Institution: University of Lincoln

Unit of Assessment: 6 Agriculture, Veterinary and Food Science

1. Unit context and structure, research and impact strategy

1.1 Context and Structure

This statement presents research from three distinct academic units in the College of Science: The School of Life Sciences (SLS), the Lincoln Institute for Agri-Food Technology (LIAT) and the National Centre for Food Manufacturing (NCFM). Within SLS, activity is focused within two research groups, described in (1) and (2) below.

1. The **Animal Behaviour, Cognition and Welfare Research Group (ABCW)** focuses on clinical animal behaviour**,** companion animal welfare and cold-blooded care, with a growing stream of activity applied to farm animals, including avian and ruminant health.
2. The **Evolution and Ecology Research Group (E&E)** has established strengths in applied microbiology (especially the emergence of antibiotic resistance in agriculture) and ecology (including environmentally friendly control of invasive agricultural pests). It has recently developed critical mass in biophysics – studying organisms through the lens of physics, engineering and applied mathematics with application to global environmental change processes and robotics – and in soil science, developing indicators of soil health.
3. The **Lincoln Institute for Agri-Food Technology (LIAT),** formed 2015 and situated at our Riseholme agricultural campus, provides an institutional focus for interdisciplinary and collaborative research using emerging technologies (e.g. robotics, digitalisation) to support the sustainable intensification of agri-food supply chains.
4. The **National Centre for Food Manufacturing** (**NCFM**), situated at our Holbeach campus at the heart of the Lincolnshire food manufacturing industry, undertakes collaborative research and innovation across the food manufacturing industry, including applications of robotics and machine learning, digitalisation, food analysis, productivity, sustainability and product / process development.

1.2 Achievement of strategic aims for research

The University has invested in substantial growth in the UoA during the census period, reflecting its pivotal alignment with four of the University's six thematic priority research areas (Rurality, Digitalization, Sustainability, Health and Wellbeing – see Institutional Environment Statement), and with our guiding 'local to global' strategic principal, through its collaborative work with local stakeholders in the agri-food industry to address global challenges in food security and sustainability. The successful growth strategy is reflected in the increase in FTE (from 14 to 33.5) and research income (from £2.3m to £14.6m). We have maintained our high-level REF 2014 aims with some reorientation of objectives, as described below:

Aim 1. To enable, prioritise and promote agricultural, food and veterinary research through:

<u>1i. Provide a vibrant research environment attracting world-leading scientists</u>

The strategy detailed below has allowed the UoA to increase submitted FTE from 14 to 33.5. Investment in staff has occurred at all levels including professorial, mid- and early-career, especially within the priority areas of animal health (**Butter, Clegg, Roberts, Dunn**), plant sciences and ecology (**Qie, Stott, Varga, Coutts, Gould, Valluru**), agritechnology (**Pearson, Bochtis, From, Gaju, Gao**) and biophysics (**Humphries**, **Sutton**).

<u>1ii. Investment in research infrastructure, including Institutes and Centres</u>

The creation of LIAT (2015) has transformed UoL into a leading research hub for the agri-food technology sector. LIAT's strategic approach to interdisciplinary collaborative research is reflected in joint research awards with more than 50 HEI's and Research and Technology Organisations and government bodies globally, 78 businesses, and research outputs published with seven UoL schools (SLS, NCFM, Computer Sciences, Business, Engineering, Geography and Chemistry). This has helped to leverage over £64M of collaborative regional and research funding (£25M to UoL), including substantive peer reviewed awards from EPSRC, BBSRC, Research England, NERC, STFC, Innovate UK and Horizon 2020, and capital grants. Major

awards include: the £6.9m EPSRC Centre for Doctoral Training in Agri-food robotics, the £6.3m Research England "Expanding Excellence in England" Lincoln Agri-Robotics award (which has created 24 permanent posts, including 13 ECRs), and a £1.1M EPSRC Network plus award (Internet of Food Things). Major elements of LIAT's interdisciplinary research funding are returned in other UoAs, particularly Computer Science.
Since the 2014 REF assessment the University has also invested £12.7 million in the Joseph Banks Laboratories (JBL) and Minster House (animal facility), which opened in 2015, alongside the new Lincoln Science and Innovation Park. SLS has consolidated in these facilities, with the Riseholme campus redeveloped to support LIAT. These investments have been reinforced through strategically-significant external project funding (see Section 3 for further details).
During the census period the long-established NCFM has been reoriented from a primary focus on knowledge exchange with the food industry towards collaborative R&D, including the development of its own research capability and stronger interdisciplinary links across the University. This is NCFM's first inclusion in a REF return. During the census period it has helped to secure ~£8 million to support research and innovation in SMEs (including over 100 assists in the last year). A further ~£3m collaborative research funding has been secured including robotics and vision / AI inspection systems (Innovate UK & EPSRC); international food system optimisation and sustainability (Newton Bhabha and Research England); food product innovation, food safety, quality assurance and waste reduction (Innovate UK & Food Standards Agency). It is a partner in ~£12m of University interdisciplinary collaborative research projects including H2020, IUK + BBSRC, and the EPSRC CDT. As with LIAT, major elements of this funding are returned in other UoAs.

1iii. Growth from increased external income
The new research structures and individual support (described in section 3 below), have enabled an increase in external research income from £2.3m in REF 2014 to £14.6m in the current census period, a growth of 535%. Details of substantial awards are briefly mentioned above and in section 3; other major awards that have been the first of their kind for the University include: a Research Leadership Award (£1m) from the Leverhulme Trust (**Humphries**), an ERC Consolidator Award (£1.8m) from the European Research Council (**Montealegre-Z**); an international Newton Bhabha award (£1.2m with £250k going to Lincoln, **Swainson**); NC3rs BBSRC award for £390k (**Burman).**

1iv. An increase in the research student base
PhD completions have increased from 11 in REF 2014 to 25 in 2021 (118%), on a growing trajectory (22 registrations on the census date, 31/07/2020, compared to 4 on 31/07/2013). The census period has also seen the creation of the EPSRC Centre for Doctoral Training, focused on Agri-Robotics, in partnership with the Universities of Cambridge and East Anglia (£6.9M), and the EPSRC Doctoral Training Partnership (£636K) which includes Biophysics Inspired Robotics as a priority area.
Agreements with overseas Education and Innovation Agencies have grown PGR numbers, including the ANII Uruguay programme, CAPES Brazil, the Lincoln Africa Scholarship, Commonwealth Scholarships, and a joint award agreement with the University of Bern. In addition, LIAT jointly supervises 14 agriculturally relevant interdisciplinary PhD students in Computer Science and Engineering, through a BBSRC Collaborative Training Partnership on Fruit Crop Research (£1.9m).

Aim 2. To facilitate and promote interdisciplinarity through:
2i. Specific investment to expand cross-disciplinary strengths
Investment includes the creation of LIAT with staff appointments focused on cross-disciplinary research areas including Agri-Robotics, Ecology/Weed Management, Soil Science and Crop Science, which includes seven staff submitted in this UoA and five submitted in other UoAs (including Computer Science); and the reorientation of NCFM with two staff submitted in this UoA.
The University has also invested in staff to build interdisciplinary synergies between relevant Schools underpinned by our growing academic portfolio, including our programme in Ecology and Conservation shared between SLS and the School of Geography. This has been supported

through internally-funded joint PGRs (**Goddard** with Magnone & Macklin both UoA14), and SLS membership of the steering group of the new Lincoln Centre for Water and Planetary Health based within the School of Geography.

2ii. Engagement with international research networks and collaboration at all levels
Staff at all levels are supported in a range of networking activities. These include high-level international visits (e.g. Hong Kong Baptist University, resulting in **Goddard** becoming an external advisor to their Institute of Bioresources and Agriculture), and individual staff driven initiatives (e.g. **Romero**'s search for field sites in Sulawesi, Indonesia, funded through the SLS Travel Scholarship Scheme, resulting in an MoU with Hasanuddin University and collaboration with Leipzig University on the Macaca Maura Project – https://macacamauraproject.blogs.lincoln.ac.uk/).
Staff and research students are also encouraged to join relevant networks; e.g. the BBSRC sponsored Animal Welfare Research Network, through which **Burman** and **Mills** provide training in companion animal welfare (https://awrn.co.uk/event/implementing-new-methods-to-improve-companion-animal-welfare-science-caws-in-the-uk/).

1.3 Achievement of strategic aims to maximise impact
1. Increased engagement with potential stakeholders
Over the census period we have invested in people and organisational structures to maximise our interactions and co-creation with local, national and global stakeholders. The investment in creating LIAT and developing NCFM, to facilitate interactions with the agri-food sector, has been particularly critical. Exploiting our location in Lincolnshire (the UK's primary food production county), this has enabled us to secure a reputation as a leader in agri-food technologies. We have aligned activity with the UK Government's agenda to advance digitalisation of the agri-food industries and supply chains (e.g. contributing to development of the food manufacturing element of HMG's Made Smarter Review 2017). Through a range of interdisciplinary research initiatives, supported by Innovate UK & EPSRC, LIAT and NCFM have achieved high impact in this digitalisation space, including ground-breaking advancement of robotics in both agricultural systems (see Agri-robotics ICS - **Pearson, Gould)** and food manufacturing processes, the use of Machine Learning and sensor networks to optimise energy usage in chilled and frozen food storage (supermarkets), and Deep Learning vision systems to improve food safety on food manufacturing packing lines (UoA11 Digitalisation ICS - **Pearson** LIAT, **Swainson** NCFM).
We support new appointees in developing impact: for example, **Qie** received a voucher from the Productivity Programme for Greater Lincolnshire scheme to support eight days activity transferring her specialist ecological expertise to support carbon footprint accountability in a cardboard recycling company.

2. Valuing impact as an inherent feature of our research culture
We design impact into our institute and group missions. NCFM and LIAT have explicitly sector-facing missions and deep stakeholder engagement; see above. ABCW's mission is: "to use an interdisciplinary approach to translate fundamental research in behaviour and cognition, to provide innovative, practical solutions for the benefit of animal health, welfare, and society". This is evidenced through advances in animal training (see electronic training aids ICS) and problem behaviour management (see clinical animal behaviour ICS), the co-creation of patents with industry (eg US20170295825A1 **Burman, Mills**), as well as improvements in cold blooded care guidelines (**Wilkinson**'s work with the RSPCA). In addition, many researchers offer consultancy; Mills, for example, has addressed both the public and industry through the University's Animal Behaviour Clinic, which also provides clinical research material, and **Montealegre-Z** has worked with leading supermarkets (e.g. ALDI) identifying potential threats in fresh products (vegetables, fruits) potentially infested by arthropods**.**
The value we place on impact is also evident within our promotions system: within NCFM **Onarinde** (Associate Professor) was promoted in recognition of her key role in developing food microbiology and chemistry focused industrial research collaboration and **Swainson** (Professor of Industrial Food Technology) for leading strategic industrial research growth at NCFM in line with University strategy.

1.4 Research Strategy for the next five years

Our research strategy is built around the key themes and Sustainable Development Goals prioritised by the University, while respecting individual academic freedom to explore new avenues of research.

We anticipate further development in **agrifood technology**, responding to drivers including: the impact of Brexit on labour supply and supply chains, the demand for NetZero agri-food production, the transition of agricultural systems towards enhanced natural capital, and requirements to increase food system resilience and improve human diets. We will focus on the advancement of digitalisation to drive productivity, safety and quality in the food manufacturing sector, rapid expansion of our work in **soil health, ecology and biodiversity into agrisystems** (especially in relation to agricultural ecosystem health), and continue growth of our work within the **One Health – One Welfare agenda,** (especially within the area of human-animal interactions across a diversity of taxa and settings).

We also plan expansion and investment in fundamental research in **biophysics**, including applications in robotics, human and animal biomechanics and sensory perception.

Specifically, we will:

i. Respond to local priorities and global challenges

We will use our *local environment and strong stakeholder* relationships to address globally important issues. Close alignment with the Greater Lincolnshire LEP's priorities will help to build strategically important alliances to address sustainable development for the management and health of both land and animals, while meeting consumer demand, taking into account the challenges posed by climate change and emerging disease threats. "Farming breakfasts," successfully piloted by LIAT, will be extended as an engagement model with other potential end-users.

The Agri-Forwards CDT and Lincoln Agri-Robotics project have transformed our capabilities and capacity in digitalisation and robotics. We will seek similar strategic improvement from synergies between our research Institutes (LIAT), centres (NCFM) and groups (E&E, ABCW) focusing on soil health and sustainable food security. The University has initiated this strategic investment with the appointment of two new ECRs (a collaboration between E&E, LIAT and the School of Geography) to develop the key priority area relating to the effect of land use change on soil C-sequestration, water retention and biodiversity.

In parallel, we will build on our existing cross-disciplinary expertise in human-animal interactions (HAI) to develop research on the interconnected wellbeing of humans and other animals with colleagues within the School of Psychology (Kargas, Hogue, Meints), our visiting professor in HAI (McCune) and external stakeholders (including practitioners and members of Animal Assisted Intervention International) to maximise the physical and psychological benefits from being with animals, while minimising the associated risks.

ii. Strategically develop our infrastructure and researcher base

NCFM's new "Centre of Excellence in Agri-food Technologies" (£7 million capital development funded by the Greater Lincolnshire Local Enterprise Partnership, ERDF and the University) opens in 2021 as the anchor building on the new Holbeach South Lincolnshire Food Enterprise Zone (FEZ). The FEZ provides an opportunity for NCFM to intensify research on high-value food chains in collaboration with global food companies. The University has also identified facilities growth for LIAT at Riseholme as a priority for further regional funding rounds.

We will build on recent successes and partnerships to apply for further collaborative CDTs. LIAT is a partner on the CTP2 application in Fruit Crop Science which builds on the current BBSRC CTP programme in Fruit Crop Research (CTP-FCR). This application brings together businesses and researchers to provide world-class horticultural and bioscience solutions and training to address the scientific challenges faced by commercial fruit production. We will apply the successful collaborative model demonstrated by LIAT to develop similar initiatives in the other priority research areas described above.

iii. Provide targeted investment in staff, especially within areas of interdisciplinarity

This will involve a particular focus on support for collaborative grants aimed at increasing the number of ECRs and PGRs within the UoA. This has begun with University investment in Soil Science (outlined above) and will be supported through established initiatives such as The Agri Forwards CDT and Lincoln Agri Robotics. Within the area of biophysics we anticipate developments relating to the translation of our work using animals into technological systems,

such as sensory and robotic systems. For example, **Sutton's** work on elastic energy in jumping insects is already being used to develop a prototype jumping robot for the purpose of navigating and monitoring fields of crops, with the support of his colleague Sklar (Research Director for Lincoln Agri-Robotics). This prototype is designed to carry a camera through fields of leafy vegetables to look for discolourations and insect infestations in crops which are otherwise difficult to monitor.

iv. Develop and exploit new funding streams

Our research income strategy encompasses four key mechanisms:

1. Strategic investment in priority research areas with strong stakeholder support, as described above.
2. Increasing the quality of funding bids through coaching, peer review and research planning. Our formal research mentoring scheme helps colleagues to identify areas most likely to support their ambitions, and our peer review process supports the generation of well-crafted bids; see section 2.2.
3. Specific time allocation to prepare bids.
4. Encouraging collaborative research by supporting extended networking opportunities, conference participation and research visits to other institutions/organisations. For example, **Sutton's** 4-month US travel grant led to a successful NeuroNex grant application ($10M USA, ~£750k to Lincoln).

1.5. Impact strategy for the next five years

Impact is integral to our vision as a Civic University, and in this context we define it broadly to encompass measurable economic and health benefits, developing solutions to real world problems, and changing perceptions and understanding among non-academic audiences.

Our impact strategy has three main strands:

i. Co-creation to maximise impact

We will continue to strengthen our successful collaborations with local stakeholders, as outlined in 1.4i above, to co-create research that is not only relevant to local and regional communities, but also applicable to global issues, especially with regards to Food Security, Ecological Sustainability and Human-Animal Interactions.

ii. Translational and implementation research for impact

Our developing agri-food research priorities fill critical gaps in national capability, which will have major impact on labour characteristics and industrial productivity. Many food manufacturers are now looking at new working environments and markets using digital platforms to tackle the current trade balance issues facing the industry. We are leading the way in robotics, automation and artificial intelligence applications in the agri-food sector, which are in their infancy, but are set to have a transformational impact on labour and non-labour productivity. The global demand for the technology is compelling: agriculture feeds a population of 7.7bn rising to an anticipated 10bn by 2050. There is also a need to deliver sustainable products, which is driving innovation. The UK research community in this area is small and highly fragmented, but the recent investment in Lincoln Agri-Robotics acts as a leading hub for this work and its impact. This provides a platform both to sustain our current impact within agriculture and to diversify to embrace the further expertise available within E&E (Soil health and ecological sustainability) and ABCW (healthy human-animal interactions).

Much of our ongoing work in agriculture and food science is at relatively high technology readiness levels (TRL) from 4 (Component validation in the laboratory) to 7 (System prototype demonstration), commensurate with the urgency of industrial demand, and supported by government funding aimed at driving immediate industrial productivity. Recent investments facilitate a more sustainable and comprehensive research pipeline with greater emphasis on lower TRL (2 to 5) basic research. This enables longer-term transformational impact, and provide the UK with a unique Agri-food impact capability.

This approach, which we are already applying successfully in relation to agri-food technology, provides an impact model for our other research themes, including the translation of basic

ecological and microbiological work to ecosystem health and food-safety (**Goddard, Gould, Varga, Coutts**), and applying animal cognition and emotion research for better quality human-animal interactions (**Mills, Wilkinson, Burman, Romero**, **Cooper**). The work of these groupings together with that of individuals (e.g. **Humphries** on ocean ecosystems) converge on several government priority areas and provide opportunities to address broader impact themes.

iii. Support structures for impact

University structures to support impact are described in the Institutional environment statement. At a local level, dedicated senior impact leads, with extensive industrial research experience work closely to mentor colleagues and help them realise the potential impact of their work. All staff receive impact training, and the potential for research impact is identified and documented annually within *Individual Research Plans* (**IRP**) and monitored on an ongoing basis. Local and central funding and seminars are available to support impact generation. For example, **Cooper** was supported with a Research Impact Buyout Award by the College of Science which allowed a reduction in teaching duties in 2017-18, enabling him to focus on activities including liaison with regional, national and international governments and stakeholders interested in developing legislation associated with Electronic Training Aids (see related ICS).

At all three campuses academics and industry share common research spaces relating to this UoA. Over the past three years our staff have worked with over 200 local businesses - typically providing scientific and technical support - with a number of these looking to relocate their businesses closer to University of Lincoln in order to take advantage of our facilities and expertise. Phase 1 of the Lincoln Science and Innovation Park, adjacent to JBL (mentioned in the REF 2014 submission) is already at capacity; over the next five years both LSIP Phase 2 and NCFM's £7m business hub at Holbeach FEZ will come on stream to ensure we sustain the growth of our local-business related impacts. This is supported by the recent establishment of a Barclays Eagle Lab (2020) on our Riseholme campus to help new agri-food start-up businesses, including University spin-outs.

1.6 Approach to Interdisciplinary Research

Global changes in the agri-food industry require an interdisciplinary approach to develop technologies that address the challenge of maintaining food security. During the census period LIAT was developed specifically to meet the demand for interdisciplinary research in Agri-technology (agri-robotics, data analytics and digitalisation) and Agri-environment (crop physiology, soil health, natural flood management, agroforestry). Recent external awards (EPSRC CDT, BBSRC CTP, Research England E3 and Anglian Water funding) have already enabled investment in postdoctoral researchers and PhD students in these areas. LIAT collaborates extensively across the University, as evidenced by the return of LIAT staff and collaborators in Lincoln to other UoAs. This approach is now being extended to capitalise on the synergies possible with biological sciences within SLS, especially with regards to soil sciences, but also other areas of importance, including food microbiology and antibiotic resistance. Similarly, NCFM has progressed interdisciplinary research with the support of awards from EPSRC, BBSRC, H2020, FSA, Research England GCRF and Innovate UK. This has focused on food manufacturing robotics, optimisation of food supply chains and reduction of food waste (with Engineering), AI enabled vision inspection systems and self-optimising fleets for food warehouses (with Computer Science), and advancements in food safety using cutting-edge microbiological techniques with SLS staff. Building on these synergies is at the heart of our strategic plan for growth in the foreseeable future.

Within E&E there has been a consolidation around three major areas of multidisciplinary research: biophysics, biomechanics and sensory biology, with the support of external funding. Biophysics and Biomechanics have attracted and recruited research fellows and PhD students in sensory biology, physics, chemistry, engineering and mathematics, though major grants e.g. ERC-CG, Leverhulme, LRLA, The Gordon and Betty Moore Foundation [GBMF] and NeuroNex. ABCW and E&E collaborate extensively with colleagues in the School of Psychology, adding strength and depth to our biological and psychological foundations and provide fundamental insights which translates to real world impact: e.g. the comparative and applied work of humans and dogs (**Montealegre-Z, Pike, Soulsbury** and Guo [Psychology]**)**, funded by DSTL to support improvement in police and military working dog performance.

1.7. Progress towards open research

The University is committed to open data as a partner in the JISC-funded Open Research Hub project and is a signatory to the San Francisco Declaration On Research Assessment (DORA – see institutional level statement). Since May 2018 University policy on research data has been to publish data as openly as possible. Both spreadsheet and raw data are accessible in this way, when ethically allowable. Examples include hundreds of slide stacks resulting from Micro-CT scanning of insect ears, from an ERC project (**Montealegre-Z**) deposited in dryad, and the default Diamond Light Source open access service for nano-CT (Synchrotron) data collected in the same project. Video data are also shared in this way, resulting in new collaborations – for example, in relation to our work on the expression of emotion in dogs (**Mills**), we are now collaborating with computer scientists at the University of Haifa, to enable the automation of this process through deep learning and AI.

In addition, the University provides an open access store of shareable eprints. Journal Articles with ISSN and Conference Proceedings with ISSN must be deposited within 3 months of acceptance and must be made open access within the REF stated maximum embargo period. This allows green access to all published outputs. The data are curated, accessible and reusable, complying with research funder mandates, allowing a standards-based data management service.

1.8. Support for research integrity

Research integrity is governed by the University's Code of Practice for Research (see Institutional environment statement), Concordat to Support Research Integrity and the University's Research Ethics committee. All staff and PGR students receive training in ethics and use of the online ethical approval system (LEAS). All research is subject to ethical review and compliance is monitored with formal annual reviews of all approved projects. Both the Chair (**Burman** - ABCW) and deputy Chair (**Soulsbury**- E&E) of the University Non-human Research Ethics Committee are included in this UoA.

The role of ethics in research integrity, as well as promotion of the 3Rs in animal studies (**Burman**, NC3Rs Panel Member), is communicated throughout all stages of research activity, being integrated within undergraduate and post-graduate training, and in staff development (i.e. with staff acting as ethics reviewers).

2. People

2.1. Staffing strategy

There has been significant and sustained investment in growing the academic staff base in UoA6. This has seen a 140% increase from 14 FTE in REF 2021 to 33.5 FTE in REF 2021. Academic staff have been strategically recruited at all levels with interests complementary to existing groups and future research priorities. Senior academic staff are recruited or promoted to take on important leadership roles (**Pearson** – LIAT, **Swainson** – NCFM) but there is also an emphasis within recruitment for developing our own staff and ECRs, who can flourish within our research environment and priority areas. For example, in line with the UK Concordat to Support the Career Development of Researchers and our development of these, two independent post-doctoral fellows supported by the University were appointed to permanent posts at Lincoln (**Varga**, Marie Curie; and **Sutton**, Royal Society) following competitive external appointment processes. Our commitment to internal development of staff is evidenced by 7 of the 12 (10.45 FTE) professors submitted to this UoA having been internally promoted to post in the census period.

2.2. Staff development

Academic staff are fully supported in line with the provisions of the Concordat to Support the Career Development of Researchers beyond the wider mechanisms of the *University's People Strategy* through our *Personal and Professional Development Framework.* We reward success, and it is notable that 14.45 FTE (~43%) staff submitted in this UoA are employed at a senior level (Associate professor or above), with 8 (~24%) receiving internal promotions during the census period (including 3 women, 1 BAME). This is the product of the following processes:

- A research culture which includes formal developmental and mentoring for all staff through *annual developmental appraisal* and IRP. While *annual developmental appraisal* allows colleagues to focus on their overall academic development, the IRP process focuses on research progress within the context of individual, School and University aspirations. The IRP is a supportive process undertaken with senior staff (or peers in the case of the professoriate) and includes reflection on the previous year's objectives and achievements, helping staff to proactively plan for their future and develop pragmatic solutions to enable them to achieve their research potential within the wider academic context of their appointment.
- Support for early career researchers (**ECR**s) includes appointment of *ECR leads*, specific targeted training, a dedicated mentor, alongside restricted teaching loads for all new staff to provide them with more time for research and bids. Staff may extend their dedicated research time through successful grants (e.g. **Sutton** 80% on Royal Society, **Gao, Gaju, Valluru** 80% on Research England E3 and **Montealegre-Z** 55% FTE on ERC-CG). Other outcomes include the production of world leading publications e.g. **Qie** has produced publications in both Nature and Science, and **Romero** a publication in Nature Communications. New staff are also provided with internal funding and/or equipment to enable them to maintain their research momentum, whilst they seek external funding.
- Internal pump-priming funds are available to facilitate the generation of pilot data with grants of up to £25k per successful applicant. For example, an award to **Montealegre-Z** in 2016 to explore the use of 3D insect ear models for numerical analysis was used to strengthen the case for his successful ERC grant application.
- Promotion of opportunities and external awards (e.g. Innovate) specifically aimed at stimulating and facilitating exchanges between academia and business. This has been extended by the newly established AgriTech Barclays Eagle Lab at the University's Riseholme Campus.
- Promotion of engagement opportunities with external stakeholders. This includes LIAT's successful "Breakfast Briefings" between academics, external speakers, external businesses and stakeholders resulting in a number of successful collaborations; this model will be rolled out across the UoA. NCFM's multi-faceted industrial engagement agenda includes research, knowledge-exchange, training, further and higher education and apprenticeships with the food industry nationally and internationally. Within SLS, the Animal Behaviour Clinic supports industry staff development in clinical animal behaviour: e.g. technical managers for Behaviour at Ceva Animal Health which resulted in additional near market research and consultancy, in addition to the substantial projects described in the ICS on clinical animal behaviour.
- Staff are further empowered to manage their own professional development through a proportion of their income contribution from research grants returned to the PI (e.g. 10% of the contribution where a project reaches the minimum qualifying level). The level of contribution achieved is reviewed annually at College level.

2.3. Support for training and development of PGR Students

The number of **PhD completions** in this UoA has **increased more than two-fold** from 11 in the previous submission to 25. There were 22 PhD students enrolled on the census date 31/07/2013 compared to 4 on 31/07/2013. The mechanisms described below have ensured 100% PhD completions on time (<4 years FTE) for all students starting during this period. These successes are as a result of the following support and development mechanisms:

- A formal cross-disciplinary research programme (Postgraduate Research Skills for Life Scientists): research expertise within this UoA encompasses a wide range of areas including animal behaviour, cognition and welfare, evolution and ecology, biophysics, food safety and agriculture. Our formal programme emphasises the core principles of scientific research that transcend discipline, the importance of an enquiring mind and the opportunities provided from awareness of other disciplines, e.g novel statistical methods. A bespoke postgraduate training programme covers essential transferable and translational skills, including workshops on problem solving, research and presentation skills, paper writing and writing grant applications. This builds towards an annual

postgraduate symposium which gives students experience of presenting in a conference style environment.

- Expanded opportunities for PGR funding include the award of an EPSRC CDT, focused on Agri-food Robotics with the Universities of Cambridge and East Anglia (£6.9M) as well as an EPSRC Doctoral Training Partnership (£636K), which includes Biophysics Inspired Robotics. Other sources of studentship funding include UKRI (BBSRC, EPSRC, Research England), EU (ERC), Charities (Leverhulme Trust, Feline Friends, The Felix Thornley Cobbold Agri Trust, Chadacre Agri Trust, John Templeton Foundation), industry (CEVA, Cherry Valley, NIAB) and the Agriculture and Horticulture Development Board (AHDB). We also regularly offer internally funded studentships and fee waivers. PGR students have access to Santander International Scholarships for research travel and also international fieldwork opportunities in North, Central and South America, Qatar, Russia, Singapore, and United Arab Emirates.
- An academic support network: All students have at least two supervisors to ensure strong support and diversity in the expertise available to reinforce this transdisciplinary philosophy. Two PGR mentors (one male, one female) from outside a PGR student's academic discipline are also available within SLS to ensure students have access to support outside their doctoral supervisory team and advice on any non-subject specific aspect of their degree. Postgraduate research student reps are appointed annually through the Students' Union and have regular meetings with the PGR committee. These meetings give students the opportunity to raise awareness of issues and for staff to respond to issues in a proactive manner.
- Internal funding to support conference attendance and publication fees. Awards are given in recognition of high-quality work, and for outstanding work e.g. best PhD thesis.
- Formal training opportunities to enhance teaching skills. PGR students are formally supported with training to participate as demonstrators in lab practicals for undergraduate and MSc-level courses. This is overseen by academic staff and may develop into more formal lecturing opportunities in their research area to support their development towards Associate Member status of the HEA. Postgraduate students are fully integrated into their school and are also involved with committees at all levels of the organisation, including staff appointment panels.

Our training of PGR students takes into account the diverse range of careers which our graduates pursue: Several PhD students have chosen to undertake post-doctoral work within the University. Others go to postdoctoral positions at other institutions; or directly into permanent academic positions (e.g. Sriphavatsarakom, Mahidol University, Thailand). Some PhD graduates have taken up related roles in UK industry (e.g. Cracknell - Defence Science and Technology Laboratory; Brady - behaviour services manager, Dogs Trust and Wright - Guide Dogs for the Blind); or abroad (Sarria-S - Enterra Feed Corporation, Canada; Kasbaoui - Institut de Reserche en Semiochemie and Ethologie Appliquee, France).

2.4. Equality, diversity and Inclusion (EDI)

For this UoA, policy on LGBTQIA+, International Staff, Disabled Staff, PoC staff, Women in STEM and Carers and Parents are all covered by the University's Joint Equality, Diversity and Inclusion Partnership. Mental health is covered by HR, the Employee Assistance Programme and availability of the 'Togetherall' facility.

This UoA has a collaborative approach to EDI and we actively encourage under-represented groups to apply for vacancies. We are proud of an inclusive culture that values diversity as a strength; however, we recognise that we have not yet achieved equality targets within our community and this acknowledgement underpins our desire to improve these statistics. We are actively investigating further mechanisms to address this issue with the assistance of the cross-University Eleanor Glanville Centre (**EGC**) (http://eleanorglanvillecentre.lincoln.ac.uk/) which coordinates our institutional engagement with the Equality Challenge Unit's Athena SWAN/Gender & Race Equality Charters, and provides centralised support, and sharing of best practice, across all academic schools. For example, this has resulted in blind recruitment for students and increased the proportion of female students recruited as a result.

Of the 33.5 FTE in this UoA, 32.9% are females; 37.2% are non-British. Currently 31% of Senior staff (professorial level) identify as female, and distribution of ethnic groups is 76.1% white and

23.9% BAME. Staff ages range between 28 and 61, with a strong weighting towards the 30s (38%), early/mid 40s (20%), and 50's (42.4%), and therefore reflects a diverse and balanced range of experience and career stages. Moreover, 4 staff are ECRs, (defined as being within 5 years of their PhD award as of 2020), while 10/35 staff have secured their first permanent lectureship positions.

SLS has held an Athena SWAN Bronze award since 2016, and separate applications are being prepared by both LIAT and NCFM. Work on EDI is ongoing and includes:

• An active monthly EDI committee, which includes student educators, academic and post-doctoral researchers, professional services and research students. The committee is engaged in a continual self-evaluation process, implementing actions designed to improve equality and diversity. Analysis of annual monitoring statistics and the results of regular Staff Culture Surveys are carried out to better assess trends and inform the development of targeted initiatives for under-represented groups. There are also College and University EDI committees that meet monthly for Chairs of School EDI committees.

• An EDI blog linked from the main SLS website, with links to relevant EDI policies and updates from monthly EDI committee meetings.

• Internal EDI-proofing, to detect and raise awareness of unconscious bias, so we can ensure internal processes and procedures deliver a level playing field for all staff. EDI training is compulsory for all staff, and a condition of the initial 6-month probation for new staff.

• Recognising that female researchers can be disproportionately disadvantaged through maternity leave and caring responsibilities, our staff engage with the institutional Pipeline Mentoring Scheme, open to all staff, which includes 'maternity mentoring' and 'work-life balance' support pathways, alongside the more usual career progression support available. Further support for female researchers around maternity leave is provided through the EGC's Academic Returners' Research Fund (AR2F), which enables staff to sustain their research before, during and after maternity leave. This scheme has supported **Wilkinson** in the current period by providing funding for a postdoc for six months, to ensure research continuity during her period of maternity leave.

• Equality and Diversity is a standing item on senior leadership team meetings, as well as in school meetings, through for example an Athena Swan leader (**Dunn**) and deputy (**Stott, Cotter**). This permits tracking progress towards targets and commenting on our Silver Award application progress.

• EDI has also been an item in the construction of the REF submission of this UoA. The principles of transparency, inclusivity and consistency are at the heart of this process, in accordance with REF Code of Practice. The output selection is a confidential process that gives staff the chance to score their own outputs during the annual IRP review, followed by a number of simultaneous internal and external assessments. Our UoA Panel meets to decide on final scores and notifies staff individually with details of the process. This can then be used as a staff development opportunity.

3. Income, infrastructure and facilities

3.1. Research Income

In the census period this UoA submitted 406 grant bids with a success rate of 43%. Funders include UK nonRC (52.5%), UKRI (16.8%), EU (8.2%), International and other funders (3.7%). Our research income (secured funds) has increased from £2.3m (in the 2014 REF period) to £14.6m (in the current period), representing a growth of 535%. This growth has been due to our strategic focus on local, national and global priorities (food security, health and wellbeing, and sustainability) together with intensified focus on fundamental research (for example, in biophysics). The strategy described in section 1.2, has resulted in expanded collaborative networks with, for example, service users and industrial partners, and higher quality applications in line with the needs of both funders and applicant expertise, as evidenced by the achievements listed below.

- **Major grants (>£750k) awarded in the census period** to UoA6 PIs: European Research Council (£1.8m The insect cochlear, **Montealegre-Z,** 2017), EPSRC (~£1.5m, Internet of Food Things, **Pearson,** 2018), The Leverhulme Trust (£1.4m, Form and

function in a microbial world, **Humphries,** 2015), Innovate UK (£1.1m, The development of dynamic energy control mechanisms for food retailing refrigeration systems, **Pearson,** 2016); Science and Technologies Facilities Council (Synthesis of remote sensing and novel ground truth sensors to develop high resolution soil moisture forecasts in China and the UK, £1m, **Pearson,** 2016); Gordon and Betty Moore Foundation ($965,532 US, Microscale Viscosity Gradients in the Sea – **Humphries,** 2017); Research England (£6.3m, Lincoln Agri Robotics, **Pearson,** 2019); MRC (£770k, Modelling General Principles of Motion, **Sutton** 2020).

- **Awards over £100k awarded in the census period** to UoA6 PIs: BBSRC (£500k, A whole supply chain hurdle approach to control Campylobacter – **Goddard,** 2016; £210k, Development Of Novel Greenhouse Cladding Materials To Optimise Crop Growth And Quality, **Pearson,** 2015; £150k & £129k, Seeding Catalyst – **Pearson,** 2017/18); Ceva Sante Animale (£465k – advances in semiochemistry, **Mills, Pike** 2019-21), NC3Rs (£429k – automated predictive welfare assessment in fish, **Burman**), Interreg (£250k – SmartGreen **Pearson,** 2018, 2017); Innovate UK (£391k - Development & Optimisation of Fresh Produce Supply Chain, Handling and Storage Systems, **Swainson,** 2016; £329k - Trusted, Decentralised, Digital Supply Chains for the Food Industry, **Pearson** – 2020, £319k - Advanced Cooking and Cooling Technology, **Swainson,** 2015; £221k - Digitised Food Supply Chain. Fusing IoT, Blockchain and AI data layers, **Pearson**¸ 2020; £191k - Robotic flexible food manufacturing system, **Swainson**, 2016). Royal Society (£480k - jumping biomechanics and elastic materials – **Sutton,** 2019); The Leverhulme Trust (£300k - evolution of communication in insects **Montealegre-Z,** 2014); Ceres-Agritech (£299k – Forecasting harvest profiles for fruit; £294k- Forecasting harvest profiles for broccoli, £258k - Laser boom all **Pearson,** 2019/20); DSTL (£288k - Extended studies on rat and dog odour perception, **Wilkinson, Pike**, 2015-2018; £270k - Effect of light and sound on working dogs, **Wilkinson, Soulsbury, Mills**, 2019); Science and Technologies Facilities Council (£250k - Pest and Disease Emergence Prediction and Control for Sustainable Agriculture, **Pearson,** 2017); Horizon2020 (£195k - Sex-Specific Interactions in Arbuscular Mycorrhizas in an Ecological Community Context, **John**, 2015); Food Standards Agency (£121k -Developing 'Data Trusts' for the Food Supply Chain, **Pearson,** 2019).

Synergies between LIAT, NCFM and colleagues in Computer Science and Engineering emerged rapidly following a strategic review of national priorities and potential capabilities at Lincoln following REF 2014. Associated income relevant to the Agri-Food sector appears in multiple UoAs. Nonetheless, we believe it is worth indicating the breadth of this research in Agri-Food Technology. Over the 5 years, the UoL team in LIAT and NCFM have helped win more than £64m of collaborative research and regional development (including capital) funding divided across multiple partners and including 'in-kind' contributions in Agri-Food technology (25m to University of Lincoln). These centres exemplify the critical role that universities can play in supporting local economies in addition to their roles as drivers of global innovation.

- **Named collaborations on other major grants awarded to staff at Lincoln, including awards in Agriculture, Veterinary and Food considered in other UoAs**

EPSRC (£6.9m - Doctoral Training in Agri-Food Robotics, **Pearson, Swainson,** 2018; £178k - Automated Robotic Food Manufacturing System, **Swainson,** 2017); Department for Communities and Local Government (£2.7m The Greater Lincolnshire Agri-food Innovation Platform, **Pearson,** 2019); Research England (£1m -Business Incubation Development to support Food Enterprise Zones, **Swainson, Onarinde,** 2019); NERC (£813k - Northwest European Seasonal Weather Prediction from Complex Systems Modelling, **Pearson** 2020); Horizon 2020 (£768k - Intra-Logistics with Integrated Automatic Deployment: safe and scalable fleets in shared spaces, **Swainson,** 2016; £404k - MoBile Robotic PlAtforms for ACtive InspeCtion and Harvesting in AgricUltural Areas, **Pearson,** MoBile Robotic PlAtforms for ACtive InspeCtion and Harvesting in AgricUltural Areas 2019); Innovate UK (£642k - The world's first fleet of multi modal soft fruit robots, **Pearson,** 2018; £566k – Robot Highways, **Pearson,** 2020; £494k - Autonomous robots to support fruit picking, **From, Pearson,** 2017; £408k - High speed picking soft fruit robots, **Pearson,** 2018; £297k - KTP - Olympus Automation, **Swainson,** 2018;

£274k - Development and field testing of the next generation of vision-guided weeding systems, **Pearson**, 2018; £225k - Robot Tomato Harvester, **Pearson,** 2017; £187k - Novel active vision and picking head to robotically harvest soft fruit, **Pearson**, 2021; £176k - Robotic Blackgrass weeder, **Pearson,** 2018; £156k - Development of an autonomous mushroom picking robot, **Pearson,** 2017); £100k – Africa KTP (Nigeria) Temophadis International Enterprise & University of Lincoln; **Swainson,** 2020) Interreg (£297k Saline Farming - innovative agriculture to adapt to climate change and sea level rise, **Pearson,** 2017); Ceres (£242k – Ai unleashed, **Pearson,** 2021); Berry Gardens Ltd (£192k - In-Field Logistics for Soft-Fruit Production, **Pearson,** 2020);

3.2. Infrastructure and Facilities

Our strategic Investment in sustainable Institutes and Centres during the REF cycle has allowed us to repurpose and modernise facilities at LIAT, NCFM, and SLS. LIAT is based in custom-developed facilities at Riseholme (the University 200-hectare Farm Campus) and hosts the Agri Forwards CDT in agricultural robotics and Lincoln Agri-Robotics. This includes a fully robotic soft fruit farm, greenhouses, fully robotic packhouse, food handling facility, food picking robots, and auxiliary equipment allowing automated multisensory detection. LIAT also has access to vertical farm facilities based in Reading (funded by Reading University), for research on strawberries, open to both students and researchers.

At NCFM successive investment by the University and GLLEP have transformed this rural campus into an internationally important innovation hub for the food industry. The campus has nationally unique technical facilities including a food factory test facility, where NCFM pilots advanced food processing technologies with industry partners, and the use of robotics for both small and large scale food manufacturing including a "first in the world" robotic platform to batch-process food. Other on-site research facilities include: microbiology and chemistry laboratories (with further facilities available in JBL on the main Brayford campus); a new product development suite; sensory & organoleptic test centre and food processing pilot plant. These have enabled through Innovate UK investment co-development of new steam infusion cooking systems and rapid advanced cryogenic cooling technologies, which have been commercialised by partner businesses working closely with NCFM.

The Joseph Banks Laboratories (JBL) and Minster House (MH) on our Brayford Campus provide state-of-the-art facilities to support fundamental cutting edge molecular and cellular biological research, biomechanics and sensory biology. MH has whole animal facilities, for work on animal behaviour, perception, cognition and welfare. These include: fish lab with acclimatised tanks and automated tracking systems, developed as part of an NC3R project; Reptile lab, with colonies of lizards, tortoises, and snakes; Sensory perception labs especially in vision with our unique i-link and canine headset eye tracking systems, olfaction (with unique olfactory discrimination apparatus developed in association with Ceva Animal Health) and hearing (bioacoustics chamber); controlled climate insectary room with 15 incubators to maintain colonies of tropical insects; and a climatised greenhouse for plant research. An ERC-CG (**Montealegre-Z**) extended facilities further to include an imaging lab with micro-CT scanner, plus 3D microscopy system for surface roughness measurement; and a fully equipped bioacoustics lab with laser scanners, sound-proof room, anti-vibration tables, and a large range of audio and ultrasound equipment. This constitutes one of three major facilities for hearing research in animals in the UK, an investment of £502k, to which the University contributed £200k. A newly-established £65k mechanical-biological engineering lab (**Sutton**) is equipped with state-of-the-art high-speed video capture to measure elastic structures for fast movements in animals. In addition, we have a Physical Ecology lab equipped with a state-of-the-art algal growth chamber, optical microrheology and bulk rheology measurement equipment, high speed fluorescent microscopy, a 92-core server system for computational work, as well as ongoing development of cutting-edge microfluidic devices. We anticipate further growth in this facility as our work on soil health expands.

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

4.1. Research collaborations, networks and partnerships

Large-scale Collaborations. LIAT and NCFM collaborate in several large-scale networks. The £4.8m CCF CERES Agritech programme (with Cambridge, UEA, Reading, Lincoln and Herts and three research institutions) is a platform to identify, incubate, invest in and run commercially viable development projects – to date, LIAT is collaborating in/leading 11 CERES projects worth £2.1m. The €4m ILIAD EU-INTERREG programme promotes the advancement of automation and robotics for the food warehousing and food processing sectors (with Cambridge, Cranfield, Open, Surrey, Reading, UEA, Liverpool, Hertfordshire, Loughborough, Southampton, Manchester, Leeds and Sheffield Hallam). **Pearson** is PI of the EPSRC Internet of Food Things Network + (co-I's at Southampton, Exeter, UEA and Open) that has 85 active participants across UK HEI's, awarding over £300K of research funding to consortia led by ECRs. **Pearson** and **Swainson** are CO-Is of the EPSRC AgriForwards CDT with Cambridge and UEA, which includes over £3m of support from industry. **From** and **Pearson** are engaged in the Norwegian Research Council Digifoods initiative. **Bochtis** leads the H2020 BACCHUS program, a cross EU initiative to develop robotic solutions for wine producers. **Swainson** and **Pearson** also work internationally on the advancement of resilient and sustainable food supply chains in India and Kenya (Newton Bhabha and QR GCRF) with industry, academic and government partners to develop handling, storage and processing practices. Other key LIAT and NCFM partners include leading Research and Technology Organisations including: HVM Catapult, NIAB EMR, NERC Centre for Ecology and Hydrology, BBSRC Rothamsted, BBSRC John Innes Centre, Chinese Academy of Meteorological Sciences, Egerton University Kenya, Nanjing University, Punjab Agricultural University, the Innovate UK Agri-EPI centre.

Collaborative partnerships are also formed with respect to specific projects. These may be led by staff at Lincoln or an external host. For example within the census period **Goddard**'s collaborations have involved: NIAB, FERA, SRUC, ADAS and Natural England (Soil health and soil biology partnership - AHDB/BBRO); AHDB and NIAB East Malling Research including BBSRC CTP PhD students (projects to understand and control horticultural diseases); Plant and Food Research NZ Ltd (The Vineyard Ecosystem Program - New Zealand Winegrowers and the New Zealand Ministry for Innovation and Employment; Integrating biodiversity in agricultural habitats and the effect of synthetic pesticides - Plant and Food Research NZ Ltd); Oregon State University (population genomics of *Brettanomyces bruxillensis* - New Zealand Winegrowers); University of Stellenbosh (harnessing killer yeast for agriculture - Royal Society collaboration grant) and amount to more than £3m global external income. **Burman**'s expertise has underpinned academic collaborations led by Swedish University of Agricultural Sciences - Swedish Research Council (Missing the big picture: how cognitive processes influence emotions in animals) and University of Bern - Swiss National Science Foundation (Lampe PhD studentship); and expert consultancy on an NC3Rs Fellowship (MRC Harwell, UK). Collaboration has been central to our development of Biophysics at Lincoln and is wide ranging. **Montealegre-Z**'s ERC project adapting the biophysics of insect hearing to design novel acoustic sensors (£1.8m) involves collaboration with both UK (UCL, Cambridge and Strathclyde) and international collaborators (Austria, Graz; Germany, Giessen; US, Case Western Reserve University), and has opened a broad interest in the new generation of genetically engineered model organisms for non-invasive hearing research, with collaborators in Japan (Hokkaido University). Funded by NSFDEB-NERC (£950K) he and collaborators in USA (Texas A&M University), and UK. (St. Andrews) are developing a substantial project that integrates phylogenomics, biophysics, and functional genomics to unravel the evolution of acoustic communication and proteins involved in hearing in insects. He is also Co-I for a University Stirling led project "Buzz pollination: Integrating bee behaviour and floral evolution" (Leverhulme Trust, £370k). **Sutton** is part of a 5-year "MURI" grant from the US Army Research Office (USARO) which includes Duke, Harvard, Carnegie Mellon, University of Massachusetts Amherst, and the University of California Irvine. A flagship paper from this on the fundamentals of generating high-speed movements in biology and engineering (Science, 2018), and led to his collaboration in a NeuroNex multi (16) university research grant funded by the UK MRC, US NSF, Canadian Science Foundation, and ERC, to derive general principles of limb movements

across all phyla. Meanwhile **Humphries'** project "Slowing Down at Small Scales: Microscale Viscosity Gradients in the Sea" was a collaboration with UC San Diego, Scripps Institution for Oceanography (Marine Physical Laboratory) and Hawaii Institute for Marine Biology.
Visiting academic positions at Lincoln are only made after independent scrutiny and are associated with specific action plans. They may come from academia or industry and staff at Lincoln are likewise supported to hold visiting positions externally. In ABCW, visiting professor Nicol has a long-established track record in animal welfare, while visiting professor McCune was the scientific leader in human-animal interactions at Mars Petcare, based at the WALTHAM Centre for Pet Nutrition. We also consider the strategic value of visiting Fellowships for staff who were previously at Lincoln but are now working in a more applied setting (e.g. Zulch - Dogs Trust, Wright -Support Dogs and latterly Guide Dogs for the Blind, Larter -International Cat Care). These staff are all involved in actively supporting PGR students and seeking new funding opportunities. In addition we host visiting staff on sabbatical, some of whom are financially supported by Lincoln Institute for Advanced Studies (see institutional environment statement) whilst at Lincoln, e.g. Prof. Ludwig Huber, Messerli Institute Vienna. Likewise, Lincoln staff hold both longstanding (e.g. **Mills**- Nottingham Vet School) and transient visiting positions at other institutions (e.g. **Mills, Wilkinson** – both University of Kyoto, Japan and supported by the Japan Society for the Promotion of Science. **Wilkinson** - University of Trento, Italy, **Goddard** - University of Auckland, New Zealand). These, alongside less formal collaborations have enabled the *extension of our research base into new areas*, e.g. **Mills**' work on facial expression of pain in cats is now being used in Macaques and other species, and widespread post graduate and PDR supervision.
During this census period our researchers assisted in the examination of over 60 PhD theses.

4.2 Relationships with users, beneficiaries and society
As described above, LIAT and NCFM, by virtue of their strategic roles provide an interface with end-users that extend our networks beyond traditional academic collaboration. The core strategic principle of both centres is to co-ordinate collaborative and research links across the agri-food sector to address and provide solutions to 'real-world' challenges facing the agri-food, agri-technology, agri-environment and food manufacturing communities. Both engage with a diverse range of external stakeholders including local and national government bodies (GLLEP, DEFRA), public bodies (CEH, Anglian Water, Environment Agency), farming communities and businesses (via NFU), industry partners and policy influencing networks (FSA, NFU, Food and Drink Federation, IoFT). Key project partners in agri-food robotics include APRIL Robotics, Berry Gardens, ABB Robotics, Beeswax Dyson, Cranswick plc, G's Fresh Limited, MTC, NIAB, SAGA Robotics, Syngenta and Garford. Other projects are built around food processing to meet consumer needs and include research to support the demand for high speed cryogenic cooling systems (BOC Linde Group), cooking technologies (OAL Advanced SI Steam Infusion), packaging laser sealing (IUK & Commercial), intralogistics & AGVs for food warehousing (H2020) and include 4 Knowledge Transfer Partnerships in the census period (total value of £640k).
NCFM have led delivery and promotion of research and innovation to over 150 Agri-food SME businesses supported in the Greater Lincolnshire Agri-food Innovation Platform funded by the ERDF. LIAT partnered with TESCO to develop the whole TESCO refrigeration store, including computing facilities to optimise service in the presence of wider national fluctuations in electrical demand. In addition, we have had a significant policy development role supporting technology readiness levels for the next technological agricultural revolution. Contributions include the provision of support to the EPSRC / UK RAS Network, Home Office Migration Advisory Committee, DEFRA and the new Food Sector Council (**Pearson** is leading the work stream reporting to SoS for DEFRA on Agri-food RAAI). **Pearson** also led the Accelerated Automation programme as a UK response to COVID impact on farms that included consultation with 75 companies and academics. He is on the steering board of Feed UK that seeks to drive digitisation across the food industry that included consultation with 700 businesses, policy stakeholders and academia. He co-wrote the food chapter of the HMG Made Smarter Review in collaboration with the HVM Catapult, Siemens and Accenture.
Representatives from the NFU and AHDB sit on the CDT industry advisory board and actively input into the research direction for these programmes. LIAT is also actively working with

Barclays to develop strong links across commercial agricultural and venture capital for supporting agri-tech in Lincolnshire and beyond.
The animal behaviour clinic of the University also serves as an interface for researchers, the public and industry. Research and consultancy work arising from our clinical services during the census period includes substantial projects with multinational veterinary companies (Boehringer Ingelheim, Ceva Sante Animale) to smaller projects with private companies (Custom Vet Products, PetProtect), and exceeds £1.5m.

4.3. Wider contributions to research base, economy and society
All researchers in this unit are expected to contribute more generally to their disciplines through engagement with key regional, national and international roles consistent with their career stage. Researchers are actively involved in professional bodies and learned societies beyond Higher Education either as committee members or through the organisation of related conferences. Notable recognition in the census period include **Mills** – Fellowship of the Royal College of Veterinary Surgeons (2016) awarded for his contributions to advancing the scientific basis of veterinary behavioural medicine.
Nearly all staff submitted hold editorial roles in relevant scientific journals (e.g. Proceedings Royal Society B, **Burman)** with the overall ratio of editorial roles to staff in this UoA exceeding 1:1. During this census period our researchers reviewed manuscripts for over 70 different international journals including Nature, Science, PNAS, e-Life, Current Biology and reviewed grants for more than 30 national (UKRI, Royal Society) and international (including Australian, Austrian, Canadian, Dutch, French, German, Israeli, Japan, Polish, Slovak, South African, Swedish, US science foundations or their equivalent as well as EU) awarding bodies.
Strategic Advisory Panels & Expert Groups: **Pearson** is a member of the BBSRC Strategic Panel for Sustainable Agriculture and Food. **Swainson** is a member of the IFST Food Processing Group and Knowledge Transfer Network Food Industry Advisory Group. **Burman** is NC3Rs Grant Assessment Panel member; **Mills** is a member of the Morris Animal Foundation's Animal Welfare Advisory Board and **Dunn** sits on the grant advisory panel and EDI group for the British Ornithologists' Union.
Wider contributions to society include the frequent involvement of staff in both an advisory and feature role to national and international media. This includes: BBC's "The One Show", "Amazing Animals", CBC's "Think Like an Animal" (**Wilkinson**); BBC "Country file," the Financial Times and across the national and international press on Agri-robotics (**Pearson**); Japan TV NHK "Dogs recognition of emotions", "Cat Empire" a multilingual French Canadian film (Mills), as well as front-cover spreads in New Scientist and coverage in National Geographic. Lincoln research (**Sutton**) has been added to the American Association for the Advancement of Science's high school AP Biology curriculum.