Institution: University of Glasgow
Unit of Assessment:UoA6
1.Unit context and structure, research and impact strategy

1.1.Unit context and structure

Since REF2014, we have realigned our internal structure in a way that maximises our ability to deliver world-leading research and impact through an innovative integration of veterinary science and biosciences. Specifically, we have placed the highly interdisciplinary Institute of Biodiversity, Animal Health and Comparative Medicine (**BAHCM**, 51.05FTE) at the centre of our work in agricultural, veterinary and food sciences. BAHCM is one of seven Research Institutes, along with three Schools, within the College of Medical, Veterinary and Life Science (**MVLS**). Complementary strengths, e.g. in clinically oriented research and molecular virology, come from other Schools and Institutes, including the School of Veterinary Medicine (**SVM**, 9.0FTE) and the MRC University of Glasgow Centre for Virus Research (**CVR**, 2.8FTE) within the Institute of Infection, Immunity and Inflammation (**III**).

Critical inter-disciplinary expertise has been brought in through new collaborations with other units within the University of Glasgow (**UofG**), involving researchers in public health and social sciences e.g. Institute of Health and Wellbeing (**IHW**); School of Social and Political Sciences (**SSPS**), and in natural sciences and engineering e.g. School of Chemistry (**SoC**); Institute of Molecular, Cell and Systems Biology (**MCSB**); School of Engineering (**SoE**); School of Geographical and Earth Sciences (**SGES**). More broadly, an essential component of our research strategy is the wide range of internal and external partners in the UK and abroad, especially in Africa.

The number of staff within UoA6 has remained stable across the period (61.7 to 64.9FTE) while our annual research funding per FTE has increased by ~26% from £7.27M (2013/14) to an average of £9.11M pa (2014/15 - 2019/20). Due to retirals as well as internal and external moves, we have had the opportunity to significantly refresh our staffing and to align it with our strategic objectives, through 20 new appointments, 18 of which have been at a junior research level (Section 2.1). Many of these appointments have been proleptic, reflecting an exceptionally high number of successful research fellowship applications (23 awards >£100k, average £465k) during the current review period.

Strategic investment and appointments in areas that complemented our existing strengths in animal, human and ecosystem health - and bringing in technical expertise that cuts across these, such as in mathematical modelling, statistics, machine learning, and bioinformatics - has opened up new research areas and resulted in significant achievements during the review period. Key examples include:

- Strengthening of vector biology with recruitment of three new lecturer positions and investment in insectary facilities leading to innovative collaboration with SoC on vector surveillance using spectroscopy, new vector control methods with IP licensing, and award success (MRC, Wellcome Trust (**WT**) fellowships; ERC, £5.56M).
- A strategic initiative in developing bacteriology including a new £500K investment (Royal Society Wolfson award plus UofG matched funding) in laboratory infrastructure, creating the One Health Research into Bacterial Infectious Diseases (**OHRBID**) lab, five new lecturer/senior lecturer positions and links to economics and social sciences (SSPS), resulting in new income generation (e.g. MRC-funded "Supporting the National Action Plan for Antimicrobial Resistance in Tanzania", **SNAP-AMR**, £1.77M; fellowships totalling >£500k).
- Recruitment of a chair (**Hanley**) in One Health and Environmental Economics – thereby bridging into established expertise in health economics at UofG and adding an important new dimension to multi-disciplinary funding applications (e.g. MRC, ESRC/NERC, EC, total value >£2.9M).

- Appointment of a chair (**Corr**) in Small Animal Orthopaedic Surgery leading to new interdisciplinary work (with MCSB and SoE) in biomechanics and bone stem-cell research, to enable repair of large-scale bone defects in animal and human patients (Cheng 2019, Adv Sci) which received high media and public interest.

1.2.Research and impact strategy

The 'One Health' concept recognises that animal and human health and the functioning of natural ecosystems are intimately linked. The distinctive strength of UofG's UoA6 and its approach to agricultural, veterinary and food sciences is our focus on moving 'One Health' from a slogan to practical implementation, by focusing on fundamental research questions in study systems where our work can generate demonstrable impact on accelerated time scales (Sections 1.3, 4). Interdisciplinarity arises naturally from this strategy due to the complexity of biological systems once they are viewed in their actual environmental, social, and economic contexts. We attract strong early career scientists, who are often at the forefront of introducing novel and innovative ways of addressing long-standing research problems. It is these three elements - taking the research to where it is most immediately relevant, nurturing interdisciplinary thinking, and investing in the next generation of researchers – that defines our unit and approach to One Health and that underlies our success in terms of research income, outputs, and translation.

Much of our work in One Health is taking place in an international context and aimed at improving human and animal health in ways that contribute to the achievement of the Sustainable Development Goals. A unifying theme is the realisation that the complex problems underlying health and economic inequalities can only be overcome by taking into account their biological, social, economic, political and environmental dimensions. UoA6 researchers are at the forefront of this approach by collaborating with social, physical and life scientists and by building long-term partnerships with governments, academic institutions, and non-governmental organisations (NGOs) in the Global South, in particular East Africa. Thus, developing new links to social sciences (SSPS, IHW) have been important strategic steps in extending the reach and impact of our work (e.g. SNAP-AMR). Success is evident from the ability to attract significant amounts of research funding: in terms of Global Challenges Research Fund (**GCRF**) alone, UoA6 researchers have led successful bids with the total value of awards close to £6.7M.

Our integrative One Health approach also allows us to address global challenges with respect to health and sustainable food production more broadly and within a UK context. We have world leading strengths in animal physiology that underpin our search for novel scientific solutions in research challenges ranging from fisheries management and animal welfare to healthy ageing and coping with environmental change. Continued investment in unique research infrastructure (Section 3.2), new strategic recruitment (four new appointments in animal physiology) and engagement with industries (e.g. livestock, aquaculture, and energy sector) have enabled the establishment of new research foci. This has been particularly successful with respect to studying the effects of environmental stressors (e.g. rising temperatures, light pollution, harmful compounds, harvesting) on animal performance, productivity and wellbeing. By connecting fundamental research in physiology to urgent applied problems, this strategy has attracted substantial awards across a broad range of funders (EC/ER, NERC, BBSRC, NIH, Leverhulme, total >£8.7M) and generated notable outputs (e.g. Auer 2018, Nature Commun; Hindell 2020, Nature) and impact (Section 4).

Across our research portfolio, we have taken deliberate steps to ensure that the delivery of impact is firmly embedded within our activities, including:

- Building partnerships with end users and stakeholders early with the aim of fostering those relationships long term. This is evident in our work in Africa but serves as a wider model and our approach is often recognised as exemplary (e.g. 2017 BBSRC's Innovator of the Year Award, 2016 Guardian University Award).
- Leveraging institutional and external funds (e.g. UofG's knowledge exchange (**KE**) awards totalling £128k, BBSRC-Impact Accelerator (**IAA**), MRC-Confidence in Concept, and GCRF-Translational Awards; total £405k), to ensure that research findings translate into concrete

action on the ground, including the policy level (e.g. EU, national governments, Sections 1.3 and 4.).

- Securing the long-term sustainability of partnerships and research engagement through staff exchanges, studentships, industry secondments and capacity building (e.g. funding from GCRF, Commonwealth Scholarship Commission, industry partners; Sections 1.3 and 4).

1.3.Achievement of strategic aims for research and impact

In our REF2014 submission we outlined four strategic objectives (**SO**) for UoA6 which are listed below, along with brief summaries of how they have and are being achieved (new appointments/fellows indicated with asterisk*) and how they are leading to impact (highlighted in blue):

SO1.Advance the understanding of the ecology of disease within ecosystems, developing novel methods of analysis of biodiversity and quantification of health in ecosystems

Controlling vector-borne/parasitic diseases. Our strategy has been to form interdisciplinary teams of researchers that engage with low- and middle-income country (**LMIC**) partners directly and that combine expertise in vector ecology and parasitology (**Ferguson, Ranford-Cartwright, MacLeod, Gilbert*, Baldini*, Auty*, Howick***) with skills in mathematical modelling (new MRC/ERC-funded fellow **Viana*, Matthiopoulos**), statistics (**Johnson***) and machine learning (**Babayan***). The range of expertise has generated significant outputs (e.g. Viana 2016, PNAS) and allowed the team to build new effective collaborations e.g. with physical chemists (Wynne - SoC), applying mid-infrared spectroscopy to determine age and infection status of mosquitos. The work has led to substantial funding (MRC £589k) and impact activity, for example, a training workshop on machine learning in Tanzania and awards to Tanzanian partners (e.g. £750k MRC African Research Leaders Award to Ifakara Health Institute, **Ferguson** is UK PI). A flourishing collaboration with UofG's Bio-Electronics Unit has resulted in a novel method for mosquito surveillance, supported by KE funding (patent application pending). Upgrading our insectaries and adding new strategic partnerships in West Africa and Latin America has been instrumental in securing new PhD studentships and generating new funding (fellowship/awards to **Viana*, Howick*, MacLeod**; £4.97M). New recruit **Lamberton*** focusses on neglected zoonotic parasites, combining molecular, epidemiological, social science and economic aspects in innovative ways (e.g. ERC-funded SCHISTO-PERSIST £1.1M; Crellen 2016, Clin Inf Dis). Her arrival has already had synergistic effects e.g. new collaborative funding on parasitic worm control (Drugs for Neglected Diseases Initiative award to **Lamberton*, Devaney, Ranford-Cartwright**, £699k).

Adding expertise in bacteriology/antimicrobial resistance (AMR). To complement our existing strengths in parasitic and viral diseases, we identified bacteriology and AMR as important research areas to invest in. A successful application to the Wolfson Laboratory Refurbishment scheme from the Royal Society resulted in a new £500K investment in laboratory infrastructure, creating the new OHRBID lab. In parallel, we created five new positions in bacteriology (**Forde*, Lembo*, Halliday*, Oravcova*, Llewellyn***) to complement existing expertise in field/molecular epidemiology (**Cleaveland, Zadoks, Biek, Weir**) and population modelling (**Matthews, Haydon**). These investments, combined with easy access to sequencing and bioinformatics support (e.g. Glasgow Polyomics; GP) and strong collaborative ties with social scientists (e.g. newly appointed lecturer Davis, SSPS), have created powerful new partnerships. This has enabled us to secure significant new income (MRC -£2M; BBSRC -£3.3M) and fellowships (**Lembo*, Forde***) totalling >£500k and led to important publications (Subbiah 2020, Nature Commun; Caudell 2018, Lancet Planet Health). Follow-on achievements include award-winning engagement with government and other stakeholders in Tanzania (SO2) and the development of new diagnostic tests to support livestock-owning communities (SO3).

Rabies elimination. UoA6 are world leaders in delivering the science that underpins the control and elimination of rabies worldwide. Pioneering work (**Cleaveland, Haydon, Hampson, Lembo**) has helped to shape the World Health Organisation (**WHO**)'s strategy for eliminating canine rabies through mass dog vaccination. Recent work has focused on innovative approaches and new

technologies e.g. mobile phones as surveillance tools, the integration of social science data, and genomic epidemiology (e.g. Mtema 2016, PLOS Med). While maintaining a focus on sub-Saharan Africa, current work has extended its global reach with additional projects in the Americas (**Streicker, Biek, Hampson**) and the Philippines (**Hampson**) and stronger links to public health, underpinned by substantial awards (total £5.35M; WT fellowships – **Hampson, Streicker**; MRC-funding with IHWs Wyke, Craig). Strong partnerships with governments and non-governmental stakeholders (e.g. WHO, Global Alliance for Vaccines and Immunization - **GAVI**) have further ensured the delivery of significant impact for example by influencing global policy and resource allocation with respect to rabies control (Hampson 2019, Lancet Inf Dis; Impact Case Study – **ICS**, Section 4). As testimony to its strong impact and excellence, this work won the 2016 Guardian University Award for best international project.

Biodiversity and ecosystem health. Our partnerships with natural resource managers are enabling us to provide guidance on how to maintain the health of multi-use ecosystem. **Reeve** uses computational approaches to examine biodiversity changes (NERC/BBSRC; £150k), while new EC-funded research (African BioServices – **Hopcraft***, £756k, with Tanzanian National Parks, Zoos, and philanthropist donors) is assessing how local communities are benefitting from protected areas but also how human land use is changing these ecosystems in profound ways (Veldhuis 2019, Science). Often, such research naturally leads to high level impact: Bailey's study demonstrating the negative effect of trawling on vulnerable deep-sea ecosystems (Clarke 2015, Curr Biol) has since triggered a EU policy change (ICS, Section 4). The appointments of **Hanley*** (environmental economics) and **Welden*** (marine pollution), now allow us to study these types of problems in their broader interdisciplinary context (e.g. ESRC/NERC-funded award on marine plastics, £739k). The appointment of four new lecturers working at the interface of environmental change and physiology (**Boonekamp*, Dominoni*, Hill*, Stevenson***) has facilitated the creation of new research programmes (with **Monaghan** and others), most notably the role of light pollution and other environmental stressors in disrupting biological rhythms and the consequences for animal and human health. This work, also bridging into immunology (collaboration with new appointment **Babayan***) is underwritten by substantial funding from NERC (two Highlight Topic grants, £3M), Leverhulme (£950k) and BBSRC (£600k).

SO2.Conduct clinically oriented research in livestock contributing to food security, food safety and carbon-efficient production, aligned with MVLS areas of strength in ecosystem health, population biology, infection, immunity and inflammation.

Animal health and international development. Within the One Health agenda, our research examines the compounding effects of livestock diseases on livelihoods, food security and economic growth in LMIC. Maintaining a geographic focus on East Africa (Tanzania, Kenya), where research and stakeholder partnerships are well established, recent work has expanded in scope. Specifically, new research strands in animal health, with implications for food security and food safety, have been developed (e.g. Halliday 2020, Lancet Inf Dis; Bryers-Casey 2018, Nature Ecol Evol) as a direct consequence of recent infrastructure investment and staff appointments (**Auty*, Lembo*, Forde*, Halliday*, Oravcova***). Major funding for this comes from UKRI e.g. three BBSRC Zoonoses and Emerging Livestock Systems grants (£3.3M) and follow-on awards (BBSRC - £448k; Bill & Melinda Gates Foundation -£941k). Sound structures are in place for ensuring the translation of this work through strong links to governments and other stakeholders: two BBSRC IAAs (£230k), UKRI translation awards (~£300k) and flexible UofG KE funding (£22k), enabled workshops and engagement events with partners in Tanzania, which led to significant impact at the national policy level (ICS, Section 4). In recognition of its excellence and outstanding achievements in this area, the UofG team (led by Cleaveland) won a BBSRC's 'Innovators of the Year' award in 2017.

Supporting the UK livestock sector. UoA6 staff are making recognised contributions to the control of livestock pathogens and outbreak preparedness in the UK (awards to **Matthews, Mellor, Biek** totalling >£2.4M; DEFRA, BBSRC, EC e.g. Pascall 2020, PLOS Biol). The Centre of Expertise in Animal Disease Outbreaks Livestock disease in Scotland (**EPIC**), funded by the Scottish Government, provides strategic policy guidance on all aspects of animal disease management and control. EPIC has about 40 research and support staff members, of whom 7 have been based at

UofG (including **Gilbert*** and **Auty***). UoA6's Mellor is the current director of EPIC (2016-2021, £1.3M to UofG). Work on viral livestock pathogens also involves collaborations with CVR scientists (**Murcia, Willett, Hosie**, e.g. Zhu 2019, PLOS Pathog), supported by MRC's £26.3M Quinquennial Core Funds Award to CVR, which was recently designated an **OIE** (World Organisation for Animal Health) Collaborating Centre in Viral Genomics and Bioinformatics. Adding to the research base for livestock health is SVM's Centre for Production Animal Health & Food Safety (**Jonsson** and **Mellor** are members).

Building on UofG's global reputation in parasitology, researchers in our unit have been at the forefront of identifying new ways to reduce parasite burdens and to overcome the widespread problems of drug treatment failure. **Devaney** leads a UK-wide consortium (with **Mable, Britton, Matthews, Laing***) that aims to identify the genetic changes underlying anthelmintic drug resistance by bundling expertise in parasitology, evolutionary genomics, mathematical modelling, climate change and agricultural economics (BBSRC strategic LoLa award: BUG consortium, £1.36M). Early achievements include contribution to the first comparative genomic analysis of major parasitic worms (International Helminth Genomes Consortium 2019, Nature Genet) and a WT clinical research fellowship (**Laing*,** £934k). Complementary BBSRC-funded work examines mechanisms of resistance using an experimental worm model (**A Page**, £386k).

SO3.Invent new approaches to diagnosis, prophylaxis, and therapy for animal health problems in all species and develop technology that links advances in sensor systems, imaging, and bioengineering with recent advances in animal biology in health and disease.

New data and technologies. The digitisation of large-scale animal health data is creating powerful opportunities for epidemiological evaluations of risk factors and interventions. **Parkin** is a world leader in equine health and leverages large data sets provided by the horse racing industry to identify risk factor for racing injuries and how they could be prevented. Strong buy-in from the industry and charities has provided significant funding (£638k in total e.g. Horserace Betting Levy Board, The Horse Trust, The Jockey Club) and resulted in fundamental change in horse racing practices (ICS, Section 4). State-of-the-art remote sensing technologies are used to develop and assess sustainable approaches for livestock production by **Jonsson** (with industry partner Harbro and SGES; BBSRC, £329k). **McKeegan** and **Bain** are internationally recognised experts for improving food safety and animal welfare in poultry, **Hill*** and **Jonsson** have complementary expertise for cattle production. **McKeegan**'s research led to new technology for slaughter (commercialised by LiveTec) and her use of low atmospheric pressure stunning (Humane Slaughter Association Award 2019) was the first new method for poultry slaughter to be approved by the European Food Safety Authority (**EFSA**, Section 4).

Diagnostics, surveillance, and vaccines. Improving animal health requires reliable diagnostic tools and safe vaccines. Our work has brought about significant advances in field-based diagnostics, which are a major limiting factor to livestock disease control, especially in low resource settings (Halliday 2017, Science). Long-standing collaborations with The Pirbright Institute address this for foot-and-mouth-disease virus (FMDV; Section 4). For anthrax, a new staining technique, validated by PCR and culture methods, has meant a step change for rapid identification of cases (Aminu 2020, PLOS Neglect Trop Dis; **Forde*, Lembo***). This method has revealed the true extent of anthrax mortality and morbidly in Tanzania and played a major role in anthrax now being listed among the top five priority zoonotic diseases by the Tanzanian government (BBSRC/GCRF IAA, see ICS, Section 4). Documenting the extent of neglect regarding endemic anthrax has been a critical factor for securing subsequent funding by **Forde*** and **Lembo*** (BBSRC, Academy of Medical Sciences, £505k). **Willett** and **Hosie** have a successful track record of working closely with biomedical companies (e.g. Merial), which led to improved safety and reliability of pet vaccines and diagnostic tests by changing industry practices and EU legislation (Section 4).

SO4.Conduct high-quality basic laboratory science that defines molecular and cellular mechanisms in normal physiology, and that subsequently underpin the development of animal diseases.

Animal models of ageing. We are using state-of-the art tools to gain fundamental insights in animal physiology and function that are critical for understanding the conditions leading to non-communicable disease. UofG has a strong reputation for its work on aging and senescence in non-model organisms. Ground-breaking research by **Monaghan** on telomeres as markers of ageing and **Selman** and **Metcalfe** on mitochondrial function and ageing (e.g. Saline 2015, Biol Lett) has attracted substantial funding (e.g. three ERC Advanced Grants, BBSRC, MRC, NERC, the Leverhulme Trust, AXA Foundation, EC, total >£8M) and established UofG as a world leader in this field. Building on this reputation, we recently recruited **Boonekamp***, who will add complementary expertise in experimental field systems to study senescence in animal models including invertebrates. **Corr*** examines biological markers of healthy ageing in the highly topical context of animal cloning (Sinclair 2016, Nature Comm; AltMetric Score in top 1st percentile).

Animal physiology underpinning health. UoA6 hosts a critical mass of research groups interested in the mechanistic basis of organismal variation in animals, including the role of metabolism, development, and endocrine function. These groups combine a broad range of complementary technical expertise that facilitates high profile interdisciplinary projects and industry partnerships (e.g. **Eckersall** on acute phase proteins) and benefits from the access to state-of-the art technology through GP. For example, recent work on sheep examined how reproductive hormone exposure during puberty can change development and behaviour later in life or across generations (**Evans** - BBSRC, £559k, with AstraZeneca; NIH, £1.13M). The former project produced a new method for steroid profiling from biological materials using mass spectrometry (developed with GP), which found subsequent application to study hormones over time in free ranging ungulates (**Hopcraft***) and for quantifying steroids in human foetuses exposed to maternal smoking (O'Shaughnessy 2019, PLoS Biol). Similar synergistic effects are expected from the recent appointment of **Stevenson*** who adds expertise in studying biological rhythms using molecular and experimental approaches (e.g. Bao et al. 2019, PNAS), and **Boonekamp*, Dominoni*, and Hill*** who have overlapping interests with other groups but add complementary expertise in animal ecology and welfare.

Fish biology and physiology. Our strength in fish biology, including its relation to aquaculture and fisheries, stems from a critical mass of researchers with complementary expertise (**Adams, Bailey, Elmer, Killen, Llewellyn*, Metcalfe, Parsons**), creating an interdisciplinary perspective integrating ecology, physiology, behaviour, evolution, disease, and food production. The group further benefits from state-of-the-art aquaria and research facilities (Section 3.2). Current projects are not only notable for their broad funding base (awards since 2014 totalling >£7M; BBSRC, NERC, EC, two ERC Advanced and one ERC Starting Grants) and outputs (e.g. Jacobs 2018, Nature Ecol Evol; McLean 2018, Curr Biol) but also for their strong track record of attracting industry awards (£499k, e.g. in the energy sector (SSE), fish health (BioMar Ltd, Scottish Aquaculture Innovation Centre) and environmental protection (Zero Waste Scotland)). An important step has been the appointment of **Llewellyn***, who has added complementary expertise in fish microbiota and disease, which has already led to new collaborative awards (e.g. £588k BBSRC-funded award with **Metcalfe** and SoE; EU-funded 'Beyond 2020' consortium, £2M). Expertise in respiratory physiology brought in by **Killen** (permanently recruited in 2017 after two consecutive NERC fellowships) has led to extensive collaborations (with **Metcalfe, Parsons, Lindstrom**) on fish metabolic phenotypes and evolution induced by harvesting and climate change (e.g. multiple NERC awards, value >£1.7M; ERC Starting Grant PHYSFISH, £1.15M).

1.4.Future strategic aims for research and impact (2021-2026)

Our recruitment strategy has strengthened and extended our interdisciplinary research potential, including a strong cohort of promising early career scientists, while strong ties to non-academic partners have enabled immediate impact with end users and beneficiaries. Combined, these steps put us in a strong position to advance our future research agenda in agricultural, veterinary and food sciences. Specifically, our strategic recruitment will facilitate creation of agile and fluid

interdisciplinary research teams that are well positioned to successfully address current research challenges at the UK and global scale (e.g. combining disease control, social science and economics). We have further identified areas of international excellence and reputation where we have had demonstrable success in terms of funding, outputs and impact that puts us ahead of most UK competitors: *Population & Ecosystem Health, Food Security and Production, Diagnostics and Disease Prevention and Basic Function & Physiology of Animals*. Within these four themes, our specific aims are to:

1)Population & Ecosystem Health

- enhance the understanding of the ecology of infectious diseases and how zoonotic and vector-borne pathogens affect biological systems, from individuals to species communities, in the context of environmental change
- contribute to science underpinning disease elimination and resistance management using interdisciplinary approaches including evolutionary biology, modelling, qualitative social science, and economics
- support the development of new ways to maintain the health and functioning of ecosystems in the face of increased anthropogenic pressure

2)Food Security & Production

- provide the science base for sustainable production of food in the UK and abroad
- develop better tools for disease outbreak response and forecasting through integration of environmental, biological, and social science data
- help to achieve major development goals in the global South by breaking the feedback loops between poverty and neglect for animal and zoonotic diseases and engage in international capacity strengthening

3)Diagnostics & Disease Prevention

- develop new approaches for enhancing animal health and welfare through better diagnostic and assessment tools, leveraging continued advances in omics technologies, imaging, and computation
- identify novel ways to treat and prevent non-communicable diseases of farm and companion animals

4)Basic Function & Physiology of Animals

- increase our understanding of the natural variation in physiological processes and phenotypes and their response to anthropogenic selection pressures (e.g. environmental toxins, light pollution, global warming, over-fishing)
- develop markers of ageing in animal populations to uncover the environmental factors influencing ageing processes and their ecological and physiological consequences
- understand how physiological and immunological processes unfold in the wild through model systems that combine work in free-ranging populations, semi-wild settings, and laboratory experiments
- understand how physiological processes can be programmed by conditions experienced during earlier life stages

1.5.Research Integrity

UofG has engrained the importance of research integrity aspiration at an institutional level and our approach is now showcased as exemplary by the UK Research Integrity Office and Royal Society. Open access (OA) publishing for example is promoted through Enlighten (UofG's repository service for published research material), which allows to continuously track OA compliance. Where OA has

not been addressed, individual PIs are contacted and requested to confirm when action has been taken. New staff are encouraged to attend briefing sessions on OA for publications and research data management. The success of this strategy is particularly evident for UoA6: the percentage of our outputs that are fully OA has risen from 40% to 97% (2014-2019) and staff web pages directly link not only to publications but also open data sets. All staff within UoA6 have ORCID numbers, allowing unambiguous assignment of research outputs to individuals.

All PIs and postgraduate students are required to undertake research integrity training and adhere to the University's code of practice in research. Likewise, The University's Postgraduate Research (**PGR**) Code of Practice sets out guidelines to students and staff for each stage in a postgraduate student's life (Section 2.3).

Strict guidelines and review mechanisms ensure that ethical approval is in place before any research involving animal or human subjects is carried out. The SVM Ethics and Welfare Committee considers applications for prospective studies and retrospective analyses/clinical audit concerning all veterinary species. The College Ethics Committee oversees projects involving questionnaires, which ask personal questions of the owner/human subject. For projects that fall under the Animal Scientific Procedures Act 1986, the Animal Welfare and Ethics Research Committee considers ethical approval.

Strong emphasis is placed on providing resources and training to facilitate KE and impact (Section 2.2) and on effective sharing and management of research data. To facilitate the latter, biostatisticians and bioinformaticians are embedded within Institutes/Schools. There is a strong ethos of supporting open-data and open-software through public repositories (e.g. Dryad, Zenodo, Figshare, GitHub), or dedicated web interfaces e.g. Scottish COVID-19 Response Consortium (Reeve/Mathews lead the RAMP modelling initiative); CVR's RABV-GLUE (rabies virus genome analysis tool; **Biek, Hampson, Streicker**).

2.People

2.1.Staffing strategy

We aim to provide an environment to support a positive and vibrant interdisciplinary research culture with a strong emphasis on the provision of early career development. The total number of staff (67 representing 64.9FTEs) being returned comprises 28 professors, 8 readers, 10 senior lecturers, 12 lecturers, 2 veterinary clinicians, and 7 independently funded research fellows, of which a high proportion meet the REF-definition of early career researchers (**ECR**s), increasing from 8% in REF2014 to 19% in 2020.

Recruitment. Our staffing strategy over the past review period has focussed on filling identified gaps in skills and expertise (e.g. bacteriology, economics) and on expanding areas of strength (e.g. vector biology, physiology). This has facilitated the creation of broader research teams that are able to address the complex, interdisciplinary research questions that typify One Health. Another major focus for recruitment has been to enhance our capabilities in computational biology and novel technologies (e.g. mathematical modelling, statistics, machine learning, bioinformatics), which are themes that cut across many research systems and are thus strengthening our research base more generally. Filling these positions involved a roughly even combination of targeted recruitment and open searches.

Key new appointments during the past review period include chairs in One Health and Environmental Economics (**Hanley**), and Small Animal Orthopaedic Surgery (**Corr**). In addition, we have made numerous new early career appointments: **Forde, Oravcova** (bacteriology), **Lembo, Halliday** (bacteriology/epidemiology), **Llewellyn** (fish microbiome/disease), **Welden** (marine pollution), **Lamberton** (parasitology), **Johnson, Viana** (modelling/statistics), **Hopcraft** (tropical ecology), **Baldini, Auty** (vector biology), **Dominoni** (urban ecology/physiology), **Stevenson, Hill, Boonekamp** (physiology), **Babayan** (immunology/bioinformatics), and **Weir** (infectious disease/ bioinformatics).

Fellowships. We have a vigorous programme to assist the development of Fellowship applications including writing support, internal review of applications, connecting applicants with previous award holders, and practice interviews. The UofG Lord Kelvin Adam Smith (**LKAS**) Leadership Fellowships provide up to £100k of additional support to fellowship applicants, and a further one-year salary support for 3- and 4-year fellowships. The success of this programme is indicated by the 23 fellowship awards >£100k made to UoA6 over the REF period. Examples of prestigious fellowship awards include

- WT Sir Henry Dale to **Streicker** (2015), **Howick** (2020), **Fornace** (starts 2021)
- WT Senior Fellowships to **Hampson** (2018), **MacLeod** (2018), **Streicker** (2020)
- WT Sir Henry Wellcome to **Quintana** (starts 2021)
- WT Clinical Research Career Development Fellowship to **Laing** (2019)
- BBSRC Future Leader Fellowship to **Forde** (2018)
- Leverhulme Leadership Award to **Stevenson** (2019); Early Career Fellowship to **Jacobs** (2020)
- Nine EC Marie Curie Fellowships awarded to ECRs

Our retention of fellows is excellent: over the past decade, we have made permanent commitments to seven senior fellowship holders (4F: 3M) and only two fellowship holders (1F: 1M) have left.

Internal links. Many of our staff have joint appointments between BAHCM and SVM or links with other units and centres within UofG, e.g.

- The Wellcome Centre for Integrative Parasitology (WCIP) (**Cleaveland, Haydon, Lamberton, Howick**)
- The MRC-UofG Centre for Virus Research (CVR) (**Hosie, Murcia, Willett** are based there, **Streicker** is joint appointment, **Biek, Cleaveland, Reeve** are affiliated)
- Scottish Centre for Production Animal Health & Food Safety (**Jonsson** is Programme Director, **Mellor**)
- Glasgow Centre for International Development (**Haydon** is Director)
- The Boyd Orr Centre for Population and Ecosystem Health (**Reeve, Lembo, Matthews** share directorship)

2.2.Staff development

Mentoring. All staff and postdocs are strongly encouraged to take advantage of the mentoring schemes available both locally within Schools and Institutes and at the College level. This variety provides a choice regarding the gender, seniority, and discipline of their mentor. New appointments are provided with a 'mentoring toolkit' as part of their induction to help them navigate this process. Particular emphasis is placed on providing strong mentorship to ECRs (see below).

Communication. Issues relating to staffing and support can be raised locally (e.g. Institute Management Group, School Executive Committee; 1:1 surgeries with Institute and School Directors or at College Management Group meetings). Staff surveys are conducted within Institutes and Schools, and in the main indicate a high level of staff satisfaction (Section 2.4). Quality control for of research outputs and grant proposals is supported through several initiatives (details below).

Shared Interest Groups (SIGs). Staff members are strongly encouraged to form and contribute to SIGs, which bring together researchers from within the unit as well as other parts of the university on specific themes ('e.g. 'Vector Biology and Disease'; 'Physiology and Welfare'). SIGs are run according to the needs and ideas of their members; most have their own budgets and seminars and invite speakers and organise workshops or annual meetings. SIGs also play a critical role in

providing support structures for PhD students, postdocs and ECRs by creating opportunities for practice talks or internal reviews of manuscripts and funding applications.

Seminars. Seminars are arranged at SIG, Institute/School and College levels, providing staff and students with regular opportunities to discuss ongoing and proposed research; external speakers are invited where appropriate to enhance discussions. Sponsored events and award lectures (e.g. Blodwyn Lloyd Bins, Darwin Day, Sir William Weipers, Richard M Elliot Memorial Award, Sir Michael Stoker Award) also provide staff and students with an opportunity to nominate and invite external speakers who are leaders in their field.

Training courses. The University's Researcher Development Initiative runs a number of bespoke courses that are available to staff and PGRs on research governance and organization – staff are encouraged through the Performance and Development Review (P&DR) process to enrol for these courses as part of their personal development.

Research outputs. Continuing emphasis is placed on quality rather than quantity of outputs. Staff are encouraged to be realistically ambitious and reassured at P&DR that the time required to develop the highest quality of research is understood, and pressure to deliver publications on a short-term basis is minimised. Support mechanisms to facilitate this include:

- workshops and hold writing retreats on how to write a 4* paper; option to have abstracts reviewed by our Research Abstract Review committee before submission
- internal peer-review of full papers (particularly encouraged for the highest quality submissions); similar support is available in the preparation of cover letters and in potential handling of reviewer's comments and appeals
- access to statisticians and bioinformaticians to assist in all aspects of study design and in the publication of results
- our Institute communications team ensuring that any new publications and newsworthy items relating to our research are publicised via social media (e.g. Twitter, Facebook)
- line managers tracking the quality of outputs annually through the P&DR process and provide advice on how yet unattained aims regarding high-quality outputs could be achieved
- representation on the MVLS Research and Knowledge Exchange Committee, which ensures that policy decisions regarding outputs are communicated to all staff within the unit

Supported by these measures, our research has resulted in high-quality and highly-cited outputs over the past review period:

- publications in major general science journals (e.g. Science, Nature, Nature Communications, PNAS, PLoS Biology, eLife) make up >1/3 of our submitted REF outputs
- our >1600 outputs have received on average 16.25 citations per output (excluding self citations) and 10% (including reviews) are in the top 5% cited papers worldwide based on Field Weighted Citation Impact (FWCI) scores
- our overall FWCI values are above the Russell Group average in 8 out of 9 applicable subject areas

Promotion. P&DR is used to ensure that all staff are fully aware of the promotions policy and that they are mentored and supported towards producing competitive applications. The need to put stronger emphasis on promotion mentoring was recognised by the Athena Swan Self-Assessment-Team (SAT, Section 2.4), initially to address gender inequalities, but ultimately to benefit all staff. Within the current REF period we have promoted 9 staff to Professor (6F:3M), 8 to Reader (4F:4M) and 11 to Grade 9 roles (e.g. Senior Lecturer; 3F:8M); with an overall success rate for promotion applications of 85% (F:83%, M:87%).

Early Career Researchers (ECRs). The high rate of early career recruitment necessitates a strong emphasis on providing career development opportunities. All new earlier career academic staff participate in UofG's Early Career Development Programme which includes the provision of training and support in research leadership. The scheme involves pairing ECRs with senior mentors matched to the ECR's needs and preferences. Some ECRs (e.g. **Lembo, Elmer, Lamberton**) have also won places on the prestigious Scottish Crucible programme. The support structures in place have contributed to many ECRs securing competitive research awards e.g. ERC Starting Grants to **Killen, Lamberton, Viana** (total >£3.3M).

Training and advice on generating impact. In REF2014, 3/4 of our impact cases were judged to be world-leading (4*). Following on from this success, an Impact Champion (**IC**; **Zadoks**, succeeded by **Biek**) was appointed. The IC works with the College's Impact Strategy Working Group and Research and Knowledge Exchange Committee to support the identification, generation, evidencing and publicising of impact and to advise staff members on these issues.

Staff are further encouraged and supported in the development of impact through:

- University-run KE and impact events for staff (e.g. One Health engagement days with non-academic partners, Impact Evaluation Workshop led by external expert, opportunity audits)
- UofG offering guidance and resources on collecting research impact evidence and providing advice and a centrally managed KE and impact repository
- our STEM ambassadors and the INSPIRE Research Ambassador Network (a UK-wide initiative designed to engage veterinary undergraduates with research)
- Incentivising impact-generating activities through internal KE flexible funding (14 staff have been awarded a total of £128.5K)

2.3.Postgraduate research students (PGRs)

We have increased our number of doctoral degree students from 79.2 (2013/14) to 86.0 (2019/20) and of doctoral awards per annum from 17.8 to 30.6. Per year, this corresponds to an average supervisory load of 1.67 students and of 0.47 degrees awarded per staff FTE.

PGR funding. We have been particularly successful in generating increased opportunities for international postgraduate students, including:

- Bill and Melinda Gates - Enhancing the Health and Productivity of Livestock (2 awards)
- BBSRC-DFID - 'Zoonoses and Emerging Livestock Systems' associated studentship programme (3 programme awards)
- EC - European ITN Joint Doctorate programme in Molecular Animal Nutrition
- a joint PhD programme in One Health created by the Universities of Glasgow and Edinburgh in 2019 (4 awards) and the Lord Kelvin Adam Smith studentship scheme (6 awards), both of which are open to international students
- Commonwealth PhD scholarships (3 awards)

Due to these initiatives, the number of international doctoral students proportioned to UoA6 has nearly doubled from 25.3 (2013/14) to 47.5 (2019/20).

Additional studentships are provided through participation in Doctoral Training Programs (DTPs, e.g. MRC – Precision Medicine; NERC – IAPETUS, WT – Integrative Infection Biology). However, funding remains challenging at a national level particularly in veterinary research, so we have recognised the need to identify new alternative sources of PGR support. Our strategy has been to develop strong links with a diverse base of non-academic partners (NGOs, innovation centres, charities, and industry) that facilitate sharing of studentships costs (usually 50:50). This has led to >10 co-funded studentships over the past review period. We have further exploited our interdisciplinary reach that enables us to work across boundaries in new ways (e.g. successful

applications for NERC and BBSRC CASE studentships). Finally, we have been successful in securing PhD positions funded internally by UofG, including scholarships at the CVR (MRC-funded and Dost-Newton), the Vet Fund (8 awarded since 2014) and internal College-funded studentships.

This broad funding strategy is working: our high number of PGR students per staff FTE (1.67) puts us third overall in the UK (HESA data, Veterinary Sciences) since REF2014.

PGR recruitment. Our PGR recruitment strategy is predicated on:

- Broad advertising and close liaison with MVLS Graduate School to attract high quality applicants from diverse backgrounds, including protected characteristics
- The establishment of five high-quality Masters programmes (~80 PGT students per year) that act as a 'feeder' for our PhD programme
- Actively encouraging staff to engage with undergraduate students in research studies, including intercalated programmes, honours and PGT students, to engage not only the best students but also attracting more veterinary students into research, and onto clinical academic pathways

PGR training, supervision and completion. Once PGR students are in post, thorough support and quality assurance mechanisms are put in place, including:

- A comprehensive one-week induction programme, including a two-day retreat at our field station at Loch Lomond
- A minimum of two supervisors per student to ensure breadth and continuity in supervision throughout the project. All supervisors have to undergo regular training by attending PGR supervisor workshops organised by the College
- Appointing two PGR assessors to each student, who are not part of the supervisor team and who oversee the induction process and progress through annual progress meetings. This enables early identification of issues affecting a student's progress, and ensuring appropriate training is provided in a timely manner
- Sound administrative support structures provided by the College's Graduate School and local PGR convenors, including a dedicated online system for tracking student progress and assessor reviews
- Mechanisms for gathering PGR feedback by working closely with PGR student representatives and PGR representation on our Athena Swan SAT
- Pastoral support to PGR students that link into the Student Representative Council and other support agencies across the University
- Organising library support/training, writing support and research integrity workshops. PGR students also have access to a wide range of technical training courses through our Masters programmes (e.g. statistics, mathematical modelling, bioinformatics, data science)
- Student-led organisation of social events and provision of a network for academic support (including writing groups and retreats)
- Weekly seminars, where each student gives a research talk/ project update at least once a year. In addition to receiving important academic feedback, this allows the students to develop and practice their presentation skills
- Travel scholarships provided by UofG, allowing PGR students to attend and present data at national/international conferences (e.g. CVR travel awards)

These structures and mechanisms are highly effective: our four-year (pro-rata) completion rate for PhD students has remained consistently high (>95%) over the past review period.

The COVID19 pandemic and subsequent lockdown has created specific problems for our PGR students. Where the lockdown or personal circumstances caused a significant delay in studies, we

enabled affected students to apply for a fully funded extension to their studies. Since the scheme was implemented, four students have secured funded extensions with a further twelve receiving additional time ranging from 3-6 months.

2.4.Equality, Diversity and Inclusion

Consistent with the UofG's policies on improving Equality, Diversity and Inclusion (ED&I), all within UoA6 are firmly committed to this goal, and hold Silver Athena Swan Accreditation.

More broadly, there are common initiatives and actions in place across UoA6 aimed at ensuring that strategies for improving ED&I benefit all staff. This includes subgroups focusing on particular actions ranging from staff consultation, promotions, induction, workload, mentoring, policies, information and training, sharing best practice, wellbeing at work, to culture and communications. Events to promote equality and diversity within our research community include networking lunches and coffee mornings, dealing with harassment at work, resilience and mental health training and seminars, female researchers network, LGBT days, and equality and diversity training (all new and existing staff need to complete this, including unconscious bias training). Guidelines and activities aimed at furthering equality and diversity have been established: committee memberships are rotated and take account of gender balance, timings of social gatherings are planned so that they are inclusive of those with caring responsibilities; meetings are limited to 90 minutes and scheduled during core hours, and the provision of social space is prioritised at all sites across the campus. A community garden has been set up and enthusiastically staffed by volunteers at the University Farm at Cochno to provide a family-friendly environment to meet and interact.

Some key examples of recent actions include:

- Monitoring progress through annual collection of baseline data and supporting evidence from staff (questionnaires and focus group meetings)
- Annual collection of data on post-graduate applications, retention, and the experience and views of our post-graduate community
- Promoting key career transition points, appointments and promotions: embedding promotion mentoring into P&DR process; annual workshops on promotion, recognition and reward; job descriptions using language that is gender sensitive; supporting flexible working; fair and transparent allocation of workload across all domains and genders (workload modelling)
- Celebrating and raising awareness about LGBT scientists by establishing an annual LGBT in STEMM day (held since 2018, money raised for local LGBT charities)
- Increase representation by inviting staff from minority groups (LGBT, BME & disabilities, including hidden disabilities) and promote diverse role models in science

Recent examples of success for UoA6 arising from action plans include:

- 6 out of 9 promotions to professor since 2014 have been female
- At the professorial level, 40% of staff are currently female, exceeding UK average (23%, HESA 2017/18 for Veterinary Sciences) and gender ratios across all grades are approaching 50:50
- Our ability to attract and retain top female scientists is illustrated by UoA6 female researchers consistently outperforming male researchers with regards to annual research income

To assess outcomes, staff surveys are conducted about every two years. Using the latest BAHCM survey as an example (response rate >90%), this reveals significant progress with respect to equality and diversity outcomes:

- 91% of females and 94% of males agreed that "*The Institute is a great place to work/ I enjoy working in the Institute*"
- 93% of females and 94% of males agreed that "*The atmosphere in the Institute is inclusive for both women and men*"

- 98% of women and 98% of men answered yes to "*Do you feel you have been treated fairly regardless of your gender in respect to day-to-day treatment at work?*"

All staff involved in REF processes (including output review and selection) within the UoA undertook mandatory training including ED&I principles, unconscious bias, and sensitive data handling. In accordance with the University's Code of Practice, outputs were selected and allocated to authors to maximise the UoA's GPA. An interim equality impact assessment of our methodology indicated no significant bias against any protected characteristic.

3.Income, infrastructure and facilities

3.1.Income

Funding portfolio. Our annual research income has grown by ~26%, from £7.27M (2013/14) to an average of £9.11M (2014/15 - 2019/20). Over the REF period, UoA6 has secured >£64M in external research funding as a proportioned part of a portfolio of >£100M of awards. Over 40% of our funding was provided by UK research councils, for which annual income has increased by >40% (from £2.6M to £3.8M pa). However, our funding base is broad, reflecting our reach into other research disciplines and strong links to UK government, international partners, and funders. Successful applications from the EU have increased more than two-fold from £0.72M to £1.69M pa and similarly UK Government awards have increased by 70% from £0.77M to £1.34M pa. Average annual income from Overseas sources has doubled since 2013/14 and now provides 7% of all income. Income from UK Charities is steady, averaging £1.57M pa.

Across the Unit, 100% of submitted staff have held research grant funding over the review period. Annual research income per FTE has increased from £118K in 2013/14 to an average of £142K pa in the years since then, which would place us 3rd in the Russell Group (HESA cost centre 109, Veterinary Sciences).

Looking at our new grant awards (since REF2014), our top 10 funders are:
BBSRC: £13.07M; MRC: £7.22M; WT: £7.47M; EC: £5.96M; ERC: £3.34M; NERC: £4.49M; Scottish Government: £3.70M; Leverhulme Trust: £2.08M; Bill and Melinda Gates Foundation: £1.52M; DEFRA: £1.47M.

Examples of notable awards >£1M include (*indicates new staff/fellows):

- Social, economic and environmental drivers of zoonoses in Tanzania (SEEDZ). **Cleaveland, Matthews**. BBSRC, £2.26M
- Counting the cost of living: mitochondrial efficiency, environmental conditions, and performance in the wild (MitoWild). **Metcalfe**. ERC, £2.15M
- Supporting the National Action Plan for Antimicrobial Resistance in Tanzania (SNAP-AMR). **Matthews, Hanley*, Zadoks, Oravcova*, Lembo***. MRC, £1.77M
- Building Upon the Genome: using *H. contortus* genomic resources to develop novel interventions to control endemic GI parasites (BUG consortium). **Devanay, Mable, Laing*, Matthews**. BBSCR, £1.36M
- Novel low-cost diagnostic tools and their impact in Africa. **Lamberton***. EPSRC, £1.33M
- The Role of Physiology in the Causes and Consequences of Fisheries-Induced Evolution (PHYSFISH). **Killen**. ERC, £1.15M
- Transgenerational consequences of pre-conceptional and in utero exposure to real-life chemical mixtures on fertility and metabolic health. **Evans**. NIH, £1.13M
- New approaches to characterise *Schistosoma mansoni* infections persisting despite mass drug administration (SCHISTO-PERSIST). **Lamberton***. ERC, £1.11M

- Circadian disruption by light pollution: extent, health consequences and mitigation in songbirds. **Dominoni*, Monaghan, Babayan***. NERC, £1.10M
- Modelling to Optimize Vector Elimination: Destabilising mosquito populations (MOVE). **Viana***. ERC, £1.1M

In addition, we had notable success with specific programmes, including:

- BBSRC-DFID funded 'Zoonoses and Emerging Livestock Systems' – awarded 3 out of 11 funded UK-wide (**Cleaveland** and others, total £3.3M)
- NSF-NIH-UKRI co-funded 'Ecology and Evolution of Infectious Disease'– in 2019/20, 3 of 5 US-UK awards went to UoA6 (**Murcia, Streicker, Hopcraft*/Devaney**; total £2.2M)
- UKRI-funded GCRF – UoA6 members secured >£6.6M in funding
- WT fellowships with a total value of >£8.5M (Section 2.1)
- 'Strategies to Prevent Spillover' (STOP Spillover) a five-year, $100 million project funded by US Agency for International Development (USAID) – UofG's UoA6 is only UK participant, receiving £1.5M (from 2021)

Supporting funding acquisition. Since REF2014, we have continued to optimise the acquisition and management of our research funding through a series of measures including:

- A new research management support structure for assisting with grants from conception to completion. Members of this team are physically embedded within our local research environments and support new applications (including organisation of internal review), manage existing grants, and prepare lists of funding opportunities for staff on a fortnightly basis
- Research Committees embedded within BAHCM (Researcher Support and Development Fund) and SVM (Vet Fund) award pump-priming funds and contribute to PhD studentships in order to catalyse larger grant applications, (particularly if interdisciplinary or ECR-led)
- The University provides training courses on writing grant applications and research leadership for ECRs and PIs

3.2.Infrastructure and facilities

New investments. We have made significant investments in infrastructure since REF2014 that have enabled us to expand our research base, provide access to novel resources and collaborations internally and externally, and to generate new funding and impact. Further details are provided in Section 1, but notable examples of such investments include:

- A strategic initiative in developing bacteriology, including a new £500K investment in laboratory infrastructure (OHRBID lab) along with five new staff positions, resulting in major funding success and award recognition (Section 1.3)
- A new £5M investment in the Scottish Centre for Macromolecular Imaging, new insectaries (£545K funded by MRC), and a new bioinformatic hub (all within the CVR) that supports collaborative research with CVR staff members on viral pathogens including morbilliviruses - **Cleaveland/Lembo/Auty/Willet** (e.g. Viana 2015, PNAS), zoonotic viruses – **Streicker** (e.g. Babayan 2018, Science; Mollentze 2020, PNAS) and arboviruses – **Biek** (e.g. Pascall 2020, PLOS Biol)
- SVM's purpose built £15M Small Animal Hospital provides excellent opportunities to evaluate new approaches in companion animal health. Enabled by this, the newly appointed chair for orthopaedic surgery (**Corr**) has been collaborating cross-College (SoE, MCSB) on a ground-breaking method for bone-regeneration (Cheng 2019, Adv Sci) which received much media interest and has paved the way for novel therapies in human land mine victims (led by SoE, £2.8M charity funding)

- Refurbishments of eight temperature-controlled aquarium rooms (with both seawater and freshwater supply) and new animal procedures room to support four new staff appointments and to strengthen research in fish biology and physiology, an area in which we secured awards totalling >£8M (Section 1.3)
- Lab and insectaries refurbishment plus technician appointment, supporting three new staff appointments, to expand our research in vector-borne and parasitic diseases, associated with substantial awards/fellowships (total close to £5M, Section 1.3) and high profile outputs (e.g. Howick 2019, Science; Alam 2019, Science)
- A new space for a mathematical biology and modelling hub (accommodating **Reeve, Matthews, Johnson** and their groups)
- Investment of £5.3M into The Mary Stewart Building, a new social and teaching space on the Garscube estate, where SVM, CVR, and parts of BAHCM are based, encouraging research and teaching interactions across unit boundaries
- A £113M Advanced Research Centre part of UofG's ambitious £1Bn campus redevelopment plan, to be completed in 2021. 'International Development' (including One Health) will be one of five research themes to be hosted at this interdisciplinary centre and several UoA6 PIs and their groups will be based there

Existing facilities and infrastructure. We continue to benefit from access to first class research facilities and services including

- Our award-winning field station (Scottish Centre for Ecology and the Natural Environment – SCENE) on the shores of Loch Lomond that supports research in fish biology, limnology, and terrestrial ecology. Consisting of state-of-the-art teaching and research labs completed in 2014, SCENE also facilitates critical links to external partners such as Loch Lomond National Park, The Loughs Agency and NatureScot, to address applied issues (e.g. conservation and management of marine and freshwater fish stocks). The partnerships and the exceptional research facilities available at SCENE have resulted in additional income, including a new EU-funded award (SeaMonitor, £390k, **Adams**), and new awards to **Metcalfe, Killen, Elmer** (NERC, ERC, total >£7).
- UofG's Cochno Farm and Research Centre, which operates as a commercial farm and supports a range of teaching and research activities. Appointment of a research farm manager has facilitated wider interaction and use of the facilities (e.g. NERC - stress and light pollution, £1.10M; NIH – sewage exposure, £1.13M).
- A Bioelectronics facility embedded in the College to create bespoke electronic hardware and supporting software for research. This has been instrumental in finding new and innovative technical solutions e.g. mosquito electrocuting trap to provide safe sampling of human biting activity (UofG KE award to **Ferguson's** team, patent pending) and automated systems for tracking fish movement in the wild (supporting work by **Adams, Killen, Metcalfe, Parsons**).
- Access to state-of-the-art high-throughput sequencing, metabolomics, proteomics and transcriptomics through **GP**. This has facilitated new research breakthroughs (Section 1.3) and has enabled UoA6 researchers to be at the forefront of using whole genome data for pathogen surveillance. Facilitated by a WT-funded pump prime funding scheme (ISSF) administered by GP, pathogen genomics has been an important platform for UofG researchers, especially ECRs establishing themselves as coming leaders in the field: Hampson's group used an ISSF award to develop a novel 'lab-in-a-suitcase' approach for genomic surveillance of rabies virus in LMIC and to deliver in-country workshops (which provided an opportunity to pivot to SARS-Cov-2 sequencing with a recent MRC award, £601k); Forde secured a BBSRC Future Leader Fellowship with a focus on bacterial genomics; Llewellyn acquired internal KE and IAA funding to validate a field-based test kit for pathogen detection from environmental DNA using a metagenomic approach; Mable is extending genomic tools to the control of bacterial pathogens in crops as part of a broader consortium (BBSRC, £2M).

- Support from UofGs dedicated Communications & Public Affairs team that helps to promote our research (e.g. One Health is featured as one of six UofG's research 'beacons'), and assists with all forms of media relations.

4.Collaboration and contribution to the research base, economy and society

A key feature of our research strategy, and thus our approach to One Health, is to establish 'research platforms' (comprising networks of closely interwoven relationships with stakeholders outwith the university) and an evidence-base (founded on secure partnerships), which we use to generate a productive track record, and then expand the disciplinary scope of the platform. Often this expansion is to different scales e.g. 'down' to more molecular understanding, or 'up' to considering the economics or qualitative social science surrounding a research question. This has proven a successful model, most demonstrable with our work in Africa (see below), early work in Latin America (**Streicker** - control of vampire bat rabies, **Llewellyn/Ferguson** – vector-borne disease control) and South East Asia (**Hampson** – control of canine rabies), but evident also in our conservation work in both marine (**Bailey** - EU legislation defining a lower limit to trawl fisheries) and terrestrial environments (**Hopcraft** - fencing policies for dryland ecosystems), and in parasitology (**Devaney** – control of helminths in livestock). This strategy is underpinned by a new Chair in Environmental and One Health Economics (**Hanley**), the appointment of a strong cohort of interdisciplinary researchers (see 2.1), and a process of continual outreach between population and community-level researchers, UofG social scientists (SSPS), basic scientists within the Unit (virology; CVR), and affiliated centres (e.g. molecular parasitology; WCIP) and, for example, non-communicable disease researchers outside the Unit (IHW).

Partnerships in Africa. Specific attention is drawn to research platforms in Tanzania – where we have a close working relationship with the Nelson Mandela African Institute of Science and Technology (research and training supported by BBSRC, BMGF, a Leverhulme Africa Award, a joint MSc programme that is philanthropically funded), with Tanzanian conservation bodies (TAWIRI, TANAPA, TAWA), with Ifakara Health Institute (research and training supported by MRC and BMGF funding), and newer initiatives in Uganda and Burkina Faso (ERC grants to **Lamberton, Viana**). Links with this area, and with West Africa, are facilitated through our participation in major initiatives like the WT funded DELTAS award Afrique-One ASPIRE and TRYPANOGEN and their research and capacity strengthening activities. All of this activity underwrites much staff movement, with visits and exchanges now being routine. A major academic collaborator in our work in Africa is the Paul G. Allen School for Global Animal Health, at Washington State University (USA). Our research and capacity-strengthening activities in conservation and ecosystem management in Tanzania receive support from the Tudor Family Foundation, Zurich Zoo, and the Karimjee Jivanjee Foundation.

Members of our unit have founded and are major contributors to the Boyd Orr Centre for Population and Ecosystem Health. The Boyd Orr Centre coordinates interdisciplinary research particularly in One Health, exploiting our strengths in infectious diseases and mathematical modelling, and linking it with social science, pure mathematics, and developing impact. This linking and development has been supported by successive GCRF-IAA and translational awards (total £538k to **Reeve, Cleaveland, Lembo**, and others), which has allowed us to strategically support projects that were close to delivering impact. A key example is our One Health work in Tanzania, where this has led to impact at the government policy level (ICS: "*From grassroots to policy: raising awareness and improving capacity to control livestock diseases of poverty in East Africa*") and to high-level recognition (BBSRC's Innovators of the Year Award in 2017).

UK research partners. We maintain research collaborations across a large network of UK research institutions including many non-academic partners. Two notable examples of strategic importance for our work on animal health are:

- The Pirbright Institute: long-term collaborations are maintained through shared grants, research students, and staff appointments (**Reeve**). Our long-standing joint work on FMDV is a prime example – in recent work, **Cleaveland** and **Lembo** helped in the evaluation of a new field-ready PCR test developed at Pirbright (Howson 2018, Transb Emerg Dis) that

would enable targeted, serotype-specific vaccination as a feasible FMDV control strategy (Bryers-Casey 2018, Nature Ecol Evol).

- Moredun Research Institute: range of joint projects and studentships, most notably new work on parasitic nematodes (**Britton, Devaney**; WT Collaborative award, £1M), bovine mastitis (**Eckersall, Zadoks**; Innovate UK, £234k) and tick-borne pathogens (**Biek, Gilbert**; Scottish Government/EPIC funding, BBSRC studentship). **Zadoks** (left 2019) was a joint appointment.

Other important partners in terms of sustained interaction and joints projects over the past review period include the James Hutton Institute, Animal and Plant Health Agency, NatureScot, NERC Centre for Ecology and Hydrology, and the Marine Alliance for Science and Technology for Scotland (MASTS).

Influencing policy. Members of our unit are interacting with policy makers across all levels, from global organisations to local governments (Also see 'Partnerships in Africa' above):

- **Hampson** and **Cleaveland** have long-standing connections to the WHO, Food and Agriculture Organisation, and OIE, in relation to their work on zoonotic disease control, particularly canine rabies. In 2017, **Hampson** was commissioned by the WHO to conduct a quantitative assessment of the benefits and costs of different rabies treatment options that led to a revision of WHO policy on rabies post-exposure prophylaxis (PEP). Her work also resulted in Gavi, the Vaccine Alliance, to add rabies PEP to their 2021-2025 investment strategy, which provides access across 46 developing countries (see ICS: "*Driving change and investment to international policy on rabies post-exposure prophylaxis*").
- **Cleaveland** is a member of WHO's International Commission for the Certification of Dracunculiasis Eradication (chairs working group on animal certification) and of the UKRI advisory group on Zoonoses and One Health
- **Ferguson** co-chairs the WHO's Vector Control Advisory Group, which advises WHO on new tools, technologies and approaches for the control of vectors of disease
- **Hopcraft** convenes the annual international stakeholder meeting at the iconic Serengeti National Park
- Current director of EPIC, **Mellor**, together with other EPIC members (**Matthews, Gilbert, Auty**), provides strategic advice to Scottish Government on policy decisions aimed at managing and controlling animal diseases. **Mellor**'s position is split between UofG and Health Protection Scotland, where he provides expertise on zoonotic disease prevention and control
- **Haydon** and **Metcalfe** are members of the Scientific Advisory Committee for NatureScot (formerly Scottish Natural Heritage), which advises the Scottish Government on the management and protection of the natural environment
- **Reeve** and **Matthews** lead the 'Rapid Assistance in Modelling the Pandemic' (RAMP) initiative as part of the Scottish COVID-19 Response Consortium
- **Reeve** serves as advisor on predicted seasonal influenza vaccine efficacy to WHO Consultation on the Composition of Influenza Virus Vaccines
- **Shiels** serves as expert consultant on the EC-funded DisConTools advisory group on animal diseases
- **McKeegan** is an appointed member of the UK Government expert committee on Animal Welfare

We have achieved international recognition for high-quality outputs with impact leading to policy change, including:

- EU legislation changes for a new lower limit on deep-sea trawling (**Bailey**, ICS: "*Development of EU legislation that protects vulnerable deep-sea species and ecosystems by defining a lower limit to trawl fisheries*")

- Research by **McKeegan** led the EFSA to approve low atmospheric pressure stunning as a new method to use for poultry slaughter in the EU, and to rank it as the stunning technology with the lowest welfare hazard
- changes to US Jockey Club / Fédération Equestre Internationale rules resulting in worldwide reductions in injury risk and consequent improvements in equine welfare for race and endurance horses (**Parkin**, ICS: "*Raising the standard of equine welfare to reduce injuries across race and endurance sports worldwide*")
- **Willet** and **Hosie**'s discovery of endogenous retroviruses in widely used feline cell lines implied the potential presence of fully replication competent viruses in any commercial product derived from these cell lines. Collaboration with industry partners (Merial co-funded award), facilitated by Innovate UK and Defra funding, enabled development of a biotechnological solution. This has resulted in new EU legislation and allowed commercial partners to produce safer and more reliable pet vaccines and diagnostic tests
- changes to management plans for internationally endangered freshwater mussels across multiple UK stakeholders (NatureScot, SEPA, energy companies; **Adams**)

Engagement with Industry and Commercial Partners. Members of our unit are working closely with industrial partners in animal health and production, with partners contribution close to £700k to our research income. Examples include:

- consultancy and advisory roles (e.g. **McKeegan, Bain** - poultry production/welfare, **Reeve** - FMDV vaccination with MSD/Merck Animal Health, AgResults); secondments within commercial companies (e.g. **Jonsson** with Harbro Ltd, rumen health)
- joining up with industry to generate research and training networks (**Eckersall** leading European ITN in Molecular Animal Nutrition MANNA)
- leveraging joint grant funding (e.g. **Willet/Hosie** with Merial on Defra-funded project on animal vaccine safety)
- co-developing new products (e.g. **Eckersall, Llewellyn** with aquaculture industry companies BioMar Ltd and Marine Harvest (Scotland) Ltd on fish parasite/disease diagnostics; **Evans, Hastie** with Ferring Controlled Therapeutics on drug delivery systems, **McKeegan** with LiveTec on humane slaughter technology)

Outreach and public engagement. Staff and students are actively encouraged to get involved in outreach and public engagement activates to maximise the impact of their work. Such activities are recognised and rewarded through the P&DR process and have included:

- Social media – active Twitter, Facebook, Instagram accounts and contribution to online platforms (e.g. Reddit Ask a Scientist, Storify.com, VetGems, MVLS ScienceDen)
- Podcasts – two highly successful podcast formats and associated online blogs (Naturally speaking, >70 episodes; Contagious Thinking, >20 episodes)
- Public science events – exhibits and activities at Glasgow Science Festival, Pint of Science, Royal Highland Show, MRC Festival of Science

Media coverage. Our work is regularly covered by the general media. Notable recent examples include:

- **Hopcraft** contributing to Channel 5 series 'The Great African Migration' with Ben Fogle
- **Biek/Gilbert/Mellor** being interviewed for two 30min features on Lyme disease in the UK (BBC ALBA, BBC Scotland)
- **Evans**' research into effect of music genres on stress levels of kennelled dogs (https://youtu.be/kGKK3Bqtioo)

- **Corr's** work on bone healing, which was covered extensively in the media (incl. extended BBC news piece), after saving the leg of Eva the dog in the first clinical test
- **Streicker** being interviewed by BBC's Good Morning Scotland on bats as zoonotic reservoirs

Funding panels. Members of our unit are shaping decisions about science funding and strategy through membership on panels of major funders e.g. UKRI-FLF (**Mable** chairs panel), BBSRC (**Britton, Cleaveland, Devaney, Ferguson, Matthews, McKeegan, Selman**), NERC (**Mable, Matthiopoulos**), MRC (**Haydon**), WT (**Cleaveland, Hampson, Selman**), Leverhulme (**Ranford-Cartwright**), Royal Society (**Cleaveland, Ranford-Cartwright**), EC/ERC (**Monaghan, Ranford-Cartwright**).

Peer-review and publishing. We contribute as editors or editorial board members across leading scientific journals in our field e.g. Animal Conservation (**Hanley**), Biology Letters (**Matthiopoulos**), BMC Veterinary Research (**Cleaveland**), British Poultry Science (**McKeegan**), EcoHealth (**Streicker**), Ecology of Freshwater Fish (**Adams**), Epidemics (**Haydon, Matthews**), Equine Veterinary Journal (**Murcia**), Evolutionary Biology (**Parsons**), Experimental Gerontology (**Selman**), Heredity (**Mable**), Journal of Animal Ecology (**Dominoni**), International Journal for Parasitology (**Britton**), Methods in Ecology & Evolution (**Matthiopoulos**), Molecular Ecology (**Biek**), Molecular and Biochemical Parasitology (**A Page**), Parasitology (**Ranford-Cartwright**), Parasites & Vectors (**Ferguson, Lamberton**), PLOS Neglected Tropical Diseases (**Lamberton, Ranford-Cartwright, Streicker**), PLOS Pathogens (**Lamberton**), Proceedings Royal Society London B (**Llewellyn**), Resource and Energy Economics (**Hanley**).

Conference organisation. We hosted the 18th 'Ecology and Evolution of Infectious Disease' conference in 2018 (first time outside of US), which was attended by >350 delegates (**Streicker, Hampson, Biek**). We also hosted the 2020 conference of The Association for Veterinary Teaching and Research Work as a virtual event (**Cameron**). We regularly host shorter workshops and international symposia on specific topics e.g. 'bovine tuberculosis' (2017), 'FMDV in East Africa' (2019) or organise symposia at major scientific conferences.

Recognition and awards. There has been a great deal of recognition of the achievements of both individuals and teams, with prestigious awards including:

- Appointment as Fellow of the Royal Society, the Academy of Medical Sciences, US National Academy of Medicine, Royal Society Leeuwenhoek medal, the RSTMH George Macdonald medal and the Zoological Society of London Frink medal (**Cleaveland**)
- Guardian University award 2016 Best International Project; Fellow of the Royal Society Edinburgh (**Hampson**)
- BBSRC Innovator of Year award 2017 (International Impact) (led by **Cleaveland**)
- joint first prize in the 2018 Ebbe Nielsen Challenge, an annual innovation competition run by the Global Biodiversity Informatics Facility (**R Page**)
- Humane Slaughter Award 2019 from the Humane Slaughter Association (**McKeegan**)
- Zoological Society of London Science medal (**Ferguson, Hampson**)
- Royal Society of Edinburgh Patrick Neill Medal (**Lembo**)
- Association for the Study of Animal Behaviour and Zoological Society of London Frink medal (**Monaghan**)
- President's medal from Society for Experimental Biology (**Killen**)
- Fisheries Society of the British Isles Science medal (**Elmer, Killen**) and Beverton medal (**Metcalfe**)
- Philip Leverhulme Prize, National Geographic Emerging Explorer, and Wellcome-Beit Prize (**Streicker**)