Institution: University of Cambridge
Unit of Assessment: 6 Agriculture, Food and Veterinary Sciences

1. Unit context and structure, research and impact strategy

1.1 Structure and context

The Department of Veterinary Medicine at the University of Cambridge offers an outstanding environment for world-class research that maintains a portfolio of excellence in veterinary science, fully integrated with the wider University. The Unit's 57 researchers (51.9 FTE) are drawn from a breadth of disciplines, encompassing human and veterinary medicine, fundamental biology, translational research and mathematics. Since 2014 our Unit has continued to develop, with a research strategy that builds on existing strengths and research priorities leading to a substantial growth in research activity, evidenced by increases in research income, industrial collaborations, new spinout companies, key appointments, and new investments in research infrastructure.

The majority of researchers are housed on our West Cambridge Site with others based across the Schools of Biological Sciences, Physical Sciences and Clinical Medicine as part of intra-university collaborations and interdisciplinary research.

Box 1 Unit research themes and researchers:

Infection and Immunity (21 individuals): This theme includes research groups (*individual PIs listed in brackets*) in Bacteriology (Grant, Mastroeni, Tucker, Patto and Holmes), Virology (Heeney, Blacklaws, Tiley and Frost until 2019), Immunology (Bryant, Schwaeble and until 2020 Kaufman), Parasitology (Cantacessi), Biominerals (Powell), and Prion disease (Bujdoso and Thackray).

Disease Dynamics (18 individuals): This theme encompasses mathematical and big data approaches to understanding and controlling disease at the population level including research groups in Epidemiology (Wood and Trotter), Mathematics (Restif and Conlan), and Microbial Genomics (Parkhill and Weinert).

Systems Pathology (18 individuals): This broad theme brings together research groups working on the Musculoskeletal system and Orthopaedics (Allen & Radke), Veterinary & Comparative Pathology (Archer, Constantino-Casas, Watson and Williams), Animal Behaviour & Welfare (Pearce), Oncology (Dobson and Murchison), Neuroscience (Káradóttir), Mammary Gland Biology (Hughes), Red Blood Cell Physiology (Gibson), Soft Tissue Surgery (Owen), and Comparative Genetics (Sargan).

Research themes

Research activity is presented across three broad themes (see box above and Figure 1) that represent core research strengths and critical mass. However, since projects frequently cover innovative basic studies through to translational research, work often involves collaborative activity in a range of interdisciplinary areas. We have attempted to illustrate the diversity and interdisciplinarity of our research

through the Venn diagrams in Figure 1. This shows how our researchers have defined their own research interests in terms of our primary themes and a number of cross-cutting sub-themes.

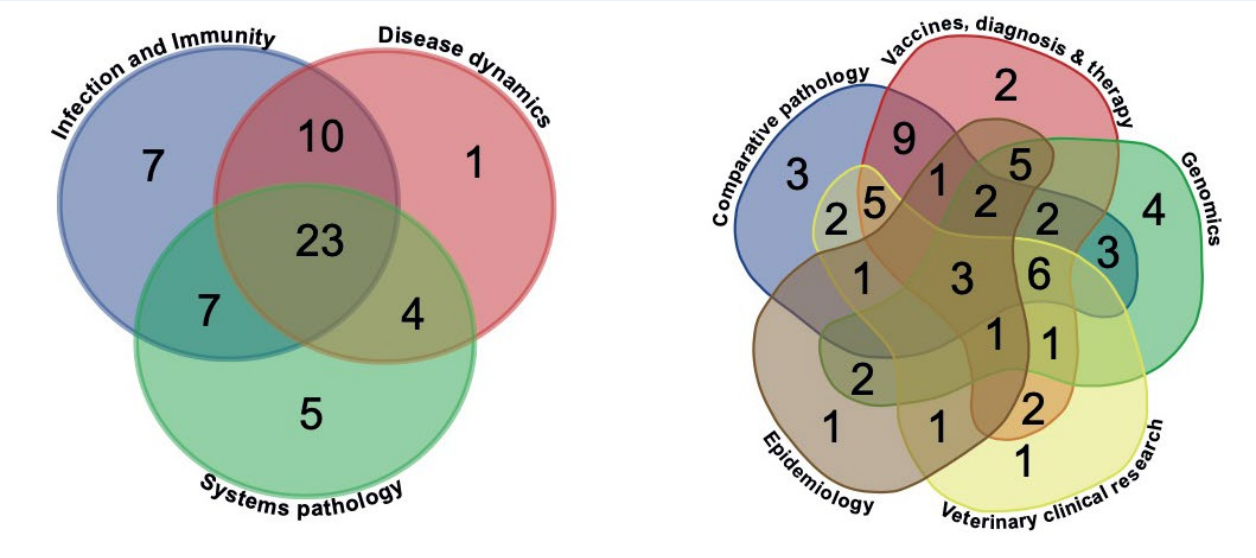

Figure 1. Venn diagrams show how our 57 individual UoA6 researchers describe their own research in terms of our three primary themes, and according to five cross-cutting sub-themes illustrating the broad range and interdisciplinary nature of our research. The numbers reflect concentration of interest.

The Unit sits in a rich collaborative environment both on campus and across the wider University. Our researchers are supported in their pursuit of external opportunities for interdisciplinary and comparative biomedical research, and are strongly encouraged to integrate with the excellent local research laboratories in cognate disciplines. An example is the 2019 cross appointment of **Bryant**'s research activities and large research group between the Department of Veterinary Medicine and School of Clinical Medicine. In this way, she promotes the two-way flow of expertise, strengthening opportunities in comparative biomedical research for both Units. Similarly, **T. Williams** undertakes joint research in the Cambridge Institute of Medical Research and **Hughes** in the Department of Pathology. These satellite laboratories provide access to additional state-of-the-art equipment and infrastructure, relevant expertise and mentorship, and opportunities to develop further interdisciplinary collaborations.

A supportive environment for collaboration

University Strategic Interdisciplinary Research Centres (IRC) and Initiatives.
Within the Unit researchers have membership in the following IRCs, Initiatives and Networks, which support cross-city meetings and collaboration: Infectious Diseases (28), Food Security (2), Public Health (9), Immunology (9), Neuroscience (3), Stem Cells (1), Cancer (5), Global Challenges (3), Reproduction (1), Data Driven Discovery (1), Conservation (2), Musculoskeletal Sciences (2) and Physical Biology (1). **Bryant** is co-Chair of Cambridge Immunology Network, **Wood** is co-Chair of Cambridge Infectious Diseases IRC and **Grant** and **Tucker** are members of the steering committee for the Global Food Security IRC. Membership of these initiatives has led to greater involvement in University-wide academic activities in general, access to a broader range of scientific facilities and direct support for knowledge exchange and government policy-relevant discussions.

Centre for Science and Policy (CSaP) Visiting Fellows programme
Policy makers visit Cambridge to meet with leading researchers in their field of interest. Since 2014 our researchers have hosted 39 visits from policy fellows from HM Treasury, Veterinary Medicines Directorate, Food Standards Agency, Defra, Abcam, and GSK. Since the beginning of the pandemic, CSaP, Cambridge Infectious Diseases and Cambridge Immunology have collaborated to present both a University-wide weekly COVID-19 relevant seminar programme and to provide detailed policy briefings for senior government civil servants.

Collegiate Cambridge
Thirty members of the Unit have College associations including research fellowships, directors of studies, and tutorships (providing pastoral care). Links between the Unit and the Colleges are often exploited to help with accommodation and to help integrate visitors more fully into the social networks that Colleges offer. Senior visiting researchers (e.g. PIs on sabbaticals from their home universities) are provided with visiting or overseas fellowships by Colleges which, again, broaden collaborative opportunities.

A rich environment for interdisciplinarity

The Unit's buildings are located on a primarily physical sciences and technology campus, and so the Unit's scientists and clinicians are well situated to develop cross-disciplinary collaborations with Engineering, Physics, Chemistry and Mathematics. For example, **Bryant** has built on collaborations with Chemistry and Physics to apply state-of-the-art imaging to identify important innate immune signalling processes that have implications in the development of inflammatory diseases such as Alzheimer's and Parkinson's disease. **Holmes & Patto** work with the Department of Physics developing a low-cost culture-based system to determine the microbiological quality of water sources for use in low-income countries. **Gibson** has collaborations in Chemistry examining surface damage of sickle cells, **Cantacessi** collaborates with Chemical Engineering and Biotechnology in development of an *in vitro* system for parasite-microbiome-host interactions. **Allen** has extensive collaborations with Engineering in the areas of skeletal biomechanics and robotics. **Pearce** collaborates with behavioural ecologists in Zoology on the epidemiology of TB infection in wildlife.

Engagement with stakeholders

We strive to promote a culture that actively exploits new methodologies, developing expertise to address the priorities and ambitions of stakeholders in animal health, agriculture, public health, and veterinary medicine for the benefit of society. The Unit's strong links to policy makers, combined with the international reputations of our scientists, underpin impact cases on bovine tuberculosis (**Wood** and **Conlan**) , meningitis vaccination (**Trotter**, case study submitted to UoA 5), sustainable international pig meat production (**Tucker**, **Maskell** and **Weinert**), antimicrobial resistance (**Holmes**) and equine welfare (**Maskell**). This is illustrated by engagement at the national and international levels: **Wood** and **Conlan** on UK and Ethiopian tuberculosis policy, **Tucker** on Myanmar pig health policy; **Trotter** and **Jephcott** on global public health with the World Health Organisation; the number of spinout companies set up by Unit staff (6); industry collaborations (e.g. **Bryant** Glaxo Smith Kline research fellowship, **Mastroeni** and **Grant** with Astra Zeneca, **Weinert** and **Tucker** with Pig Improvement Company-PIC and Ceva Animal Health), as well as extensive engagement with breed clubs and owners to raise awareness of canine health conditions (**Sargan**, **Dobson**, **Ladlow**, **Liu**, **Kalmar**, **Skelly**). The extensive research partnerships and collaborations that are the foundations of the Unit's success are described more fully elsewhere, including in collaborations (Section 4.1).

1.2 Strategic priorities from 2014

Our priority, as it was in REF2014, is to deliver outstanding research around the theme of "One Health". Some highlights since REF2014 are shown in a text box in this section. Our strategic priorities from 2014 also included building a world-class postgraduate education programme both for basic research, applied research and clinical research (as part of our clinical training programme, which is described in detail in 2.3 below).

Some Research highlights

Infection and Immunity:

- Development of a Clinical MALDI-ToF Mass Spectrometry Assay for SARS-CoV-2. **Heeney**
- Development of a novel approach to diagnose transmissible neurodegenerative diseases in humans and animals. **Bujdoso & Thackray**
- Development of a vaccine that works for *Streptococcus suis* infection in pigs. **Weinert**, **Wells & Tucker**.
- Discovery of the H17N10 bat influenza receptor (MHC-11) the receptor on our immune cells that this virus uses to enter/infect them. **Carnell**
- Discovery of the susceptibility of major MRSA lineages to simple penicillins in combination with beta-lactamase inhibitors. **Holmes**
- Establishing that pathogenic bacteria tend to have smaller genomes than their closest non-pathogenic relatives and the potential reasons for this. **Weinert & Murray**
- Genomic variations leading to alterations in cell morphology of *Campylobacter* spp. and other fundamental studies on *Campylobacter*. **Grant and Mastroeni**
- Discovery that human placenta has no microbiome but can contain potential pathogens. Helping to establish quality control standards for the investigation of metagenomes from 'clean' samples. **Parkhill**
- Identifying the negative impact of parasite infections on the health and homeostasis of the gut microbiome of herbivore species. **Cantacessi**
- Discovery of new mechanism which co-ordinates a number of cell killing pathways in inflammation. **Bryant**
- Development of a novel trivalent Marburg, Ebola and Lassa fever virus vaccine. **Heeney.**

Disease Dynamics:

- Using a combination of field studies, experiments and mathematical models to understand drivers of zoonotic virus epidemics in bats and to other species. **Restif & Wood**
- Epidemiological work informing international vaccine policy for both meningitis vaccines and rabies vaccines. **Trotter**

Systems pathology:

- Discovery of the cancer genes and driver mutations involved in initially causing the mammalian transmissible cancers, and which favour their adaptation. **Murchison**
- Non-invasive assessments and diagnosis for brachycephalic obstructive airway syndrome (BOAS), validation of new surgical techniques, conformational risk factors, and genetic causes. **Sargan, Liu and Ladlow**
- Showing that oligodendrocyte precursor cells (OPCs), the stem cells that carry out myelination, acquire ion-channels, and become differentially heterogeneous with age and region. **Karadottir**
- Development of novel approaches to using technology to improve the technical precision of orthopaedic surgery in patients. **Allen**
- Developing the use of the world's first deep water ultrasound machine to monitor breeding activity and ecology of the endangered species of Reef Manta Ray (M. alfredi) in order to better inform international conservation management plans. **Pearce**

Strategic review and planning

In June 2017, we invited leading peer researchers to undertake a thorough independent external strategic review of research in the Unit as part of a University-wide programme. The review panel were very positive about research in the Unit and made recommendations which led to the implementation of a number of organisational changes. These have included: an investment of over £500k annually in additional clinical staff time to provide dedicated research time for clinicians; improvements to our internal communications structures, as well as a revision of our research strategy; and relocation of social space to a more central location within the Department with additional catering provision and the organisation of more regular informal networking events ('happy hours').

Our strategic planning process is undertaken on a five-year cycle to provide the framework for our allocation of resources and research support activities. Recent examples of strategic support include the integration in 2018 of the Biomineral Research Group from the MRC Human Nutrition Unit, laboratory upgrades funded by a Wolfson Royal Society Refurbishment Grant in 2017 with matching funding from the University, and the commitment of funds for a new £1.3M 3T magnetic resonance imaging facility. A sustained effort and investment in targeted support has led to a substantial increase in research funding from £4.4M in 2014 to £6.34M in 2020 (exceeding £7M in 2019), with large awards in areas of international strategic importance from BBSRC, DfID, MRC, Innovate UK, Wellcome Trust, and industry.

Our future strategic research priorities:

- To develop a **critical mass of expertise in genomics and big data**, building our bioinformatics capabilities. The appointment of Julian **Parkhill** FRS to the Marks and Spencer Professorship brings the opportunity to build on existing capabilities and interests in this area, in particular the further expansion of whole genome sequencing to veterinary research and medicine.
- To **establish a centre of excellence in quantitative imaging**, from microscopy to MRI. We have recently made substantial investment in state-of-the-art imaging equipment that will allow us to develop advanced imaging techniques from the molecular scale (mass cytometry, confocal, bioluminescence imaging) up to the whole animal (3T MRI). This is a long-term plan which we expect to grow with colleagues in physical, mathematical and engineering sciences over the next 10 years facilitated by our location on a predominantly physical sciences campus.
- To strengthen research support allowing for **growth in veterinary clinical and translational research**. There has been strategic investment in developing a veterinary clinical trials infrastructure (including the recent employment of a dedicated clinical research coordinator) and a tissue biorepository that can serve as a route to enable future One Health-focused clinical research. We are investing in a state-of-the-art medical records system integrated with a network of local veterinary healthcare providers to improve our capacity for epidemiological and clinical research.

1.3 Research Culture

Our researchers have a strong track record of sharing research outputs and providing open access to our data and software tools. This openness promotes non-discriminatory access to research (scholarships, posts, samples, data, reagents, software etc.), promoting equality and diversity. We strongly encourage the publication of research data alongside our outputs.

Disease Dynamics sharing highlights

- **Trotter** and **Conlan** developed a transmission model for norovirus suitable for evaluating possible vaccination strategies delivered as an open source model and inference framework.
- **Conlan**'s work on novel contact data sets, has been shared with the research community and contributed to the crowd-shared data collection associated with the BBC Four documentary "Contagion! The BBC Four Pandemic" (Feb 2018). That dataset has subsequently been used to parameterise spatial models to understand the spread of COVID-19 and measures to leave lockdown.
- **Frost** published models and code on GitHub, used by research groups worldwide. He led **Epirecipes**, a three-day workshop in 2018 aimed at implementing different epidemiological models and mathematical models of infectious disease transmission. The result has been the publication of an Open Source textbook of computer models.

Infection and Immunity sharing highlights

- Routine deposition of whole genome sequence data in open access databases such as the primary sequence repositories (EMBL / GenBank / DDBJ).
- Genomic data and more enriched metadata have also been made available through bespoke databases, including Enterobase, MicroReact, Pathogen Watch and BIGSdb. We also contribute to MicrobesNG.
- Novel bacterial species or significant strains have been placed in international culture collections such as NCTC and ATCC.
- **Parkhill** led the community resource NCTC3000 project, the largest collection of complete genomes for type and reference strains in the world.
- **Cantacessi** launched MICHELINdb in 2019, an open access resource for mining of sequence data and associated metadata linked to available literature on helminth-microbiota interactions (http://helminthsandmicrobes.vet.cam.ac.uk/).

Systems pathology sharing highlights:

- Anatomic pathology share research material generated through their activities across UoAs. For example, **Hughes** maintains an archive of formalin fixed blocks from mammary glands at all developmental stages.
- Work undertaken by **Powell** and **Wills** has led to the publication of software and algorithms for state-of-the-art tissue imaging.

The Unit operates an **Ethics and Welfare** committee (Chaired by **Gibson**) which reviews approximately 50 applications each year for clinical research not involving human participants, including many student elective projects. The committee includes the University's Named Veterinary Surgeon alongside clinical specialists. Specialist ethical review operated through other departments in the University is used for research involving people or research involving NHS patients when appropriate. Multiple university training sessions, some obligatory, for all staff and students, deal with issues of research integrity, legal and ethical obligations, data protection, record keeping and professional standards. This ethos is cascaded through the research teams and forms part of the progression training for post-docs and graduate students. Further specialist training and continuity training on research ethics and integrity (e.g. the implementation of the Nagoya Protocol) are included in research staff meetings and seminars.

2. People

2.1 Staffing strategy

Our staffing strategy adheres to the overall Cambridge ethos of seeking research excellence in alignment with a commitment to equality and diversity (E&D), our research profile and teaching needs. For established or already-funded posts that have become available, the recruitment net is cast wide through open advertising. All staff involved in selection during recruitment undergo mandatory training in improving recruitment and E&D, including the recognition and management of implicit bias. Attention is given to ensuring that individuals from under-represented backgrounds are encouraged to apply for positions at all levels.

Since 2014, three PIs have joined the Unit in evolving areas of strategic importance. **Matthew Allen** was recruited from The Ohio State University, USA in 2014 to establish a new Surgical Discovery Centre, focused on applying state of the art robotics, imaging and 3D printing technology towards the development of better orthopaedic treatment options. The appointment of **Julian Parkhill** FRS in 2019 to an endowed Professorship has enhanced our critical mass in genomics and bioinformatics capabilities. **Jerry Wells** from Wageningen, funded through a collaborative EU project, has added strength in bacterial genomics and pathobiology, building on collaborations with **Tucker** and **Weinert**.

Integrating substantial new research groups into the Unit

- **Jonathan Powell's** Biomineral Research Group (**Ravin Jugdaosingh, Rachel Hewitt** and **Katharina Kessler**) arrived in 2018, with substantial funding, from the MRC Human Nutrition Unit. It has established new analytical capabilities for the Unit in quantitative cell imaging and elemental/isotope analysis and led to exciting new internal collaborations.
- **Powell** and **Singh**'s collaboration with **McCrone** has resulted in the development and testing of antimicrobial wound barriers based on materials pre-approved for use in food animals.
- **Hewitt** and **Watson** have collaborated to obtain Petsavers funding for a Master's research project on the detection of autoantibodies in feline and canine samples.
- **Schwaeble** enhances the Unit's fundamental research on immunology, delivering pioneering work in the discovery of a new activation pathway of the complement system, and leads an industry funded group working to develop new therapeutic reagents and technologies for clinical applications, including new antimicrobial agents.
- **Schwaeble** and **Powell** both bring substantial experience in IP development and licensing, and in addition to championing the commercial exploitation of research in the Unit, have enhanced our competitiveness in novel therapeutic and diagnostic developments.

Strategic junior academic appointments have supported career development and development of talent in key areas. **Weinert**, currently a Sir Henry Dale Fellow studying the ecology and genomics of bacterial pathogens, has received a proleptic faculty position. Five of our early career researchers hold University or College-based Junior Research Fellowships (JRFs: **Jephcott, Murray, Hardwick** & **Wills**), which represent an excellent opportunity to undertake independent research demonstrating their potential as future PIs. **Patto** is a Borysiewicz Biomedical Sciences Fellow undertaking entrepreneurial, interdisciplinary research in imaging and microbiology in collaboration with **Holmes**.

2.2 Staff development and support

The expansion of our HR team with 2 additional posts has enhanced our ability to develop and support all staff. Unit research staff are allocated local mentors to help them with their personal development and to assist with difficulties that they may encounter at all stages of their careers. Research staff take part in an annual review and development process which appraises them against agreed performance targets and is focused on helping them to prepare for submission to internal promotion schemes. Discussion of impact strategy forms part of the annual staff review and development process, in which all academic staff are invited to identify the potential impact and stakeholders of their research, and steps towards achieving this.

The review process also identifies specific training for personal development for each individual to deliver their agreed research and other personal objectives. Since 2014, four of our staff have been promoted to Professor (one woman, three men), four to Reader (two men, two women), and nine to Senior Lecturer (five women, four men). Professional development and management training is offered to all staff with management responsibility and this programme will be extended and repeated for continuing professional development and for incoming faculty members.

Support for early career researchers

Our thriving postdoctoral community has been much strengthened by the establishment of the Postdoc Academy (https://www.postdocacademy.cam.ac.uk/). All postdoctoral researchers have access to the resources provided by membership of the Postdoc Academy. The Academy offers direct support to postdocs, including induction and orientation advice on arrival for all postdocs, and access to a comprehensive range of relevant professional development and training activities, for example in knowledge exchange and commercialisation. The Academy also works with and supports the three grassroots postdoctoral organisations in the University (Postdocs of Cambridge Society, Entrepreneurial Postdocs of Cambridge and the Postdoc Chairs' Network).

Locally there is a postdoctoral committee which meets regularly to feed back on their requirements for a supportive working environment. We introduced monthly postdoc "Happy Hours" linked to seminars from internationally recognised external speakers to facilitate networking skills and to encourage them to develop new collaborations as well as to explore career development opportunities. Postdocs are represented on relevant Departmental committees to encourage their engagement in all aspects of governance. Our postdocs are supported through postdoctoral mentoring schemes offered through the University Postdoc Academy.

Appointing the highest calibre scientists has to be combined with appropriate institutional support. Newly appointed clinical academic staff are given protected research time across their 5 year probation period to enable them to develop their research programmes. Many of our clinicians are in the early stages of their careers so we further support them by embedding them within established research groups able to provide mentorship in their chosen field of interest. For example, **T. Williams** has embedded links with Professor Fiona Karet's nephrology research group at the Cambridge Institute for Medical Research, and Kate **Hughes** has active research links with the Department of Pathology. This early support helps new staff to develop relevant research skills and collaborations to produce publications, draft grants and to gain mentorship in their chosen research area.

Equality and Diversity
Our commitment to equality and diversity is illustrated in our approach to the REF staff selection process, which took a highly inclusive approach: PIs (and individuals themselves) were asked to nominate (or encourage to self-nominate) all eligible research staff possibly meeting the criteria for research independence.

We received 6 applications from early career researchers (4 men and 2 women) supported by PIs. All applications were approved. Overall the split within the Unit was 55% men and 44% women.

All research outputs were reviewed twice, and output selection undertaken by means of a computer algorithm that allocated outputs based on internally assessed quality scores.

New staff are also supported to secure funding to help them develop their research for grant proposals, and the University offers internal funding schemes for new and established staff to support basic science research and translational work. Over the REF period we have averaged a 60% success rate for applications for project and bridging funding supported by one of the university's internal funds, the Isaac Newton Trust (awards to **Williams, Weinert** and **Cantacessi)** and from the University's **Returning Carers' Scheme** (**Cantacessi, Murchison, Weinert, Peachey**).

Sabbatical Leave

All members of Faculty have access to, and are encouraged to take up, our fully paid sabbatical leave (one term for every two years worked). Since August 2013, six members of staff have taken seven periods of sabbatical leave between them. Significant developments in research programmes have emerged from recent sabbaticals including organoid usage **(Watson, Hughes),** educational research (**Brearley**), murine mutagenesis and industrial collaboration (**Bryant**), and owner-reported clinical outcomes assessment (**Radke)**.

Supporting families
- Eligible staff are encouraged to apply for the **Returning Carers Scheme**, which funds career- and professional development following career breaks or a period of leave with caring responsibilities.
- Staff in the Unit have received 14 awards between 2014 and 2019, which may extend to funding short term RA employment to complete specific projects.
- Returning staff are offered additional career mentoring.
- Staff with urgent family needs are encouraged to apply for emergency leave, flexible working or other support measures.

The Department of Veterinary Medicine holds an Athena SWAN Bronze award (July 2017). The Department's E&D committee have been working with academic leadership and there is good evidence for positive advancements relating to E&D. The 2019 University staff survey indicated that the three most improved areas were "I am satisfied with the support and flexibility offered to help me balance my work and home life"; "I believe that individual differences are valued in my area of the University" and "I have the opportunity to discuss my development needs and performance regularly". Within the Unit, there is strong support for the University's wellbeing

initiatives. Department-wide social events are organised throughout the year, including **celebrations of International Women's, Men's and Families' Days and Mental Health Awareness coffee mornings**, as well as smaller 'coffee clubs' that offer a discussion forum for staff with particular areas of concern: e.g. working parents and clinical staff. Staff are also able to take advantage of the **University Staff Counselling Service** and are encouraged to use the on campus **University Sports Centre**, which supports students, staff and the wider community in pursuit of their health and wellbeing.

Staff are encouraged to access networks integrating and supporting staff with protected characteristics: the **LGBT+ Staff Network** provides support and advice to LGBT+ staff; the **BAME Staff Network** for staff who identify as BAME or have an interest in BAME matters to come together to support the development of race equality at the University; **SPACE**, a network for members of the University with caring responsibilities for children and the **Women's Staff Network** for all female staff.

2.3 Research students

The approach to recruitment of doctoral research students and evidence of studentships

The Unit recruits 8-12 research students per year, some as members of institutional cohorts funded by the BBSRC, the MRC and the Wellcome Trust; and others directly into the Unit. Postgraduate students leaving the Veterinary School are well placed to guide research, industry or government policy in "One Health" issues. We have expanded opportunities for postgraduate training in comparative biomedical research as part of our previous strategic planning cycle, ensuring that we are at the heart of the BBSRC DTP and have provided the academic director for the University's DTP. We are fully represented on the **Wellcome Trust Clinical PhD programme**, which involves UEA and the Welcome Trust Sanger Institute, and contribute to the Wellcome Trust Infection, Immunology and Inflammation PhD programme. **Holmes** helped found and contributes to the management of the Medical Research Foundation funded **Antimicrobial Resistance DTP**. The integration of research into our undergraduate teaching was acknowledged in our 2019 RCVS accreditation visit, which especially commended us on the excellence of our integrated research and teaching strategy. A number of our alumni have won significant research fellowships, including Dr Sarah Caddy (a research fellow at the Cambridge Institute for Therapeutic Immunology and Infectious Disease) and Dr Eleanor Raffan (who now holds a faculty position in the Department of Physiology, Development and Neuroscience). In addition to research mentoring and supervision for clinical scholars, we also offer a dedicated introductory clinical research training course in collaboration with the AO Foundation for incoming interns, residents and clinically-oriented PhD students.

We work hard to widen participation in our postgraduate education by encouraging early informal approaches to potential supervisors (through our website) and participating in both intramural and extramural summer research placement schemes. A standardised scoring system has been developed for the whole University to allow cross-comparisons to be made and ensure that the most promising research students are fairly chosen. During the assessment period, we have had 75 PhD students. An overview of our current students, and those graduated during the assessment period, are provided in Table 1.

Although not on full-time research programmes, our trainee veterinary clinical fellows all make research contributions as required by the discipline-specific European Colleges.

Funding source	No.	%
Independent	14	18
Wellcome Trust	6	8
BBSRC	16	21
Cambridge Trust	12	16
UK charity	3	4
Intramural	4	5
Gates foundation	6	8
Industry	2	3
Overseas agencies	5	7
MRC/MRF	5	6
NIH	2	3

Origin	No.	%
UK	24	32
Europe	19	25
N. America	7	9
S. America	6	8
Africa	9	12
Asia	8	11
Other	2	3

Gender	No.	%
Male	30	40
Female	45	60

Full/Part time	No.	%
Part time	6	8
Full time	69	92

Table 1. Summary of funding sources and demographics of current and graduated PhD students

Monitoring and support mechanisms linked to evidence of progress and of successful completions

Monitoring of progress is achieved mainly through feedback from supervisors and additional advisors or supervision teams. Supervisors are required to meet students regularly in one-to-one meetings. Wider supervisory teams meet with students twice per term, and supervisors provide termly written reports. College tutors also meet with students at least once per year to discuss progression and wellbeing. The CamSIS reporting system is used by the departments and Colleges to record progress and share reports for both academic progress and pastoral care. Formal progression from probationary status for PhD students includes the production of a first-year report, which is orally examined by at least two examiners. A further brief report is required at the end of the second year. Our completion rates average > 95%.

Evidence of the effective progress of students in this UoA includes research outputs, prizes and other markers of esteem won by students. The cohort of research students registered during the assessment period have published 118 papers as a result of their PhD work and hold or share in 4 patents. Two current students have been accepted as Residents in the European College of Veterinary Public Health. They have won six external conference platform or poster prizes. Three have won major international prizes (the Kennel Club Charitable Trust Postgraduate Student Inspiration Award, 2017, 2019 & 2020; Harold M. Weintraub Graduate Student Award 2020 from the Fred Hutch Institute), and six others have added to their research impact through winning external grants. The Colleges have also awarded numerous small grants.

Details of the support provided to research students in terms of skills development and preparation for their future career

Students are required to take skills-based courses in personal effectiveness, engaging others, career progression and research expertise, through a combination of online and in person courses. All research students and junior clinical staff are required to contribute to the Unit's weekly seminar series of speakers. In addition, our students and postdocs present a poster or give a blitz (5') talk at our biannual research afternoons. Expert talks at these events have recently included entrepreneurship, working in industry, and ensuring research impacts government policy. Students are further prepared to communicate their science through being taught the fundamentals of scientific writing, platform speaking in short talks or longer presentations, and scientific poster presentation by academic staff. Our students are able to engage with mixed academic audiences through their colleges, learning to communicate complex ideas to critical audiences in lay terms.

Students have opportunities for contact with industry and other external working environments through the BBSRC DTP's "PIPs" internships, through various inter- and intra- University programmes such as Enterprise TECH PhD+, Innovation iTeams, through CASE studentships or their projects. Our students have gone on to success in this area, including one who founded a company based on their work that already has obtained £15M of investment.

3. Income, infrastructure and facilities

3.1 Funding Strategy

The Unit's research income for the assessment period was £39,554,636 and annual income increased, markedly from the start of the assessment period (£4.4M in 2014) to its completion (£6.3M in 2020).

We have vigorously pursued opportunities for expansion and development internationally. Our longstanding research strengths in infection dynamics, especially zoonoses, coupled with established collaborations with partners in the UK and in low-to-middle income countries (LMICs) have led to **an increasing numbers of large collaborative projects** addressing One Health issues funded in China, India, USA, Ethiopia, Myanmar, Nigeria and Ghana. This is particularly exemplified by flagship programmes in Myanmar and Ethiopia. With a commitment to capacity building, **Wood** actively sought philanthropic funding to establish the Cambridge-Africa Alborada Research Fund (£4M over ten years with additional £1M for a programme manager), co-ordinated under the Cambridge-Africa programme directed by **Trotter.** This fund supports research across all schools in the University and links a Cambridge researcher with a sub-Saharan African academic or researcher, with £400k available annually.

A commitment to knowledge exchange has underpinned the strategic development of industry partnerships. With support from a dedicated research facilitator, researchers have been supported to develop collaborative relationships, resulting in a number of successes. Our researchers work closely with Cambridge Enterprise to facilitate the commercialisation of research, activity that is greatly enhanced by the entrepreneurial ecosystem that Cambridge offers, with access to advice from **Entrepreneurs in Residence**, and programmes to support business development in the Judge Business School.

Researchers including **Heeney** and **Allen** have benefited from 'Enterprise Tech' a programme at the Judge Business School in which early career researchers develop their entrepreneurial skills by undertaking commercial feasibility assessments of developed technology. They also receive a commercial feasibility report prepared by their allocated team of Cambridge students. The Unit has taken a positive approach to the hosting of collaborative University spinout companies and currently hosts researchers from four such companies (Polypharmakos, Diosynvax, Waterscope and Entomics).

Workshops are held throughout the year to offer researchers the opportunity to engage with business, industry and public or third sector bodies, alongside training in effectively communicating with different sectors. These are supplemented by research exchange schemes, which offer opportunities for exploratory work with industry. We have taken advantage of the University's membership of **EIT Food**, a European Knowledge and Innovation Community, which provides access to collaborative funding with industry (including SME) and academic partners from across the food sector.

Activities within Clinical Research are coordinated by the Clinical Research Committee, chaired by **Allen** in his role as Director of Clinical Research, and projects within the Queen's Veterinary School Hospital are overseen by a dedicated 1.0 FTE Clinical Research Coordinator. Current clinical research projects within surgery include ongoing work from the BOAS group (**Ladlow**, **Liu,**

Sargan); several studies exploring novel technologies for assessing lameness in dogs (**Allen**); the use of machine vision and neural networks to derive 3D motion patterns from simple 3D video footage in dogs (**Allen**, in collaboration with the Department of Engineering); development of a Big Data approach to veterinary clinical trials (**Radke**); and the development of a 3D virtual environment for preoperative planning of orthopaedic and other surgeries (**Allen**). Medicine projects include studies on a novel digital stethoscope (**Watson**) and a clinical trial on the use of circulating tumour cells as predictors if disease progression in canine osteosarcoma (**Allen** and **Dobson**). Within Neurology there are new projects looking at clinical outcomes following intervertebral disc surgery and also on the role of proinflammatory cytokines as prognostic markers in disc disease in dogs (**Freeman**).

3.2 Organisational Infrastructure for Impact

Support personnel and activities

Research Support and Facilitation

- A **Research Facilitator** (0.8 FTE, appointed 2015) provides dedicated support to Unit staff in identifying opportunities for strategic collaboration and knowledge exchange as well as advising and providing support for grant applications and impact development.
- A **full time Grants and Graduate Students Administrator** assists in preparing the financial aspects of grant applications, and undertakes all administration for graduate students.
- Research support staff based within the Unit are particularly valuable in supporting collaborative work, providing rapid costing of complex multi-institutional grants, and interfacing with the University Research and Contracts offices and Legal Services, essential for effective collaboration agreement development.
- These posts relieve PIs running grants, or applying for grants, from most of the administrative work involved with obtaining costings and setting up contracts.
- Our research administration also play a key role in promoting stakeholder interactions with appropriate governance and oversight. Relevant opportunities for stakeholder interaction (e.g. vacancies in UKRI panels, calls for evidence etc.) are publicised as they arise, and suitably qualified researchers encouraged to respond.
- Investment in a local support team allows Unit researchers to host visiting researchers while ensuring the legitimacy of visitors and their welfare (including health and safety).
- The Unit hosts a specialist veterinary library with electronic and/or paper subscriptions to every major journal covering the field. **Our librarian (0.6FE) provides training and support** to help with literature searches, obtaining copies of articles not otherwise available, training for database searching etc.

Impact and translation support

- The **Bioscience Impact team** based within the School of Biological Sciences and the **Office for Translational Research** based in the School of Clinical Medicine provide additional support in impact development and to Unit researchers.
- These groups administer University impact acceleration awards, support Unit staff in impact development strategy, help with the development of industry partnerships, and manage liaison with the strategic partners of the University, in particular GSK and Astra Zeneca.
- **Cambridge Academy of Therapeutic Science (CATS**) is a strategic research initiative established to facilitate the development of new therapeutics and support the education and training of the next generation of world-leading researchers. Unit staff benefit from access to Industry Experts in Residence as part of CATS who offer researchers advice on the applicability of specific ideas to drug discovery, diagnostics and device, as well as translational grant applications.
- We are well connected to other excellent technology development and transfer support within the University, including **Cambridge Enterprise**, via its network of Department and Institute-based knowledge exchange facilitators.

In addition to formal termly staff meetings in which staff discuss research and impact plans, we also host regular informal research discussion meetings, which provide an opportunity for more long-term planning for collaborative research ideas. With the Bioscience Impact Team we run a regular ‘drop in’ clinic for discussion of impact plans, to develop ideas and identify potential external collaborators and support funding. An optional internal peer-review panel is available for all grants, which benefits from the interdisciplinary makeup of our staff, and provides the

opportunity for further improvement in grant applications. Capitalising on our expertise in mathematics and modelling, our Unit offers an in-house statistics consulting service to all its staff, which, since its inception in 2017, has advised on appropriate statistical design and analysis of over 40 projects.

Biannual research afternoons attended by the whole Department, feature outstanding plenary speakers, sessions on impact, open access, research integrity, as well as research presentations and posters from within the Unit in order to foster and encourage discourse and collaboration within the Unit. The Unit regularly hosts visiting researchers and PhD students from other universities and research institutes so that they can develop or cement research collaborations. We host two weekly seminar series, one for invited speakers (external to the Unit), and an internal seminar series, which each week features a mixture of clinical and non-clinical research and offers opportunities for early career researchers to present. A number of additional collaborative lab meetings and special interest groups are organised to offer researchers with complementary interests the opportunity to discuss ideas and develop grant proposals: monthly lunchtime 'Shetland Seminars' run by **Powell**, 'Worms and Bugs' talks involving the Infection Dynamics team and the 'Extracellular Vesicles Special Interest Group' run by **T.Williams**. All these are coordinated locally but membership is open University-wide. Researchers are also encouraged to access to the wide range of thematic seminar series and talks offered on a daily basis across the University.

3.3 Operational Infrastructure

The Unit has a number of physically discrete research laboratories, each with different core functions and facilities that include a specially equipped BSL-3 laboratory suite that offers cell sorting capabilities, extensive BSL-2 facilities and more general molecular biology, microbiology, biochemistry and chemistry laboratory suites. The Unit also benefits from access to facilities across the University through collaborations and linkages enhanced by our commitment to cross university initiatives. For example, core genomics facilities at the CRUK have been used by **Grant**, **Holmes**, **Kalmar** and **Allen** to perform next generation sequencing. Similarly, the Cambridge Advanced Imaging Centre has been used heavily by **Wills, T. Williams** and **Hughes**, although the advanced microscopy in our local imaging centre has now allowed freer access to advanced confocal microscopy.

We have substantially enhanced wet and dry lab access opportunities for scientists and clinicians across the Unit, with new staffed facilities established for state-of-art PCR analysis, elemental and isotope analyses and cell culture and quantitative imaging, and a flow cytometry facility for use with containment level 3 pathogens. The integration of the **Powell** Group from the MRC brought with it the establishment of a world class trace element and particle analysis facility within the Unit, including two advanced ICP mass spectrometers (total market value ~£2M) and a £250K upgrade of laboratory environments. In 2019, we began the establishment of a £1.6M 3T large animal MRI facility and £750K investment in quantitative microscopy and cell imaging and tissue microscopy suite that will drive the use of A.I. approaches to enable quantitative image analysis, digital pathology and tissue mapping.

The award of a Wolfson Royal Society Refurbishment Grant to **Bryant** in 2017 enabled a £187K upgrade of a key microbiology and immunology laboratory block. Support for whole genome sequencing and bioinformatics has been enhanced within the Unit with the provision of Oxford Nanopore Technologies and Illumina Miseq sequencing facilities on site. Genomics research also

benefits from the proximity of CRUK Core Genomics facility and the Wellcome Sanger Institute (see 4.1).

Every PI in the Unit is also able to access processor time and storage on the University's High Performance Research Computing cluster. A nominal annual budget of up to £3k is allocated to each PI in the School of Biological Sciences and may be used for storage, processor time, or the provision of virtual machines. Dedicated processor clusters have also been installed locally for individual research groups. The Unit has an on-going investment policy ensuring that state-of-the-art networking is maintained to provide the high speeds and bandwidths needed for 'big data' research. The Unit's IT infrastructure is serviced by five dedicated IT support staff based within the Unit contracted from the University IT Service. Microbial genomics also makes considerable use of shared bioinformatics resources. Collaborative projects led by PIs in this Unit studying AMR in India and China are using the MRC CLIMB bioinformatics computing resource which enables researchers in the Unit and collaborators from developing countries to undertake training and analyse sequence data.

The Unit maintains and hosts a number of unique databases on local hardware including: BOAS database, IMS for obesity studies, dog genomics, metagenomic datasets for pigs and humans, ovine mastitis data (tissue samples and microbiology results; in collaboration with investigators at NMBU) clinical databases, a tissue/tumour archive, and the clinical pathology archive.

Other more specialised shared facilities that are used include Enterobase and Pathogenwatch that enable sequence data from bacterial isolates to be analysed in a broader population context. The Unit also benefits from an extensive, online scheme to ensure cross-University access to shared equipment.

From Strategic planning to infrastructure improvement to research innovation

- The Unit maintains a veterinary clinical research facility together with funding for a research nurse to help with clinical research. The Unit has pioneered the use of Whole-body barometric plethysmography (WBBP) as a method of assessing BOAS severity (see impact case study). We were the first UK Vet School to obtain a plethysmography chamber to develop a testing scheme and now offer a regular assessment clinic for owners, which has allowed us to build up our own dataset which we are working towards making open access. The testing also provides a quantified and evidence-based justification for surgery to ameliorate the condition in the worst affected individuals (see Impact Case **Sargan/Ladlow**) and also feeds into a jointly administered programme with the Kennel Club.
- We established our Surgical Discovery Centre in 2015 (**Allen**) and appointed a dedicated Clinical Research Coordinator to oversee clinical trials activities within the clinics. The Centre includes a state-of-the-art clinical gait laboratory that allows for detailed investigations of both normal locomotion and of lameness in small animals. The Centre is also home to a dedicated robotic joint simulator that can be used to recreate walking patterns in dogs and other species - using this robot, it is possible to evaluate the effectiveness of new veterinary implant systems, without the need to undertake testing in animals. Current focus areas include the knee, elbow and tarsus joints in dogs.
- We have world-class clinical pathology, with purpose-built labs completed in 2014 containing state of the art equipment such as flow cytology which are used extensively both for clinical and blue-skies research.
- The Unit has a long history of clinical research in canine cancer, which is enhanced through the availability of a linear accelerator machine for research into cancer therapeutics.
- The University Farm provides a 300-ewe flock and a 180-cow dairy farm for research access. The dairy has a robotic milking parlour and a computerised recording system that has greatly assisted research on mastitis, antimicrobial resistance (**Holmes**– see impact case study), metagenomics, and the development of new anti- lameness therapeutics (**Powell**/**McCrone**).

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

Research in this Unit is enhanced by substantial intra- and extra-mural collaborations. Of the 1300 papers published by our Unit during the assessment period, over a quarter involve intra-unit collaboration. (Intra-mural and other individually driven multi-disciplinary collaborations, central to the Unit's strategy, are captured elsewhere in the document, especially under staffing). Genomics research particularly benefits from the proximity of the world class sequencing facilities. For example, the CRUK Core Genomics facility offers next generation sequencing capability (used by **Allen**, **Grant** and **Kalmar**) and the Wellcome Sanger Institute is a world leader in sequencing (used by **Murchison**, **Cantacessi**, **Holmes**, **Wood**, **Sargan**, **Parkhill** and **van Tonder**). As noted above (staffing), several researchers embed some of their research in other Cambridge departments.

In addition to engagement with the University's Strategic Research Initiatives, Networks and Centres, there is active participation in many other cross-university initiatives. **Trotter** is Director of the Cambridge-Africa Programme and, with **Wood**, she sits on the University of Cambridge–Public Health England Academic Liaison Committee. **Allen** participates in the steering committee for the Paediatric Cancer Programme, based out of the Cancer Centre at the Biomedical Campus. **Wood** chairs the West Cambridge Communications Group and sits on the West and North West Cambridge Academic Board, which are working to enhance collaboration and improve sharing of equipment and other resource around the growing West Cambridge campus. All of these roles allow key leaders to identify opportunities that exist around the Cambridge network that can be exploited in developing research activities, which contributes towards the growing levels of research grant income in the Unit.

Researchers in the Unit have extensive collaborations within the national network of veterinary institutions. **Grant** is part of the Quadram Institute's strategic research programme 'Microbes in the Food Chain', supported by the BBSRC. **Wood, Conlan** and **Parkhill** have extensive collaborations with scientists across the APHA network. Locally, there were strong and long-standing collaborations with the Animal Health Trust, especially with **Sargan** in canine genetics and **Parkhill** and Maskell in microbiology. **Wood** and **Tiley** have long standing collaborations with the Pirbright Institute in virology. **Holmes** is co-Investigator on the Antimicrobial Resistance NIHR HPRU at Imperial. **Parkhill** is co-Investigator on two NIHR HPRUs (Imperial and Warwick), which are jointly managed with PHE and **Trotter** is co-Investigator of Immunisation HPRU at LSHTM.

The Unit has had active collaborations in a number of major international programmes in Vietnam (Oxford University) and Malawi (Liverpool University), as well as with institutions linked through the Cambridge-Africa Programme, including the University of Ghana and Makerere University in Uganda. There are many other national and international, overseas collaborations that are central to individual investigators' work, including in Ethiopia, Myanmar, India and China, based around more individual collaborative approaches, for example, **Heeney** developing a trivalent Lassa, Ebola and Marburg vaccine with collaborators in Nigeria.

Since 2014, researchers from the Unit have received funding totalling £228,302 from the Cambridge-Africa Alborada Research Fund for 17 collaborative projects with researchers from Ghana, Kenya, Nigeria, Rwanda, Tanzania, Uganda and Botswana. **Weinert, Bryant, Wells** and

Tucker are playing a significant role in a 4.5-year €4.9M H2020 programme 'PIGSs', exploring *Streptococcus suis*: interactions of pathogen, host and environment. Three of our investigators have been awarded prestigious Wellcome Trust fellowships, with **Murchison** receiving an Investigator Award in 2014, **Weinert** a Sir Henry Dale Fellowship in 2015, and **Bryant** a Senior Investigator Award in 2016.

Research addressing global challenges

Many of our projects contain significant training and capacity building elements designed to increase the quantity and quality of research undertaken in partner countries. We lead two seven-year multi-funder, multi-partner Zoonoses and Emerging Livestock Systems (ZELS) programmes. Both projects are focused on achieving real local impact through a combination of research, anthropology and policy engagement. Both were awarded funded extensions to develop greater impact from the research.

- '**ETHICOBOTS**' (£3.4M) led by **Wood** and **Conlan** with partners in the UK and Ethiopia – a project focused on developing controls for animal and zoonotic bovine tuberculosis in Ethiopia;
- **Myanmar Pigs Partnership** is an integrated management-based approach for surveillance and control of zoonoses in emerging livestock systems in South East Asia, (£2M) and has been led by **Tucker** in collaboration with partners at the Institute for Development Studies, University of Oxford Clinical Research Unit, Vietnam, and Myanmar Livestock Breeding and Veterinary Department. Specifically, this explores livestock management practices in Myanmar.

- Work on bovine tuberculosis control strategies (**Wood** and **Conlan**) with ETHICOBOTS has been expanded through two awards from the Bill and Melinda Gates Foundation and DfID in collaboration with Penn State University, to extend the focus from Ethiopia to include India and specifically to develop cattle vaccination approaches.
- **NEOSTAR**, a collaborative RCUK - India DBT project (£1.35M) led by **Holmes** is investigating the contribution of antimicrobial resistance in livestock to human disease in North East India, in a joint social science and microbiology study.
- **Holmes** is also a partner in the **DETECTIVE** consortium working on transmission of AMR in China (Birmingham/Cambridge/China) (£2.68M) and the lead in a UK-China AMR Partnership Initiative investigating livestock-associated MRSA in China and the UK (£780k).

4.1 Knowledge exchange

The city of Cambridge is home to a vibrant ecosystem of SMEs and large pharmaceutical companies, and many of our researchers are engaged in active collaboration with commercial entities or in establishing spin outs from the University. For example, **Bryant** holds a **Genentech Visiting Professorship** and, from 2016-20, held a Fellowship with the **GSK Immunology Catalyst**, which embedded her within their laboratories three days per week; she maintains strong and active links with both companies. **Grant** has a researcher embedded within the GSK-supported **Tres Cantos Open Laboratory Foundation** in Spain using their high throughput screening capabilities to study enteric pathogens. **Grant, Bujdoso and Thackray** have been awarded impact acceleration funding to explore opportunities for collaboration on the safety of Black Soldier Fly larvae for food waste processing with a local start up, **Entomics** which has involved hosting researchers from the company in our laboratories. The Unit has also been successful in obtaining substantial translational funding. **Bryant** obtained awards from the Apollo Therapeutics Fund (a collaborative venture between Imperial College London, University College London, University of Cambridge and AstraZeneca, GSK, Johnson & Johnson Innovation) for the

development of selective Toll-Like Receptor 4 (TLR4) antagonists for Alzheimer's Disease. **Heeney** leads on several projects totalling £4.7M from Innovate UK and BBSRC, focused on developing and trialling a novel trivalent Ebola, Marburg and Lassa vaccine, and a further $2M from the Bill and Melinda Gates Foundation to apply similar technology for the development of a universal influenza vaccine.

Researchers act in an advisory capacity to numerous industry partners: e.g. **Cantacessi** is veterinary consultant for Bayer Animal Health and Boeringher Ingelheim Animal Health (small animal parasiticides); **Pearce** advises Vetsonic (UK) Ltd: on the development of new veterinary products, **Trotter** and **Conlan** advise Takeda Pharmaceuticals on vaccination models for norovirus, **Tucker** consults for Genus PIC and for Carthage Professional Swine Management (PSM). **Allen** leads the global canine total knee replacement for BioMedtrix (UK). Commercial sponsorship from Omeros Corporation (USA, £2.5M) also funds **Schwaeble**'s Complement laboratory.

Open data, open research

As part of our commitment to encouraging best practice in allowing research to be replicated, we ensure that full datasets are placed into the public domain and that any software developed as part of a study is deposited in standard code repositories such as GitHub. We routinely publish all mathematical and statistical models to make them available for peer-testing. There are a number of examples of research outputs returned from the Unit that promote best practice in the field, including **Parkhill**'s work on contamination of reagents in sequencing, **Conlan** on fitting dynamic models to data in bovine TB using Bayesian methods, **Frost** on developing functional molecular clock dating in phylogenies for fast evolving viruses, and **Allen** incorporating structured reviews of animal protocols as part of the manuscript review processing orthopaedic research. **Hughes** is a member of the International Harmonization of Nomenclature and Diagnostic Criteria (INHAND) working group for description of rabbit pathology lesions in a consistent and reproducible manner.

Stakeholder engagement for impact

Individuals within the Unit have wide-ranging relationships with research user stakeholders and beneficiaries. The Unit encourages and promotes membership of governmental, industry and non-governmental panels and management bodies. Collaborations with external bodies include the WHO, DHSC, Defra, EU-FMD, the European Food Safety Authority, the Food Standards Agency, industry bodies and companies, the Fleming Fund, APHA, PHE, the Roslin Institute, GO-Science, MSF, BVA, BSAVA, BEVA and the Kennel Club. As evidenced in their impact case study, **Conlan** and **Wood** have been commissioned by Defra to address specific policy-relevant questions on bovine TB control, **Wood** is a member of Defra's TB Eradication Advisory Group, sat on the panel for the Godfray review of the government's 25 Year Bovine TB Strategy and via the ETHICOBOTS collaboration interacts with policy makers in Ethiopia. **Wood** works closely with the NFU around the development of bovine TB policy and **Wood** and **Conlan** are frequent speakers at events organised by NFU and other organisations on bTB policy. In addition **Wood** has sat on a GO-Science live outbreak contingency planning exercise, chaired the Defra-Science Advisory Council sub-committee on exotic diseases, sits on the Fleming Fund Technical Advisory Group and was nominated by the Chief Veterinary Officer to join the EU Foot and Mouth Disease Standing Technical Committee. In line with the Unit's commitment to One Health focused research impact, **Jephcott**'s anthropological research on disease outbreaks of unknown origin has led to her contributing data collection tools for WHO's disease outbreak toolkit (https://www.who.int/emergencies/outbreak-toolkit). **Trotter** has continued to advise the WHO and

Gavi, the Vaccine Alliance on rabies and meningitis vaccination which has led to changes in international vaccine strategy and on outbreak response (impact case study submitted to UoA5). **Trotter**, **Conlan** and **Parkhill** advise Public Health England (PHE) on meningitis vaccination, genomics, bioinformatics, AMR and infectious diseases, through holding honorary contracts and sitting on specific advisory boards, including PHE Genomics Implementation Working Group and Department of Health Chief Medical Officer's genomics advisory panel. **Holmes** and **Parkhill** sit on the management board of a National Health Research Unit (NHRU) on Antimicrobial Resistance (based at Imperial College), and **Parkhill** is a Co-I on an NHRU in Genomics and Enabling Data based at Warwick. **Tucker** works nationally and internationally on pig health through the Food Standards Agency, sitting on its Advisory Committee on the Microbiological Safety of Food (ACMSF), as well as through Defra. The result of these has been research that has had profound policy implications globally: on the UK strategy for TB control and EU policy for antibiotic use in livestock (both impact case studies). As part of our commitment to the 3Rs for the use of animals in research, **Bujdoso** and **Thackray**'s work on transgenic fruit flies has led to the development of a low cost, fast and efficient Drosophila-based blood test to diagnose variant Creutzfeldt-Jakob disease (vCJD), which is being transferred to the APHA, and has led to an NIH grant application, through a collaboration with Colorado State University, USA, to implement a blood test for human and animal prion diseases.

We interact closely with important client/owner stakeholder groups for companion and farm animals, an approach that is promoted throughout the Unit's work wherever possible. For example, our BOAS team (**Liu, Sargan, Ladlow, Kalmar**) spent substantial time engaging with breed clubs and animal charities to raise the profile of the issue in affected breeds. This engagement also helped determine how best to deliver the results of their research in order to maximise its impact (see impact case study). This has led to the formal establishment of the University of Cambridge - Kennel Club Respiratory Function Grading Scheme and to changes in breed standards which will encourage breeders to select for healthier dogs. Similarly, the work undertaken by **Tucker** and **Maskell** in developing better diagnostics and therapeutics for pig pathogens, has been successfully implemented through well-established relationships with some of the largest pig breeders worldwide. **Allen** is a member of the Veterinary Advisory Committee for the Horserace Betting Levy Board. As evidenced in their impact case study, **Holmes**' engagement with Dairy UK and the National Milk laboratories has helped inform discussions within the industry that has led to considerable reductions in this sector's use of antibiotics. **Parkhill** and **Holmes** research involves collaboration with local and national PHE staff.

4.2 Contribution to Society and Economy

Our Unit is fully committed to supporting public engagement and outreach activities. In collaboration with the University's Office of External Affairs and Communications, research in the Unit has attracted considerable media interest, with over 2000 references to our research made by news providers worldwide since 2014 (source: Altmetrics). Particular attention has focused on research on transmissible tumours in Tasmanian devils (**Murchison**), studies of Ebola transmission and detection (**Restif**, **Jephcott** and **Wood**), work on brachycephalic dog breeds (**Sargan** and **Ladlow**), bovine TB control (**Wood** and **Conlan**) and research on antimicrobial resistance (**Holmes** and **Parkhill**), which have been featured by numerous leading news organisations, and in television news or documentary items.

Public engagement activities

Researchers are encouraged to actively engage the public with their research, supported by a central Public Engagement team. Unit researchers regularly give research talks at local schools, and the Unit hosts events and open days during the annual Cambridge Science Festival, ranging from interactive sessions on modelling disease transmission in populations to how we use molecular biology to help us understand antibiotic resistance. A citizen science research project led by **Conlan** has involved the recruitment of local schools to collect data on social networks within the school while swabbing the noses of the students to obtain isolates of *Staphylococcus aureus*. Whole genome sequencing was used to indicate whether there had been transmission of *S. aureus* between students. The students and their teachers were closely integrated into the research team to provide an exciting educational experience, with the students themselves analysing and presenting the data collected in their schools to scientists in the Unit. The complete set of data from multiple schools has provided a substantial data set helping to answer questions about likely transmission pathways and frequency of transmission events informing epidemiological models. In 2018 **Kessler** ran a nutrition workshop in the Gambia aimed at training staff and field workers of the MRC The Gambia Unit and local community members to help address nutrition deficiencies and undernutrition in populations exposed to high infection rates, and in 2019 a workshop in agriculture and nutrition for female smallholder farmers in West Kenya.

Spinout companies arising from this Unit

- **DIOSynVax** is a company specialising in novel and rapid approaches to vaccine development, led by **Heeney.** In 2020 the research switched to developing a COVID-19 vaccine during the lockdown.
- **Polypharmakos** is a collaboration between the Royal Botanic Gardens at Kew and **Holmes**, **Bryant** and **Maskell** that has raised funding for the discovery of novel antimicrobial therapies from plant extracts.
- **Waterscope** is the delivery arm of work by **Patto** and **Holmes** developing a low-cost system for determining water quality.
- **NextGen Diagnostics** is a genomics-based diagnostics company co-founded by **Parkhill** and Professor Sharon Peacock (Department of Medicine) with a US-based entrepreneur.
- **Univursa** is an early career researcher led start up that builds on the anthropological research undertaken by **Jephcott** and modelling skills of **Restif** and **Russell** to create analytic tools for rapidly detecting and diagnosing disease outbreaks, including in resource-limited and emergency settings.
- **NoBACZ Ltd** founded by Powell and colleagues in 2020 delivering metal-based, spray on antimicrobial dressings for better wound management.
- **Omeros Center for Complement and Inflammation Research (OC3IR)** established by **Schwaeble** aims to characterize further the role and response of the complement system in endothelial injury, implicated in a wide range of diseases including thrombotic microangiopathies, kidney diseases and central nervous system disorders.

Response to the COVID-19 pandemic
When normal research activity was curtailed in early 2020 members of the Unit responded to calls for help.

- We contributed RT-PCR equipment to the Lighthouse Labs.
- Members of staff were co-opted to help with Heeney's work on a COVID-19 vaccine.
- Other staff members volunteered to assist with COVID-19 testing at the Lighthouse Lab in Milton Keynes, the AstraZeneca/GlaxoSmithKline testing lab and the testing facility run within the Department of Medicine.
- Surplus PPE stocks were donated to the Dept of Medicine and a local hospice.

4.3 Contribution to sustainability of the discipline

One of our main stakeholder groups is the body of the veterinary profession in clinical practice. Staff are encouraged to join, engage with and become officers of the British Veterinary Association and its specialist divisions, including the British Small Animal Veterinary Association (BSAVA), British Cattle Veterinary Association and British Equine Veterinary Association, as well as European colleges responsible for the award of specialist qualifications (i.e. European and American Specialist Boards) leading to six staff members serving as officers for nine professional bodies including: **Watson** as honorary secretary of BSAVA (2014) and president of the Board of ECVIM (2017-19), **Williams** as a BSAVA council member 2013-19, director/trustee 2013-19 and chair (2013-16) of the Metropolitan regional committee, and sits on the BSAVA Education committee (2019-). **Wood** is publications officer at BEVA, **Hughes** is current President of the British Society of Veterinary Pathology, and member of the Royal College of Pathologists Special Advisory Committee for Veterinary Pathology and RCPath Research Committee. At the European level, **Williams** is treasurer and board member of the European College of Veterinary Clinical Pathology.

The Unit also organises continuing professional development meetings held at the Veterinary School where members of the Unit are able to present findings of research they have conducted and contributed to when describing current best veterinary clinical practice to practitioners. Since 2014, **Herrtage, Dobson, Henson, Owen, Allen, Radke, Ladlow, Freeman, Watson, Reading, Skelly** and **Holmes** have contributed to CPD events on topics including: Cushings and Addisons, canine osteoarthritis, BOAS, wound management, cardiology, evidence based veterinary medicine and small animal medicine. Our interactions with practitioners provide valuable insights into the areas of clinical research that are of greatest concern to them and their clients.

The Unit makes a considerable contribution to the management and editing of academic journals in our diverse fields of research. Some 20 Unit researchers hold editorships and editorial board memberships for over 43 journals, including Biology Letters, Equine Veterinary Journal, FEMS Pathogens and Disease, Frontiers in Veterinary Medicine, Genome Research, Immunobiology, International Journal for Parasitology, Journal of Biological Chemistry, Journal of Immunology, Journal of Orthopaedic Research, mBio, Microbes and Infection, Microbial Genomics, Parasites & Vectors, PLoS Computational Biology, PLoS Neglected Tropical Diseases, PLoS One, PLoS Pathogens, Scientific Reports and Vet Record. In addition, members of the Unit have undertaken peer review for over 280 different journals which is encouraged and recognised within the Unit. The organisation and delivery of academic conferences is another important element of sustaining a cohesive discipline. Seventeen members of the Unit have been chairs or members of organising

committees for 46 different national and international conferences over the review period, and given over 230 keynote addresses. **Conlan** and **Restif** developed and sustain an internationally recognised two-week course, teaching infectious disease dynamics as part of the annual programme of Wellcome Trust Advanced Courses. There are places for 20 individuals to attend each annual course which are consistently oversubscribed.

Membership of funding body grant awarding panels, and peer review of submitted grants represents an important contribution to the scientific community. Unit researchers serve on grant panels for the BBSRC, MRC, Horserace Betting Levy Board and the Wellcome Trust in addition to 67 other national and international funding bodies active in our disciplines. Unit researchers have also been invited to contribute to reviews of peer institutions: **Bryant** was invited to join a review of INSERM, France; **Wood** of OUCRU for the Wellcome Trust, Glasgow Vet School and veterinary research at the University of Nottingham. Within the UK, Grant sits on Quadram Institute Bioscience advisory groups, **Wood** sits on the Science Advisory Boards of the Roslin Institute and APHA and **Parkhill** is on the board of the Pasteur Institute.

4.4 Broader Indicators of Contribution

Parkhill is a Fellow of the Royal Society (2014), EMBO, the American Academy of Microbiology and the Academy of Medical Sciences and is a visiting professor at the University of Oxford and LSHTM. In 2016 **Bryant** was awarded a prestigious fellowship within the Immunology Catalyst at GSK, as well as a visiting professorship at Genentech and Fellowship of the Society of Pharmacology. Karadottir was elected as a 2014 FENS-Kavli Network of Excellence Scholar (one of 20 in Europe) and the 2015 Allen Distinguished Investigator Award in 2015 (one of five worldwide, the first time a UK scientist was selected.) Many faculty members have been awarded Fellowship of RCVS due to meritorious contribution to knowledge and practice, including **Holmes**, **Wood**, **Dobson**, **Watson** and **Herrtage**. Maskell was awarded an honorary associateship of the RCVS in **2017** for his contribution to pathogen research and animal-focused science.

In 2014 **Murchison** was awarded the Philip Leverhulme Prize in Cancer Research, UK Future Leaders in Cancer Research Prize, and British Association for Cancer Research-AstraZeneca Young Scientist Frank Rose Award. **Karadottir** won the 2015 Lister Institute Research Prize and the 2017 biennial Fabiane Carvalho Miranda International Prize for MS-related research and myelin biology. **Herrtage** won the 2018 European Board of Veterinary Specialisation Award for 'outstanding contributions to veterinary specialisation'. **Watson** won the Woodrow Award by the BSAVA in 2017 for outstanding contribution to small animal veterinary medicine, **Parkhill** was awarded the 2020 Marjory Stephenson Prize for outstanding contribution of current importance in microbiology by the Microbiology Society. Gibson won the 2018 Oman Research Award. **Thackray** won the 2018 Abcam Postdoctoral Research Prize for research above and beyond her service years. **Cantacessi** was awarded the Odile Bain Memorial Prize for excellence in Veterinary Parasitology Research.

We regularly nominate researchers for impact/public engagement awards (e.g. **Sargan** and **Ladlow**'s work on BOAS won a Vice Chancellor's Public Engagement award, whilst Dan Tucker was nominated for BBSRC innovator of the year). **Jephcott** was runner up in Cambridge Enterprise's Postdoc Business Plan Competition alongside a graduate student of **Restif**'s, Emma Glennon.

Research excellence is a key metric of success within the Unit and all of these individual awards are celebrated within the Department and are widely publicised.