Institution: Royal Veterinary College (RVC)

Unit of Assessment: 6

a. Overview: The RVC adheres to the fundamental University principle that its teaching should be informed and enlivened by reference to underlying research and that all teachers should be research active, or at least research aware. RVC intends to maintain and develop its character as a research-led institution. Significant growth in student numbers and diversification in educational programmes funded a 60% growth in RVC academic staff (2001-2008). Our strategy of appointing early-career researchers (ECRs) of promise and investing in their development, coupled with an international recruitment policy, has delivered and sustained a vibrant community of forward-looking and collaborative scientists during REF2014 and has led to enhanced quantity and quality of research funding. RCUK funding has increased 3.2 fold compared to RAE2008 with a 1.7 fold increase in total income (£/fte/year) and 1.5 fold increase in PGR students graduating. Development of specialist clinicians as researchers is an important strategic goal to provide role models for the next generation of veterinary scientists and translators of biomedical science to advances in clinical practice. We include 68% of our eligible staff in REF2014 showing that the majority are research active. Thus we have successfully expanded high quality research across our research groups, remaining a mature and sustainable research-led specialist institution.

Research Groups are cross-departmental fora providing critical but supportive intellectual environments for those with similar interests; and facilities and expertise for those with similar requirements. Research Group Leaders are experienced scientists who act as mentors, facilitating collaborative opportunities across traditional disciplines. Each group brings scientists from different disciplines to address problems from the molecular, whole animal and population level. We have particular strength in depth in veterinary epidemiology, whole animal (integrative) physiology, comparative pathology, immunology, protozology and medicine (through clinician scientists). We are developing strength in agricultural economics (social sciences of the implementation of disease control strategies) and aim to build capacity in mathematical and computational biology.

We have refreshed our research groupings since RAE2008 to ensure their focus meets national and international priorities. We now manage six Groups within two Programmes. Overview at the Programme level fosters interdisciplinary contributions, exchange of ideas and dissemination of good practice in developing: (i) internal and external collaboration; (ii) interdisciplinary research projects; (iii) ECRs. Programme committees input to strategic decision-making through Research Strategy Committee (RSC), comprising Programme Leaders; Heads of: academic departments, Graduate School, and RVC Enterprise; ECRs and research professors. RSC is chaired by the Vice Principal – Research and Innovation (VPRI) and reports to Academic Board. The underpinning philosophy of the Programmes and how they address global priorities is outlined below.

Comparative Physiology and Medicine (CPM) exploits the access we have to veterinary patients, with opportunities to study these as models of human disease in comparison with laboratory animals and human patients. Veterinary patients have advantages and relevance for the study of degenerative diseases of ageing; those influenced by chronic effects of exercise; and diet - each a national priority and international concern. This Programme also cultivates much-needed integrative physiologists: able to test novel cell and molecular biology findings in animal models (adopting a comparative approach) and/or translate them into treatments for veterinary or human patients. It comprises two established Groups - Musculoskeletal Biology; and Cardiovascular and Inflammation Biology and Metabolism – and one developing Group - Immune Regulation and Cancer. Each Group in the Programme benefits from a foundation of: (i) sustained research capability in integrative animal physiology underpinning biomedicine; (ii) capacity attained in clinician scientists through proactive staff development; (iii) partnerships fostered between basic biomedical and clinician scientists; (iv) input from strong academic disciplines of pathology and epidemiology; (v) institutional standardisation of clinical records and development of VetCompass to access data from primary practices, facilitating the systematic study veterinary patients.

Livestock Production and Health (LPH) fosters collaboration between academics working at the population and ecosystem level (epidemiologists, public health, economics, wildlife experts); those working at the herd, individual animal and molecular level (clinician scientists, pathologists, immunologists, reproduction and welfare scientists); and microbiologists focusing on the pathogen.

Threats to food security from (re-)emerging diseases of livestock are a high global priority and LPH strategy is driven by a 30-50 year perspective of this issue. We recognise that to solve problems

that limit livestock productivity, our research must provide individual technical solutions that also take account of socio-economic conditions. Their implementation must also be supported through partnerships with government and industry. This ethos has informed our strategy in developing expertise to understand behaviour of societies. In synergy, agricultural economics has been targeted as a new area of focus, with further development of strategic partnerships at national and international levels (see section e). LPH Programme has 3 established inter-related groups: Ecosystems Health; Safe and Sustainable food; and Host-Pathogen Interaction and Vaccinology.

b. Research strategy

Here we present developments, achievements, aims and future plans of the Research Groups

1. Comparative Physiology and Medicine (CPM) Programme is led by **Dominic Wells**, recruited from Imperial College (2010). As a physiologist working on neuromuscular diseases, an excellent biomedical scientist with experience of translating basic science into novel treatments for human patients and a veterinarian keen to use veterinary patient as models for human neuro-muscular disease, he is ideally suited to lead and disseminate the underpinning CPM strategy.

1.1. Musculoskeletal Biology (MSK) Group: Our commitment to a strong research base underpinning and informing our teaching and clinical work is a strategy exemplified most clearly by the MSK Group. How the structure of different organisms is adapted to their function, taking account of their environment and lifestyle, is fundamental to understanding how healthy animals work and the pathophysiological basis of diseases of aging. The RVC has studied the adaptation of MSK tissues to physical activity for the last 30 years. The success of MSK research at the RVC is founded on excellent fundamental biomedical research that continues to be competitive in attracting Wellcome Trust, RCUK and, most recently, European Research Council (ERC) funding. The Structure and Motion Laboratory (SML) is a world class centre for comparative biomechanics of locomotion developed by Alan Wilson and lies at the heart of our MSK research strategy. Its team has established an international reputation for pioneering innovation in data acquisition and analysis resulting from their interdisciplinary systems based approach. The SML is complemented by excellent biomedical scientists working at the cell and molecular level on the structure and function of the neuromuscular system, bones, joints and tendons.

The MSK Group aims to define and analyse: (1) the mechanical environment of the musculo-skeletal system and elucidate mechanisms regulating development, mechanical responsiveness, maintenance and repair of the architecture of bones, joints and tendons; (2) fundamental principles constraining locomotor economy and performance through comparative analysis of locomotor system; (3) pathophysiology of neuromuscular, bone, joint and tendon dysfunction, developing novel therapies in a way that promotes translation into human and veterinary clinical practice

We have recruited high quality scientists from other disciplines to develop the SML. **Andrew Spence** (physicist; RCUK Fellow) recruited from UC Berkeley, has successfully transitioned into a lectureship (2012) securing EPSRC and BBSRC project grants. **Thilo Pfau** joined the SML as a bioengineer from UC Berkeley and was appointed to a lectureship in 2008. He has developed multi-sensor GPS-enhanced gait analysis systems for field and clinical use. **Richard Bomphrey,** a bioengineer with expertise in fluid biomechanics applied to insect flight, joined the SML in 2013 transferring his EPSRC fellowship from Oxford. Clinician scientist (Equine Surgeon), **Thomas Witte** (SML PhD graduate) was appointed to a lectureship in 2009 following clinical training in Cornell. Evolutionary biologists **Peter Falkingham** (from Manchester in 2012), **Stephanie Pierce** an internal recruit in 2013 and **Chris Richards** (recruited from Harvard; 2013 to take up his ERC Starter Award) have all joined Royal Society Leverhulme Senior Research Fellow (SRF), Hutchinson to create critical mass in evolutionary biomechanics. Zoologists, Usherwood (Wellcome SRF) and Daley, and clinical imaging specialist Weller make a core of 11 PIs from different disciplines working in SML. Wilson has also brought **Professors Roger Woledge and Nancy Curtin** from Imperial College (2012) to set up a muscle energetics lab and transfer their expertise on measurement of muscle contraction efficiency to the RVC. The environment Wilson has created, encourages curiosity driven research, benefiting from the perspectives of many disciplines and attracting international visiting scientists. The quality of Wilson's science is recognised by his ERC Advanced grant (awarded in 2012) – the first veterinarian to hold such an award.

The Neuromuscular Lab was formed in 2010 linking Piercy, an equine neurologist with two recruits from Imperial College, **Dominic Wells** and **Susan Brown** funded by MRC, BBSRC, medical

charities and industry partners**.** They aim to understand the mechanisms of veterinary and human neuromuscular disease and to translate their findings into novel therapies for these conditions of high unmet medical need. A recent Wellcome award supports a colony of dystrophic dogs underlining their reputation for translational research in muscular dystrophy. Further translational work relates to novel treatments for laryngeal paralysis using thoroughbred horses with naturally occurring disease. This new area complements ongoing fundamental research in muscle development (Dhoot, Allen and Macharia) and molecular basis of myosin function (Chantler).

The Tendon Biology Lab led by Roger Smith has pioneered the use of mesenchymal stem cells for tendon injury in horses, which has been recognised by an MRC grant to translate this technology into man. The third established lab of the group, Bone and Joint Research is led by Pitsillides. This has been strengthened by recruitment of **Michael Doube**, a veterinarian and expert in bone imaging, from the Max-Planck Institute (2012) and ARUK research fellow **Isabel Orriss** from UCL (2013) for her expertise in purinergic signalling in bone. Their skills complement those of Chenu, Dudhia, and Mukherjee in bone and joint physiology, biochemistry and development respectively. Epidemiologist, Verheyen provides expertise in the study of bone, joint and tendon injuries in racehorses and new recruit **Nick Bell** (from Bristol, 2010) provides expertise in cattle lameness.

A developing area within the MSK Group brings together neurologists, developmental biologists, pharmacologists and behaviourists to develop novel models of neuropathic pain. Volk (Neurologist) and McGonnell (Developmental Biologist) have successfully characterised the structural basis for syringomyelia in CKCS dogs. **Ludovic Pelligand** (internal recruit; 2010), a clinical pharmacologist, will work with Volk and behaviourist **Siobhan Abeyesinghe** (RCUK Fellow; appointed lecturer in 2012) to use syringomyelia as a model of neuropathic pain. Model development is an important aspect of the CPM programme in general and the MSK Group in particular. Russell has made a powerful addition to the Programme by devising zebrafish models of epilepsy. Future success in obtaining significant funding in fundamental and applied neuroscience is targeted for development of a new multi-disciplinary neurosciences research group in the next REF period.

Principal Achievements of the MSK Group include: (1) Discovery and establishment of a novel dystrophic dog at the RVC centre for translational research in Duchenne muscular dystrophy; (2) Demonstration that manoeuvrability rather than outright speed is key in cheetah hunting success using equipment devised by RVC to capture the first detailed dynamics of a hunting mammal; (3) Development of an adjustable pre-clinical murine model for applying controlled loading, non-invasively, to the tibia and the knee joint for use in bone and joint research.

Future Plans: The future of MSK biology lies in learning how to measure more from our animal subjects and apply sophisticated mathematical techniques to analyse all resulting data, building models to predict how systems function at all levels, (including the gene and molecule) in health and disease and in response to defined perturbations. Examples of ongoing and future research, which demonstrate this approach, involve the use of: (a) hypergravity to link biomechanics to understanding molecular basis of the adaptations of muscle and bone to sustained increased load (Wellcome Trust; 2011-16); (b) optogenetics to study neuromechanical integration in fast locomotion (BBSRC; 2013-17); (c) siRNA in insects to determine genes controlling wing shape and efficiency of flight (funding pending); (d) Mouse models of accelerated cartilage degeneration and novel joint loading systems to study genes influencing cartilage regeneration (BBSRC 2012-15).

Translational research will develop novel treatments for: (a) Muscular Dystrophy using a new dog model (Wellcome 2013-17); (b) [text removed for publication]; (c) Intrasynovial tendon injuries in equine and human patients (MRC 2012-15).

To capitalise on our strength in evolutionary biomechanics and the recent appointment in evolutionary genetics we will make further appointments linking these 2 areas with developmental biology to establish a world class group of locomotor evolutionary and developmental biologists.

1.2 Cardiovascular and Inflammation Biology and Metabolism (CVIBM) group aims to understand the basic biology underpinning mammalian vascular, cardiac and renal function in health and disease. Overarching aims are to: (1) Define the molecular mechanisms regulating endothelial and vascular cell functions in response to inflammatory mediators, metabolites, dietary components and hormones; (2) Determine how diet and altered metabolism contribute to tissue (dys)function, with focus on adipose tissue and muscle. Diseases and conditions associated with ageing and exacerbated by poor lifestyle choices are characterised by impaired vascular

homeostasis. Vascular cell biology is a Group central focus with academics working on human and animal endothelial cells (ECs), vascular smooth cells, leukocytes and platelets, and on cell-cell communication in vessels, fat and muscle. EC biologist, Wheeler-Jones heads this Group which has strong clinical scientist representation with veterinary patients as research subjects. These research themes are relevant to disease processes characterised by EC dysfunction, insulin resistance, inflammation, and dysregulated angiogenesis including atherosclerosis, heart disease, metabolic syndrome, hypertension, kidney disease, obesity and cancer.

Development of research expertise in EC biology has occurred through recruitment of **David Bishop-Bailey** from QMUL (2013), greatly complementing the expertise in EC biology (Wheeler-Jones and Lawson), vascular and inflammatory cell pharmacology (Elliott and Cunningham) and lipid biochemistry (Botham). Bishop-Bailey is an expert in the epoxygenase pathway and the inter-actions of its products with PPAR receptors. EC biology has applications to tissue regeneration, including fracture and tendon repair, and to aspects of Immune regulation and cancer, hence there are many links between researchers in CVIBM and other Groups within the CPM Programme.

Obesity and insulin resistance are major cardiovascular risk factors. Recruitment of **Barbara Cannon** (from Herriot Watt; 2009) and veterinarian **Mark Cleasby** (from Garvan Institute; 2008) provide fat cell and whole animal muscle biology expertise respectively. These appointments have provided high quality biomedical science to complement clinician scientists, including **Stijn Niessen** (internal recruit, 2009) interested in feline diabetes. He joins Menzies-Gow, Catchpole and Church working on equine, canine and feline insulin resistance respectively.

Other clinical research within CVIBM includes investigation of EC (dys)function in dogs with mitral regurgitation (Boswood), cats with hypertrophic cardiomyopathy (Luis Fuentes and Connolly) and horses with laminitis (Elliott and Menzies-Gow). Vascular dysfunction is relevant to chronic kidney disease progression where hypertension, phosphate retention and proteinuria contribute. **Rosanne Jepson** (internal recruit, 2011) strengthens our clinical nephrology team (Elliott and Syme). Many of these important diseases are major problems of ageing humans so are potential models of complex human diseases. Having characterised large patient cohorts followed longitudinally we are well placed to exploit new genomic resources to undertake comparative studies in future aims.

The CVIBM Group shows how the College's investment in epidemiological and statistical skills has improved the quality of our clinical research. With the appointment of statistician **Yu-Mei Chang** (from Leeds in 2009) this investment continues. The development of VetCompass, masterminded by Church and Brodbelt, has made case records from 180 veterinary practices (500,000 patients) available to study complex but common diseases in detail. This resource will continue to grow.

Principal Achievements: (1) Defined the involvement of COX enzyme-derived products in human EC motility and survival, suggesting how these mediators regulate angiogenesis and explaining the potential impact of COX antagonists on vascular function, tissue development and repair, and support of tumour growth; (2) Identified novel protective mechanisms triggered by dietary fatty acids in ECs and macrophages, suggesting how diet might modify inflammation; (3) Provided evidence for angiogenesis regulators and consequent vascularisation of adipose tissue depots with functional relevance for adipose tissue metabolism and energy expenditure, providing new targets for controlling obesity and Type II diabetes; (4) defined mechanism of insulin resistance in skeletal muscle, contributing to new ways of managing insulin resistance linked with obesity (Type 2 diabetes); (5) Defined markers of progression of feline CKD (phosphate, FGF-23, proteinuria) and canine heart failure (NT-pro-BNP and troponin I in mitral valve disease); (6) Identified associations between genetic polymorphisms in the melanocortin receptor 4 gene and diabetes in obese cats.

Future Plans: A unifying theme is the role of systemic inflammation in the pathophysiology of different states characterised by altered metabolism, including cardiovascular disease, type 2 diabetes and obesity and the influence of dietary lipids. Specific plans include to: (i) Build on exciting data from the BBSRC DRINC project to optimise the ratio of bioactive dietary unsaturated fatty acids to protect the cardiovascular system (Industry partnership; 2014-2016); (ii) Explore the concept of myostatin inhibition by destructive exon skipping in prevention of sarcopenia of ageing to determine whether this protects against type 2 diabetes related to obesity (Diabetes UK; 2014-2016); (iii) Determine the role of lipid mediators derived from epoxygenases in vascular inflammation and hypertension (BHF; 2012-2015). We will progress our clinical research to: (i) [text removed for publication]; (ii) Validate predictive markers of mitral valve disease progression to

heart failure in clinical cases identified through VetCompass (PetPlan; 2013-2016). In addition, we will work with medical partners to exploit genomic data on diabetes (type 1 & 2), CKD and hypertension in dogs and cats.

1.3 Immune Regulation and Cancer (ICR) Group's key goal is to understand the regulatory mechanisms that maintain immune tolerance and how they fail in the context of autoimmune, inflammatory and neoplastic disease. The Group developed from a critical mass in immunology created during RAE2008, complemented by clinician scientists, pathologists, and developmental biologists, many of whom collaborate to capitalise on access to veterinary patient material.

A key area of interest is regulatory T cell (Treg) biology. Group leader, Garden (clinician scientist), has characterised the function of canine Tregs and, working with the Babraham Institute, continues to study the suppressive mechanisms of murine Tregs. **Bradley Cobb**, recruited from Imperial College (2008), has complementary expertise in microRNA biology and is applying this to elucidate murine Treg development and function. De Mestre and Johns have characterised the role of Tregs in equine sepsis and equine placental development, collaborating with Cornell University. Palmer studies the mechanisms of immune-scenescence. Clinical immunologist, Catchpole, has defined genetic polymorphisms and auto-antigens that characterise canine type 1 diabetes as a model for latent onset diabetes of the adult and works with Palmer on the impact of immune-scenescence on vaccination in geriatric dogs. Innate immunity is a focus of our applied immunologists who work with clinician scientists to investigate disease pathophysiology. Canine inflammatory bowel disease (IBD) is an exemplar where failure of mucosal tolerance due to dysfunction of pathogen recognition receptors is implicated. Allenspach, a clinician-scientist, collaborates with Werling to characterise the role of Toll-like receptors and bacterial dysbiosis in IBD in German shepherd dogs.

Healthy ageing and regulation of cellular quality (autophagy) are biological processes, dysfunction of which may underlie disordered growth leading to cancers. **Michelangelo Campanella**, recruited from UCL (2008) has expertise in mitochondrial function and autophagy. He joins McGonnell, Dhoot and Fowkes, who apply their cell biology expertise to study cancer in 'One Health' collaborations with medical schools. All work with Ken Smith, a veterinary pathologist with interest in oncology. With Wellcome support, Smith is training PhD level veterinary pathologists, in collaboration with QMUL and MRC Harwell to build capacity in research literate veterinary pathologists to meet biomedical science's needs. Creation of a specialty clinical oncology service and a tissue archiving facility managed by our Clinical Investigation Centre is the final piece in a strategy to develop this field as an area of strength for RVC's basic and translational research.

Principal Achievements – we have defined: (1) the role of miR-155 in Tregs development and demonstrated the importance of the beta chain in assessments of T cell receptor diversity in Tregs; (2) the signal transduction pathways involved in the induction of regulatory T cells from conventional helper T cells; (3) IF_1 as crucial factor in cell metabolism and apoptosis through regulation of F1Fo-ATPase and showed its loss of function leads to defective haem synthesis in developing erythroblasts; (4) the prognostic value of Snail2 in canine osteosarcoma and defined this protein's function in regulating cell motility and invasion; (5) Devised a selective siRNA method of knocking down mutant canine KIT, expressed by some malignant canine mast cells.

Future Plans: By the next REF comparative cancer research will become established through further clinician recruitment, their development as researchers and consolidation of partnership with medical schools. Specific projects include: (1) Determine how C-natriuretic peptide influences somatotroph specific gene expression in human and feline somatotrophinomas in collaboration with Oxford (BBSRC 2013-16); (2) Define the role of the mitochondrial Translocator Protein in evading apoptosis and dysregulation of autophagy in cat and dog mammary tumours (Petplan 2013-16); (3) Validate diffuse large B cell canine lymphoma as a model of human non-Hodgkin lymphoma in terms of its immune phenotype and immune regulation (internal funds from RVC and QMUL: 2013-17). In addition, we plan to sustain core basic science in immunology and pursue the elucidation of post-transcriptional molecular mechanisms of T cell ontogeny and function

2. Livestock Production and Health (LPH) Programme brings together scientists from multiple disciplines addressing issues of global importance relating to food security and public health. It builds on the success of our Infection and Immunity Group (RAE2008), founded on excellence in veterinary epidemiology and public health established under Pfeiffer's leadership. New approaches are required to meet current and future challenges of food security, particularly to prevent or

control emerging zoonotic disease threats. This requires a systems approach to dealing with health problems in animals and people, integrating knowledge generated by complementary disciplines. We have championed a more holistic approach to issues associated with livestock rearing in a welfare friendly way to sustain global needs, by integrating wildlife medicine, animal welfare, reproduction and genetics and agricultural economics into this Programme. Animal protein production is dependent on species with most efficient growth rates and established intensive production systems (pigs, poultry and fish). We have increased our focus on pigs and chickens, to address some of the endemic infectious disease problems that dramatically limit their productivity, whilst retaining international expertise in cattle and sheep. **Fiona Tomley** (from IAH; 2010) leads this Programme, providing strategic vision and experience of interdisciplinary research. Tomley's expertise in apicomplexan parasite biology means that, with McKeever and **Damer Blake** (from IAH 2010), RVC has critical mass in this important group livestock parasites. Agricultural Economist, **Jonathan Rushton** (2009; from FAO, Rome) with his wealth of experience in global agricultural systems, is a valuable addition. He has flourished in academia being promoted to chair within 3 years, developing strong links, within and external to the RVC, contributing substantially to ESH and SSF groups and adding value to programmes of work (e.g. Coccidiosis, Postweaning multisystemic wasting syndrome (PMWS), and highly pathogenic avian influenza (HPAI)).

2.1 Ecosystems Health (ESH) Group developed from the international need to understand factors (biological, environmental and socioeconomic) that influence pathogen flow between wildlife, domestic livestock, companion animals and humans so that (re-)emergence of disease threats can be predicted and control strategies devised to contain them. Pfeiffer leads this group and has built on his international profile in REF2014 as world leading in veterinary epidemiology doing research that translates into policy and practice. His group's standing is recognised by FAO - RVC is the first European Vet School to be designated as a FAO reference centre in Veterinary Epidemiology. There are now 9.2fte epidemiologists (up from 6 in RAE2008) with a further 2 fte in Agricultural Economics. He has attracted £7.3M in grants as PI from Wellcome, EU-FP7, DEFRA, DFiD and FAO and has evolved the group to have an interdisciplinary systems philosophy, centred on scientific excellence. Other academics leading research programmes in ESH include McKeever (*Theileria parva* funded consecutively by Wellcome, EU-FP7 and Gates Foundation) and Rushton, whose work on value chains and cost-effectiveness, complements that of Pfeiffer and McKeever.

Pfeiffer is mentoring new academics including **Julian Drewe** (internal recruit; 2012) who brings specialist expertise in wildlife health; **Barbara Häsler**, an agricultural economist recruited in 2013 to build capacity in this discipline; **Guillaume Fournié** (internal recruit; 2011) appointed to increase capacity to use novel modelling methods and **Martha Betson** (from Liverpool; 2012) a molecular epidemiologist working at the human-animal interface. Pfeiffer has an excellent track record of developing new academics into successful PIs – Guitian, Verheyen, and Brodbelt have progressed under his guidance. Guitian now leads public health and food safety research.

Pfeiffer has pioneered the use of knowledge-driven modelling. The ESH Group now use mixed methods, integrating quantitative approaches such spatial and social network analysis with qualitative social science methods, to study endemic and emerging infections of veterinary and zoonotic importance. HPAI (H5N1, H7N9), African swine fever, Rift Valley fever and Peste des petits ruminants (PPR) have been major foci of research in collaboration with national (Pirbright in particular) and international partners. Built on strong primary field research, the group intensively engages in policy advice and recommendations for infectious disease control and prevention, as evidenced through membership in national (bovine tuberculosis), EU (disease surveillance) and international (H7N9) policy advisory groups. The ESH Group is responsive to policy development needs and has consolidated its reputation as world experts in risk analysis through Pfeiffer's leadership of the 12 partner FP-7 consortium grant RISKSUR. Field research in developing countries is important as this is where future new global infectious diseases threats are most likely to emerge. RVC and LSHTM are members of Sub-Saharan Africa centre for infectious diseases (Wellcome and Rockerfeller capacity building programme in One Medicine; 2009-14) involving 7 African countries and led by RVC visiting Professor Rweyemamu. All senior academics in ESH Group have experience of working in developing countries and strong links with the International Livestock Research Institute (ILRI), Kenya, the China Animal Health and Epidemiology Centre, Dept of Veterinary Tropical Diseases, University of Pretoria and Chiang Mai University, Thailand.

Antimicrobial resistance (AMR) is a global ESH issue. Transfer of resistance genes in zoonotic

organisms to commensals and transfer of bacteria between species are proposed to result from veterinary use of antimicrobials. Stärk co-ordinated the EUFP-7 Pilgrim grant (2009-12) which focused on pigs as a source of MRSA-ST398, an emerging livestock production issue. **Anette Loeffler** (Dermatologist, internal recruit 2008) and Lloyd developed a skin colonisation model in gnotobiotic pigs to complement the epidemiology data and allow robust mathematical model development by the Pilgrim project. Good (bacteriologist) works on RNA silencing of essential bacterial genes as an alternative to traditional antibacterials. Lees (Emeritus) employs PK-PD modelling and population kinetics in DEFRA funded field studies of calf pneumonia to determine optimal antimicrobial dosing and inform licensing policy (see impact case study). Similar approaches were used in studying contagious bovine pleuropneumonia (CBBP) control in cattle in Kenya (McKeever, BBSRC CIDLID grant). **Stuart Reid's** recruitment (Glasgow 2011) has brought a high quality and internationally collaborative dimension to AMR research. Ecological approaches facilitated by high throughput sequencing and novel mathematical methods are used to determine the origins of AMR zoonotic bacteria in humans and animals geographically co-located.

Principal Achievements have been to: (1) define the importance of duck abundance and rice cropping intensity to HPAI risk in SE Asia; (2) use social network analysis to identify large scale spread of AI via live bird markets and show the effect of targeted interventions through disinfection at key hubs; (3) challenged the established view that animals are the predominant source of Salmonella infections in Scotland through molecular epidemiological studies; (4) show that aminoglycosides cause misfolding of bacterial proteins, an effect that is inhibited by chaperonins

Future Plans are to: (1) develop practical frameworks and decision support tools for the design of cost-effective risk-based surveillance systems that integrate the most recent advances in epidemiological methodologies in Europe (RISKUR programme – EUFP-7 2012-15) and China (LINK-TADs programme – EUFP-7 2013-16); (2) develop improved vaccines for the control of East Coast Fever in sub-Saharan Africa (Gates Foundation 2013-17); (3) determine the role wildlife in PPR emergence in Africa, Turkey and Europe using a risk analysis approach and improve surveillance methods in wildlife habitats by non-invasive techniques (BBSRC - ANHIWA 2014-17).

Strategic developments over the next 5 years will see RVC consolidate existing links with Pirbright and a medical school partner to provide veterinary epidemiology, economics and pathology expertise into a tripartite hub of excellence in One Health. Internal collaboration with the SML will allow the ESH Group to benefit from the tools Wilson is developing to track interactions between wild animals and livestock to understand risks of disease transmission. New appointments will add veterinary ethics and aquaculture expertise to the Group. Our extensive collaborations with livestock enterprises will generate samples for AMR research, adopting phylogenetic approaches to molecular epidemiology data to understand the socioeconomic drivers in farming systems that perpetuate AMR and compromise food safety and human health. This research goal will inform recruitment to a lectureship in public health and future collaborations with the Sanger Institute.

2.2 Safe and Sustainable Food (SSF) Group: This new group focuses on problems of farming systems primarily in developed countries, particularly those of a priority in the UK. Rushton's understanding of livestock production and the drivers for their development makes him the ideal leader of SSF whose aim is to increase economic and welfare resilience of farm systems by prioritising research into diseases that threaten productivity, food security and public health. SSF comprises research programmes in different disciplines (Epidemiology, Public Health, Reproduction, Genetics, Welfare, Economics) to exploit synergies, share resources and foster collaboration. Programmes highlighted in RAE2008 on dairy cow fertility (DC Wathes), bovine viral diarrhoea (BVD; Brownlie), bovine TB (Pfeiffer, Kendall and Drewe) and Johne's disease (Guitian) remain well funded and benefit from collaboration with welfare scientists and economists. For example, RVC is part of a Dairy-Co consortium (£2.5M; led by Nottingham; 2011-16) generating knowledge to improve calf rearing (DC Wathes), defining Johne's disease control systems (Guitian), identifying calf welfare indicators (Burn and Bell) and co-ordinating national data collection.

RVC leads the Agrifood Training Partnership in Intensive Livestock (BBSRC; 2011-16) which aims to up-skill the Agrifood Industry through professional development. This reflects our increasing focus on intensively reared chickens and pigs. The Animal Welfare programme (BBSRC; 2005-11) led by CM Wathes (retired 2013) brought welfare scientists (**Abeyesinghe and Burn**) and agricultural bioengineer (Demmers) to the RVC with facilities to study pigs and poultry in simulated

on farm conditions. Work on PMWS (BBSRC; 2008-13) saw epidemiologists, immunologists and pathologists working with welfare scientists to gather data from the field and laboratory and use it to re-create PMWS in a model system within a controlled environment. High level engagement with pig farmers in this project (140 involved) generated material and stimulated follow-on work on swine influenza (BBSRC), *M. hyopneumoniae* (Marie Curie Fellowship) and PCV-2 vaccine development and economics of PMWS, making pig diseases a vibrant research area at the RVC.

The SSF group acquired expertise in poultry through recruitment of Tomley and Blake whose established research programme focuses on coccidiosis in chickens. Much of their work is molecular (section 2.3), however, they have strong links with industry and combine epidemiological field research (exploiting large data recorded in the intensive chicken industry) with controlled experiments. They collaborate with Rushton on the socio-economics of coccidiosis and Blake works with Guitian and Good to determine if experimental observations that co-infection of *Eimeria* with *C jejuni* reduces systemic colonisation are relevant commercially, which complements ongoing work on epidemiology, transmission and impact of *C. jejuni* in UK and developing countries.

For sustainable agricultural systems optimising reproduction is vital. RVC has a tradition of excellent fundamental and applied reproduction research. Work by a team of 6 PIs (Wathes, Pollott, Fouladi, Khalid, Abayasekara, Cheng) has studied mechanisms whereby nutrition, disease status and genotype affect conception and maintenance of a healthy embryo to term. In dairy cows functional genomics have been used to investigate how the reproductive tract responds to infection. Genotyping of commercial and rare breeds has revealed novel polymorphisms associated with survival traits. In both cattle and sheep basic studies have shown how dietary polyunsaturated fatty acids can influence fertility via effects on the ovary, oocyte and reproductive tract, while *in vivo* work has defined how hyaluronan, a key constituent of extracellular matrix, influences cervical softening and embryo attachment. Co-operation with China, (ICUK grant; 2008) has led to collaboration with Huazhong Agricultural University (HZAU) with exchange visits of academic staff and PhD students (BBSRC, EU and Chinese funding) yielding great benefits.

Many recent advances are underpinned by increasing reliance on genetics, bioinformatics and genomics (led by Pollott and Cheng). To develop this area further we have recruited **Denis Larkin** from Aberystwyth (2013). He conducts cutting edge research in genome evolution and led analysis of chromosome evolution in the international pig genome project detecting over 100 evolutionary rearrangements that distinguish pigs from other mammals. His work has application to livestock and companion animal species. In addition to Larkin, **Professor Zhang** has joined the RVC for 2 years (from HZAU; 2013-15) bringing her expertise in farm animal genomics to work with Werling on genetics of disease livestock resistance. A strategic post in bioinformatics has been created to build capacity in bioinformatics and work alongside Chang, the College statistician.

Future plans: In the next 5 years we will build on the success of establishing agricultural economics at the RVC. Lectureships will be created in Agricultural Business and Veterinary Ethics (Wellcome Fellow already in post) associated with a School of Agriculture, formed in collaboration with University of Hertfordshire and Rothamsted Research. Links to the LIDC's Leverhulme Trust Agrihealth Centre (2011-16) will sustain an international development perspective. SSF's research goals will be to explore the socioeconomic drivers behind the question of who pays for national disease control schemes (e.g. defining cost effective strategies for BSE/Scrapie surveillance; DEFRA: 2013-15) and use methods and tools such as the institutional analysis, development framework and lean supply chain management in animal health and disease management. Focus on intensive livestock will increase and expansion of pathology and clinical expertise in pigs and poultry will support excellent fundamental and applied infectious disease research.

In parallel we will build a world class farm animal genomics group around Larkin through strategic fellowships to plan for succession of DC Wathes and Pollott. The goal is for RVC to become a major player in international farm animal genomics leading evolutionary approaches. We will: (1) Generate bioinformatic tools for comparative genome analysis (BBSRC; 2012-15); (2) Assemble genome sequences from 25-30 species of birds to study avian chromosome evolution and develop an on-line resource displaying synteny blocks and evolutionary break points for avian researchers (BBSRC 2013-17); (3) identify genotypes controlling variation in important dairy cow phenotypes, to appreciate how these are influenced by external factors (EU-FP7 GplusE; 2014-18); (4) Improve dairy cattle innate immune function by identifying key genes in affected innate immunity signalling pathways and then selectively breeding for these (EU-FP7 Marie Curie Fellowship; 2013-15).

2.3 Host Pathogen Interactions and Vaccinology (HPIV) Group: Understanding how pathogens interact with their hosts at molecular and whole animal level, to enable novel control strategies, is essential to address issues of strategic importance to farmed livestock. Tomley leads this Group which aims to: (1) understand molecular interactions of pathogen genes with those of their hosts; (2) increase knowledge of disease pathology, immunology, and genetics of host responses; (3) identify antigens that induce potent immunoprotective responses**;** (4) develop and test prototype vaccines and vaccine delivery platforms. Since RAE2008 there has been increased emphasis on important (re-)emerging animal diseases, including zoonoses, and the adoption of an inter-disciplinary approach to ensure that impacts of HPIV science translate into the field in collaboration with others in the LPH Programme. This is facilitated by the Centre for Emerging, Endemic and Exotic Diseases (CEEED), a £4M combined wet-laboratory and study facility that opened in 2008.

The HPIV group has significant strengths in pathogenesis of bacterial respiratory disease and pneumonia, including work on mycobacterial metabolism (Kendall), streptococcal virulence (Slater) joined by **Simon Priestnall** (board certified pathologist; internal recruit 2011) who collaborates with the Animal Health Trust. A major focus has developed in the study of *Mycoplasma* species affecting dogs (Brownlie), pigs (Rycroft) and cattle (CBPP; McKeever) supported by pathologists (K Smith, Priestnall & **Martineau**). McKeever has led an international multi-disciplinary team in the evaluation of novel vaccines and antimicrobials for control of CBPP, alongside development of an early diagnostic field test funded consecutively by Wellcome and BBSRC. Rycroft collaborates with three UK partners in a BBSRC LoLa to develop novel diagnostics and vaccines for pig respiratory diseases, combining cutting-edge genomic technologies with robust infection models.

Viral diseases are an important priority as highlighted by the PMWS programme (BBSRC 2008-13) led by immunologist Werling. Other key viruses under study include BVDV (Brownlie & Werling) and canine respiratory coronavirus (Brownlie & Priestnall). Since RAE2008 three virologists have retired and four posts have been filled strategically to promote research in viral vaccinology and host-virus interactions. **Carole Thomas** (internal recruit; 2012) provides molecular expertise in pestiviruses, virus-host transcriptomics and *in vivo* trials of vaccine efficacy. **Rob Noad** (from LSHTM; 2009) has expertise in producing recombinant proteins to construct viral-like particles as prototype vaccines in insect cells. **Henny Martineau** (from Moredun; 2011) adds expertise in viral pathogenesis and pathology as a result of her work with Jaagsiekte retrovirus of sheep. Most recently **Camilla Benfield** was appointed (from Cambridge; 2013) to bring expertise in virus proteins that modulate host cell signalling pathways and contribute to virus virulence. Her post is part of a strategic agreement for staff exchange between RVC and Pirbright Institute, with which strong links have continued for research into FMD, African Swine Fever and PPR viruses.

Parasitic disease research has seen the most significant developments in the HPVI Group since 2008. RVC now has depth of expertise as well as specialised lab and animal facilities for handling parasitic protozoa and worms. Strengths include immunoparasitology of protozoa that constrain cattle production in sub-Saharan Africa (McKeever; see section 2.1), and basic studies on the control of parasitic infections by the immune system (Lawrence). In 2010 **Tomley and Blake** brought their research on coccidial parasites of chickens including in vivo and in vitro models of host-parasite interaction, genetics, genomics and proteomics from IAH Compton. They have attracted >£2M of BBSRC and Industry funding for studies on mechanisms of parasite attachment and invasion of the host gut, population genetics, development of *Eimeria* parasites as novel vaccine vectors, and genetic mapping of resistance and differential vaccine responses of chickens to Eimeria. Using established national and international collaborations they are working with Rushton and Guitian to develop an RVC centre of excellence for research on poultry diseases.

Principal Achievements of this group include: (1) developed a system for generating random transposon insertion mutants in *M. hyopneumoniae*; (2) defined stage-specific regulation of gene expression and protein function in *E tenella* and provided a molecular basis for site-specific Eimeria spp. development within the chicken gut; (3) mapped genetic loci integral to escape from strain-specific immune killing in *E maxima* and identified new vaccine candidates relevant to all apicomplexan parasites; (4) Showed PCV-2 selectively increases the expression of immune-related and pro-apoptotic genes in monocyte-derived dendritic cells helping to define the pathogenesis of PMWS; (5) identified lineage negative dendritic cells in bovine blood which mount a strong type I IFN response and are activated by $BVDV_{ncp}$ strains causing acute disease

Future Plans: Research focus will continue to develop supported by the established capacity in pig and ruminant genetics and collaborations with Roslin for chicken genetics, particularly in relation to disease resistance. Specifically we plan to: (1) identify regions of the chicken genome associated with resistance/susceptibility to infection (BBSRC AHC; 2014-17); (2) define the molecular interactions that occur when coccidial parasites invade host cells (BBSRC; 2014-17); (3) examine the genetics and epidemiology of host-microbiota interactions in poultry (BBSRC FADH; 2014-17); (4) [text removed for publication]; (5) Use transposon insertion mutants in *Mycoplasma* spp. to generate knowledge in disease pathogenesis and inform vaccine development across species with particular focus on pigs (BBSRC LoLa; 2011-2016) and poultry; (6) [text removed for publication]; (7) Advance understanding of host-pathogen interactions in mastitis (BBSRC, ANHIWA 2014-17).

c. People:

i. Staffing strategy and staff development: The RVC has a vibrant researcher recruitment and development strategy which aims to: (i) build and sustain research capacity through fellowships leading to lectureships; (ii) develop critical mass of clinician scientists; (iii) support early career academics through seed-corn funding, mentoring in grant writing and PhD student co-supervision. During REF2014, we recruited 32 researchers new to academia to build critical mass and sustain a balance of experienced researchers and new talent. About 72% of the researchers in our return have been in academia at least 6 years with 28% starting their 1st academic post during REF2014.

Strategic Fellowships – with additional R funding that resulted from success in RAE2008, we funded competitive fellowships to add to our RCUK (2006-12) and Wellcome VIP (2007-11) funding. Ten of the 32 new researchers came via these schemes, establishing independence whilst embedded within RVC research groups before taking on teaching and administration. Fellowships have been used strategically to plan for succession and build capacity. We expect to continue this strategy in the next period and have budgeted for ten 3 year strategic research fellowships within our corporate plan (2014-19). The excellent research environment we have created has also led to an increased number of externally funded fellowships held at the RVC (currently 9; EPSRC (1), Wellcome Trust (3; SRF, University Award and Clinical Fellow), Royal Society (1; Leverhulme Trust SRF), ARUK (1) and EU (4; 1 ERC Starting; 3 Marie Curie Awards).

Clinician scientists – In 2001 we recognised a need to provide specialist clinicians with PhD training due to a shortage of research trained clinical specialists to fill vacancies in our expanding Clinical departments. We have used strategic funding to: (i) attract PhD trained clinical specialists to the RVC; (ii) offer clinical specialists PhD opportunities if they show an aptitude for research; (iii) maintain at least 3 specialists in each clinical discipline to allow off clinic time for research; (iv) support clinical research through: (a) high quality training in epidemiological methods and statistics; (b) developed a data collection system for disciplined study of clinical cases (VetCompass; RVC hospitals and 180 partner practices). Improved quality of research by clinician scientists led to 25% (27/107) of our RAE2008 academics being actively involved in clinical service, higher than any other veterinary submission. We have sustained this capacity of excellence, with 11 new recruits, giving 29/113 of our REF2014 being academics active in clinical service; 43% completed their PhDs with groups at the RVC, greatly facilitating basic science-clinical collaborations. As a result of these measures, the quality of research involving veterinary clinical patients has greatly improved since 2001 and now is integrated into each of our research groups. The use of veterinary patients as models for human disease is a major component of our research strategy. We recognise that providing clinician scientists with time to develop research collaborations and broaden their post-doctoral research experience is important if they are to fulfil their potential in research. We plan to use a proportion of our strategic fellowship funds to enable clinician scientists to spend time away from the RVC working with biomedical and medical partners.

Supporting new academics: We continue to recruit the brightest new talent to academia and place high importance in supporting them. Our internal grant scheme (IGS) provides new academics with experience in the peer review grant process and seed-corn funding to generate pilot data for major grants. New academics are closely monitored and assisted by group leaders who serve on grant bodies. Most new recruits obtain a PhD studentship, co-supervised with an experienced academic, thus fostering internal collaboration. Within the REF2014 period, 9 RCUK new investigator awards have been granted to RVC and one Wellcome University Award suggesting we help our new academics to be competitive for high quality funding. Overall, 63% of

our REF2014 new academics have secured a major grant within 2 years of their appointment. We monitor success rates closely and use feedback from external peer review to work with academics to improve on subsequent submissions. We aim to build on our recent successes in the ERC and support our top researchers to make successful applications at the starter and consolidator stages.

Implementation of the concordat to support career development of contract researchers

The RVC has: (i) embraced the principles underpinning the concordat; (ii) established a code of practice (CoP) for researchers; (iii) stimulated contract researchers to form a strong identity through the Researcher Association (RA) represented on Academic Board and its subcommittees. The RVC gained the HR Excellence in Research award in 2012, has applied for the Athena Swan Bronze Award and will work towards achieving silver and gold awards in future. A working group (chaired by VPRI) comprised of 3 members of the RA, Director of HR, academic staff development officer, Head of the Graduate School and 2 senior PIs oversees the implementation of the code of practice. The group meets every 6 months and receives first destination data of contract researchers, information from exit interviews and feedback from the CROS survey which the RVC promotes. We engage actively with Vitae and map our training aimed specifically for ECRs to the Researcher Development Framework. The RVC CoP expects contract researchers to take responsibility for their development plan but requires support from their manager in building that plan into their appraisal. Contract researchers are supported to attend international meeting, to enter the BBSRC Biotechnology YES competition and deliver their own public engagement events. Our IGS is open to contract researchers to gain experience of peer review grant process. Additional transferrable skills training is provided through the staff development programme, sections of which are tailored to the needs of ECRs and integrated with the PhD transferable skills programme. Budget for researcher development lies with the VPRI. This also provides small amounts of bridging of contract researchers between grants if optimal for their career development.

Supporting equality and diversity: To ensure equality and diversity is at the heart of RVC strategy, a Single Equality Scheme was published in 2010 following wide consultation and will be reviewed in 2014. We recognised the need to address gender inequality in our research staff and, since 2011, have ensured that all appointments boards have a gender balance in panel membership. In RAE 2008 the male to female ratios of all staff and professorial staff returned were 2.14:1 and 4:1 respectively whereas in REF 2014 they are 1.67:1 and 2.15:1. These data show significant progress over the last 5 years towards achieving gender equality which is an issue across the sector. Women remain under-represented in RVC senior positions. Further work is necessary to address this as these positions of leadership influence our strategic direction.

ii. Research students: The RVC has a vibrant research training environment for PhD students led by the Head of the Graduate School who co-ordinates our key transferrable skills training. The quality of our research training is recognised by BBSRC through the award of two consecutive doctoral training grants (2006-12 and 2009-15). RVC is part of a BBSRC funded UCL led doctoral training partnership (DTP; 2012-18) with Birkbeck, LSHTM, King's College with 10% of the allocated students. Our increase in BBSRC responsive mode funding will make us a strong partner for future DTPs. RVC out-competed all other veterinary schools in attracting successful candidates for the Wellcome Veterinary Research Training Initiative, hosting 29% of awardees in collaboration with biomedical institutes. We are well placed to provide skills training in whole animal physiology across all species with unique facilities and expertise for livestock. The SML provides research opportunities of exceptional quality, integrating systems involved in locomotion at a whole animal level, applying maths and computer science to real world biological problems. The ESH group have networks of contacts to support PhD students doing field work in developing countries and take a holistic approach to the disease problems they study within the societies they affect. Addition of agricultural economics expertise widens opportunities to study societal determinants of disease control strategy success. We plan to build capacity in agricultural economics and add veterinary ethics to develop interdisciplinary research training programmes in ESH with international partners through Horizon 2020 Marie Curie schemes. Modular training in inter-professional working will be provided for PGRs within our One Health Masters (with LSHTM).

We have built on the quantitative skills support offered to researchers by epidemiologists by appointing a full time statistician to support PG student training. This gives: (i) highly effective hands on training to use statistical tools; (ii) one-to-one advice allowing ECRs and PG students to tackle the most difficult concepts using their own data. We have extended this by appointing a

Bioinformatician, (currently 3 year fixed term) and plan to make this a permanent position. The RVC offers PGR students excellent opportunities to engage with industry and learn about entrepreneurship. RVC Enterprise teaches PGR students about IP protection and commercialisation. We work closely with industry and using the CASE scheme - of 126 PGR students active at the RVC (July 2013), 22 are BBSRC CASE students and 15 others have Industry partners. The success of London Biosciences Innovation Centre (LBIC) has brought RVC Researchers in contact with many SMEs interested in accessing expertise in the biomedical and veterinary sector. With our planned reorganisation of non-clinical commercial activity, these opportunities will increase (see section e).

d. Income, infrastructure and facilities

The RVC currently manages 244 active research and training grants valued at £44.6M – a 17.7% increase from the time of submission of RAE2008. By value, 45% of active grants are from RCUK. RVC is in the top 30 HEIs which BBSRC fund - testament to the high quality of our research given our small specialist status. Research strategy is set by RSC, chaired by VPR-I (constitution - section b), which reports to Academic Board. RSC recommends priorities for investment (human and infrastructure). The VPR-I has research budgetary responsibility reporting to Senior Management Group and College Council. He is a board member of the London Biosciences Innovation Centre (LBIC) and responsible for the HEIF budget (£1M p.a.). He line manages senior staff involved grant administration, business development and knowledge transfer, laboratory and animal services. He is responsible for RVC's Good Research Practice Policies which comply with the Joint Code of Practice on Research and the Research Integrity Concordat.

We have a rolling programme of upgrade and enhancement of research facilities driven by our research strategy. To support the majority of our research, the priorities are: (i) high quality experimental animal facilities to enable microbial challenge work and biomechanical studies of animals of all sizes; (ii) cell and molecular laboratory facilities with category 3 labs for infectious disease work; (iii) imaging (single cell to whole animal; shared with clinical services) with cell sorting for immunology research. Specific major infrastructure investments over REF2014 include:

(a) £8M investment (HEFCE SIF plus Wolfson Foundation) in the newly built Teaching And Research Centre (Hawkshead Campus). This provides 3 multiuser research labs, cell culture facilities, office space for academics, PGRs and RAs and dissection room (shared by teaching and research), practical classroom with flexible layout and social learning space for undergraduates. This facility brings UG students into the heart of our research activity in line with our philosophy that teaching should be informed by our research. These labs host many UG student projects;
(b) £700K Extension of the Structure and Motion Laboratory (HEFC SIF plus Wolfson Foundation) to double its size accommodating the significant growth in research activity and planning for future needs in line with new appointments made over the REF2014 period;
(c) £250K investment in animal facilities to: (i) adapt these for coccidiosis challenge work following the appointments of Tomley and Blake; (ii) to create a SAPO compliant facility for maintaining ticks for *Theileria* challenge work; (iii) to create a zebrafish facility for developmental biologists.

Future planned specific developments (2014-15) of animal facilities include updating of experimental pig facilities for breeding lines of disease resistant pigs and adaptation of our Controlled Environment Building to allow pathogen challenge work for vaccine development. Planned major capital investment involves a £30M programme (2014-19) to replace buildings dating from the 1950s (Hawkshead - includes research labs) and refurbishment at the Camden Campus which will benefit both teaching and research. RVC Council has approved this in principle.

We budget £180K pa for routine maintenance, repair and replacement of equipment and other support systems (software licences etc.). This is met from external grants (access charges) and HEFCE R funding. The capital investment for new facilities includes a budget to equip these. RVC's Animal Care Trust (ACT) will fund equipment for research if a strong case is made. Access charges are managed to allow planned investment in new equipment when strategic need occurs. Significant investments include: (a) £300K Standing MRI for equine clinical research; (b) £250K to upgrade MicroCT facility for bone research (funded by Wellcome Trust and RVC ACT); (c) £60K Investment in HPC cluster linked to Larkin appointment; (d) £500K for software development of VetCompass to access clinical data from partner practices (2008-13). We will continue this successful strategy of managing investment in equipment and support systems for research. A major planned investment is in development of a research data management system (2013-2015) to improve data security and allow public access (when appropriate) ensuring RCUK compliance.

A project manager has been appointed (2 year fixed term) and the estimated initial investment in this scheme has been budgeted at £150K p.a.

We strongly encourage collaboration with other HEIs offering access to facilities. Our technical skills in dealing with experimental animals are sought after. The facilities are made available whether or not RVC academics are involved - collaborations grow out of service provision. UCL groups in particular use our large animal facilities and surgical expertise (sheep and pig models – collaborative MRC grants resulting). We are a partner in a BBSRC LoLa (with Imperial, Cambridge and LSHTM) on pig bacterial respiratory disease and host the challenge studies. Our micro-CT facility is used by 3 groups at Imperial (Bioengineering) with whom Pitsillides holds collaborative BBSRC grants. Our biomechanics laboratory is used in collaboration with other HEI departments, particularly UCL Computer Sciences (see section e). We plan to establish a wind tunnel facility in the extended SML to study biomechanics of flight which will become a national resource for the biosciences research community and physical scientists interested in bioinspired robotic design.

Animal and technical expertise attracts companies to our innovation centre (LBIC). Expansion of space offered to SMEs has occurred through a £250K refurbishment of vacant laboratories (2008-13) to accommodate clients selected based on their fit with RVC research. Academic-commercial collaboration has been stimulated through a proof of concept scheme (HEIF; 2011-15) and promotion of CASE partnerships for PGR students and has already led to strong collaborations with four companies generating matched funding of £180K. We plan to restructure management of lab facilities, animal services and business development to co-ordinate our offering, market more effectively to commercial partners our basic science and clinical expertise (consultancy or collaboration), large animal models and access to veterinary patient models. Our plan is to grow non-clinical service commercial net income from £250K per annum to £1M over the next 5 years.

e. Collaboration or contribution to the discipline or research base

Contribution to the discipline or research base: Our research strategy is aligned with RCUK research priorities with focus on Food Security, One Health, Excellent Bioscience Underpinning Health and Healthy Ageing. We undertake research that derives benefits for animal and human health and well-being, informing clinical practice and our professional educational programmes.

As evidenced by high quality funding, high profile publications and invitations to present and collaborate internationally, we are leading advances in our discipline particularly in: (i) comparative biomechanics of animal locomotion; (ii) animal models (including veterinary patients) of neuromuscular disease for use in translational medicine; (iii) veterinary epidemiology, particularly in the application of risk analysis to devise cost effective risk based surveillance of livestock disease; (iv) apicomplexan parasite biology and livestock disease; (v) the interaction between nutrition and genomics on dairy cattle health and productivity.

The leaders of these areas are invited to serve on grant awarding committees or strategy boards. In 2008-13 these included: Wilson (BBSRC; Royal Society); Tomley (BBSRC; Deputy Chair Panel A from 2014/NC3Rs); Wells (BBSRC/ NC3Rs/AFM); Pfeiffer (BBSRC/ Wellcome/ National Institute of Animal Health); DC Wathes (BBSRC- Animal Health Clubs); Rushton (BBSRC); Elliott (BBSRC; Petplan); Pitsillides (ARUK; ERC); Stärk (Swiss Federal Office); Werling (BBSRC); Cannon (ERC); Campanella (BBSRC). This activity contributes to scientific development of their fields and enables them to guide others in preparation of compelling proposals to address funders' priority areas. RVC staff held approximately 45 invited editorial board memberships on 35 journals (2008-13).

RVC is pioneering in its approach to accessing veterinary patient data and devising methods to mine it on a scale that will take evidence-based veterinary practice to a new level over the next 10 years through engagement with primary care practice to conduct much needed clinical research.

Mechanisms to promote collaborative research: As a specialist institution with research in a single REF UoA, RVC encourages external collaborations regionally, nationally and internationally to provide complementary expertise and resources. International recruitment at all levels provides ready-made routes to networks of potential partners (30% of the academics in REF2014 were trained outside the UK). We encourage our research-active academics to take an outward facing approach to collaboration, recognising that the most successful relationships are driven by mutual scientific interest rather than institutional direction. A number of approaches are taken to foster this. We take advantage of our position within the heart of London's biomedical research community to host focus research forums, (e.g. Myology, Matrix Biology and Vascular Biology).

To facilitate the resource-intensive tasks of consortium building, we employ grant-writing consultants. This has increased success in accessing EU funding (2.2 fold; REF2014 vs. RAE2008), fulfilling a strategic target set in 2010. We currently hold 6 EUFP-7 consortium grants (leading one), 2 ANIHWA grants (leading one) and co-ordinate one large networking grant through the Lifelong learning programme. All of these are in the LPH Programme. Consortium grants are held by the MSK Biology Group with SML working across disciplines (see below) and the Neuromuscular lab being part of two large Muscular Dystrophy consortia (Wellcome and AFM funded). The establishment of the muscular dystrophy dog colony will provide new collaborative opportunities in the future. It is crucial that we stimulate partnerships between veterinary and medical researchers in other areas of the CPM Programme. To this end from 2014, RVC will co-fund seed-corn collaborative projects with academics in the Medical Biosciences Division of Oxford University to stimulate One Health projects that involve medical/veterinary collaboration, with the goal that these will lead to major project grant applications to MRC or other funders.

The establishment of the Francis Crick Institute in 2015, 400m from the Camden Campus, will provide further substantial opportunities for research collaboration in biomedical fields. An exercise to map complementary research interests has been undertaken with the Institute's Director of Science to facilitate this. The Crick has sponsored the LBIC-run Biopioneer Bootcamps and has exhibited at RVC Lates Events to our mutual benefit.

Strategies to foster interdisciplinary research: Membership of the London International Development Centre (LIDC), (RVC, LSHTM, Birkbeck, SOAS and Institute of Education), provides a further vehicle supporting complex multi-partner grant applications for interdisciplinary research. LIDC has co-ordinated 12 programmes which have received external funding since it was set up in 2008, seven of which involve RVC as a partner. The two largest are Leverhulme Trust Agrihealth Centre and Wellcome Trust funded South African Centre for Infectious Diseases (One Health capacity-building award). RVC leads agricultural economic research in this and in a number of One Health Consortia through Rushton's rapidly developing international reputation. Rushton is a partner in MRC and BBSRC interdisciplinary international grants on the socio-economic factors impacting on disease emergence in Nairobi and maintenance and dissemination of antibiotic resistance in the Greater Serengeti Ecosystem (NSF/NIH co-funded), respectively.

The ethos of the SML is to work across scientific disciplines. A productive collaboration between the SML and UCL Computer Sciences, with Stephen Hailes, its Head, holding a visiting RVC professorship, has secured consecutive EPSRC programme grants; Sensing for sport and managed exercise (2006-10) and Cooperative Aerodynamics and Radio-based Dynamic Animal Localisation (2010-14). The recent appointment of EPSRC Career Acceleration Fellow, Bomphrey, augments this relationship, which aims to be sustained through planned EPSRC platform funding.

Responsiveness to national and international priorities and initiatives: Our researchers are well placed to both influence and respond to National and Global priorities and policy issues in research, working with external partners across disciplines. This is evidenced by diverse streams of activity: our close engagement with government agencies (AHVLA surveillance centre; FSA training; DEFRA policies on TB, BVDV control and antimicrobial resistance and animal welfare; EFSA recognised supplier of research services and FAO Reference Centre for Veterinary Epidemiology; see Impact template). Over the last 5 years, RVC has been successful in BBSRC-led CEDFAS, CIDLID, DRINC, Animal Health Club and FADH initiatives. RVC, in collaboration with ILRI was funded by DFiD to scope out the knowledge gaps in the risks of zoonoses emerging from Livestock systems in developing countries. This work has informed the structure of the cross-research council Zoonoses and Emerging Livestock Systems Initiative. RVC staff lead 4 and are involved in 2 other multipartner interdisciplinary proposals submitted in September 2013.

In conclusion, RVC as a small specialist institution leads in some significant areas of our discipline where we have developed critical mass of high quality forward thinking scientists. The focus on these areas coupled with our enthusiasm to work collaboratively with international as well as local partners puts our research mission in a strong and sustainable position.