96% overall satisfaction score. The PRES2013 outcome in postgraduate research shown above demonstrates the same trend. The sustainability of this performance is evident from the continued growth in student numbers, international partnerships and strong industry relationships.

d. Income, infrastructure and facilities

Our objective in RAE2008 was to translate the synergies between The Roslin Institute and R(D)SVS into a substantial increase in quality and quantity of research activity. The co-location and joint submission with SRUC extended this ambition to a larger partnership. The Institute Strategic Programme Grant (ISPG) to Roslin has been frozen at 2008 levels, as has the main research provider grant to SRUC. Nevertheless, the total competitive research income across the submission has increased each year from £33.8M in 2008 to a current combined total of £51.8m in 2013 and now includes 3% direct funding from industry (as well as many co-funded projects such as BBSRC industry partner awards and CASE studentships). SRUC has only been eligible for RCUK funding since 2010. Our combined success rate of 40% with BBSRC over the past two years places us well above the national average of 29%, and alongside John Innes Centre as the leading BBSRC National Institute of Bioscience (www.bbsrc.ac.uk/funding/apply/success-rates.aspx).

The new, shared research building at Easter Bush was occupied in March 2011. The design and delivery of this building, ahead of time and on a budget of £59M, is a clear indication of the commitment of UoE and SRUC, who together funded a quarter of the cost, to the development of Animal Sciences research. The design of the building, with open plan office space and shared laboratory environments encourages multidisciplinary research and maximises interactions. It includes a new laboratory animal facility, with space for around 35,000 mice in individually ventilated cages. Since occupying the building, we have invested more than £3M in new equipment including two photon and live cell imaging, confocal microscopy, mass spectrometry and next generation sequencing, to produce a genuinely world-leading research Institute.

The new specified pathogen-free (SPF) avian facility at Easter Bush, to be part of the National Avian Research Facility (NARF; www.narf.ac.uk), is a partnership with The Pirbright Institute. Construction commenced on the SPF building in August 2013. A new conventional avian facility, with family pens and capacity for around 3,000 birds and an avian transgenics unit, has been built adjacent to the Institute, and officially opened in September 2013. The total investment in avian research at Easter Bush is £14M. The NARF has already attracted an additional £600K as a Wellcome Trust Biological Resource Centre and a 5 year National Capability Award from BBSRC.

Our research benefits from access to one of the largest remaining experimental farm estates (>4,000ha) in the UK, including dairy herds near Edinburgh (Langhill) and Dumfries (Crichton), sheep flocks near Easter Bush (Dryden, Easter Bush, Woodhouselee, Castlelaw) and the West Highlands (Kirkton), avian facilities at Easter Bush and Ayr (Auchincruive), pig and beef research facilities at Easter Howgate, adjacent to the Bush Estate, including state-of-the-art respirometers for measuring greenhouse gas emissions from livestock, and other GHG measurement equipment (GreenCow; *circa* £2.5M investment). We share access to the extensive infectious disease challenge facilities at Moredun Research Institute. Over half of our farm estate is devoted to farming systems research platforms with a high degree of animal and land based instrumentation and recording. These farm research platforms cover all the main temperate farm enterprises. They include extensive time series databases covering both animal and land based activities stretching back 30 years or more. These 'whole farm' experiments form invaluable resources for the interdisciplinary and participative research necessary to address the grand challenges that currently face agriculture and the rural sector.

The building of our new joint research building was accompanied by an £11M investment in Easter Bush campus infrastructure; including provision of an on-site estates support hub, improved roads, utilities and drainage. There are current plans to invest in a BioMass plant to provide power to the site, and further reduce costs. This investment contributes to the ongoing sustainability of the overall research facilities at Easter Bush. Outline planning permission has been sought for the whole site, and Midlothian Council has adopted an Animal Biosciences Sector Action Plan within

its Economic Development Framework. The Council has also supported the formation of an Easter Bush Development Board. The current ambition is to seek funding for the relocation of the SRUC headquarters, land economy and crop research and HE activity to Easter Bush and the development of a Large Animal Research and Imaging Facility (LARIF). The University has committed to the design phase of the LARIF and investment in £2M of major equipment to establish *in vivo* imaging of large animals with PET/CT, MRI and ultrasound.

The co-location of SRUC groups with a broader focus on crops, land use and agronomy will provide a more holistic perspective to our agriculture research. Overall, we have realised our ambition from RAE2008 to consolidate and expand our resources and realise the synergies amongst the EBRC partners. A clear development plan is in place that aims to create a true centre of excellence of global relevance to veterinary and agricultural research.

e. Collaboration or contribution to the discipline or research base

Our research strength in agriculture and veterinary medicine is built upon multi-level strategic partnerships with many academic and industry groups. Our highest level of collaboration is with each other, and this is growing rapidly since co-location provided many more opportunities. We will continue to develop external collaborations that produce genuine synergy and maintain international competitiveness. We will foster new programmes with the BBSRC National Institutes of Bioscience (NIB), with other Major Research Providers in Scotland (notably the James Hutton and Rowett Institutes) and with other veterinary schools, especially Glasgow. NIB interactions with The Pirbright Institute (especially in the avian and virology and genomics/informatics areas), Babraham Institute, The Genome Analysis Centre (TGAC) and Institute for Biological, Environmental and Rural Sciences (IBERS), but not excluding the Institute of Food Research, John Innes Centre and Rothamsted, are coordinated through quarterly meetings of the Directors and there are already many joint projects.

The EBRC relationship is supported by joint appointments (e.g. Banos, genomics; Lawrence-A, animal behaviour and welfare) and by co-location in The Roslin Institute Building. A BBSRC-funded Immunological Toolbox project links with Moredun researchers in the development of reagents for the study of livestock immunology. The Scottish Government-funded Centre of Excellence in Animal Disease Outbreaks (EPIC) includes as partners the University of Glasgow, Moredun and Biomathematics and Statistics Scotland. The Scottish Government-funded Strategic Partnership in Animal Science Excellence (SPASE) links EBRC with all the other Scottish universities with activities in the sector. Initiatives in climate change-related research via the SRUC Carbon Management Centre (www.sruc.ac.uk/info/120173/carbon_management_centre) create strong links in research and postgraduate training to UoE research in geosciences, the Climate Change Centre (www.climatechangecentre.org.uk/home.html) and the Scottish Government-funded Centre of Excellence in Climate Change (www.climatexchange.org.uk/), which involves all of the major Scottish universities.

Our international strategy involves strategic partnerships with research organisations in Australia (CSIRO Livestock Industries/Queensland Department of Primary Industries, University of Queensland), New Zealand (University of Otago/AgResearch), North America (multiple organisations including University of Iowa, University of Alberta and USDA), Japan (with RIKEN through the FANTOM5 Consortium), China (especially through the Chinese Agricultural University and Peking University) the National Institute for Animal Biotechnology in Hyderabad, India and many of the CGIAR-funded Institutes, notably the International Livestock Research Institute (ILRI).

Association with the powerful University of Edinburgh bioscience community provides numerous opportunities. We sit strategically within the College of Medicine and Veterinary Medicine (CMVM) and as members of the College Strategy Committee and College Research Committee are well placed to promote the “One Biology, One Health” agenda linking medical researchers at the Queens Medical Research Institute at Little France and research at Easter Bush. Our veterinary practices and surveillance centres across Scotland provide access to expertise and opportunities to develop projects in companion animal, equine and livestock medicine and to influence the provision of care. A major driver for the new Centre for Comparative Pathology is to address the critical shortage of pathology expertise and training in the UK across the spectrum of human, companion and livestock animals and experimental animal.

There are many joint programmes with the BBSRC-funded Centre for Synthetic and Systems

Biology Edinburgh (Synthsys: http://www.synthsys.ed.ac.uk). The formation of Edinburgh Genomics places us at the forefront of genome research in the UK. Haley and Tenesa have joint appointments with the MRC Human Genetics Unit, translating knowledge of the genetics of complex traits from animals to humans, and *vice versa*. In the area of stem cell biology, there is a close partnership with the Scottish Centre for Regenerative Medicine. In the infectious disease area, we are the largest component of Edinburgh Infectious Diseases, and several researchers are members of the Wellcome Trust Centre for Immunology, Infection and Evolution. In the neuroscience area, we collaborate closely with the National CJD Surveillance Unit and with TSE researchers at AHVLA.

Outside of Scotland, we continue to promote strategic alliances and engagement with multinational networks and consortia. Many of these revolve around the genetics and genomics of major livestock species and include active participation in genome (re)sequencing and annotation (notably with EBI/Sanger), SABRE (Cutting-Edge Genomics for Sustainable Animal Breeding), Quantomics, EADGENE (European Animal Disease Genomics Network of Excellence), PRRSNet (Porcine reproductive and respiratory syndrome in network in Europe), European Farm Animal Industrial Platform, NADIR (Network of Animal Disease Infectiology Research) and ELIXIR. EADGENE2 is a formal network agreement engaging us with most of the major animal sciences organisations in Europe. We are also connected with many international consortia in the TSE research area. In the experimental animal area, we are involved with the rat knockout consortium (EURATRANS) and with the MRC-sponsored International Mouse Knockout Consortium. Recent recruit, Prof. Cheeseman will retain a joint appointment with MRC Harwell and Professor Opriessnig with Iowa State University.

We have driven the development of the Animal Task Force – a network of EU animal scientists helping to shape EU Horizon 2020 strategy, in which EBRC is the UK representative member. We have active research collaborations in more than 50 countries, including longstanding collaborations in Europe via EU-funded research and training programmes. These include FP7 projects on Legume Futures, Greenhouse Milk, Greenpig, Para-TB Tools, TB-Step and Animal Welfare Indicators. Other funded research collaborations are with AgResearch (NZ), Iowa State University, EMBRAPA (Brazil), Nanjing Agricultural University (China) and Inner Mongolia Agricultural University. In sub-Saharan Africa the Global Health Academy has numerous partnerships, and there are particularly strong links between SRUC and Lilongwe University of Agriculture and Natural Resources, Malawi, including joint research, and staff and student exchange.

The large majority of PIs contribute to development of their disciplines via editorships on journals and as office bearers in numerous societies, notably the British Society for Animal Sciences (BSAS; www.bsas.org), where Simm is past-president and Bishop is the next Vice-President, Wall, Rooke, Athanasiadou, Baxter have been office bearers and the BSAS office is accommodated along with the Biosciences KTN at Easter Bush. We have contributed to discipline development via leading roles in AVTRW (Athanasiadou); International Society for Applied Ethology (Sandilands, Dwyer, Haskell); WPSA (Sparks) and European Association for Animal Production (Coffey). In the veterinary area, Philbey is Senior Scientific Editor of Veterinary Journal, Argyle serves on RCVS Council and is Editor-in-Chief (EIC) of Veterinary Comparative Oncology and others are Editors for Veterinary Research, Veterinary Record, Equine Veterinary Journal, Journal of Veterinary Medicine and Education, Veterinary Clinical Pathology, Veterinary Dermatology and Journal of Small Animal Practice. Whitelaw is EIC of Transgenic Research and Hocking of British Poultry Journal. Banos is Senior Editor of the Journal of Dairy Science. We provide multiple members of Editorial Boards of journals including Journal of Leukocyte Biology, Journal of Dairy Science, BMC Genomics, Animal Genetics, Animal, Heredity, PLOS Genetics, Animal Biotechnology and Journal of Agricultural Science.

We have provided members of organising committees of at least 50 international meetings since 2008, notably the biennial International Society for Animal Genetics, which we hosted in Edinburgh in 2010 (>600 participants) and a recent conference on Sustainable Intensification with delegates from 30 countries. We have also been drivers of the joint BSAS/AVTRW/AVF meetings in the UK. The availability of a conference facility and auditorium in The Roslin Institute Building has expedited the engagement with discipline societies. Recent conferences at Roslin have included

the Chick Meeting (2011), International Staphylococcus Meeting (2011) and XIIth Avian Immunology Research Group (2012) and the Scottish Neuroscience Meeting (2013).

Several of our group leaders made significant contributions to the Foresight 2011 Project Global Food and Farming Futures. The UK Agri-tech Strategy (2013) explicitly mentioned our research on genetic modification in animals. SRUC Principal Webb contributes via the Leadership Council. SRUC is a member of Farming Futures; Webb is on the Strategy Board. Many of our PIs often act as consultants to UK and Scottish Government and serve on numerous advisory boards. Hume was on the expert panel for Gates Foundation Livestock Development Policy, the SAB of the new National Institute for Animal Biotechnology in Hyderabad and has had a long-standing leadership role in the FANTOM Consortium. Archibald is a member of the International Committee of the Royal Society of Edinburgh and the Advisory Board of ELIXIR. Morrison-I and Hopkins served on the Defra TB Advisory Group and Stevens-M as consultant of food-borne zoonoses to Defra. Mitchell is a member of the European Food Safety Authority Panel on Animal Health and Welfare. Banos is convenor of the Scientific Advisory Committee for the International Bull Evaluation Service (Interbull). Simm chairs and Woolliams is a member of the Defra and Devolved Administrations' expert committee on Farm Animal Genetic Resources and Conington sits on the Farm Animal Welfare Committee.

In summary, we are outward-facing organisations. Our discipline base extends across almost the entire spectrum of the life sciences and our researchers make contributions at every level of the scientific community. The engagement in research of all of our staff and students and our ability to translate basic science into practical solutions underscores the vibrancy of our research environment. The critical mass of the EBRC, our clear strategic vision and strong infrastructure supports our sustainability in a highly competitive international environment. Whilst we would emphasise the collective strength at Easter Bush, we have also actively promoted the Scottish Partnership for Animal Sciences Excellence (SPASE), which includes Universities of Glasgow, St Andrews, Aberdeen and Stirling. This cooperation has attracted funding from the Scottish Government's Rural and Environment Science and Analytical Services Division (RESAS) and funds several joint projects amongst the EBRC partners. We are also partners in the University of Stirling-led Scottish Aquaculture Innovation Centre. An independent report commissioned by Scottish Enterprise concludes, ***"Available scientific indicators suggest that Scotland has the largest concentration of animal science related expertise anywhere in Europe, and moreover, the vision to become the world leaders in animal science is attainable"*** (www.roslin.ed.ac.uk/about-roslin/documents/opportunities-animal-health-report.pdf). That is certainly our vision for the next five years. Based upon our strengths in Veterinary Medicine, Agriculture, Farming Systems and Environment research, and our international profile, we aim to translate that strength into sustainable solutions to the challenge of Future Food and Environmental Security and Animal and Human Health.