

Institution: Nottingham Trent University (NTU)
Unit of Assessment: C14 – Geography and Environmental Studies
1. Unit context and structure, research and impact strategy Overview The vision in this Unit of Assessment (UoA) is to continue to produce internationally excellent research that tackles the global grand challenges of climate change: how to conserve ecosystems (Whiteford ^A, <i>Ecology Letters</i>); how to adapt to changes in weather (Barber ^A, <i>Biological Reviews</i>); how to use water and other resources sustainably (Pan ^A, <i>Science of the Total Environment</i>); how to feed the rapidly increasing global population (Lu ^A, <i>Journal of the American Society for Horticultural Science</i>); and how to supply the world's energy demands (Pan ^B, <i>Journal of Cleaner Production</i>). Research returned in this UoA makes a major contribution to the University's Sustainable Futures research theme (see REF5a). It encompasses environmental and ecosystem sustainability, sustainable use of resources, and sustainable production of food. These align closely with six of the United Nations' Sustainable Development Goals (6. clean water and sanitation; 7. affordable and clean energy; 12. responsible consumption and production; 13. climate action; 14. life below water; and 15. life on land). Excellence in research is delivered through international and interdisciplinary collaboration and an environment that rewards innovation and encourages generation of new ideas. The majority (77%) of staff returned in this UoA are in the School of Animal, Rural and Environmental Sciences (ARES) with the remainder from the School of Science and Technology (SST). The strategy since REF 2014 of targeted recruitment of new staff and personalised support for existing colleagues, alongside major investment in research facilities, has resulted in an increase in all research-related activity, including: • expanding the headcount of research-active staff from 13 to 18; • growing the number of professors from none to six; • raising the number of PhD students more than five-fold from 10 to 57, with a similar rise in PhD completions in the period from 4 to 17; • resulting in significantly greater quantity (over five-fold increase) and quality of papers (77% in Q1 journals in REF2021 compared to 52% in REF2014); and • winning greater grant expenditure (over four-fold increase). Since REF2014, the ARES Research Centre has been created to act as a supportive environment for the development of ideas and delivery of projects. It comprises four research groups, three of which strengthen research interests aligned with the UoA: 1. Ecology and Conservation. 2. Natural Environment. 3. Sustainable Agriculture and Food Security. Together, these research groups have made important contributions to Geographical and Environmental disciplines, driving our understanding of the challenges raised by climate change and finite global resources. In Ecology and Conservation (led by Yarnell), the research has: 1) developed a new understanding of how climate change and anthropogenic pressures impacts individual species (Yarnell^A, <i>Biological Conservation</i>), communities (Stubbing^A, <i>Science</i>), and evolutionary processes (Barber^B, <i>Philosophical Transactions of the Royal Society B: Biological Sciences</i>); 2) provided advances in understanding non-native invasion biology (Smith^A, <i>Proceedings of the</i>

Royal Society B: Biological Sciences); and 3) how perception of predation risk can shape evolutionary characters in prey species (Barber^C, *Ecology Letters*).

In **Natural Environment** (led by Midgley), the research has: 1) been world-leading in geo-engineering for freshwater lake restoration (Pan^C, *Environmental Science and Technology*); 2) used new empirical data and modelling to better understand the global phosphorous cycle (Mortimer^A, *PNAS*); 3) enabled the National Trust to extend its blanket bog restoration programme (Labadz, Impact Case Study, REF3); and 4) developed methods to explore glacier recession (Midgley^A, *Geomorphology*).

In **Sustainable Agriculture and Food Security** (led by Burton), the research has: 1) pioneered vertical farming practices (Lu^B, *Environmental and Experimental Botany*) with external partners such as MicroMix Plant Health Ltd, Zero Carbon Foods Ltd, and ICL Group; 2) used biomolecular and chemical approaches to improve crop resistance to disease and drought (Lu^C, *Genes*); 3) developed novel sustainable food sources for poultry production (Burton^A, *Poultry Science*); and 4) demonstrated the emergence of herbicide resistance in a major agricultural weed (Hicks^A, *Nature Ecology and Evolution*).

Each research group has disciplinary identity where staff share common laboratory, infrastructure and developmental opportunities. Interdisciplinary research is fostered between groups via fortnightly research seminars, bimonthly research group meetings, and an annual research conference. Under the direction of the group leader, each research group provides subject-level strategic overview of future research directions and identifies upcoming funding opportunities along with developmental and resource needs. They provide a supportive environment where more senior staff mentor PGR students, PDRAs and early career staff on all aspects of research, including opportunities for feedback on articles, grant proposals and new research directions.

These groups also actively engage with NTU's strategic research priority areas (REF5a) which are interdisciplinary and benefit from internal funding of up to £120k pa, with particular involvement in those on Sustainable Futures, Global Heritage, and Health and Wellbeing.

Overall research leadership is provided by the Dean (Mortimer, joined from the University of Leeds) and Deputy Dean (Barber, joined from the University of Leicester) who work with the Research Group Heads. Both the Dean and Deputy Dean have considerable research leadership experience in their respective fields of environmental geochemistry and animal biology, with over 171 peer-reviewed outputs between them. They collaborate with the Associate Dean for Research (ADR), a role which was created in each academic school in 2015 to further enhance research leadership and drive implementation of research strategy (REF5a). Both Pan and Burton have undertaken this role ahead of the recent appointment of Hirst (joined from the University of Liverpool after the census date). Hirst works with the Research Group Heads to support staff in developing their research outputs and grant capture, whilst setting out clear expectations and targets in line with the strategy. The ADR is also a member of the University Research Committee and University Leadership Team providing for direct strategic alignment between UoA and institutional approaches to research.

Research and impact strategy in REF2021

Strategic investment has facilitated sustained growth in high quality research, impact and major improvements in the research environment since the previous REF cycle. All the research and impact objectives highlighted in REF2014 have been fulfilled (see data in Table 1):

- (a) The UoA has successfully enabled research-active staff to reach their potential as evidenced by the production of 371 peer reviewed outputs since 2014, a five-fold increase on the last REF period.
- (b) Furthermore, the volume and diversity of external research funding applications has increased from £725K attracted across 35 projects in REF2014 to £3M from 20 projects.

- (c) Opportunities for ECR staff to become research-active have been provided as shown by two staff members being promoted to professor (Barber, Burton as of August 1st, 2020), four staff being promoted to associate professor (Bencsik, Burton, Stubbington and Yarnell), the establishment of other colleagues into established research pathways (Di Bonito, Midgley, Uzal and Whiteford), while employing high quality ECRs (Hicks and Barlow).
- (d) The research culture has been broadened and deepened through the formation of new research groups, very significant growth in PGR numbers from 10 to 57, and provision of dedicated support for researcher development (see Section 2).
- (e) Staff in the UoA have been supported with time and internal funding in the REF period to ensure that impact is built into the UoA's research from the start. This is seen in the third of our PGR students being match-funded by external organisations, significant Innovate UK awards to Lu (see below), and the growth in research income from companies from £98k in 2013/14 to £463k in 2019/20 (REF4b).
- (f) The UoA has expanded the number and range of external organisations that benefit from research through impact. This is seen in the growth of collaborative projects set out in Section 4 involving, amongst others, the Environment Agency, the National Trust, the Moors for the Future Partnership, and the People's Trust for Endangered Species.
- (g) The infrastructure and physical estate have been developed in support of a growing research base through investment in £11M in facilities, £0.44M in equipment, and £0.34M in internal research funding since REF2014. This investment represents significant growth in the UoA's ability to lead advances in Geography and Environmental studies over the next 5 years and beyond.

Table 1. Strategic growth in Research at ARES since REF2014

	REF2014	REF2021
Cat A staff (FTE)	13	18
PhD registrations	10	57
PhD completions	4	17
Total peer-reviewed publications	68	371
Research income	£725K	£3M
Professors (as at census date)	0	6
Postdoctoral researchers	2	14

The UoA takes a synergistic approach to research and impact that builds both into research projects. This approach is supported by funding to enable the research to deliver impact where necessary. This is evidenced by the £819k invested in the Animal Nutrition Facility enabling work with partners such as AB Vista and AB Agri, £276k in a vertical farming facility leading to work with Fischer Farms and an investment of £35k in remote sensing technologies which has led to £130k of contract research with a range of partners (see details in Section 4). This approach is also seen in our two impact cases studies. Pan's work on eutrophication and harmful algal blooms has led to the commercial development of a patented technology that removes algal blooms from water sources, controls eutrophication, and restores water quality. Through licensing agreements, the technology has generated revenue for two Chinese companies, created new employment, production capacity, and societal impact (see Section 4 and REF3). Clutterbuck, Labadz and Midgley have identified new areas of geographically significant blanket bog in Spain and provided evidence to protect it from development allowing the Spanish provincial governments of Bizkaia and Cantabria and the National Trust to extend protection of blanket bog (see Section 4 and REF3).

Future research and impact strategy

The research and impact vision for the next 5 years is to grow and maintain rigour in research that embeds sustainability ever more deeply into its core concerns to meet some of society's biggest challenges. The UoA will continue to produce internationally-excellent research and impact that benefits society, using a multidisciplinary approach and novel methods to tackle problems associated with the Anthropocene. This approach builds on current strengths of

solving societal problems, crucially including those of industrial partners. In terms of broad themes, the research groups will focus on the following key areas:

1. **Ecology and Conservation:** Understanding the ecological consequences of environmental change caused by human activity by studying a range of taxa to inform current and future conservation management. Research from within this section includes developing survey methods for hedgehogs now used by the Wildlife Trust and the ecological assessments of urban ecosystems.
2. **Natural Environment:** Understanding environmental change associated with the Anthropocene and delivering innovative approaches for sustainable management and utilisation of resources. Research within this group includes peatland assessments detailed in our impact case study (Clutterbuck, Labadz and Midgley).
3. **Sustainable Agriculture and Food Security:** Working in partnership with industry to deliver innovative ideas and multidisciplinary approaches to feed the growing global population including the improvement of commercial feeds for livestock and developing drought resistant crops.

The UoA's strategy for research and impact over the last seven years has had demonstrable success as set out above and therefore the future strategy builds on this with further specific objectives:

1. Increase external research income, targeting both existing and new industrial partners and increased applications through UKRI, particularly for larger, collaborative programmes.
2. Further develop the level of scientific analysis and exegesis required for internationally-leading publications through active mentoring and external collaboration.
3. Through internal development and strategic recruitment, increase the number of staff delivering excellent research and impact.
4. Continue to invest in time and funding to ensure that impact is integral to our research projects, and therefore integrated into research plans from the outset, thereby extending the range of impact partners.
5. Increase the number of externally funded PGR students, including through match-funded projects and doctoral training partnerships.
6. Increase international collaboration including through NTU Global (see REF5a) and specifically an Eastern Africa Centre, building further on NTU's existing links in the region, in order to deepen and enhance research, training and teaching opportunities (REF5a).
7. Further improve research infrastructure including a genomics and ecology research laboratory, which is at an advanced stage of planning, and through investment in other facilities targeted on areas of strategic growth in the Research Centres.

Research integrity and ethics

Matters relating to research integrity, including research ethics, are overseen centrally and managed locally. The University Research Committee, chaired by the Deputy Vice-Chancellor – Research and Enterprise, and reporting to the Academic Board, is responsible for the development and monitoring of research integrity policies and procedures. Robust scrutiny of projects undertaken by staff and PGR candidates within the UoA is overseen by a local research ethics committee, which includes staff from across the departments within the School. This approach ensures projects are scrutinised from different disciplinary perspectives. Staff and students also have access to online modules relating to different aspects of research integrity and research-related developmental opportunities via the University (see REF5a).

2. People

Staffing strategy

Staffing strategy centres on the targeted recruitment of world-leading researchers to broaden and deepen current research strengths alongside personalised developmental support for existing staff. Six new professorial appointments have been made since 2014, where colleagues joined from a range of established research-intensive universities. In addition to Mortimer (Leeds) and Barber (Leicester), these are, Lu (Nottingham), Pan (the Chinese Academy of Sciences, Beijing), Wilson (De Montfort/Rare Breeds Survival Trust) and Smith (St Andrews). Two early-career researcher (ECR) appointments have also been made. The research team is international (28%) and has a gender balance of 66% male and 33% female.

These professorial appointments were made strategically to provide senior academic leadership to research in sustainable agriculture (Lu), statistical modelling (Smith), and ecological engineering (Pan). These appointments have facilitated the REF2014 strategy to deliver world-leading research and impact. For example, Lu has placed NTU at the forefront of sustainable agriculture, attracting over £1.5M in Innovate UK funding to improve the productivity and sustainability of hydroponic growing systems and to increase drought resistance in crops; this led to a range of high-profile publications (*Lu^D Environmental and Experimental Botany*).

Having addressed the need for research leadership and senior experience identified as key in REF2014, the focus has shifted to building the capability of both new ECRs and existing colleagues. ECRs with potential to be world-leading have been employed to enhance the Natural Environment (Hicks) and Ecology and Conservation (Barlow) Research Groups, adding expertise in evolution of herbicide resistance and genomics respectively. Strategic development and investment in existing staff have led to the promotion of two members of staff to professor (Barber, Burton as of August 1st, 2020), and four to associate professor (Bencsik, Burton, Stubbington and Yarnell) to further support productive research groups.

Support and development for staff

Staff are key to achieving research excellence and delivering impact. The NTU Appraisal system is designed to support individual aspirations and empower staff to reach their potential (see REF5a). The cornerstone is the Individual Research Plan (IRP) through which academic colleagues (below professor), research assistants and postdoctoral research fellows are supported by research mentors who help them develop their annual IRPs. These are then used for objective setting during appraisals. IRPs and appraisals identify developmental needs such as training, visits to international collaborators and conference attendance, all of which secure support from staff development budgets.

The research aims of individual staff are realised by accessing time, training, and resources within an intellectually stimulating environment. Research time for staff with significant responsibility for research is provided through a workload allowance. Teaching buyout for research sabbaticals is another way dedicated research time is allocated and in this REF cycle £112k has been allocated to advance research. For example, Midgley used his sabbatical to demonstrate the potential value of Structure from Motion photogrammetry and unmanned aerial vehicles for monitoring environmental change (Midgley^B, *Remote Sensing*).

Research training is important for developing skills and expertise within ARES. Staff have access to research-related developmental opportunities via the University (see REF5a), and bespoke activities are also provided within the UoA (e.g. paper writing, grant writing and statistical modelling workshops led by Smith). A grant club and a coding club help to develop and support grant writing skills and coding development of staff. These clubs meet monthly to discuss grant proposals, new ideas, and advanced data handling and analysis and are attended by academic staff and Postgraduate Research (PGR) students. They also facilitate cross-research interaction and help develop the research community.

Peer support and provision of an intellectually stimulating environment is further facilitated via the research groups, which provide dynamic environments for researchers at all levels (PGRs through to the professoriate) to share draft ideas, manuscripts and proposals for discussion. This is borne out in the results of the most recent University Staff Survey within ARES, which confirmed high levels of satisfaction with the support they receive from work colleagues (90%) and that their line managers respect and value them (89%).

Access to internal funding (£343K) has facilitated staff in the delivery of their research. Internal funding has been used to: ensure the smooth operation of well-equipped laboratories; provide additional resources for doctoral projects where scaling up will yield better data and robust inference; and give opportunities for conference attendance, networking and collaboration. All new members of academic staff are awarded £4K funding to kick-start research activity. There are also annual seedcorn and follow-on funding calls from NTU Strategic Research Themes, from which C14 staff have gained £84K (£54K Sustainable Futures; £11K Global Heritage; £19K Health and Wellbeing). These have led to new international collaborations in Kenya (Di Bonito), advances in sustainable agriculture (Lu), and new investigations into the impacts of invasive species (Yarnell). Internal funding has proved essential to targeting investment at staff to develop new research areas, form new partnerships nationally and internationally, and for initial research that lays the foundations for grant applications. These internal rounds are competitive and based upon ensuring that we target funding towards early career researchers and into strategically important areas to the School.

Equality, diversity and inclusion

Our School is a vibrant place to work, enriched by the diversity of perspectives, cultures and backgrounds brought by our students, staff, visitors, and local, national and international partners. Within our research groups, we recognise that diverse teams encourage more creative and innovative solutions to tackle the global grand challenges of climate change.

The University was awarded the bronze Athena Swan charter mark in April 2019 (see REF5a) and targets a silver submission in 2023. Supporting this, the School strategy aims to make a bronze submission in 2022. A School team is currently conducting reviews, including cultural surveys on gender identification, promotion prospects and support, as a basis for developing an action plan for moving towards gender equality. Our School's Athena Swan champion leads these efforts and coordinates School-level Equality, Diversity and Inclusion (EDI) activities including nominations to the Advance HE Aurora programme (5 individuals have attended this since 2014), events for International Women's week, and Black History month. The EDI intranet links staff to relevant University networks, policies and resources.

Staff training improves knowledge and understanding of equality and diversity within the workplace, for example, including unconscious bias and trans-awareness workshops. The University also provides mandatory online courses on equality and diversity.

Recruitment across the School uses gender decoding of recruitment materials and mixed-gender interview panels, to attract a more diverse staff pool. Across all academic staff in ARES, 64% identified as women, 6% declared as being Black Asian and Minority Ethnic (BAME), and 6% declared with a disability in 2019. The international outlook of the UoA is also enhanced by the number of international colleagues (28%). The UoA is actively supporting the Athena SWAN institutional KPI target to increase the percentage representation of women within the NTU professoriate to 35% by 2022.

We also encourage a flexible and inclusive approach for staff working from home, or remotely. For example, the Support of Academic Returners (SOAR) scheme funds up to £5k following a period of caring-related leave to support career pathway development.

Staff perception of EDI issues is very positive. Across the School, the 2018 Staff Survey showed 94% agreement with *all* statements of equality of opportunity and protected characteristics, including "I believe the University is committed to equality of opportunity for all of its staff".

Support and development for postdoctoral researchers and PGRs

Postdoctoral researchers and PGRs are integral to our research community, providing valuable contributions to research groups, seminars and internal research conferences. This postdoctoral research community has grown from two during REF2014 to 14 across the REF2021 period. Postdoctoral staff are supported through the same processes as academic staff, including academic staff training opportunities, mentoring and support to attend external and internal events. They are encouraged to engage with the Vitae Research Development Framework to achieve professional development as they strive for research excellence, innovation and impact. The collegiate research environment at ARES has helped enable postdoctoral researchers to reach their potential as independent researchers. This is exemplified by a large number of first authored outputs by Bian on the importance of light colour in food plant development, with the findings being applied by international companies.

The PGR community is also flourishing within the ARES environment. Since REF2014, PGR numbers have increased from 10 to 57. Of these, 38% are international, including six from continental Europe. Funding of the registered PGRs comes from the NTU Studentship Scheme (32%), through studentships match-funded by NTU and external collaborators (33%), and the remaining 35% are fully externally funded. All PGRs in the ARES Research Centre have their own desk and computer and are located in rooms based within their research group to facilitate interaction and peer support.

The UoA also benefits from inclusion in The Nottingham Biotechnology and Biological Sciences Research Council (BBSRC) Doctoral Training Partnership, incorporating the University of Nottingham, NTU and the National Biofilms Innovation Centre. It offers fully funded, four-year PhD studentships that are aligned to strategic priorities supported by the BBSRC and will further grow PGR numbers. The first candidate from this partnership started in October 2020. The UoA does not award professional doctorates.

The Doctoral School manages doctoral training and administration (see REF5a). All PGRs have at least two supervisors who oversee research planning and progress, with 12 mandatory meetings each year. PGRs produce annual monitoring reports to oversee progress and provide a formal process of feedback from supervisory teams in association with an internal independent assessor. These processes are overseen by a School Research Degrees Committee which reports to the University Research Degrees Committee.

The PGR Tutor, their deputy and the PGR representative facilitate regular social and scientific meetings for PGRs to build a sense of doctoral community locally. PGRs join one or more of the research groups and attend School research seminars, present at and chair some of the seminars and become involved in their organisation. Many PGRs undertake teaching, after completing an NTU qualification. Other development opportunities for PGRs and supervisors have included sessions on publication offered by the library research officer and workshops on paper writing, grant writing and statistical modelling provided by experienced research staff (Smith).

All PGRs enrol on the NTU Doctorate Plus Programme of workshops and training events to support their professional development. These events map to the Vitae Researcher Development Framework (see REF5a). Where specialised training needs are identified, PGRs secure support to attend external training courses or apply for external funding to support training (for example: NERC Biomolecular Analysis Facility at the University of Sheffield; £57K - Yarnell). Where external training has been provided, PGRs are requested to share newly developed skills and knowledge with research groups or via seminars.

All PGRs are encouraged to publish in peer-reviewed journals before thesis submission and to present at international conferences. Since REF2014, PGRs have published over 30 papers. For example, Tonkin (Midgley^C, *Boreas*) used novel ground penetrating radar to document the internal structural characteristics of moraines.

The champion for the Concordat to Support the Career Development of Researchers (Scholey) actively supports the development of early career researchers. As a result, many of our PGR graduates are independent early career researchers, securing appointments to research or lecturing posts across the world, e.g. Morgan (University of New England) and Root-Gutteridge (Syracuse University USA), from where they retain collaborative links with staff in the UoA.

3. Income, infrastructure and facilities

Income

A total of 120 external research grants totalling over £3M have been won since REF2014. These included two awards from the EU (£481K), two awards from UK Research Councils (£24K), 57 from industry and commerce (£1.9M), 15 from UK Government agencies (£192K) and 19 from charitable foundations (£333K).

These data demonstrate that a considerable strength of the UoA is its ability to attract funding from industry, government agencies and charitable foundations. For example, the Sustainable Agriculture and Food Security Research Group works closely with industry, attracting over £1.8M in funding since 2014, resulting in 24 outputs for Burton (e.g. Burton^B, *Animal*) and 20 outputs for Lu (e.g. Lu^D, *Plant Biotechnology Journal*). Researchers also work closely with charities and support knowledge exchange. For example, researchers in the Ecology and Conservation Research Group (Yarnell and Uzal) have received over £100K from the People's Trust for Endangered Species' (PTES), to inform hedgehog conservation management. Working with PTES, this research incorporates citizen science leading to considerable impact as evidenced by over 40 conservation organisations using the methods to engage the public in scientific monitoring programmes.

Infrastructure

The majority of staff in the UoA are members of ARES, which has a significant physical infrastructure within which to deliver world-leading research in Geography and Environmental Studies. It possesses 200 hectares of land covering a range of habitats and a full working farm; hence it is itself a living laboratory providing a wide range of opportunities for sustainability research. Staff also have full access to the extensive research facilities provided at Clifton and City Campuses, from which the staff from SST returned within this UoA also benefit (see REF5a).

Research is supported by an expanded University Research Operations team who cover both pre- and post-award grant preparation and management. During the REF cycle, NTU invested in a full research lifecycle research information management system, Worktribe, to support this work (see REF5a).

Since REF2014, there has been significant capital investment in the ARES Research Centre's infrastructure and equipment. This has enabled the UoA to meet strategic research goals and enhance the vitality and sustainability of research. These facilities include:

- Animal Nutrition Research (£819K)
- Sustainable Agriculture facility: glasshouse, growth rooms, and container farm (£276K)
- Geospatial facilities and equipment (£50K)
- Integrated Water Energy Food (iWEF) facility (£233K)
- Lyth Building: new teaching and research space that includes: (a) environmental research laboratory; (b) geospatial computer cluster; and (c) new PGR suite (£10.2M)

Alongside the investment in facilities and infrastructure, ARES has invested in technical support staff, which includes a new Technical Team Leader for Laboratories, a Senior Technician for the Food Laboratory, and a Technical Specialist for Agriculture. Overall, this brings the number of ARES technical support staff from 19 in 2014 to 29 in 2020. There has also been an increase in the number of technical support staff funded by external income from one to five, as a result of

42 contracts worth £1.2M awarded to the Animal Nutrition Research Facility. The University is a signatory of the Science Council's Technician Commitment, which aims to support career development and sustainability for technical support staff in research.

Facilities

Main research facilities include:

(1) Animal Nutrition Research Facility

This facility is equipped to research the interplay between nutrition, environmental sustainability and gut health. It is widely used by the agri-sector for their research and development needs, including both UK and multinational companies (e.g. AB Agri). The building houses two environmentally-controlled poultry growth rooms, a micro-scale feed mill, and a nutrition laboratory with £266K worth of analytical equipment that facilitates research on skeletal development of birds and mammals. The wider investment has led to income of over £1.5M in REF2021 period. A key focus of research conducted here addresses the problem of premature death of chickens due to poor bone health; this affects 343 million chickens raised annually for food production. Research has demonstrated the essential biological role of silicon on bone health and produced a bioavailable form of the mineral to increase bone strength, thereby addressing issues of welfare while increasing production efficiency in the supply chain and reducing waste.

The facility also supports 700 hours of UG research experience annually, as well as an average of seven PGRs. It underpins collaborative research with many other UK universities (Leicester, Nottingham, Roslin Institute, Scotland's Rural College and Harper Adams).

(2) Sustainable Agriculture Facilities

NTU has invested £276K to establish a world-class vertical farming facility for research, training, and innovation. The Sustainable Agriculture and Food Security Research Group has several research projects in this field funded by Innovate UK, BBSRC and other external funding bodies. Total awarded grants are over £1.8M since 2016 helping to develop strong links with industry and other institutes in both the UK and China. Research from these facilities has changed crop growing practices across 18 companies/research institutes (e.g. Fischer Farms and Bangladesh Agricultural University) to help improve sustainable and efficient crop production. Specific facility components include:

- a) Plant growth rooms: a state-of-the-art plant growth facility provides the highest-quality research environment within which to produce plants. It is a multi-tiered growth room that provides 180m² of growing space, with flexible moving trolleys and easily adjustable LED lighting systems. These can be programmed to generate an optimised LED light wavelength recipe unique for each plant species and different developmental stages.
- b) Shipping container farm: a fully automated and controlled-environment container farm with hydroponic and aeroponic growing systems with LED lighting has been developed for smart green growth. The farm is powered by a photovoltaic solar system of 15 kWh capacity built onto the roof of the container providing more sustainable and efficient use of energy. The whole growing system is controlled via an app, and Azure's cutting-edge resources (Microsoft) have been used to ensure the highest possible degree of precision over plant resource capture leading to optimization of crop growth and improved produce quality.
- c) Glasshouse: glasshouse facilities for vertical farming provide vertical multi-tier recirculating hydroponic/aeroponic growing systems with mobile benches, growth lamps and environmental controls to enable quality research and teaching. The glasshouse has attracted over 3,000 visitors in the last two years including 150 from industry and is likely to generate considerable impact on crop production systems in the near future.

(3) Geospatial Facilities

NTU funded equipment has greatly contributed to advancements in geospatial analysis. Drones, remote sensing equipment, cameras, and imagery processing are transforming our ability to track environmental change. For example, investment (£35K) in drones for aerial image acquisition has enabled world-leading research (over 200 citations from two outputs) by using high-resolution imagery to improve understanding of landscape processes. The investment in remote sensing technologies has generated income from contract research (£130K total) from Moors for the Future Partnership, the National Trust and internationally from the Government of Bizkaia (Spain). The geospatial facilities have also helped researchers lead the way in updating the global peatland inventory, monitoring the impacts of restoration, and informing national and global peatland monitoring initiatives.

(4) iWEF

Research in the Integrated Water Energy and Food research facility (iWEF) is world leading and has resulted >60 publications in Q1 journals in Environmental Science since 2014. The iWEF is a multidisciplinary research platform designed to study water and soil remediation by removing pollutants from waters (e.g. nutrients) and soils (e.g. metals and persistent organic pollutants) using microalgae and nano technologies. The extracted pollutants and algal biomass are used as a resource for green energy and soil remediation materials, the latter helping safe agricultural crop production. This research has been supported by internal investment in facilities including, but not limited to, experimental columns used to simulate eutrophication in shallow and deep lakes, photo reactors for algae cultivation and oxygen nanobubble generators (£233K). iWEF research has also led to a Patent, "Aquatic Vegetation Restoration Device and Method" (NO.: WO/2018/234791) which has been licenced (£20K) to a Chinese Company (Yantai Harmful Algal Bloom Control and Ecological Restoration Technology Co. Ltd.) for five years. The iWEF facility has helped secure £137K in external funds from two research contracts from Yantai Harmful Algal Bloom Control and Ecological Restoration Technology Co. Ltd. (£116K) and Hunan Zhongke Water Environment Management Co., Ltd. (£21K).

(5) Environmental Research laboratories

The Lyth environmental research laboratory completed in 2020 is designed as a multidisciplinary space. It supports internationally important research in Geography and Environmental Studies and will be essential to achieving the UoA's future strategic research aims (see Section 1). A range of researchers from across the UoA who conduct experiments to understand natural processes will benefit from facilities that allow the analysis of environmental samples (water, soil, sediment and macroinvertebrates). Facilities include sample preparation (e.g. ultrasonication, digestion and calcination), storage (ultra-low temperature freezer), sterilisation (autoclave), nutrient (AutoAnalyzer, Seal analytical Ltd), elemental analysis (Elementar Ltd.) and organic pollutant or nutrient detection (GC-MS, Shimadzu Ltd.).

4. Collaboration and contribution to the research base, economy and society**Collaborations, networks and partnerships**

The UoA's global outlook focusses on addressing challenges arising from climate change and finite global resources. Understandably, therefore, since REF2014 89% of papers have had external partner institutions, with 64% including an international partner. As detailed in Section 2, ARES provides financial support to establish new international collaborations, as well as staff development funds to sustain existing relationships. ARES also has several strategic international partnerships:

- (1) In 2017, ARES established a Joint Research Institute in Sustainable Agriculture with Jiangsu Academy of Agricultural Sciences (JAAS) in Nanjing, China. This has led to a funded postdoctoral training scheme where ECRs from JAAS spend 1-2 years at NTU developing their scientific skills and improving their English. To date, three postdoctoral research Fellows have visited, producing eight high quality publications in the fields of global food security and production (e.g. Lu^F, *Genes*).

(2) In 2019, ARES established a network in Kenya to evaluate the effectiveness and sustainability of reintroduction of indigenous forest. The network includes Jomo Kenyatta University (JKU), Mount Kenya University (MKU) and the Brackenhurst Limuru Eco-campus (founded by a historical link to NTU's Brackenhurst campus in Nottinghamshire). Since then, a memorandum of understanding has been signed and plans are being developed to strengthen our work in the region (see Section 1). The network has also secured ERASMUS+ funding to support this work (€120K). Staff are also working with the Kenyan Wildlife Trust (KWT) to secure the long-term conservation of the Greater Mara Ecosystem through scientific research and capacity building activities, such as mentoring opportunities. The pillar of this initiative is the creation of the One Mara Research Hub (OMRH) and NTU is represented by Uzal.

(3) ARES has also recently established a Sustainable Agriculture network (Global Challenges Research Fund, £30K, PI: Lu) with China, Bangladesh, and Malawi.

(i) Other international collaboration

NTU prioritises international collaboration through its NTU Global team (REF5a) and the UoA has collaborations with more than 80 countries. For example, the iWEF facility collaborates closely with China, attracting a range of visiting postdocs and scholars funded by Jiangsu Academy of Agricultural Sciences, China and the China Scholarship Council.

International collaborations mean that staff in the UoA have global influence. For example, Pan is a world leader in the field of lake restoration after developing Modified Local Soil (MLS) technology to achieve multiple functions of harmful algal bloom removal and eutrophication control. The iWEF facility has demonstrated significant impact by restoring freshwater lakes in China, leading to improved biodiversity and benefits to local economies. Through licensing agreements, the technology has generated revenue for two Chinese companies, created new employment and production capacity, and shaped these companies' investment strategies. It has also been used as part of a wider freshwater protection strategy for one of New Zealand's largest lakes (see REF3 Impact Case Study).

Many staff collaborate with EU partners to advance research knowledge within subject disciplines leading to world-leading outputs (e.g. Barber^C, *Ecology Letters*). Bencsik is collaborating with 17 EU partners on the 'b-good project' to promote sustainable honey beekeeping in the face of pollution, invasive pests and climate mediated threats, which will help safeguard bee pollination services (Research Executive Agency €8M – 9% to NTU). Examples of other staff with EU collaborators include: Smith (Czech Academy of Sciences, Czech Republic and University of Lodz, Poland), Mortimer (German Research Centre for Geosciences, Potsdam, University of Crete) and Barlow (Leibniz Institute for Zoo and Wildlife Research).

(ii) Collaborations with UK Universities

Staff in the UoA have extensive UK research networks, with 85% of all outputs having a UK-based collaborator. Staff also work closely with UK collaborators on external funding bids. For example, Yarnell's successful grant applications (>£100K) to the PTES have also had collaborators from the Universities of Reading, Cambridge, Cardiff, Brighton and the UK Government's Animal and Plant Health Agency. This research has resulted in development of novel citizen science methods for monitoring species of conservation concern (Yarnell^B, *Remote Sensing in Ecology and Conservation*) while also informing release protocols for rehabilitated animals that have been implemented by the Royal Society for the Prevention of Cruelty to Animals (RSPCA) (Yarnell^C, *European Journal of Wildlife Research*).

(iii) Collaborations with industry and government

Much of the UoA's research is applied in its nature and includes close collaboration with industry to find research-driven solutions to industry needs. Burton and Lu collaborate with industry

partners to improve sustainable food production systems. The Natural Environment Research Group has had success in attracting contract research for water regulatory authorities and moorland interest groups (£82K). In addition, the Ecology and Conservation Research Group collaborate closely with Government agencies. For example, Stubbington's drying rivers research collaborates on £202K worth of projects with the Environment Agency (EA) and the Centre for Ecology and Hydrology (CEH) valuing Nature Programme, supporting two PGRs and two postdoctoral research fellows.

(iv) 50:50 studentships

Submitted staff have successfully taken advantage of NTU's match-funded PhD scheme (see REF5a) resulting in 10 PhDs funded by industry (Guanasena, AB Agri, Purico), Government agencies (EA) and charities (PTES), generating >£290K to support wider research aims within the UoA.

(v) Visiting researchers

ARES has 18 visiting fellows and two honorary and one visiting professor, who collectively have helped broaden the research leadership team and provide support and collaboration with existing research staff.

Wider activities and contributions to the research base, economy and society

Researchers at ARES contribute to the Geography and Environmental Studies research base in numerous ways.

Visiting professorships are held by Mortimer (Leeds), Smith (Lodz, Poland and Czech Academy of Sciences, Czech Republic), Lu (Jiangsu Academy of Agricultural Sciences) and Pan (Chinese Academy of Sciences) which facilitates research collaboration and knowledge exchange.

Staff hold editorial positions with 10 journals, including Smith and Stubbington as Editor-in-Chief for *Journal of Vertebrate Biology* and *Fundamental and Applied Limnology*, respectively. Staff research quality has been recognised through invited Guest Editorship for a special edition of *Water* (Pan). Staff have also contributed to national (Mortimer, NERC Peer Review College Member) and international review panels (Smith, Czech Academy of Sciences). Staff are also members of advisory panels (e.g. Pan, UK Research & Innovation (UKRI) Sustainable Advisory Group and membership of NERC-Responsible Research Framework) and contribute to national and international grant reviews for NERC (Mortimer, Smith, Yarnell), BBSRC (Burton, Mortimer, Smith), Australian Research Council (Mortimer), Austrian Science Fund (Smith), Czech Grant Agency (Smith), Polish National Science Centre (Smith), Royal Society (Mortimer) and the National Research Foundation South Africa (Yarnell).

Staff within the UoA also hold leadership positions with learned institutions such as the President of UK Branch of the World's Poultry Science Association (Burton), President of the Fisheries Society of the British Isles (Barber), and Chairman of the Royal Society of Biology East Midlands Branch (Wilson). Other contributions to research networks include committee membership of IUCN Specialist groups for hyaena (Yarnell), Science and Technology Facilities Council Food Network Champion for Asia (Lu), Expert Scientific Advisory Committee to the Department of Environment, Food and Rural Affairs (Wilson), and Policy Expert for the European Regional Focal Point within the European Commission (Wilson).

The quality of research is evident in prestigious awards and fellowships including the Chinese National Prize on Hydrology and Ecology (Pan), NCN Polonez Fellowship (funded under Horizon 2020 as a Marie Skłodowska-Curie action) (Smith), fellowships of the Royal Geographical Society (Midgley) and Royal Society of Chemistry, Joseph Black Medal and Award (Wilson).

Dissemination of research at conferences is a key element of communicating the quality research produced by the UoA. Dissemination has resulted in keynote presentations by Pan, Stubbington, Mortimer and Burton during the submission period. For example, Pan was the

keynote speaker at the American Chemical Society (ACS) symposium (256th ACS National Meeting in Boston, USA (2018), and led an INDO-UK workshop on Waste Water Management (Newton fund and Royal Society of Chemistry, 2019).

The UoA is also a strong advocate of research-informed teaching with ARES-led research in undergraduate and postgraduate taught courses. Undergraduates are also encouraged to collaborate on research projects, which is facilitated through the SPUR (Scholarship Projects for Undergraduate Researchers) scheme (see REF5a). It provides staff with the opportunity to mentor and receive assistance from an undergraduate student and enables students to gain research experience and contribute to the production of new knowledge in their field. SPUR projects also feed back into the curriculum to benefit the wider student community. Since 2014, 13 scholarships have resulted in five outputs.

Staff in the UoA also actively engage in outreach. For example, Smith held a Royal Society Partnership Grant in collaboration with primary schools in the Outer Hebrides with a project “Why did the stickleback lose its spines?”. The research of the UoA has also inspired work in the Arts and Humanities with Bencsik’s collaboration with artist Wolfgang Buttress securing a £6M commission to design the UK pavilion of the 2015 World Exhibition. The exhibit was based around the multi-sensory experience of a beehive, derived from real-time sensor data streamed from a honeybee colony. This award-winning building is now housed at Kew Gardens, with subsequent pieces commissioned at Glastonbury and Abu Dhabi. Meanwhile, the associated sensors and software are under development for applications in commercial honey farming (Bencsik^A, *PLoS ONE*).

Summary

This submission demonstrates the step-change in the research environment since REF2014, resulting in a tangible improvement in quantity and quality of research within the UoA. All research metrics associated with the UoA have improved, as evidenced by income, quality of outputs and increasing research staff and PGR numbers. Our ambitious research strategy will build on this success to sustain and enhance our research environment to optimise the ambition to deliver research solutions to global climate change issues across society and the environment.

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