Institution: University of Aberdeen

Unit of Assessment: UoA 5: Biological Sciences

Section 1. Unit context and structure, research and impact strategy

1A. UNIT STRUCTURE

This submission brings together a select group of 17 researchers (total FTE = 16.5) from the Schools of Biological Sciences (SBS) and Medicine, Medical Sciences and Nutrition (SMMSN) at the University of Aberdeen with common interests and internationally recognised expertise in aspects of systems-wide integrative physiology.

The **School of Biological Sciences (SBS)** has a broad research portfolio that incorporates theoretical, empirical and experimental studies that span from gene to global scales on animals, plants and microbes with a cross-cutting theme of understanding the biological consequences of environmental change. For UoA5, researchers are drawn from the *Integrative Physiology* research cluster, which emphasises the integrative processes and functions of organisms at all levels of structural complexity from gene to whole organism. The key research groupings include internationally recognised research on the causes and consequences of variation in animal energy expenditure (**Bize, Derous, Mitchell, Speakman**), fish immunology and physiology (**Holland, Martin, Secombes, Wang**), physiological and immunological interrelationships between parasites, pathogens and hosts (**Bowman, Sternberg**), the behavioural and evolutionary consequences of varying nutrition for individuals, populations and species (**Morimoto**) and comparative genomics of functional, behavioural and phenotypic variation (**Manfredini, Wenzel**).

The **School of Medicine, Medical Sciences and Nutrition (SMMSN)** is comprised of multiple research Institutes with cross-cutting research programmes. For UoA5, researchers are drawn from the Institute of Medical Sciences' *Infection and Immunity Programme*, with specific focus on using systems biology approaches to understand the molecular mechanisms underpinning gene expression, RNA modification and protein synthesis in eukaryotic cells (**Stansfield**), post-transcriptional control mechanisms and spliced leader trans-splicing in *C. elegans* and other parasitic nematodes (**Connolly**, **Pettit**), molecular processes in oomycete pathogens (**van West**) and host-pathogen proteome interactions (**Stead**).

Across SBS and SMMSN there are several areas of major research synergy and cross-School collaborations which have been developed through joint research grants, partnership within the BBSRC-funded *EastBio* and NERC-funded *QUADRAT* and *SUPER* Doctoral Training Partnerships (DTPs) and interactions mediated through national Research Pooling initiatives including the *Scottish Alliance for Scottish Universities Life Sciences Alliance* (SULSA) and *Marine Alliance for Science & Technology for Scotland* (MASTS). These have helped shape areas of clear research strength where we enjoy international profile for leading-edge science that is translated into applied impact. The submission includes world leaders in **animal energetics** research and **fish immunology and fish health.**

Our **Animal Energetics** grouping is at the forefront of research on animal energy balance. Animal energetics is spearheaded by Professor John **Speakman** FRS and has expanded through the REF period with the strategic recruitment of **Bize, Derous**, **Mitchell** and **Morimoto**. Their work spans from ecological studies of the role of energy balance in free-living animals, to studies of the drivers of body weight regulation, and the phenomenon of calorie restriction. They operate the largest lab facility in the world for the study of free-living energy demands using the doubly-labelled water method, which **Speakman** developed, and are the international partner of

choice for such investigations; almost half of all such studies in mammals have been performed in association with this lab. A characteristic feature of the work of the group is to generate paradigm changing ideas about energy balance and its consequences across multiple fields. These include the heat dissipation limit theory pertaining to limits on metabolic performance, the "drifty gene" hypothesis regarding body weight regulation and the "clean cupboards" hypothesis regarding calorie restrictions effects on lifespan. The reach and significance of **Speakman's** research has been recognised by him being one of only 28 scientists in the world to be simultaneously a Fellow of the Royal Society (elected 2018), the US National Academy of Sciences (elected 2020) and the Chinese National Academy (elected 2019).

There has been strategic investment in staffing around **Speakman** to both extend and expand the scope of animal energetics work: **Bize** dovetails the role of mitochondrial function and oxidative stress in metabolism and energetics in wild living birds and mammals; **Derous** works at the nexus between metabolism, environmental stress and health to identify novel health markers in marine mammals in applied veterinary contexts; **Mitchell** focusses on the relationships between energy expenditure, obesity and health in mice; and **Morimoto** examines the eco-ethological and evolutionary consequences of varying nutrition among individuals.

Our **Fish Immunology and Fish Health** research grouping, centred on the Scottish Fish Immunology Research Centre (www.abdn.ac.uk/sfirc) (directed by **Martin**) and the International Centre for Aquaculture Research and Development (www.abdn.ac.uk/icard) (directed by **Van West**) delivers leading-edge research on fish immunology in relation to fish health, vaccine research, physiology and immune system evolution. This work has contributed directly to both fundamental knowledge and applications that have positively impacted the aquaculture industry.

The group has pioneered studies on the molecular basis of fish immune responses (**Secombes, Martin, Holland**, **Wang**) and are recognised as the world leader for cytokine discovery and function, which continues now with functional annotations of the whole genomes available for multiple fish species using RNA-seq, ATAC-seq and ChiP-Seq following immune challenge. Key advances have been made in lymphocyte and leukocyte differentiation, which is central to vaccine efficacy and immunological memory. Highlights include the demonstration of IL12 as a central molecule for induction of immunological memory and IL22 as a potential marker for protective responses at mucosal surfaces (**Wang**). This knowledge gained mainly in salmonids is being transferred to other farmed fish species through our international links. The group has been the first globally to develop a gene knockdown platform for salmonid cell lines for investigation of antiviral signalling using crispr/cas9 approaches, leading to novel insights of regulatory mechanisms in species with a recent whole genome duplication. Research on the relationship between fish nutrition and systemic immune function is another core research area (**Martin, Secombes, Wang**) with novel hypothesis being tested around nutritional programming and early intestinal immune tolerance. Applied areas for health-related research include the impact on mucosal health, microbiota communities and post-smolt performance in the marine environment. To facilitate much of the basic research, state-of-the-art aquarium facilities within the zoology building contain recirculating freshwater and saltwater systems, additionally there is a pathogen challenge room where both vaccine trials and disease challenges are carried out.

Van West leads the largest research lab globally studying fish pathogenic oomycetes. A major research focus is to investigate the infection processes of oomycetes of farmed fish and shellfish, develop new ways of reducing the impact of these diseases (see impact case study) and novel immersion-based vaccination strategies of farmed fish. In 2015 the International Centre for Aquaculture Research and Development (ICARD) was strategically established (directed by **van West**) to provide a hub to facilitate interaction with the aquaculture industry. ICARD includes 25 PIs from a range of disciplines across the University including biology, medicine, economics, social science and engineering to provide a unique "farm to fork"

interdisciplinary approach to identify research questions, develop collaborations and execute research in farmed fish health, disease and nutrition.

1B. RESEARCH STRATEGY

Research activity and strategy within SBS and SMMSN Institutes is overseen by dedicated research committees comprising Directors of Research, the Heads of School, and research active staff at different stages of career including ECRs. These respective research committees meet regularly for information exchange, horizon scanning activities, and peer review grant applications and papers. There is an emphasis for promoting collaboration and innovative research ideas by distribution of discretionary research funds to pump prime emerging opportunities. Both the School Directors of Research sit on the University Research Policy Committee chaired by the University Vice Principal for Research, which is a crucial conduit for inputting into the institutional research vision and overseeing research governance and ethics procedures (section 3D).

Research Strategy REF2014 – REF2021

For REF2014, the University made a broad submission to UoA5 that included 89 FTE from three major research institutes with research centred around whole-organismal biology, medical sciences and nutrition respectively. 83% of our overall research activity and profile, 100% of our impact portfolio and 100% of our research environment was considered world leading or internationally excellent (4*/3*). Since 2014, the University has undergone major organisational and strategic restructuring with the previous College structure being replaced by an organisation structure at the level of individual Schools. This has enabled significant realignment of research focus to reflect the interdisciplinary research pillars central to the University's 20-year strategic plan (abdn.ac.uk/2040/) and around which major research investment and teaching and learning activity will be built. Reflecting this, for REF2021, the University made the strategic decision to focus our UoA5 submission around research excellence in integrative physiology, and move researchers previously submitted to REF2014 UoA5 with emphasis on clinical biomedical science into REF2021 UoA1 and others with environmental sciences profile to UoA7. This has allowed for more concerted and engineered delivery of the stated objectives for UoA5 from REF2014:

1) Integration of 'omics technologies: The Unit has traditional strength in using transcriptomic, proteomic and genomics-based approaches to characterise the immunogenome and immune response (**Bowman, Holland, Martin, Secombes, Speakman, van West**), understand the mechanics of mRNA processing in pathogenic and other nematodes (**Connolly, Pettitt, Stansfield**), identify responses of organisms to parasites and pathogens (**Bowman, Holland, Sternberg)** and monitoring physiological responses to varying calorific intake and energy expenditure (**Mitchell, Speakman, Bize**). This critical mass has been extended by the targeted recruitment of new staff into the Unit who also bring new expertise in the use of multi 'omics approaches and bioinformatic analyses in the context of nutritional intake (**Derous**), social behaviour (**Manfredini**) and genotype-phenotypic interaction (**Wenzel**).

The Unit's capacity for developing and exploiting 'omics approaches has been further enabled by continued investment in the University's Centre for Genome Enabled Biology and Medicine (www.abdn.ac.uk/genomics). This offers the research infrastructure and bioinformatics support to facilitate leading edge research across a broad taxonomic range of animal, plant and microbial systems. There has been targeted investment around emerging single cell genomic and transcriptomic analyses and third generation DNA sequencing technologies to ensure that the latest approaches for leveraging 'omics data are available. In parallel, there has been

focussed investment in the University Proteomics facility (led by **Stead**). To maximize the use of 'omics technology and ensure staff obtain maximum benefit from facilities, regular workshops and technology roadshows are run to provide upskilling opportunities and training for staff. Pump-priming financial support for researchers to kick-start genomic analysis is available and has been used by Unit staff to generate whole genome sequences and other genomic resources that underpin subsequent larger grant applications (e.g. Wenzel's work supported by BBRSC on the genomics of enigmatic slime moulds).

2) Bioinformatic, quantitative and modelling capacity: the unit recognises that the rate at which 'omics data can be generated is far greater than the capacity to analyse it to leverage biologically meaningful insight. As such, the unit has invested to enhance our bioinformatic and analytical capability. We strategically recruited bioinformaticians during the REF period (**Manfredini** and **Wenzel**) with focus on expertise that encompasses both model- and non-model species systems and experience of dovetailing bioinformatics with statistics and complex predictive models. Moreover, there has been a major upgrade our high-performance computing capacity (see section 3C) and staff training opportunities to underpin the move towards big data analytics.

Research Strategy REF2021 ONWARDS

The research strategy is centred on enhancing research grant income, research student numbers, publication citations, facilities and partnerships and international collaboration. There are several cross-cutting objectives that underpin our strategic research moving forward:

1) Interdisciplinarity: The University's new 20-year strategic plan (www.abdn.ac.uk/2040) identifies challenge-led, interdisciplinary research as central to our ambition. Both fundamental discovery research and pathways to impact demand interdisciplinary solutions that will emerge from broad collaborations, increasingly with the dovetailing of social science perspectives. This activity will gain added impetus through the University-prioritised *Health, Nutrition & Wellbeing*, *Data & Artificial Intelligence* and *Environment & Biodiversity* interdisciplinary themes, which will provide a springboard through which different disciplines can integrate to magnify their impact and generate new synergies. In the context of UoA5, these themes provide a nexus for combining food security, aquaculture, obesity, genomics and disease mitigation aspects of our research portfolio.

2) Translational research and pathways to impact: The Unit enjoys close interrelationships with a range of government, industry and other stake-holder groups through which we identify research needs, forge collaboration, translate our research and leverage influence and impact. Our strategy is to consolidate existing partnerships and exploit new collaborative opportunities. This is being mediated through initiatives such as ICARD that provides an interface between the aquaculture industry and university academics. This momentum will be further enhanced through the University interdisciplinary themes which offer a vehicle for dialogue between science and end-users to identify and address relevant questions, and translate science to deliver real economic and societal impact. We will also develop closer links through our existing DTP collaborations and interactions, using student training and placement as a conduit to closer research links.

3) Capacity building: We will continue to place people at the heart of our strategy, ensuring that our newly appointed staff have the support to build collaborative networks, focus their research around leading edge questions linked to societally relevant issues, secure research funding and effectively translate research to impact. We will look to build on our existing DTP and EU ITN networks to forge new collaborations to provide more critical mass around key research

challenges. We will also continue our tradition of attracting and supporting independent research fellows who align with existing research strengths and where we can develop careers.

4) Robust, reproducible and open research: The Unit's research and impact strategies are directed to all aspects of research integrity and governance, transparent, robust and reproducible research practice and open data and publication. This enables the delivery of the highest quality research, maximises dissemination of research findings to facilitate both academic and non-academic impact, and leverages future collaboration and interaction. We will continue to ensure that all our research practice conforms to the policies and practices laid down in the University's *Research Governance Framework* that itself complies with Universities UK *Concordat to Support Research Integrity* and the UK Research Integrity Office *Code of Practice* (section 3D).

1C. IMPACT STRATEGY

Translating research excellence into non-academic impact is central to the Unit's research strategy. The two impact case studies within this submission exemplify the type of translational research activity undertaken and illustrate the Unit's impact strategy in practice. These, however, represent only a portion of our activity that is benefitting the awareness, attitude, behaviour, policy, process and understanding of various end-user groups, from local community to government and industry.

Other examples of ongoing research that is having positive impacts across a range of REF-defined areas, but are not yet fully realised for a formal impact case study include:

Martin's research developing functional fish feeds used by the aquaculture industry. These are more sustainable than traditional fish feeds based on marine sourced protein and exploit alternative raw materials. These diets are also designed to improve fish health via nutrition and enhanced immune function, improving robustness of the fish at critical life history stages. Working with industrial multinational feed manufacturer partners (e.g. Alltech, BioMar, Skretting, Cargill, Mowi) functional feeds have been developed for reduced sea lice burden, recovery following viral infection, improved antiviral responses and enhanced immunological memory for vaccines. Ongoing research is focussing on the emerging theory of nutritional programming and how first feeding diets can impact growth efficiency during later life.

Bowman's work on honey-bee health focuses on control strategies for the main global pest of the bees and cause of colony collapse, the Varroa destructor mite and the associated deformed wing virus. Research involves parallel strands that include: 1) gene knockdowns to identify druggable targets in varroa. One target (Target-VX) that now underpins patent applications (WO2015001336A2 & WO2016110691A1) is susceptible to repurposed human pharmaceuticals causing >95% varroa mortality within two days but is benign to bees. Further, a low cost health food supplement kills varroa via Target-VX that is safe for humans, bees and the environment so is a stand-out treatment for the beekeeping community; 2) specific volatile kairomone ("smell") profiles from bee larvae are required to induce varroa egg laying and that these can be artificially manipulated in hives to induce inappropriate varroa egg production. This innovative intervention is now being used in bee breeding programmes across multiple countries.

Sternberg's research on protozoal disease and vector exposure immunodiagnostics has led to translational validation studies of novel rapid diagnostic tests for Human African Trypanosomiasis (HAT). The work carried out with the Foundation for Innovative New Diagnostics demonstrated the sensitivity and specificity of the "SD Bioline HAT" rapid test (https://www.finddx.org/pricing/sd-bioline-hat/) that is now being used as a first line diagnostic screen in West Africa. Following similar immunodiagostic approaches to vector challenge as

public and animal health surveillance tools in the control of South American trypanosomiasis (Chagas disease).

Our strategy to maximise impact is structured around the following routes:

1) Maintaining and enhancing our high-quality research portfolio addressing key societal issues and industry needs: Our long-term interactions with a range of non-academic partners ensures that our research activity aligns with industry needs, and recursive interaction is enabled through research interactions mediated through initiatives such as ICARD. In 2019, a major University-wide research mapping exercise used machine-learning approaches to align all the University research outputs within the REF period to UN Sustainable Development Goals to broker inter-, multi- and transdisciplinary collaboration that were previously refractory. This is being used to coordinate researchers across disciplines and provide horizon-scanning capability for emerging research opportunities that ensures that research emphasis is underpinned by societal need. This activity is helping consolidate the "farm-to-fork" multidisciplinary research approach of ICARD by identifying new collaboration with social scientists and law.

2) Researcher training: Impact training is embedded in staff development programmes for researchers at all levels. A Researcher Development Unit provides tailored training for staff on how to consider and deliver impact from development through execution of a project. It provides workshops and networking opportunities across disciplines with focus on knowledge exchange, communicating research to the public, interacting with end-users, entrepreneurship and research commercialisation.

3) Engagement with stake-holder and decision making groups: The Unit recognises that impact is maximised through effective and recursive interaction with key end-user groups. This ensures that the research being undertaken is relevant to address stake-holder needs, and that Unit staff are positioned to influence research priorities and future research agendas. In many cases our relationships with end-users are based upon successful, long-term interactions. Strategic initiatives such as SFIRC/ICARD have been established to maximise communication, where research has industry links. We ensure relationships are maintained by inclusion of end-users in student supervision and as collaborators on research grants, by researcher and student placement in end-user organisations, and by funding research showcasing events, meet-and-greet sessions and workshops relevant to policy makers and practitioners. We support staff to participate in Boards, Committee and Advisory Groups where there are clear opportunities for end-user engagement and to leverage impact (see section 4).

4) Knowledge exchange and public engagement: The unit is supported by: (i) a Public Engagement in Research Unit (PERU) which has a remit to promote and implement an active researcher-led public engagement programme. Unit staff exploit local, national and international opportunities to disseminate results and impact. Our efforts in this area have been recognised through awards to staff such as **Pettitt's** Genetics Society JBS Haldane Prize Lecture award (2020), which *"recognises an individual for outstanding ability to communicate topical subjects in genetics research, widely interpreted, to an interested lay audience";* (ii) A dedicated Knowledge Exchange and Transfer Fund to promote impact and KE and pump-prime projects that enhance relationships with industry, public or third sector partners. Unit staff have benefitted from >GBP20K support from this fund which has helped develop two patents (to **van West** and **Stansfield**) and nine disclosures (including **Bowman, Dooley, van West, Pettitt, Secombes** and **Wang**) (iii) a dedicated Communications Team (CT) which forms the critical link between researchers and the public through local, national, specialist and international media. The CT issues ~ 400 press releases a year, in addition to regularly placing stories with key media, and identifying researchers for expert comment. Key examples where the CT has enabled worldwide exposure for high impact research include **Bowman's** work on the effects of varroa destructor

mites for vectoring deformed wing virus in honeybees and subsequent colony collapse. This research has featured in over 40 popular science and newspaper articles, six television interviews, nine radio interviews and a significant social media footprint.

5) Exploitation of commercialisation potential: The Unit is supported by a Research and Innovation (R&I) team (www.abdn.ac.uk/business-info/research-innovation/) of business development and commercialisation professionals who help translate research excellence into commercial application and knowledge transfer activities. There are dedicated R&I staff in Schools to ensure the most appropriate routes to impact are identified and exploited. They help develop a researcher's Pathways to Impact plans and provide administrative and logistical support to ensure its implementation, which includes protection of intellectual property, patent application and spin-out companies. As examples, R&I supported all aspects of translational aspects of **Bowman's** research on the control Varroa mite infestation in bees that has led to two patents being filed (WO2015001336A2 and WO2016110691A1). R&I also coordinated the commercialisation of **Secombes's** fish immunology research through the spin-out of Vertebrate Antibodies Ltd (VAL) that develops antibodies, recombinant proteins and AI approaches for epitope targeting to key protein targets for use in immunoassays.

Section 2. People

2A. STAFFING STRATEGY AND STAFF DEVELOPMENT

The REF period has seen focussed appointment of staff that are aligned with research priorities and strategy (section 1). Our recruitment policy has been to target early career researchers on an upward trajectory towards becoming future research group leaders. This is coupled with a strong commitment to the development, training and mentoring of researchers at every stage of their career. Underpinning all this is ensuring we nurture and maintain an environment that promotes opportunity, equality, diversity and inclusion.

SBS has recently undergone a major recruitment campaign involving six new lectureship positions, and eight *Academic Fellowship* positions. Two are directly aligned with UoA5 research strengths, including lectureships in fish immunology (**Holland**) and functional genomics (**Manfredini**). Our *Academic Fellowship* initiative is to support early career postdoctoral researchers transition into faculty positions aligned with current research strengths. These positions mirror research fellowship schemes offered by UKRI, providing the support yet academic freedom for the Fellows to undertake independent research and develop their own research groups, with proleptic appointment onto academic staff. Submitted to this Unit are **Derous**, **Morimoto** and **Wenzel**.

All new academic staff prepare a three-year plan of objectives with an assigned mentor, which is reviewed annually and forms part of a 36-month probation. Staff identify training needs from the outset, and these are filled through the course of probation. New staff are given lighter teaching and administration loads to allow them to establish their research groups. They are also provided with dedicated laboratory space and start-up funds to pump-prime applications and develop research networks. All new start staff are prioritised for a PhD student within their first year via one of our DTP or directed studentship schemes.

All staff have an assigned Academic Line Manager (ALM) who coordinates an annual appraisal. This exercise provides opportunities for staff to reflect of research activity over the previous 12 months, identify impediments to progress and consider target setting for the coming year. It also strategically informs research, teaching and administration loads and identifies requirements and opportunities for staff development for which there is a dedicated budget. A Framework for

Academic Expectation model is provided to enable staff to benchmark their research activity and performance with colleagues, and shape equity in teaching and administrative loads for different stages of career.

The recruitment of independent research fellows (IRF) is a key part of our research strategy. There is an established framework for mentoring postdoctoral staff and we offer an application development and mentoring programme for potential fellowship applicants that involves a "traffic light" system to ensure individuals are directed to appropriate funding opportunities and provided with bespoke support for application and career development. Over the REF period we have hosted a number of highly prestigious independent fellows across various schemes funded by Royal Society, NERC, EU (Marie Curie) and Wellcome Trust. **Wang** is an example of support for independent ECR via an industrial route, part-supported by Vertebrate Antibodies Limited.

The University is a signatory of the *Researcher Development Concordat* with an action plan to address the principles and obligations around research environment and culture, employment practices and professional and career development policy and practice for research staff. Our approach for the transparent and robust assessment of research quality for any and all purposes is compliant with the principles and practices that laid down within the San Francisco Declaration on Research Assessment (DORA), of which the University is a signatory, and the Leiden Manifesto. As such no reference to citation metrics or impact factor are included in job application review, promotion documentation or annual review and appraisal.

We retain a number of Teaching & Scholarship lectureships to strategic areas. These positions are not intended for research active staff but enhance our research activity by freeing up time to enable high profile researchers to maximise research application, output and impact. The success of this strategy is evidenced by three members of SBS academic staff with long-term reduced teaching loads being awarded major academic honours, most notably **Speakman** being elected as a Fellow of the Royal Society of London, US National Academy of Sciences and the Chinese National Academy during the past REF period.

All research staff are supported through the **Aberdeen Grants Academy** (AGA) during all stages of a research grant life cycle. The Grants Academy is run by a team of business development and commercialisation professionals whose role is to flag new funding opportunities for staff, stimulate discussion and generate new ideas for grant applications through meetings such as the *Conversations on…* sandpit meetings and *Grant Foundry* events, offer training in effective grant writing, support in the development of grant applications, organise internal peer-review of applications, provide interview preparation where required, develop open data management plans, facilitate the effective translation of research excellence into non-academic impact, and enable knowledge transfer activities, patent application and spin-out companies. AGA also manages several internal funds to pump-prime research and knowledge exchange activities associated with GCRF applications, the Wellcome Trust Institutional Strategic Support Fund, a core facilities voucher scheme, and a Research Enhancement Scheme for external grant applications that were highly graded by funding panels but remained unfunded, and where specific improvement can be targeted prior to resubmission. These have provided support of over GBP55K to Unit staff during the REF period.

2B. SUPPORT TRAINING AND SUPERVISION OF PhD STUDENTS.

The training and development of PhD students is a fundamental component of our research strategy. The 17 staff submitted to UoA5 supervised a total of 83 FTE students since 2014. The Unit is a partner in three UKRI doctoral training partnerships (DTP) and two Centres for Doctoral Training (CDT). The BBSRC EastBio DTP is a partnership between the Universities of

Aberdeen, Dundee, Edinburgh, St Andrews and Stirling, delivering doctoral training across the biosciences. EastBio-DTP (originally devised and led by **Connolly**) supports 60 studentships per year and is now in its third cycle of funding after renewal in 2015 and 2019, which is a testament to the high quality of training delivered. The NERC funded QUADRAT-DTP is a new partnership between University of Aberdeen and Queen's University Belfast supporting 20 students per year for five years in the areas of environmental and natural sciences. This provides a major impetus for collaboration and a cross-School cohort of students providing critical mass in interdisciplinary research. The NERC funded SUPER-DTP involves eight Scottish University partners, with a research focus on the broad themes of environmental dynamics, biodiversity and challenged ecosystems.

We also recruit students through joint funded strategic partnerships such as with Marine Scotland Science (MarCRF), Scottish Aquaculture Innovation Centre (SAIC; www.sustainableaquaculture.com/) and through Scottish Government research pooling initiatives including Marine Alliance for Science and Technology Scotland (MASTS; www.masts.ac.uk) and Scottish Universities Life Science Alliance (SULSA; www.sulsa.ac.uk). The University has improved the international reach of its PGR programme with its *Elphinstone Scholarship* initiative, which provides a full international tuition fee waiver to allow the best students from across the world to train at the University. SBS and SMMS also support industrial funded PhD studentships using various models for co-funding. These have been especially productive for enabling collaboration with the aquaculture sector, with companies including BioMar, Skretting, Mowi, Alltech, Elanco, Cargill, Scottish Sea Farms and Xelect all co-funding at least one studentship during the REF period.

The University Graduate School oversees all aspects of PhD student appointments, training and monitoring of progress. Candidates are selected based on strict criteria that include the academic calibre of the student, motivation and potential ability to complete a PhD programme and engage as part of a broader postgraduate cohort. Each student has a minimum of two supervisors, and an advisor to provide independent advice. Supervisors must undertake training on effective supervision, and hold weekly formal meetings with students. Student progress is monitored through six-monthly reviews, which provides an opportunity for students to reflect on achievement and map out future plans. These are reviewed by the School Postgraduate Officer and the Graduate School. A formal 9-month review of student progress is made by written report, oral presentation and a viva with two members of staff. Students may be confirmed for entry into year two, recommended for a remedial programme of work or halted from progression. In year 2 students submit a written report in the form of a draft manuscript and present a poster at an internal "Research Day". In year 3 students give a longer oral presentation at an annual postgraduate symposium run within each School. At 27 months students submit a thesis plan and progress is reviewed until completion. The success of our training environment is evidenced in our thesis submission rate of 94% for the REF period.

All PhD students follow a "T-shaped" training model, whereby they develop disciplinary excellence around a specific research project but also gain a breadth of knowledge and a diverse, transferable core and generic skills base to ensure that they graduate with a broad outlook and are competitive for a range of different career paths. Development of research and transferable core skills are defined in a student's *Personal Development Plan*. Mandatory training courses include an induction workshop on scientific conduct, research ethics and governance, health and safety, project design, scientific writing, data handling, statistics, presentation skills, entrepreneurship and knowledge exchange. Central to training is the provision of non-academic placement experience for students. This is a formal part of training across the DTPs and involves a 3 month secondment with a research partner not directly associated with the student's project. This provides students with an opportunity to develop skills and experience away from an academic environment. We also provide *Research Experience Placements* for undergraduate students from STEM subjects outwith biological sciences as part of our DTPs to facilitate multidisciplinary interaction and widen participation.

An integral part of our PhD student DTP training is around professional development, leading to a Chartered Management Institute (CMI) level 7 Certificate in Strategic Management and Leadership (QUADRAT DTP) or a PG Certificate in Researcher Professional Development (SUPER DTP). We encourage all students to gain professional accreditation where appropriate (e.g. Royal Society of Biology, associate fellowship status with Advance HE); present and discuss their research at international conferences; participate in internal and external seminar series; lead journal clubs and research discussion groups. This is exemplified by the *Aberdeen Study Group*, a student organised and student-led network who interact to share and develop coding skills (R, Python, Perl) and facilitate co-working.

2C. HOW THE UNIT SUPPORTS AND PROMOTES EQUALITY, DIVERSITY AND INCLUSION

Inclusivity is central to the University's 2040 strategy (www.abdn.ac.uk/2040), and the promotion of equality, diversity and inclusion remains core to the activity and strategy of the Unit. Schools have an Equality, Diversity & Inclusion committee, and a separate Athena Swan committee leading the Schools' next stage of accreditation from current bronze status. All staff and students undertake EDI training and refresher exercises. We blend formal accreditation with informal approaches to raising awareness and providing support around EDI issues. This has been informed by a series of staff surveys that consider how policy and practice could be improved. Input has led to changes in working practice that include: gender-balanced interview panels for all appointments at any level; inclusion of an EDI question as part of the interview process; including a male and female point of contact for any job adverts; policy that meetings, seminars and events occur within core working hours of 10:00-16:00; gender balanced seminar speaker programmes; monitoring and adjustment of all electronic and printed material for gender balance and ethnic diversity; family-friendly social events; encouraging ECRs to join and lead administrative and strategic committees; increased awareness of bullying and harassment procedures; formation of networking groups for LGBTQ+, female, early-career and BAME staff.

Staff returning from periods of leave, including parental leave or other caring responsibilities, or after long-term ill health attend a 'return meeting' with their line manager to aid the return to work process. Long term ill health effects are managed with the help of occupational or reasonable adjustments, for example phased return, altered start and/or finish times or a period of homeworking. To help staff with disabilities the University is committed to making a wide range of adjustments, including for example flexible working and workplace adjustments.

The University has a dedicated Health, Safety and Wellbeing Committee and have put in place a range of policies and practices to support the wellbeing of staff. These include: mandatory health, safety and wellbeing training for all staff and postgraduate students; a commitment to consider proposals from staff to switch to flexible working and job sharing; an annual leave purchase scheme, allowing up to two weeks additional leave to be secured; wellbeing coordinators and mental health champions within Schools; mental health first aid and mental health awareness training for staff; mental health support services; and free off-peak membership at Aberdeen Sports Village. Supervisors are encouraged to foster supportive relationships whereby they can offer both academic and pastoral support, including directing students to central-level support if needed.

Section 3. Income, infrastructure and facilities

3A. INCOME

Staff submitted to this UoA have generated over GBP26.5M in research incomeduring the REF period. This has been awarded from a diverse range of funding agencies reflecting ability to

attract funds that cut across conventional discipline boundaries, with ca. 38.% coming from UKRI and 23% from industry.

Internationalisation and collaboration are key strategic priorities and we have prioritised expansion of our international collaborations during the REF period. This has resulted in more than GBP2.1M of new international funding via EU H2020 collaborations centred around **Bowman's** work on bee health and tick-borne infections (totalling GBP518K) and **Martin's** and **van West's** work on fish health (totalling GBP1.6M). These projects involve over 20 EU countries and Norway. Staff are also engaged in multiple UKRI networking partnerships, including Canada, India and China (**Martin**) and Brazil (**Morimoto**).

3B. INSTITUTIONAL INFRASTRUCTURE

The University provides support for researchers at all stages of the research process:

The *Aberdeen Grants Academy* (AGA) provides support developing research ideas and identifying funding opportunities. This is facilitated through the *Grants Foundry* programmes run within Schools where staff are invited to present nascent research ideas to help hone experimental design, identify collaboration and recognise appropriate sources of funding.

The *Research Financial Services* (RFS) team then undertakes project finance planning with the *Research & Innovation* (R&I; www.abdn.ac.uk/business-info/research-innovation/) team supporting grant review and submission, formation of collaboration agreements, development of pathways to impact plans, creation and protection of intellectual property and patent application.

The *Public Engagement with Research Unit* (PERU) coordinates downstream knowledge exchange and public engagement. This includes the University *Communications Team* (CT) which forms the critical link between researchers and public through local, national, specialist and international media. CT issues ~ 400 press releases a year, in addition to regularly placing stories with key media, and identifying researchers for expert comment.

IT services support all aspects of research data management and archiving, with 2TB being automatically provided for all staff and individual projects. The *Library, Special Collections and Museums* directorate coordinates aspects of Open Research, running the Aberdeen University Research Archive (*AURA*), our open access repository for data, plus coordinating green or gold route open access for publications (section 3D).

3C. FACILITIES

The University provides world class core analytical facilities for researchers, organised through a suite of **Technology Hubs**. Each hub is managed by an experienced facility manager partnered with an academic to interface with internal and external users, and provides research advice, training, support and service delivery around key areas. Equipment upgrade and renewal is delivered through a combination of external grant funding and institutional support. The genomics, cytometry, chromatography/spectrometry, microscopy/histology, proteomics and antibody/peptide library screening technology hubs (see below) are key elements in delivering the Unit's research strategy, and these have seen overall investment in infrastructure and facilities of over GBP7M since REF2014.

Genomics research is supported through the Centre for Genome Enabled Biology and Medicine (CGEBM; www.abdn.ac.uk/genomics). This has seen major investment in staff to

provide increased bioinformatics capacity, and updated/expanded multi-'omics hardware, which includes Illumina MiSeq, NextSeq500, Ion Torrent proton and Oxford Nanopore GridION sequencers and a 10x Genomics Chromium system for single cell sequencing applications. To support increased bioinformatics and biostatistical analysis there has also been an upgrade of the Maxwell high-performance computing cluster, giving researchers access to 1240 CPU cores, 12TB of RAM and 1PB of storage.

The **Cytometry** technology hub provides a range of Becton Dickinson and Attune NxT cytometers and a BD Influx cytometric cell sorter, a BioPlex 200 for multiplex bead analysis, and an Image Stream for single cell image cytometry (which is one of only two in Scotland).

The **Microscopy and Histology** technology hub delivers confocal laser scanning microscopy; LSM 880 with Airyscan LSM170 confocal, and a spinning disk, UltraVIEW 3D live cell imaging system, a range of fluorescent upright and invert microscopes, with JEOL transmission and Zeiss scanning electron microscopes, plus Skyscan 1072 and Nikon XT225ST Computed Tomography systems. Recent investment has delivered a Carl Zeiss GeminiSEM 300 high resolution Field Emission Scanning Electron Microscope (FESEM) with secondary electron, backscattered electron and cathodoluminescence detectors.

The **Proteomics/Mass Spectrometry** hub has available a range of ICP-MS, LC-ICP-MS. Routine techniques including MPOES, FAAS, HG-AAS, FIA, GC-FID/ECD and TOC are available as is a field deployable field Picarro. Recent investments in analysis include a quadrupole-Orbitrap Thermo Scientific Q Exactive tandem mass spectrometry system, a mass spectrometer for stable isotope ratio measurements, MALDI Imaging Mass Spectrometer, and Biacore SPR. These are supplemented with automated sample digestion units.

Other facilities supporting research across the Unit include the Scottish Biologics Facility, providing antibody and peptide library screening services; and the Medical Research Facility, providing a rodent and Xenopus model organism facility. We also have outstanding aquarium facilities following a GBP1.5M refurbishment that includes freshwater and seawater systems, a separate biosecure freshwater pathogen challenge facility and isolated zebrafish tanks for use with GM models.

The University has invested GBP38 million in a state-of-the-art *Science Teaching Hub* facility (opening Spring 2022) where there will be a consolidation of all science laboratory classes. While this will mainly be for teaching and learning, the ground floor of this building will be a dedicated space for public engagement and science outreach. It will also offer a unique space for research skills training for both staff and PGR students. This facility will also enable focussed investment to transform previous teaching and learning laboratory spaces dispersed across Schools into multiple group occupancy laboratory space designed and fitted for specific research activities/sub-disciplines. This will future-proof research needs aligned with current strategic research priorities, enhance capacity, widen applications, upskill the technical and research teams and activate new multidisciplinary collaborations.

3D. RESEARCH INTEGRITY AND GOVERNANCE, UNDERPINNING ROBUST, REPRODUCIBLE AND OPEN SCIENCE

The University's *Research Governance Framework* underpins all aspects of research integrity and governance, robust and reproducible research practice and open data and publication. This framework complies with standards and practices set out in Universities UK *Concordat to Support Research Integrity* and the UK Research Integrity Office (UKRIO) *Code of Practice* to

deliver the highest standards of excellence, honesty, integrity, rigour, transparency, accountability, care and respect and foster both disciplinary and interdisciplinary approaches.

The University's Research Policy Committee (RPC), chaired by the Vice Principal for Research, has overarching responsibility for ensuring rigour and consistency in our research ethics and governance arrangements, which reports upwards to University senior management and Court. There are clear mechanisms in place to monitor research governance practice involving independent scrutiny and assessment by the University Deans and Vice-Principle for Research. An annual exercise is also undertaken whereby the data provenance of a random selection of publications is verified by research Directors.

Research involving animals is governed by the Advisory Group to the Establishment Licence Holder and the Animal Welfare and Ethical Review Body (AWERB) which carries out robust ethical review on all research proposals submitted to the Home Office as part of personal and project licence application. There is a Biological Safety Committee that oversees research using genetic modification and wild-type organisms, a separate ethics committee for research involving interaction with the public and external bodies through questionnaires, and a Nagoya Protocol oversight group to ensure compliance around any biodiscovery activity.

The University recognises the importance of open research, incorporating the FAIR (Findability, Accessibility, Interoperability, and Reusability) principles which are being applied to *Open Access*, *Data* and *Platforms/Tools*. The University has a policy for Research Data Management and all PIs include a data management plan in research proposals. We comply with the UKRI open data mandate as described in the *Concordat for Open Data* and deposit all data and metadata into EIDC, BODC and relevant online repositories such as Genbank, Array Express and Ensemble. The Unit supports and encourages publication of R Markdown, PERL and Python scripts via DRYAD, *figshare*, GitHub and equivalent open repositories. These open data resources are all mirrored on the Aberdeen University Research Archive (AURA) our Institutional open access repository managed by the *Library, Special Collections and Museums* directorate. Unit staff have published 115 datasets on AURA since 2014.

The strategic use of the UKRI/Wellcome block grant enables gold-route publication of high-impact publications with green-route publication for all other manuscripts. The Unit supports and encourages pre-print submission onto BioRXiv.

Training is undertaken for all aspects of research ethics, open research and research integrity and governance that is mandatory for tenured staff and part of the induction activity for new start researchers. This training is also embedded within the core and generic training modules for PhD students within the Quadrat and EastBio DTP.

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

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

4A. COLLABORATION

We have an outstanding track-record of international and national collaboration. Since 2014 successful collaboration (defined as joint peer-reviewed scientific papers, joint doctoral student supervision and joint active grants) by the 17 staff has involved over 900 different external research institutions across industry, universities and governmental organisations). Our sustained interactions with salmon aquaculture industry partners ensures our collaborations delivers major economic benefit. This is exemplified by the impact case study by **van West** where industry partners detail annual cost savings of >GBP1M through reduced salmon loss with control the *Saprolegnia* pathogen.

In many cases our relationships with end-users are based upon successful, long-term interactions (e.g. Marine Scotland Science (MSS), Centre for Environment, Fisheries and Aquaculture Science (CEFAS), Scottish Salmon Producers Organisation). We ensure relationships are maintained by staff involvement in science advisory boards (section 4C); inclusion of end-users in student supervision and as collaborators on research grants; by researcher placement in end-user organisations; and by funding research showcasing events, and workshops relevant to industry, policy makers and practitioners.

Collaborator networks and multidisciplinary research activity are enhanced through Scottish Research Pooling initiatives including the Scottish Universities Life Sciences Alliance (SULSA) and Marine Alliance for Science & Technology for Scotland (MASTS), and doctoral training partnerships (BBSRC EastBio, NERC SUPER, NERC QUADRAT). These fold in 11 HEI and 27 non-HEI partners.

Examples of long-term strategic partnerships include those with the Chinese Academy of Science (CAS), with **Speakman** being seconded part time to work at the Institute of Genetics and Developmental biology in Beijing, and the Shenzhen Institute of Advanced Technology. This has led to multiple collaborations between CAS and University of Aberdeen, and a formal agreement to establish a dual degree programme for PhD students. **Secombes** has long term collaborations with CAS Institute of Hydrobiology in Wuhan and is currently honorary associate Professor at Universities of Qingdao Agricultural University, Shanghai Ocean University and Fujian Agriculture and Forestry University. **Secombes** and **Martin** also have strong links through British Council with University of Veterinary and Animal Sciences, Lahore University, Pakistan and Kerala University of Fisheries and Ocean Studies, Kerala, India.

4B. AWARDS

The reach and significance of **Speakman's** research has been recognised by a series of high-profile awards. He was elected Fellow of the Royal Society (2018), the US National Academy of Sciences (2020) and the Chinese National Academy (2019) and is now only one of 28 scientists globally who simultaneously hold fellowships for UK, US and Chinese National Academies. He was the first Briton to win the Chinese Academy of Sciences International Collaboration award (2015), and the first non-Chinese recipient of a Novonordisk 'Great Wall' professorship. He has won several international awards including the Scholander-Irving prize and the Osborne-Mendel prize by the American Nutrition Society.

Other awards for the Unit include Fellowship of the Royal Society of Edinburgh (**van West**); Royal Statistical Society (**Derous**, **Morimoto**, **Speakman**); Linnean Society (**Morimoto**); Royal Society of Arts (**Morimoto**); Royal Entomological Society (**Morimoto**); Genetics Society (**Petitt** as Honorary Secretary).

4C. SCIENTIFIC ADVISORY ROLES

A key indicator of the wider influence of our research is the range of key science advisory roles held by Unit staff. Selected examples include: Scientific Panel of the CNRS Hubert Curien Pluridisciplinary Institute (**Bize**); Scottish Government Varroa working group (**Bowman**); BBSRC/NERC Aquaculture Research Hub UK (**Martin**); IAEA scientific advisory panel (**Speakman**); BBSRC Network in Biotech and Bioengineering (**Stansfield**); International Commission on Trichinellosis (**Connolly**)

4D. PEER REVIEW

Participation in the scientific peer review process is an expectation of all staff, with involvement reflecting experience. Several staff have chaired or participated on major national and international grant award committees, including Norway – Norwegian Research Council (**Bowman, Martin, Van West**); Canada - Genome Canada (**Bowman, Martin**); Romania - Executive Agency for Research, Development and Innovation (**Bowman**); Chile - Concurso de Proyectos (**Martin**); France **-** Appel à projets générique (**Martin**); Germany - Deutsche Forschungsgemeinschaft (**Pettitt**); Austria - FWF der Wissenschaftsfonds (**Martin**); EU - Scientific Expert Panel (**Martin**); Portugal **-** Animal and Veterinary Sciences and Agro-Food Biotechnology Evaluation Panel (**Martin**); Poland - Innovation in Politics Institute (**Morimoto**); **UK** - Royal Society (**Speakman**); Royal Society of Edinburgh (**Speakman**); BBSRC (**Speakman, Stansfield**); British Ecological Society (**Wenzel**).

4E. EDITORIAL ROLES

Staff are encouraged and supported to be editors of journals. These include *Science* (**Speakman**), *Frontiers in Ecology & Evolution* (**Bize, Morimoto**), *Frontiers in Immunology* (**Martin**), *Genes* (**Martin**), *Brazilian Journal of Entomology* (**Morimoto**), *Insects* (**Morimoto, Wenzel**), *Neotropical Entomology* (**Morimoto**), *Fish & Shellfish Immunology* (**Secombes**).

Similarly, staff are actively engaged in editorial review boards of international journals including *Parasitology* (**Bowman**), *Frontiers in Immunology* (**Holland**), *Frontiers in Physiology* (**Derous**), *Journal of Comparative Physiology* (**Speakman**); *Biology Letters* (**Speakman**); *Molecular Metabolism* (founding board member) (**Speakman**); *Journal of Genetics and Genomics* (**Speakman**); *Physiological and Biochemical Zoology* (**Speakman**); *Annals of Human Genetics* (**Speakman**); *International Journal of Obesity* (**Speakman**); *Life Science* (**Speakman**); *Philosophical transactions of the Royal Society* (**Speakman**).

4F. CONFERENCE ORGANISATION

To promote collaboration staff have been involved in the organisation of major international conferences including Society of Experimental Biology (**Derous**), EAFP International Conference (**Holland**), Mucosal Health in Aquaculture (**Martin**), International Congress on Integrative Salmonid Biology (**Martin**), Translation UK (**Stansfield**), International Society of Fish and Shellfish Immunology (**Secombes**).