

Institution: University of Greenwich
Unit of Assessment: 6 - Agriculture, Veterinary & Food Science
<p>1. Unit context and structure, research and impact strategy</p> <p>Overview</p> <p>The Natural Resources Institute (NRI) (nri.org) is a vibrant interdisciplinary research unit, which puts addressing the UN Sustainable Development Goals (SDGs) at its core. It delivers significant improvements to food and agricultural systems, mainly in low- and middle-income countries (LMICs). With critical mass focused on research excellence and its translation into impact, NRI's research environment is underpinned by a global and diverse partnership network (>500 organisations in 60 countries).</p> <p>The excellence of NRI's research was recognised with a Research England 'Expanding Excellence in England' (E3) Award (£7.5m) in 2019. The impact achieved by NRI's activities has been recognised by two Queen's Anniversary Prizes for Further and Higher Education (QAP): 2015 <i>Cassava for Food Security</i> and 2019 <i>Innovative, Sustainable Pest Control</i>, adding to an award in 2001 for work on Food Security in Africa.</p> <p>NRI's research spans UoA6 (47.03 full time equivalents (FTE)) and UoA22 (23.30 FTE) reflecting broad interdisciplinarity. The UoA's specialised Research Groups contribute to challenge-led, interdisciplinary Development Programmes. NRI's environment supports career progression and development from postgraduate researcher to senior professor. It nurtures research leadership, reflected in high staff retention (>90% of staff submitted REF2014 retained for REF2021, excluding retirements), a high proportion of submitted staff promoted during the REF period, including seven to professor, and a low proportion of staff on fixed term appointments (10%). Diversity of staff within the unit has increased, with %female staff increasing from 24% to 41% and %Black, Asian and Minority Ethnic (BAME) increasing from 4% to 33%.</p> <p>Achievement of Strategic Aims</p> <p>In this period, NRI implemented its strategy 'Knowledge to Feed the World', underlining its ambitious mission: 'To discover, apply and share knowledge in support of global food security, sustainable development and poverty reduction'. Key elements of the strategy taken from the REF2014 submission and subsequent outcomes are summarised below and in Table 1.</p> <ul style="list-style-type: none"> • Grow external research income. Research income has increased 140% in the REF cycle (from £19.3m in REF2014 to £46.3m) against a target of 35%, including a six-fold increase in Research Council funding. • Develop Research Groups and Development Programmes. NRI has significantly evolved its matrix of Research Groups and Development Programmes (described below), the bedrock of the unit's growth, vitality and sustainability. • Grow UK/European focused work. We achieved our ambition to expand the amount of research and enterprise in UK and Europe (new projects £2.44m) whilst retaining a focus on LMIC food and agriculture systems. This has culminated in two major UKRI awards (2020): Strength in Places Project "Growing Kent and Medway" (£17.9m led by NIAB-EMR (NRI budget £2.8m) and the NRI-led UK Food Systems Centre for Doctoral Training (CDT) (£5.0m). • Win larger projects to ensure effectiveness of operations. In addition to the E3 Award, Strength in Places and UK Food Systems CDT projects, other significant projects include: the African Cassava Whitefly Project (Phase 2) (Bill and Melinda Gates Foundation (BMGF), £8.53m); Cassava Adding Value for Africa (CAVA) (Phase 2) (BMGF, £13.07m); Sustainability-Intensification Trade-offs in Coffee Agroforestry (BBSRC, £1.37m); Natural Pest Regulation on Orphan Crop Legumes (BBSRC, £0.99m); Gains from Losses of Root and Tuber Crops (EU, £2.37m); Cassava Growth Markets (EU, £2.33m); D-Factory (EU, €7.20m); African Post-Harvest Loss Information Systems (BMGF, £2.42m); Enabling Research Tools for Cassava and Yam Virologists and Breeders (BMGF, £1.8m);

Unit-level environment template (REF5b)

DualCassava (Africa Union, £0.7m); Human Decoy Mosquito Trap (MRC, £0.56m) and UK-China Agritech (BBSRC-Newton, 0.42m).

- **Develop a research portfolio funded by industry, Horticulture Development Company (HDC) and Technology Strategy Board (TSB).** Since 2014, UoA6 staff have engaged in 29 Innovate UK (previously TSB) and Agriculture and Horticulture Development Board (previously HDC) projects (£1.38m).
- **Maintain focus on high quality peer reviewed output whilst expanding other forms of dissemination, including public engagement.** Peer reviewed journal output (UoA6) has increased by 128%, with Q1 publications (by SJR) increasing by 142%, increasing volume and quality. NRI communications team increased from 1 to 2.5 FTE enhancing research dissemination (74 press articles in 2019/2020; unique website views doubled since 2018) and social media (30-fold increase since 2014). Examples of public engagement are in Box 1.

Table 1: Summary performance metrics.

Performance target area	REF2014	REF2021	%Increase
Staff submitted	23.5	47.03	100%
Total research income/year (average over period)	£3.86m	£6.61m	71%
Research Council average income/year	£0.12m	£0.74m	524%
PhD completions	15	36	140%
Published outputs in period (submitted staff)	298	680 (11,398 citations)	128%
Field weighted citation impact	1.63	2.13	
Publications in Q1 Journal Quartile by SJR	226	549	142%

Wider research environment

NRI has a total staff of 112.53 FTE (47.03 FTE UoA6; 23.3 FTE UoA22; 13.6 FTE focused on teaching or enterprise and 28.2 FTE professional services staff providing technical or administrative project delivery support). A high proportion (84%) of academic staff have significant responsibility for research (SRR).

NRI is part of the Faculty of Engineering and Science and collaborates extensively with colleagues in the University. Staff/Postgraduate research (PGR) students benefit from a campus-based research hub that provides services from the University's Research and Enterprise Training Institute (RETI) and University researcher support services.

NRI's Professional Services team support project delivery using an ISO9001 accredited research management system ensuring compliance with funder requirements and University financial/procedural regulations. A robust due diligence process for sub-contractors addresses key issues including safeguarding, money laundering, modern slavery, anti-terrorism, fraud, data protection, conflict of interest, use of animals, use of human tissue, bribery, insurance, research ethics, health and safety. Independent committees considered research ethics at Faculty and University levels. Research degrees are overseen by a tightly governed Faculty Research Degrees Committee reporting to the University Research and Enterprise Committee.

Staff contribute to a growing research-led teaching portfolio (e.g. new MSc Programmes in Global Environmental Change and Food Innovation, and BSc Climate Change), with student projects aligned to core research activities.

Staff and PGR students participate in both 'Research Groups' and impact-focused 'Development Programmes' addressing major development challenges (Figure 1). Staff and PGR students primarily align to one Research Group, and often have secondary affiliations, but contribute to multiple Development Programmes. Research Groups and Development Programmes are actively managed to ensure success.

Unit-level environment template (REF5b)

Delivering Research Excellence through Research Groups

NRI's Research Groups (RGs) (Table 2) support research, using common specialised facilities, methods and approaches. Combined with the Development Programmes these are the main part of the NRI Research Environment (Figure 1). NRI's Research Groups have evolved from those in REF2014 reflecting the growth of the unit and the research agenda. The Postharvest and Value Addition Group became the Food Systems Group, significantly strengthened with the E3 Award with skills in food safety, food innovation and food systems for improved nutrition. Aquatic Biotechnology and Biology Group is new, following growth and investment under the leadership of **Harvey**, attracting £1.4m in retained external income.

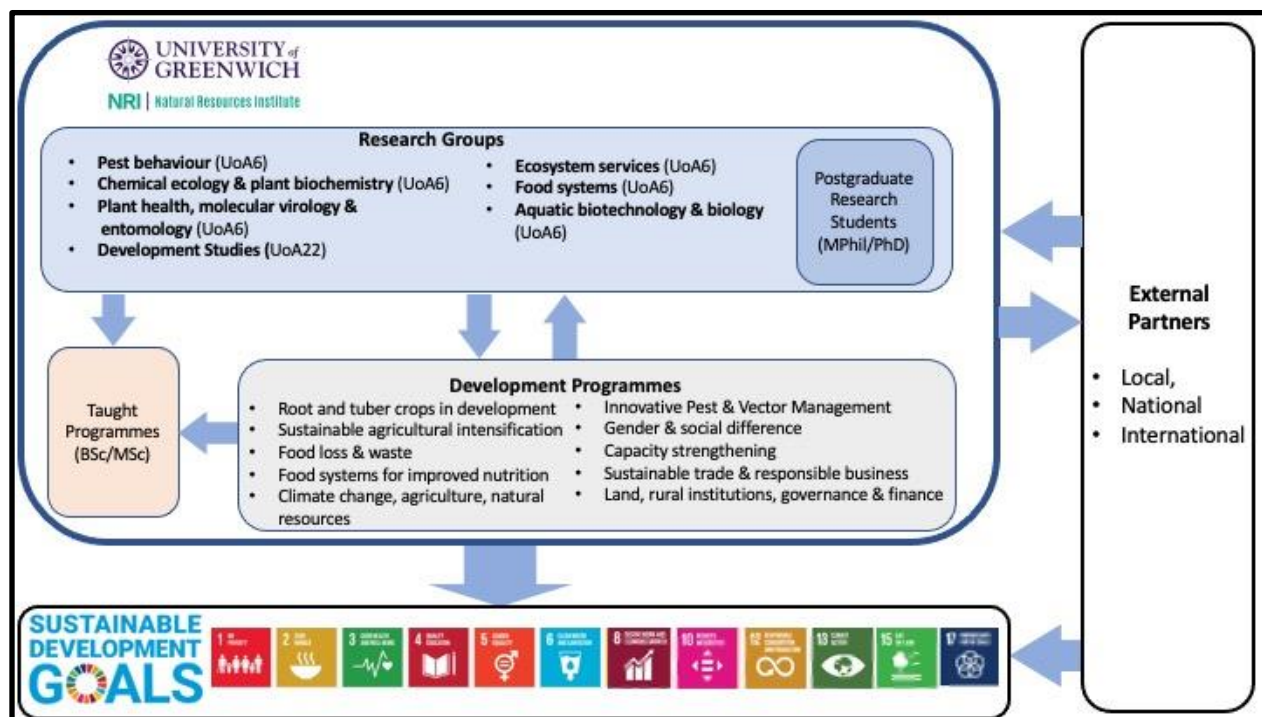


Figure 1. UoA6 embedded in the Natural Resources Institute research and impact environment.

Table 2. Research Groups and their development since 2014

RG REF2014	Staff FTE REF2014	RG REF2021	Staff FTE REF2021
Pest behaviour	3.9	Pest behaviour	7.9
Chemical ecology & plant biochemistry	3.6	Chemical ecology & plant biochemistry	6.1
Eco-system services	2.2	Ecosystem services	8.6
Agriculture biosecurity, molecular biology & entomology	6.4	Plant health, molecular virology & entomology	6.0
Postharvest and value addition	7.4	Food systems	13.63
		Aquatic biotechnology & biology	4.8
Total	23.5	Total	47.03

Pest Behaviour Group (PBG) (lead Hopkins with Arnold, Belmain, Cheke, Dobson, Emami, Gibson, Hawkes, Reynolds, and Vale), investigates the behaviour and ecology of vertebrate and invertebrate pests and disease vectors of crops, livestock and people, pollinator ecology and other beneficial insects. PBG has made significant contributions to understanding the migration and

landscape scale movements, feeding, mating and oviposition of tropical and European pests and vectors. Examples include:

- an innovative mosquito trap (**Gibson/Hawkes**) replicating the traditional human landing catch with superior results and without exposure to the risks of being bitten by vector insects (doi.org/10.1038/s41598-017-17632-3; Patent: [EP3324734B1](https://patent.google.com/patent/EP3324734B1); [BBC TV](https://www.bbc.com/news/health-41598017));
- evidence that the presence of domestic predators discourages pest rodent activity (**Belmain**). When two different types of predator are both present, they create a landscape of fear for foraging rodents (doi.org/10.1371/journal.pone.0171593);
- evidence that the microbiota from mosquitoes mirrors the environment in which mosquitoes live, demonstrating they have different populations, improving understanding of the spread of disease (**Hopkins**) (doi.org/10.1038/srep22806).

Chemical Ecology & Plant Biochemistry Group (PEPBG) (lead **Stevenson** with **Bray, Hall, Fernandez-Grandon, Harte** and **Woolley**), identifies, synthesises, and formulates natural products from plants and animals that mediate the biology and behaviour of beneficial insects and pests on crops, forests, livestock and people. Pheromones and other semiochemicals are used in traps for monitoring and controlling pests; host attractants of disease vectors in plants and animals; and compounds that mediate interactions between plants and insects and optimise pollination and natural pest regulation. Examples include:

- discovering that trees and shrubs in complex forest communities have adapted to avoid pest attack by producing odours so similar to neighbouring trees that they are difficult to distinguish as a food source (**Stevenson**) (doi.org/10.1126/science.aba2965);
- identifying the compounds that attract pollinating midges to cocoa flowers and are essential for production of cocoa pods (**Arnold/Bray/Hall/Stevenson**) (doi.org/10.1007/s10886-019-01118-9);
- developing and testing a synthetic pheromone lure for sand fly vector of the neglected tropical disease visceral leishmaniasis across Brazil (**Bray**) (doi.org/10.1371/journal.pntd.0002723).

Ecosystem Services Group (ESG) (lead **Haggar**, with **Büchi, Cerretelli, Chancellor, Coast, Lara-Estrada, Paradelo-Perez, Rodenburg** and **Yang**) research the functioning and management of UK and tropical agro-ecosystems, including climate adaptation and mitigation in agricultural systems; economic and environmental trade-offs in sustainable agriculture; sustainable soil fertility; the role of conservation practices in supporting biodiversity. Examples include:

- **Haggar** studied coffee growers in Nicaragua, finding that all producers with sustainability certifications have better farm environmental performance than non-certified farms for some indicators (doi.org/10.1016/j.ecolind.2017.04.023).
- **Büchi** found agricultural intensification reduces microbial network complexity and the abundance of keystone taxa in roots (<https://doi.org/10.1038/s41396-019-0383-2>).
- **Rodenburg** mapped the genetic variation in host resistance and tolerance across rice genotypes to the parasitic weed *Striga*, addressing this massive source of crop losses (doi.org/10.1111/nph.14451).

Plant Health, Molecular Virology & Entomology (PHMVE) (co-lead **Seal/Gowda** with **Armitage, Bouvaine, Colvin, Silva**, and **Thompson**) investigates the molecular characterisation of fungi, tropical plant viruses and insect pests and gene expression through sequencing and bioinformatics technologies. PHMVE develops disease control technologies, supports international breeding programmes, and investigates virus diseases of cassava and yams. PHMVE is pivotal in research and capacity development in international networks, such as BBSRC CONNECTED, particularly in sub-Saharan Africa. Examples include:

- **Colvin** applied his experience of the spread of plant disease to demonstrate how facemask use could radically reduce the spread of COVID-19 during the pandemic (doi.org/10.1098/rspa.2020.0376) (top 5% of all research outputs by Altmetric).

- **Colvin/Seal** revealed five new sub-Saharan *Bemisia tabaci* whitefly species, findings that support control of one of the world's devastating crop pests and plant-virus disease vectors (doi.org/10.1038/s41598-018-20956-3).

Food Systems Group (FSG) (lead **Westby** with **Acharya, Bechoff, Bettridge, Brown, de Bruyn, Colgan, Dominguez-Salas, Nikolaou, Parmar, Precoppe, Grace, Stathers, Tomlins** and **Wesana**) addresses food systems from production to consumption, focusing on LMICs. FSG enhances financial and nutritional crop value, storage and preservation, food processing, food safety and quality improving the livelihoods and nutritional status of vulnerable populations. The [Produce Quality Centre](#) (lead **Colgan**) is integral to FSG with specialised facilities enabling leading work on the quality, storage, and shelf life of fresh produce. FSG also studies the use and impact of single-use plastic films for fresh produce preservation, making significant progress on replacing plastic film content with natural cassava starch at an industrial scale in India (Newton Bhabha Fund). Examples include:

- **Brown**, using 580,000 observations of children from 53 countries, demonstrated how precipitation extremes since 1990 are associated with inferior child nutrition (<https://doi.org/10.1073/pnas.1905228116>).
- Research on gene expression in apples with bitter pit disorder, a storage quality issue with significant commercial cost, identified candidate genes offering a potential solution (**Colgan**) (<https://gala.gre.ac.uk/id/eprint/19927/>).
- **Stathers** led the team which systematically synthesised the evidence on interventions for crop postharvest loss reduction in sub-Saharan Africa and South Asia informing SDG2 investment decision-making, revealing the huge knowledge gap on the socio-economic and environmental impacts of postharvest loss reduction interventions (doi.org/10.1038/s41893-020-00622-1).

Aquatic Biotechnology & Biology (ABBG) (lead **Harvey** with **Milledge, Miest, Sui, Xu**), studies the sustainable use of water resources under changing climatic conditions to improve the health of aquatic animal species, particularly marine and freshwater fish, their immunocompetence, health and welfare in aquaculture systems. ABBG work on micro- and macro-algae for food security and plant proteins, bioactive compounds, antioxidants, pigments, and biofuels. Examples include:

- Characterising the microalga *Dunaliella salina* in the **Harvey**-led €10m FP7 CO₂ microalgae D-Factory, with patents [WO/2019/097219](#), (Production of *Dunaliella*, **Harvey/Xu**, 2019); [WO/2018/141978](#) (Algal Strains, **Harvey/Xu**, 2018) describing production of rare β -carotene isomers and colourless carotenoids (doi.org/10.3390/antiox8050123);
- **Miest** found that rising temperature negatively affected hatch and early growth of the European Eel, indicating that ocean warming will further challenge this threatened species (doi.org/10.1371/journal.pone.0182726).

Delivering research impact

NRI's approach to delivering research impact has seven important elements:

- Challenge-orientated interdisciplinary research and knowledge exchange themes articulated through **Development Programmes**.
- **Interdisciplinarity** is considered essential to addressing complex food and agricultural system challenges. NRI staff come from >35 disciplines (staff mainly submitted to UoA6 and 22, but also 8, 12 and 17) and collaborate through interdisciplinary research activities with colleagues in NRI and partner organisations. Examples include:
 - Conceptual paper on sustainable agricultural intensification (<https://doi.org/10.1080/14735903.2020.1818483>); **Haggar, Rodenburg, Nelson** (UoA22), Lamboll (UoA22).
 - Lessons on scaling cassava value chain development (<https://doi.org/10.3362/2046-1887.2015.004>) (Lamboll (UoA22), Nelson (UoA22)/Martin (UoA22), Graffham, **Westby**).

- Determinants of postharvest losses (including nutritional) in value chains (<https://doi.org/10.1007/s12571-019-00949-4>) Shee (UoA22), **Stathers, Bechoff, Bennett** (UoA22).
- **Partnerships**, described below in detail, are critical to achieving impact. Each NRI Development Programme collaborates with a broad spectrum of partners to support research uptake. As an indication of the scale of partnerships, NRI signed 720 sub-contracting agreements since 2014.
- **Investment** of additional resources is often key to achieving impact. In addition to research revenues of **£58.0m** (UoAs 6 and 22), NRI staff have competitively won **£19.4m** for knowledge exchange activities to support translating research into societal impact.
- Research **promotion and dissemination** beyond peer-reviewed outputs is important for contributing to research uptake and influencing policy (Box 1). See examples of influencing policy and practice in Section 4.
- **Protection of IP**. Most of NRI's research work is pre-competitive and/or international public goods, however there are instances where the protection of IP and licencing technologies support research uptake. Examples of IP protection include: [WO2017085477A1](#) (Bee nutrition, **Stevenson**, 2017); [EP3324734B1](#) (Insect Trap, **Gibson/Hawkes**, 2017); [GB2541175b](#) (Organic particles containing viral bodies, Grzywacz (retired), 2016); [WO/2019/097219](#), (Production of *Dunaliella*, **Harvey/Xu**, 2019); [WO/2018/141978](#) (Algal Strains, **Harvey/Xu**, 2018); [WO2020098950A1](#), (Dry onion preparation, **Acharya**, 2018); [US20200253204A1](#) (Mosquito attractant formulation, **Emami**, 2020); [WO2019098923A1](#) (Plant irrigation system, **Emami**, 2018).

Box 1: Communication and engagement

Effective communication is an important component of the unit's research and impact strategy. NRI's social media following (LinkedIn, Twitter, Facebook, Instagram) has increased from ca. 400 in 2014 to >11,000 by 2020. In addition to peer reviewed journal outputs, books, and book chapters, staff's research has been reported or informed comment in the national/international media. Examples include:

- Expert comment – locust plague in East Africa (e.g. Nature (<https://doi.org/10.1038/d41586-020-00725-x>) (**Cheke**).
- Sex and Drugs and Pest Control: TedX talk. London, 2015 (**Stevenson**).
- [The Great British Urine Test](#) (Channel 5) (**Hopkins**).
- BBC 3-part report on Zika transmission in Brazil (**Bray, Fernandez-Grandon, Gibson, Hawkes, Hopkins**).
- BBC [Living with Malaria](#) (2017) (**Gibson, Hawkes**).
- BBC Earth Deadly Disasters - Mosquitoes (**Hopkins**).
- Expert comment – killing off disease causing pests – [Scientific American](#), 2019 (**Vale**).
- Expert Comment – BBC News: [Elimination of mosquitoes](#) (**Hawkes**).
- Expert Comment – bird cruelty “BBC [Inside Out – London](#)”, October 2016 (**Cheke**).
- Expert Comment following publication – use of facemasks (2020) (Newsweek, Daily Mail, and others) (**Colvin**).

There has been increased coverage of staff work in the press (e.g. 74 articles in 2019/2020). Staff have widely contributed to **public engagement**. Examples include: leading on a national ‘[Pint of Science](#)’ event (2020) (**Arnold/Harte**); Send a Cow “Big [Debate](#)” hosted by Jonathan Dimbleby (Panelist: **Westby**); Royal Society ‘[Science Matters](#)’ series of public debates in 2016 hosted by Prof Brian Cox (**Stevenson**) and the Royal Institution Christmas Lecture 2017 (**Gibson**).

Development Programmes

NRI's ten Development Programmes facilitate the organisation and communication of NRI's research and development work around specific international development challenges (Table 3). Reflecting their interdisciplinary nature and impact orientation, contributions are made by UoA6, UoA22 and enterprise-focused staff. Individuals contribute to multiple Programmes.

Table 3: Development Programmes and development challenges/opportunities addressed.

Development Programme	Leader	Development challenge/opportunity
Root and tuber crops in development	Tomlins	Tropical root crops (cassava, yams and sweetpotato) are important food security crops and innovations can improve livelihoods of poor people (SDGs 1,2,8).
Innovative pest and vector management	Hopkins /Hawkes	Pests bring dangerous human and animal diseases, destroy crops, threaten food supplies, and damage livelihoods. Finding sustainable, innovative pest management solutions protects people and the environment (SDGs 2, 3).
Sustainable agricultural intensification	Rodenburg	Agricultural systems can enhance productivity for food and nutrition security (SDGs 2, 6, 12, 13) in the face of climate change, without detriment to the environment, biodiversity or to social and gender equity
Food loss and waste reduction	Bennett**	To reduce food losses and waste to contribute to improved resource use, food security, nutrition, and health, reduced environmental impact and employment (SDGs12, 3).
Food systems for improved nutrition	de Bruyn	To create sustainable, ethical, and efficient food systems supporting human health through strategies to address diverse nutritional challenges (SDG 2) and support nutritionally vulnerable population groups.
Climate change, agriculture, and natural resources	Morton**/ Yang	Addressing climate change impacts on food security and sustainable natural resource use, with a primary focus on climate action, food security, forests and water, local institutions, and conflict (SDGs 2, 5, 13, 15).
Capacity Strengthening for Agricultural Development and Food Security	Chancellor	Human and organisational capacity constrains agricultural development in LMICs. Support is required to strengthen capacities, skills, partnerships, and policy influence in research, education, and extension (SDGs 4, 17).
Gender and social difference	Martin**/ Forsythe	To reduce inequalities and achieve gender justice in sustainable development. Gender and other social differences influence economic, social, and political opportunities of individuals and communities and affect wellbeing (SDG 5, 10).
Sustainable trade, responsible business	Nelson**	To identify strategies through which enterprise, trade and consumption can be more responsible and sustainable, to have a positive impact on workers in supply chains, communities, and global environments (SDG8).
Land, rural institutions, governance, and finance	Quan**	To strengthen governance of rural development processes, through institutional arrangements and partnerships, land and resource governance, conflict resolution, delivery of support services and inclusive opportunities (SDG1, 8, 15).

** staff submitted under UoA22.

Development Programmes are showing significant impact:

Root and tuber crops in development. BMGF has invested significantly in NRI research on cassava, sweetpotato and yams (7 projects, ca. £29m). Work on cassava was awarded the [Queen's Anniversary Prize](#) in 2015, including: (a) control of whitefly, a major vector of cassava mosaic and cassava brown streak diseases (**Colvin/Seal/Bouvaine**); (b) development and dissemination of virus resistant varieties (**Gowda**); (c) development of value chains improving the lives of small-holder farmers (**Westby/Tomlins/Precoppe**) and (d) overcoming food losses (**Tomlins/Bennett**). The work forms the basis of two impact case studies in this submission, and was awarded the [Guardian Award for Research Impact](#) (2015), the [Times Higher Award for](#)

[International Partnership of the Year](#) (2014) and the [Rockefeller Foundation Cassava Innovation Challenge](#) (2017) for an innovative solution extending cassava shelf life (Bennett/Tomlins).

Innovative pest and vector management. NRI's reputation is founded on the research excellence and impact of its research on innovative pest and vector management affecting plant, animal, and human health. This was recognised by the award of a [Queen's Anniversary Prize](#) in 2019, highlighting work in four key areas: (a) control of blackfly which transmits onchocerciasis (**Cheke**) (a case study in this submission); (b) control of horticultural crop pests based on chemical ecology (**Hall/Stevenson/Harte/Fernandez-Grandon**) (also an impact case study); (c) an innovative mosquito trap (**Gibson/Hawkes**) that replaces the human landing catch with superior results and without exposure to the risks associated with vector insect bites, and work on the spatial movement of mosquitoes (**Hopkins**); and (d) innovations in rodent control (**Belmain**).

Sustainable agricultural intensification. This expanding portfolio has funding from the Foreign Commonwealth and Development Office (FCDO); the Global Grand Challenges Fund (GCRF); Royal Society and EU. **Haggar/Rodenburg** played a leading role in the £8.0m [Sustainable Agricultural Intensification Research and Learning in Africa](#) (**SAIRLA**) **project (FCDO; 2015-2020), successfully piloting the innovative establishment of the National Learning Alliances in five countries and their use of social learning to underpin active engagement of decision makers with the programme's research.**

Food loss, waste reduction and value addition. NRI has developed a Centre for Food Loss and Waste Reduction (FLoW) linking research excellence and practical solutions. **Stathers** leads postharvest loss measurement through the BMGF funded African Postharvest Loss Information System (APHLIS+) and led the scoping review of interventions for crop postharvest loss reduction in sub-Saharan Africa and South Asia (doi.org/10.1038/s41893-020-00622-1). **Grace** and **Dominguez-Salas** have provided insights into the complex relationships between food quality, nutrition, environment and food safety ([doi.org/10.1016/S0140-6736\(16\)32124-9](https://doi.org/10.1016/S0140-6736(16)32124-9)) and the crucial role that livestock plays in infant nutrition (doi.org/10.1093/af/vfz033).

Food systems for improved nutrition - a recently expanded programme under the E3 Award with the appointments of **de Bruyn, Dominguez-Salas, Bettridge, Brown** and **Nikolaou**. Research on consumer acceptability and carotenoid retention of orange-fleshed sweetpotato (**Westby/Tomlins/ Bechoff**) has supported this new source of provitamin A, reaching 6.2 million households (estimated 29 million people) by 2019 ([Okello, 2019](#)).

Capacity strengthening for agricultural development and food security. Strengthening capacity for agricultural development and food security is central to transformative change in food and agricultural systems to which NRI is committed. Key initiatives include contributions to the FAO led "[Tropical Agriculture Platform](#)" (**Chancellor**) and the EU-funded [CDAIS](#) project (**Dobson**) strengthening agricultural innovation systems in six countries (two led by NRI) enhancing efficiency and sustainability in meeting the demands of farmers, agri-business and consumers.

Climate change, agriculture and natural resources. This programme has two Coordinating Lead Authors (chapters on agricultural production and food security (Porter) and rural areas (Morton (UoA22)), Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (2014). It has benefitted from new staff (E3 Award), enhancing competence in climate modelling (**Yang**), crop drought resistance (**Coast**), climate-related agroforestry (**Lara-Estrada**), soil climate interactions (**Paradelo-Perez**), plus 6FTE in UoA22; authorship of the award winning [Climate Change, Global Food Security and the U.S. Food System](#) (**Brown**) and two authors of [The Lancet Countdown on Health and Climate Change: responding to Converging Crises](#) (**Grace/Dominguez-Salas**).

Gender and social difference. Although, the main researchers are submitted to UoA22, the work of this programme encompasses the whole of NRI's work. The team made a significant contribution to the gender and equality focus within the CAVA project led by **Westby**, which had

demonstrable benefits for women ([Westby & Adebayo 2019](#)). This contributed to the award of the QAP (2015) and the Guardian University Award for Research Impact.

Land, rural institutions, governance and finance and **Sustainable trade, responsible business**. Researchers are mainly submitted to UoA22, where they contribute three impact case studies.

Future strategic aims and goals for research and impact

NRI's Strategy ('Knowledge for a Sustainable World') is under development alongside the new University of Greenwich Strategy, which will be finalised in 2021. The new University of Greenwich strategy is tag-lined 'Education without boundaries', aligning with NRI's vision to be a world-leading centre of research excellence on food and agricultural systems and partner of choice in creation and application of knowledge.

Key elements of the UoA's research and impact strategy are:

- Address the ambitious research priorities and development challenges detailed below, specifically on climate change, sustainable trade, and responsible business.
- Grow a world-leading portfolio of UK-focused research building on the newly awarded Growing Kent and Medway Strength in Places Programme and the UK Food Systems CDT.
- Maintain a focus on securing larger grants for operational efficiency, whilst retaining a complementary portfolio of small/medium sized projects.
- Grow research revenues at a rate of at least 5%/annum, consolidating the recent growth in staff numbers to ensure sustainability of the research environment.
- Adopt systems approaches and interdisciplinarity to ensure impact.
- Broaden the diversity of staff in leadership positions to reflect the greater diversity of NRI that has been achieved in this period.
- Adapt how research is undertaken to minimise the unit's carbon footprint.

Research Group Priorities and Development Programme priorities are detailed in Tables 4 and 5.

Table 4. Research Group Priorities

Group	Priorities (2021-2026)
Pest Behaviour	<ul style="list-style-type: none"> • Improve prevention and control strategies for rodent-borne diseases yielding high public health impact through advocacy and technical development of Integrated Pest Management programs for rodents and their ectoparasites. • Integrate knowledge generated on the ecology and movement patterns of disease vectors to support Integrated Vector Management programmes for key vectors of human and animal disease. • Fully integrate pollinators and other beneficial insects into Integrated Pest & Pollinator Management programmes across production systems
Chemical Ecology & Plant Biology	<ul style="list-style-type: none"> • Manage agricultural pests and human and animal disease vectors, exploiting naturally-occurring animal, fungal and plant produced chemicals to deliver ecosystem services supporting sustainable food and animal production. • Using a multidisciplinary approach encompassing animal behaviour, insect electrophysiology, chemical analysis and synthesis, molecular diagnostics, and bioinformatics, to elucidate the molecular and sensory mechanisms through which naturally occurring chemicals regulate interactions between organisms. • Build on the commercial success of the group's development of effective and marketable, sustainable agriculture and pest management products.

Unit-level environment template (REF5b)

Ecosystem Services	<ul style="list-style-type: none"> Determine the processes and identify responses to abiotic and biotic factors limiting crop productivity (e.g. soil fertility, climate variability, weeds, pests, pollinators, and parasites). Identify the attributes and processes that contribute to sustainable production in agricultural systems such as soil improving cropping systems, agroforestry, perennial crops (e.g. vineyards orchards) and home gardens (e.g. enset). Quantify the environmental performance (including resource use intensity and ecosystem services provision) of agricultural production systems and trade-offs with socioeconomic benefits at farm, landscape, national and global scales.
Plant Health, Molecular Virology & Entomology	<ul style="list-style-type: none"> Develop tools enhancing control of the emergence and spread of plant viral disease epidemics. Understand the molecular mechanisms of plant virus transmission by insect pests and the influence of climate change on plant-virus-vector interactions. Study devastating viral pathogen communities in different agroecological landscapes, supporting regional surveillance systems in support of biosecurity and control of pests and diseases. Develop sustainable solutions for invasive pest species, such as whiteflies, including transgenic studies and conventional research to identify natural resistance, breed cassava for whitefly resistance into farmer-preferred varieties and develop effective plant health systems.
Food Systems	<ul style="list-style-type: none"> Reduce food loss and waste, including innovations to extend shelf-life of perishable fresh produce including the development of sustainable food packaging, and to reduce environmental impacts Food security and nutrition to tackle the double burden of malnutrition and food safety including home-grown school feeding programmes.
Aquatic Biotechnology & Biology	<ul style="list-style-type: none"> Utilise algae for CO₂ sequestration and resource recovery from waste streams. Downstream bioprocessing of algal resources for human and animal nutrition, food security and green chemicals. Ecosystems research to ensure the safety and sustainability of aquatic exploitation of farmed and wild algae and aquatic animals and impact of climate change on aquatic systems.

Through its Development Programmes, NRI has set an ambitious agenda to make significant contributions to the SDGs (Table 5).

Table 5. Priorities for NRI's Development Programmes to 2030.

Development Programme	Priorities (2030)
Root and tuber crops in development	<ul style="list-style-type: none"> Co-develop innovations to overcome root crop pests and diseases to farming systems in sub-Saharan Africa. Develop traditional food processing systems for growing and urbanising populations whilst ensuring the sustainable livelihoods for those who depend on them.
Innovative pest and vector management	<ul style="list-style-type: none"> Apply newly developed techniques to enhance trapping systems for blood feeding insects, particularly improved trap technology and the application of insect behaviour to better understand insect spatial ecology. Improve prevention and control strategies for the rodent-borne diseases with high public health impact through advocacy and

	technical development of Integrated Pest Management programs for rodents and their ectoparasites.
Sustainable agricultural intensification (SAI)	<ul style="list-style-type: none"> Develop resource-efficient farming systems to increase productivity and environmental resilience, reduce crop losses and negative environmental impacts, enhance ecosystem functionality and resilience to climate change. Share knowledge through capacity development and training.
Food loss and waste reduction	<ul style="list-style-type: none"> Develop and apply interventions for loss measurement, alternative packaging, enhanced food safety and adaptive innovation. Understand the trade-offs and synergies between options for reducing losses and optimise use/reduce waste – recognising risks that upgrading ‘wastes’ may exclude opportunities for the vulnerable.
Food systems for improved nutrition	<ul style="list-style-type: none"> Develop conceptual frameworks that underpin food systems and nutrition-oriented research and their effectiveness in informing programme design, implementation, and evaluation. Harness research findings to inform effective policies and programmes for nutrition and health.
Climate change, agriculture, and natural resources	<ul style="list-style-type: none"> Undertake research that contributes to climate adaptation/resilience and understanding the relationships between: climate change and food security/ natural resource use; climate change/climate variability and conflict; and climate change and food systems, gender, and social inequality.
Capacity Strengthening	<ul style="list-style-type: none"> Develop collaborative doctoral training with African partners building on UK Food Systems CDT
Gender and social difference	<ul style="list-style-type: none"> Research on gender norms, agency and power related to inequalities, gender and agriculture, food sovereignty and diversity in food systems for nutrition.
Sustainable trade, responsible business	<ul style="list-style-type: none"> Analysis of regenerative enterprise and economy opportunities that promote renewal, reuse, regrowth and restoration.
Land, rural institutions, governance, and finance	<ul style="list-style-type: none"> Strengthening land tenure rights and reducing land conflicts without excluding small farmers from new economic opportunities.

Taking forward the strategic goals and aims

Implementing the ‘key elements of the research and impact strategy’ described above are essential for advancing the strategic goals and aims. New projects (the E3 Award, Food Systems CDT and Strength in Places - Growing Kent and Medway) give NRI the springboard to achieve the strategic goals at international, national, and local levels, respectively. The new University strategy indicates significant investment in research infrastructure supporting an enabling environment for world-leading research. The University strategy focuses on creating opportunities for individuals and society, building partnerships, and delivering impact, which are core principles to ensure NRI’s success.

2. People

Staffing Strategy and Staff Development

NRI aims to grow research quality and volume by increasing the portfolio of research projects, by applying a balanced recruitment process, bringing in staff at different stages of their research career as the volume of research grows, and by renewing the population of researchers at all career levels. NRI’s staff profile in REF2014/REF2021 is shown in Table 6. New appointments (27.23 FTE) have doubled staff numbers related to: (a) growth of external research and enterprise revenues; and (b) investment from the E3 Award.

Table 6. UoA6 staff profile by grade.

	FTE AC2/Fellow	FTE AC3/Senior Fellow	FTE AC4 (Associate Professor)	FTE AC5 (Professor)	Total (FTE)
REF2014	8	1	7	7.5	23.5
REF2021	16.4	12	5.2	13.43	47.03

The E3 Award facilitated recruitment of 22.43 FTE across NRI (13.03 FTE in UoA6), giving NRI the opportunity to strategically review its overall staffing. The investment focused on four development programmes: (a) climate change, natural resources, and agriculture; (b) food systems for improved nutrition; (c) sustainable agricultural intensification; and (d) food loss and waste reduction. In UoA6, E3 investment funded 1.43 FTE Professors, 2.0 FTE Associate Professors and 9.6 FTE Senior Fellows/Fellows. Emphasis of recruitment at Senior Fellow/Fellow level met needs identified in the pre-investment profile to ensure a diverse range of disciplines and underpin NRI's commitment to interdisciplinarity and sustainability.

UoA6 benefits from a strong cadre of Professorial Staff, world leaders in their fields, who ensure research quality and drive resource mobilisation. At this level, the UoA has 13.2 FTE, 27.7% of staff as compared with 7.7 FTE (32%) in REF2014. Growth was through promotion (**Belmain, Gibson, Hopkins, Haggar, Dobson, Gowda, Seal**) or new appointments (**Grace, Brown**).

NRI has an exceptional rate of **staff retention**. Of the 23.5 FTE submitted to REF2014, 76% are submitted to REF2021, 16% have retired, 8% (2 FTE) have moved to non-research roles or left for another institution. Of the staff submitted in REF2014, 66% of those under professorial level were promoted. NRI has reduced the percentage of staff on period appointments (to 10%), with virtually all new appointments on open-end contracts. Period appointments are mainly used where staff are appointed for specific projects, but NRI treats these staff as ECRs and aims to retain them (see Equality and Diversity Section below).

Responsibility for **staff development** (including research leadership) and quality control of research activities and outputs, rests with the Heads of NRI's Departments, under the overall leadership of the Institute's Director (**Westby**). The Research Group and Development Programme structures allow unhindered collaboration across the Institute. Staff development is managed through annual staff appraisals that provide the framework for personal development. Staff nominate a Career Pathway (Research, Enterprise, or Teaching) in their annual appraisal that informs staff development plans. This submission comprises staff on the Research Career Pathway (84% of NRI academic staff) with SRR in line with University's REF2021 Code of Practice.

Staff can tailor their personal development in line with Vitae Framework for Staff Development, drawing courses from the University's **Research and Enterprise Training Institute (RETI)**, university level or local level mentoring programmes or other opportunities agreed in the staff appraisal. RETI nurtures research and enterprise activities by creating a proactive, supportive environment for the career development of researchers. RETI works in partnership with staff and PGR students to support excellence. RETI aids researchers to develop, personally and professionally and to meet their research goals through tailored training, coaching, and mentoring. This approach is flexible, providing options for mentoring, formal training courses, participation in conferences and workshops through to externally funded fellowships (e.g. **de Bruyn** undertook a FCDO/BMGF/IMMANA fellowship), undertaking MSc programmes and in some cases registering for PhD degrees (all staff are PhD holders). Opportunities are sought to provide leadership experience (e.g. UoA22's Po and Turner are co-managers for the CDT led by **Westby**).

NRI places considerable importance on the next generation of its researchers and hence takes an inclusive view of the definition of an Early Career Researcher (ECR), letting staff self-nominate. With this definition of ECR, the submission has 20 FTE (50% female). ECRs benefit from an [Early](#)

Career Researcher Network (organised at faculty level), established in this period to support ECR development as a cohort, with skills development, promotion of interdisciplinarity and a collegiate research environment. The ECR Network's agenda is set by the ECRs and focuses on maximising their career potential supported by senior staff, RETI and Research Services Support.

Research students

In this period, 36 students completed their PhDs (15, REF2014) with 70% completing within four years. Staff have co-supervised 23 PhD completions at other institutions, contributing to the development of capacity in LMICs, highlighting the extent of international partnerships. The University funded 32 PhD Studentships in the period (20 completed) and PGR population has grown to 38.5 FTE by 2020.

NRI has an established track record of PGR supervision. It was invited to the successful BBSRC **London Interdisciplinary Doctoral Programme** (LIDo) in 2019 for its successful bid for DTP3 funding and participated in the University Alliance Biosciences Doctoral Training Programme (4 students). NRI leads the **UKRI UK Food Systems CDT** that will train 62 doctoral students.

PGR students are supervised by a team of three supervisors, with minimum combined experience of supervising at least three students to completion. Students are integrated in Research Groups and are represented in multiple fora including Research Group Leaders' Meetings, Faculty/University Research and Enterprise Committees. They also have the support of NRI's Director of Postgraduate Studies. The administration and quality control of research degrees are overseen by the Faculty Research Degrees Committee and training is organised through RETI. RETI runs and internally audits a transferable skills programme. Students working outside the UK are supported with frequent communications and a locally-appointed additional supervisor.

Students are allocated a dedicated workspace and their own networked computer, laptop (to support field/international research) and specialised software. NRI runs a one-on-one statistics support service to provide individual assistance, and provides training in statistical analyses and use of the statistical package R.

Students benefit from a student-led society (Natural Resources Institute Postgraduate Society (**NRIPS**)), which provides a support network, social events, student-organised training activities and a seminar series. NRIPS organises an annual PhD Research Symposium where first- and third-year students give oral presentations, and second-year students produce a poster. Final year students also present at the NRI research seminar series and most attend at least one national or international conference. NRI students compete in the 3-minute-thesis competition organised by RETI, winning the 'People's Choice' at [Faculty](#) and University-levels in 2020.

Students participate in targeted discussion and training groups in subjects including entomology, insect behaviour, chemistry, and molecular biology. These provide a space for presentation of research plans and findings to a group of researchers familiar with the research topics. Students are encouraged to form peer support groups, where more experienced students actively support and mentor those more recently recruited.

Students are encouraged to present their work externally and have been awarded prizes: *Christina Conroy* (Supervisor, Bray) from the Royal Entomological Society, the Society of Chemical Industry and the Worshipful Company of Fruiterers; *Claudia Carvalho* (Supervisor, Colgan) from the SCI Agrisciences Group and the 4th International Horticulture Research Conference; and *Maria Carcamo* (Supervisor, Colgan) from the Worshipful Company of Fruiterers and Biotechnology YES 2018: Unleash Your Ingenuity Award.

Equality Diversity and Inclusion (EDI)

The University of Greenwich is committed to promoting equality and diversity, and to providing an inclusive and supportive environment. This is central to NRI's commitment to excellence in all that we do. NRI's commitment to EDI is reflected in how we: (a) ensure that everyone is treated fairly and with respect; (b) recognise that students and staff have different needs; (c) ensure that no-

one experiences less favourable treatment or discrimination because of their age; any disability they may have; their ethnicity, colour or national origin; their gender; their gender identity or gender reassignment; their sexual orientation, their marital or civil partnership status; being pregnant or having recently had a baby; their religion or beliefs. The University has clear EDI [Policies and Strategies](#) guiding practice across the organisation. The University has the following accreditations/charters: HR Excellence in Research, Disability Confident, Stonewall Workplace Equality Index, Stonewall Diversity Champions (and work to submit to the Workplace Equality Index for 2021-23 is underway, where the university has held a top 100 employers position within the index on three occasions during the last REF period), Mentally Healthy Universities (this is a call to action for employers to adopt the recommendations of the government's independent review to support mental health (UUK - Step change)) and Time to Change Pledge. Within the University there are the following diversity groups and networks: LGBT+ Staff and Allies Community, Disability Staff Network, Disability Named Contact and BAME Staff Network; Women's Network, Women's Professoriate Group, Diversity Interests Group. EDI Training is mandatory (with refreshers every three years) for all staff, and "Managing Diversity" is essential for staff with management responsibilities. In addition, unconscious bias training has been rolled out for NRI staff in the period.

In line with the University wide trend, a higher proportion of UoA6 staff with significant responsibility for research (SRR) were BAME (32.7%) than those in the same subject area without SRR (21.4%). The percentage male and female (58.9, 41.1% respectively) with SRR in UoA6 was consistent with staff with SRR in the University (59.5%, 40.5%). The level of disability in the university SRR population (4.8%) was higher than in the 'without' SRR population (0%). Looking back at REF2014, a number of challenges faced in UoA6 have been addressed (Table 7).

Table 7. Progress in diversity indicators in UoA6 since REF2014.

	REF2014	REF2021
% male, %female	76%, 24%	58.9%, 41.1%
% BME staff	4%	32.7%
Female Professors	0 FTE	4.43 FTE
Female Associate Professors	2.0 FTE	2.8 FTE
% female of staff promoted		50% (8/16)
BAME Professors	0	1 FTE

Steps taken by NRI include:

- investing in training PhD students, e.g. internal scholarships to create a pipeline of talent (4.2 FTE in UoA6 have Greenwich PhDs, of which 1.4 FTE are now Professors).
- recruiting and nurturing ECRs with a view to becoming permanent members of staff. 6 FTE in this submission were recruited as Post-Doctoral Research Associates for specific projects and are now permanent members of staff.
- taking a range of additional measures in recruitment e.g. advertising job vacancies internationally to attract the best available talent globally; advertising vacancies in a wide range of media, having longer short lists to encourage diversity and use of remote interviewing to enable participation. The impact of these measures is seen in the new E3 cohort where across NRI, 60% of new appointments under the E3 were recruited from outside the UK; 50% were female and 50% BAME; and
- encouraging female staff to take advantage of the Aurora programme (5 in REF period).

The new female professorial 4.43 FTE have been achieved through new appointments (1.43 FTE), promotion (2.0 FTE) and a focus on research activity (1.0 FTE).

NRI has an excellent track record in terms of diversity of its PGR student population. As of 31 July 2020, the UoA6 PGR community was 38.5 FTE, with 56% female and 45% male with BME students representing 55% of the population. Across NRI, the whole PGR population is 53.5, with 54% female 46% male and 63% BAME. NRI encourages diversity of the student population by

advertising roles widely to attract the most diverse pool of applicants that can translate through into the selected students.

In the coming period, NRI aspires to continue to increase diversity in leadership positions. The University is committed to undertake Athena Swan accreditation and Tech Talent Charters.

3. Income, infrastructure and facilities

Research at NRI is coordinated by the Director of Research and Enterprise (Bennett, UoA22). It takes place within the context of the University's Strategic Plan, from which the NRI Strategic Plan (Knowledge for a Sustainable World) is derived. UoA6 research cuts across NRI's three operational Departments. These departments are the primary operational units for mentoring staff, maintaining professional standards, and overseeing staff development. Research and consultancy funding are coordinated across Research Groups and Development Programmes. Heads of Department, the Director of Research and Enterprise and other senior staff provide both active intellectual support for research bidding and quality control under systems validated by ISO9001:2000 to ensure quality, financial viability, and responsibility for delivery of outputs. For larger bids, and bids with both research and consultancy elements, NRI's Commercial Director, Commercial Manager and Business Development Manager also provide support. Information is disseminated throughout the Institute via the Intranet and Departmental meetings, and weekly research seminars are held on a time-tabled basis with presentations by staff members, research students, and visiting researchers.

Table 8: Natural Resources Institute research and knowledge exchange funding in the REF period.

Income source	Funding (£million)
UoA6 Research Revenues	46.30
UoA22 Research Revenues	11.72
Knowledge Exchange Revenues supporting research impact	19.39
QR funding (UKRI)	3.32
HEIF funding (UKRI)	1.10
UoA6 University PhD Scholarships	1.82
UoA22 University PhD Scholarships	0.11
Total	83.76

In order to make significant contributions to the SDGs, NRI's UoA6 research activity (£46.3m) sits within the wider context of research funded under UoA22 (£11.7m) and NRI's externally funded knowledge exchange projects (£19.4m) that support translation of research into impact (Table 8). QR funding (£3.3m) is allocated to Research Groups against peer-reviewed plans to pump-prime new initiatives, maintain key research facilities and support the PGR student experience. HEIF funds allocated to NRI (£1.1m) are used to catalyse knowledge exchange activities in line with university strategies.

Table 9: Research Revenues in REF2014 and REF2021 (£million)

Income source	REF2014 (5 yr Total)	REF2014 mean/ yr	REF2021 (7 yr Total)	REF2021 mean/ yr	%change mean/yr 2014 v 2021
UKRI Research Councils	0.59	0.12	5.16	0.74	526%
UK-based charities	0.02	0.00	0.18	0.03	422%
UK central government bodies	2.81	0.56	2.09	0.30	-47%

Unit-level environment template (REF5b)

UK industry, commerce and public corporations	0.95	0.19	0.69	0.10	-49%
EU government bodies	2.35	0.47	5.51	0.79	67%
EU industry, commerce and public corporations	0.03	0.01	0.03	0.00	
EU (excluding UK) other	0.15	0.03	1.61	0.23	661%
Non-EU-based charities/Industry and other	11.41	2.28	30.05	4.29	88%
Other sources/UK other sources	0.99	0.20	1.00	0.14	
Total	19.31	3.86	46.30	6.61	71%

Total research revenues for UoA6 (£46.3m) have **more than doubled** since REF2014 (£19.3m) (Table 9), representing a 71% increase when calculated on a revenue per annum basis. The principal sources of income were BEIS Research Councils (11.0%); UK Government (5.0%); EU Government (12.0%); and non-EU based charities and other (65%) and other sources (7%). BMGF income is reported under both non-EU charity competitive and non-EU other. Overall, 20% of revenues come from UK sources, 15% from EU and 65% from other countries representing an excellent return on UK investment.

When averaged over the REF periods, **BEIS Research Council** funding per annum has increased by 526% (Table 9). It represented 2% of 2013/2014 revenues compared with 34% in 2019/20. Significant projects include: E3 Award from Research England (Food and Nutrition Security Initiative) (£7.5m, **Westby**); Sustainability-Intensification Trade-offs in Coffee Agroforestry (BBSRC, £1.37m, **Haggar**); Natural Pest Regulation on Orphan Crop Legumes in Africa (BBSRC, £0.99m, **Stevenson**); Human Decoy Mosquito Trap (MRC, £0.56m, **Gibson**); Intelligent Control of Fresh Produce Storage (BBSRC, £0.43m, **Colgan**); Environmentally Benign Combination Biopesticides (BBSRC, £0.42m **Stevenson**); Deterrent: Spotted-Wing Drosophila (BBSRC, 0.32m, **Bray**). **Royal Society** projects include High-Throughput Sequencing Indexing to Strengthen the Yam Seed Systems (**Seal**, £0.21m) and Striga Smart Sorghum Solutions for Smallholders in East Africa (**Rodenburg**, £0.22m).

UK-based charitable income is small, but increased by 422% as a result of a project on climate resilience funded the Association of Commonwealth Universities.

UK Government projects include those funded by FCDO, TSB/Innovate UK; DEFRA Darwin Fund and AHDB (non-departmental public body under DEFRA). FCDO research funding has decreased, whilst FCDO knowledge transfer and evaluation funding as increased (included in the knowledge transfer line in Table 8). Projects include: AHDB-funded research (£0.89m); Sustainable Agricultural Intensification Research and Learning in Africa (FCDO, **Haggar**, £0.59m); Agroforests in Guatemala (DEFRA/Darwin, **Haggar** £0.28m); Nutritional Postharvest Loss Estimation Methodology (FCDO/BMGF, £0.25m, **Bechoff**).

Whilst direct **industry funding** has decreased, AHDB and Innovate UK collaborative funding has increased and is reported in other lines of Table 9. Industry-funded knowledge transfer work has increased and forms part of the knowledge transfer line in Table 8.

EU Government funding has increased by 67% when averaged over REF cycles. EU-funded projects include: D-Factory (€7.20m, **Harvey**); GRATITUDE - Gains from losses of root and tuber crops (**Tomlins**, £2.37m); Cassava Growth Markets (**Tomlins**, £2.33m); Optimisation of Pesticidal-Plants (£0.88m, **Stevenson**); Sustainable Technology to Overcome Pest Rodents in Africa (£0.83m, **Belmain**); Limiting the Impact of Cassava Brown Streak Disease (£0.51m, **Gowda**); EC Food Fortification Research Portfolio (£0.91m, **Tomlins**).

Within the **EU 'other'** category, showing a 661% increase, is the highly prestigious grant awarded to **Gibson** (£198k) from the Human Frontier Science Program (HFSP) from which 28 awardees

have gone on to receive the Nobel Prize. Also included are projects funded through Agrinatura-EEIG.

Non-EU charitable/non-EU other are combined in Table 9 and have increased by 88%. Charitable funding is from the Bill and Melinda Gates Foundation (BMGF) (>90%); McKnight Foundation and Rockefeller Foundation. Significant BMGF projects include: African Cassava Whitefly Project (Phase I) (£10.03 m), (Phase II) (£8.53m, **Colvin**); Cassava Adding Value for Africa Phase II (£13.07m, **Westby**); African Postharvest Loss Information Systems Project (£2.42m, **Stathers**); Enabling Research Tools for Cassava and Yam Virologists and Breeders (£1.8m, **Seal**); Yam Toolkits Project (£0.93m, **Seal**). McKnight Foundation includes work on pesticidal plants (£344k, **Belmain**) and sweetpotato germplasm (£159k, **Stevenson**) and Rockefeller Foundation Cassava Innovation Challenge (£388k, Bennett/**Tomlins**).

Other non-EU funding is from a wide range of funding sources, including CGIAR centres and international donors. These include: Health and Safety at Cassava Processing Centres (CIAT, £255k, **Precoppe**); Fish AgriFood Systems (WorldFish, £392k, **de Bruyn**); Gari processing with biofortified cassava (HarvestPlus, £185k, **Bechoff**); Collaborative research with RTB-CRP (CIP, £181k, **Tomlins**).

Facilities

The Medway Campus provides a suite of outstanding facilities that support UoA6 research priorities. Plant growth facilities include three large state of the art tropical glasshouses (1 new 2020, cost £906k), a smaller temperate glasshouse and a set of 16 raised beds (new 2020). This new investment significantly increases NRI's capability for climate change-related research. This is complemented by 6 growth cabinets suitable for plant growth or culturing pathogens and insects, and by the DEFRA licenced quarantine facilities and insectaries (upgraded 2015, cost £262k). These extensive facilities give NRI a competitive advantage in conducting work on tropical pests in a temperate country, e.g. NRI's extensive research on whitefly. Research on plant material and soils has been enhanced by a new agronomy laboratory (2020, cost £326k). Molecular laboratories provide infrastructure for extraction, amplification and purification of nucleic acids for sequencing in collaboration with international partners. Bioinformatics capacity, strengthened with the appointments of **Armitage** and **Emami**, benefit from the University's 57-node High Performance Computer cluster with dedicated high memory/GPU nodes complemented by two additional high specification computers dedicated to NRI, with resources suitable for the assembly and analysis of complex genomes (512GB/786GB RAM, new 2020, £46k).

Chemical and behavioural ecology research is facilitated by a suite of equipment for the collection and analysis of natural products: three entrainment kits for volatile capture; a specialist wind tunnel for pheromone lure performance testing; a Liquid Chromatography coupled Mass Spectrometer (new 2020, cost £95k) for non-volatile chemical identification; Liquid Chromatography coupled Ultraviolet Detector/Refractive Index (HPLC-UV/RI) for non-volatile chemical analysis; five Gas Chromatography coupled Flame Ionisation Detectors (GC-FIDs) for volatile compound analysis; Infrared Spectrometer (IR); three GC-MS setups with autosampler and integral software for operation, data collection and data processing, linked to a new client-server chromatography data system and seven instrument connection licences to network all existing gas chromatographs (new 2020, £102k); GC-EAD electrophysiological facilities measure the perception of compounds by recording from insect antenna and linking the response to the GC output. Behavioural studies of insects utilise a range of Y-tubes and olfactometers, including 3D tracking wind-tunnel facilities (upgraded 2017, cost £32k; upgraded 2020, cost £85k).

New during the period is the £1m 'Valgorize algal pilot facility', a food grade-facility fitted with a 400L tubular photobioreactor, 150L tubular column photobioreactor unit, 6 Algem photobioreactors, 1 HT24 photobioreactor, two algal growth units of 0.5m² and one of 3.5m² mini-raceways, plus all associated equipment to harvest and process the algal biomass. This is used to scale up production of algae under red lights to produce a powder with an ideal taste profile, balanced amino acid composition and optimal content of *9-cis* beta-carotene, a new food supplement.

Food research is supported with laboratories for food microbiology, food chemistry, two food innovation laboratories (1 new 2020, £379k), food preparation and post-harvest produce quality, and molecular biology. In 2017, NRI took over the research storage facilities of the [Produce Quality Centre](#) (PQC) at East Malling, and invested £180k in facility refurbishment, and £90k in equipment, representing a significant infrastructure increase. With support from Innovate UK and industry, NRI has worked with UK agritech companies to develop state of the art storage research equipment. The PQC has the UK's most extensive controlled atmosphere (CA) research storage facility, comprising ten adaptable controlled temperature rooms from -2°C to 30°C, with >50 chambers each capable of independent atmospheric control, and state of the art equipment for monitoring environmental conditions and produce quality attributes.

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

Strategic fit of NRI's work globally

NRI's research is aligned with the priorities in the strategy of the **GCRF**, under the objective 'equitable access to sustainable development' and the theme of '*secure and resilient food systems supported by sustainable marine resources and agriculture*', with contributions to other themes. It is also in alignment with the priorities of the FCDO which in a recent research review identified the importance of 'large-scale research investment into sustainable agriculture, to improve nutrition and food security and increase resilience to climate change in developing countries'. Research on food systems and their relationship to food and nutrition security is also a **European Union** priority. The **African Union's** Comprehensive Africa Agriculture Development Programme recognises the importance of agriculture for food and nutrition security. The E3 Award has upgraded NRI's ability to address these issues.

Strategic fit of NRI's work nationally

The Strategic Priorities Fund Food Systems Programme indicates the challenge of ensuring that UK food systems are both environmentally sustainable and support a healthy population. The need to address local economic development in the UK's most deprived areas is a serious challenge recognised by Government. The award of the Strengthen in Places 'Growing Kent and Medway' and Food Systems CDT have positioned NRI to address these key priorities.

Research collaborations, Partnerships and Networks

NRI's **long-term deep engagement** in developing- and emerging-country agriculture is unique in English higher education. Virtually all UoA6 projects involve collaboration, since 2014 numbering >500 other organisations. Within NRI's Management Team, **Chancellor** takes specific responsibility for partnerships reflecting their importance to NRI's research and impact. NRI has signed 720 sub-contracts with partners since 2014. According to Scopus, **78%** of the UoA's 680 outputs are published with authors outside the UK.

The international nature of NRI's work is indicated in Figure 2 using days spent in specific countries as an indicator. NRI's work is focused on sub-Saharan Africa, with significant activity in south Asia, specifically India, and growing collaborations in China. The map also shows collaboration with partners in research intensive countries (e.g. EU, USA, and Australia).

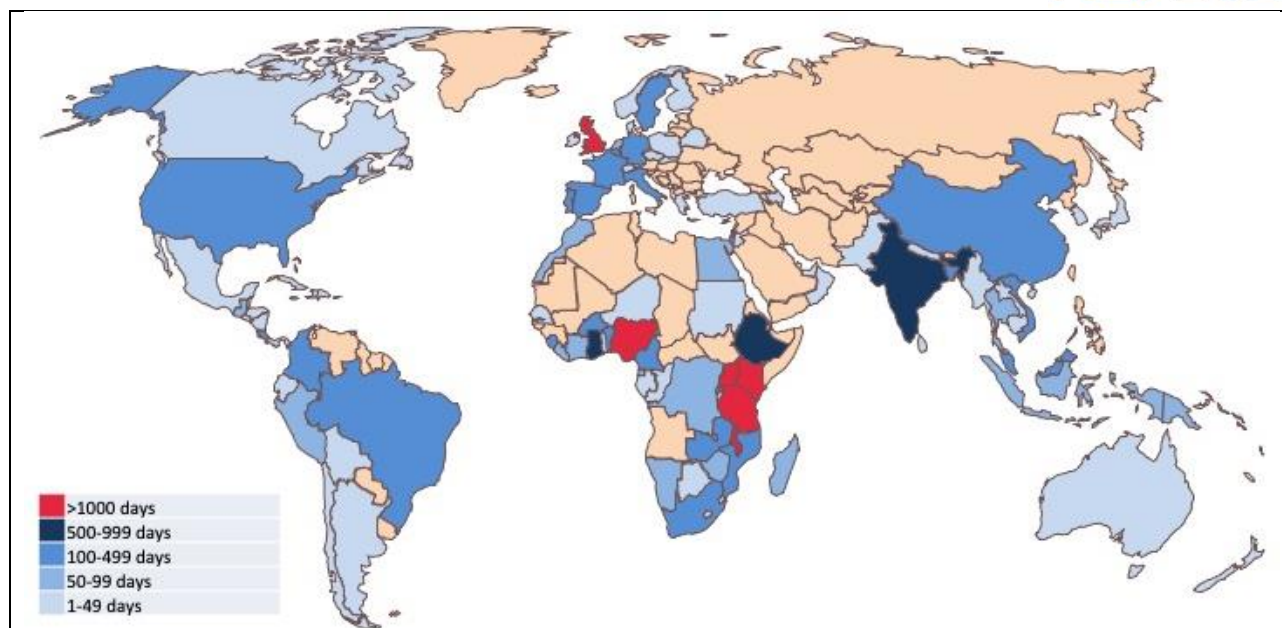


Figure 2. Map to illustrate the international nature of NRI's work. Shading indicates the number of days spent in each country since 2014 by NRI researchers.

In sub-Saharan Africa, staff have research collaborations or undertake policy or advisory work for the major regional organisations that include: Africa Union (AU), the African Union Development Agency (NEPAD); Alliance for a Green Revolution in Africa; **Forum for Agricultural Research in Africa (FARA)**; Regional Universities Forum for Capacity Building in Agriculture (*RUFORUM*); **Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA)**; and the African Forum for Agricultural Advisory Services. Additionally, NRI collaborates with a wide range of universities, national agricultural research organisations, national government departments and non-government organisations (the CAVA project (Westby) worked with >100 organisations between 2014 and 2019).

As part of the Research England's E3 Award, NRI formed a partnership as part of its Food and Nutrition Security Initiative. Partners include: African universities that are World Bank Centres of Excellence (Federal University of Agriculture, Abeokuta, Nigeria (Agricultural Development and Sustainable Environment); Haramaya University, Ethiopia (Climate Smart Agriculture); University of Eldoret, Kenya (Food Processing); Benue State University, Nigeria (Food Losses); Sokoine University, Tanzania (Rodent Pest Management/McKnight Agroecology Hub); Nelson Mandela African Institution of Science and Technology, Tanzania (Agroecology); Bayero University, Nigeria (Drylands Agriculture); Lilongwe University of Agriculture and Natural Resources, Malawi (Aquaculture and Fisheries/ McKnight Agroecology Hub); CGIAR Centre/Programmes (Worldfish, HarvestPlus, CGIAR Research Program on Roots, Tubers and Bananas and ILRI), ICIPE, Kenya and leading UK agricultural research centres (Rothamsted Research and NIAB-EMR). This has already led to four jointly funded appointments, PhD studentships and significant new funding (e.g. UK Food Systems CDT).

Research partnerships have grown with organisations in USA (e.g. on whitefly, horticulture and warehouse receipts with Cornell, Iowa State University, University of California, Riverside and Perdue University), China (on IPM, rodent control and cassava with, for example, Chinese Academy of Agricultural Sciences and Hunan University of Agricultural Sciences) and Brazil (Zika/Dengue transmission and cassava and with FIOCRUZ, including a Memorandum of Understanding with EMBRAPA).

NRI's membership of [Agrinatura](#), the European Alliance for Agricultural Knowledge for Development, with 35 members from 16 countries (> 2,000FTEs including CIRAD, Wageningen and Swedish Agricultural University), is particularly significant. NRI seconds the Director, hosts

Unit-level environment template (REF5b)

the secretariat and **Chancellor** is Vice President. Agrinatura has a strong research, advisory and support partnership with DG Development, facilitating knowledge creation and uptake.

As a reflection of planned strategic focus on UK-focused research, there has been a strengthening of national partnerships. The [UK Food Systems CDT](#), with nine academic partners, has an open 'Academy' with >50 associate partners from government, civil society and business. The [Strength in Places](#) project has open membership but centres on core collaborations with NIAB-EMR, University of Kent, Locate in Kent and 8 companies.

NRI is a founding member and provides the Coordinator for the [All Party Parliamentary Group on Food and Agriculture for Development](#). The group provides a mechanism for influencing policy on food and agriculture, presenting research findings and interfacing with Government departments.

NRI interacts with many global research and development organisations. Examples include FAO (e.g. supporting the Tropical Agriculture Platform); World Food Programme (long-term advisory support on food safety); Global Forum for Rural Advisory Services; CGIAR (multiple collaborations and reviews of collaborative research programmes (2020)).

NRI has many collaborations with industry at different scales. Selected examples include: Mars, Sainsburys, SABMiller, Russell-IPM, Berry Gardens, Thanet Earth, Barfoots, BioGents Ag, North-Eastern Starch Limited (Thailand), Tropical Starch (Ghana), GrowTech (Kenya).

Activities supporting the academic community:

- Director, UKRI [UK Food Systems CDT](#) (**Westby**).
- President of Agrinatura-EEIG (2011-2014) (**Westby**).
- Management Committee, BBSRC [London Interdisciplinary Doctoral Programme](#) (**Westby**).
- Co-chair of Independent Panel of Experts for the Innovative Methods and Metrics for Agriculture and Nutrition Actions (IMMANA) programme (BMGF/FCDO) 2020 (**Westby**).
- Co-Director of the BBSRC [NIBB 'Algae-UK'](#) (2018 – date) (**Harvey**).
- President of International Society for Tropical Root Crops (2012-2018) (**Tomlins**).
- Vice-president of the International Parasitic Plant Society (2020-date) (**Rodenburg**).
- Committee (2014-2018) Chair (2018-date) of Eukaryotic Division, [Microbiology Society](#). (**Thompson**).
- Lead expert/ keynote address to joint WHO-FAO committee on 'Innovative control approaches of rodent-borne epidemic diseases and other public health consequences of rodents' proliferation' 2019 (**Belmain**).
- Management Board, GCRF-funded Community Network for African Vector-Borne Plant Viruses ([CONNECTED](#)) (2018 to date). 1,500 members, 83 countries (**Seal/Hopkins**).
- Management Board, GCRF-funded Community Network on Blackflies, Sandflies and Biting Midges ([GNATWORK](#): Building capacity for research on vectors of neglected diseases) (2017 to date). 384 members, 44 countries (**Cheke**).
- Society of Chemical Industries, AgriScience Committee (**Hopkins**).
- Chair, Organising Committee. Symposium on The Chemical Ecology of Pollination 2016 at XXV International Congress of Entomology (**Stevenson**).
- Chair, Organising Committee '[Algae Biorefineries for Europe](#)' International conference 2017 (**Harvey**).
- RSC-Pan Africa Chemistry Network Advisory Board 2015 – date (**Harvey**).
- [European Algal Biomass Association](#) Board 2014-date (**Harvey**).

Table 10 Examples of leadership in the academic community.

	Count
Fellowship of main learned societies	30
Conferences organised/chaired	49
Workshop, mini-symposium, special sessions organised	73

Unit-level environment template (REF5b)

Plenary lectures	33
Invited or keynote lectures	102
Editorship of journal (chief or joint)	27
Member of journal Advisory Editorial Board	16
National or International Advisory Board Committees (Including UKRI)	43
Research Prizes and similar honours	33
Other...	42

Examples of NRI's staff/research **supporting policy and practice:**

- Two Coordinating Lead Authors (chapters on 'agricultural production and food security' (Porter) and 'rural areas (Morton (UoA22)'), Fifth Assessment Report of the Intergovernmental Panel on Climate Change (2014).
- Steering Committee Sweetpotato for Profit and Health Initiative, reaching 6.2 million households (estimated 29 million people) with orange-fleshed sweetpotato by 2019 (**Westby**).
- Consultancy for FAO (2016) on alternatives to fenthion for bird control, leading to some countries, e.g. Botswana, changing policy (**Cheke**).
- Member of the highly cited [Lancet Countdown for Health and Climate Change](#) (**Grace**).
- Member of Global Burden of Disease Collaborator Network contributing to two Lancet articles (730 citations) and a [New England Journal of Medicine](#) paper (2000 citations) (**Wesana**).
- Invited Team Lead/ Lead Author of [Ceres2030](#) Evidence Synthesis to inform investment decision-making for SDG2 (2020) (Evidence Synthesis: Interventions for crop postharvest loss reduction in sub-Saharan Africa and South Asia) (**Stathers**).
- Technical advisor to [AgResults](#) an innovative multi-million dollar Pay-for-Results approach incentivising private sector investment in high-impact agricultural innovations to reduce food insecurity. Kenyan On-farm Storage (2015-16) (**Stathers**).
- Member of the Asia-Pacific Malaria Elimination Network's Vector Control Working Group (**Hawkes**).
- Member of Roll Back Malaria's Vector Control Working Group (**Hawkes**).
- Co-chair, North American Carbon Program (NACP) Implementation Plan (**Brown**).
- Member, NACP Science Implementation Plan Writing Committee, 2017-date (**Brown**).
- National Academy of Science's Committee on Earth Sciences and Applications from Space, 2016 -date (**Brown**).
- Special advisor to WHO providing expertise/training on rodent-borne diseases in Madagascar 2018 (plague) and Hong Kong 2019 (rat hepatitis) (**Belmain**).
- Contribution of an 'Inspirational Project' (1/4) to the *EU Development of a Roadmap for the Blue Bioeconomy in 2019* (**Harvey**).
- DEFRA Pollinator Advisory Steering Group (**Stevenson**).
- DEFRA Group Evidence Science Advisory Committee (**Stevenson**).
- Led discussion workshop on 'Aquatic food products and new marine value chains' [FOOD 2030 launch by the EC DG Research & Innovation](#) (**Harvey**).
- Prepared evidence review report on algae, both micro-and macro-algae for the Scientific Advisory Mechanism (SAM) of the European Commission for Food from the Oceans (**Harvey**).
- Expert panel for European Commission DG Research & Innovation expert meeting on Algae Bio-Refineries (biomass production) (**Harvey**).
- Committee Member for Global Nutrition Leadership Programme (**Dominguez-Salas**).
- Potato Industry CIPC Stewardship Group (**Colgan**).

Awards and prizes awarded in addition to the QAPs already listed include:

- **Knight of French Order of Agricultural Merit** (2015) (Porter).
- **Guardian University Award** for Research Impact (2015).
- **Times Higher Award** for International Partnership of the year (2014).

Unit-level environment template (REF5b)

- USDA Abraham Lincoln Honor Award 2016 for Increasing Global Food Security for the Climate Change (**Brown**).
- Cassava work recognised in [UUK's Best Breakthroughs](#) List (2018).
- [Rockefeller Foundation Cassava Innovation Challenge](#) (Bennett/**Tomlins**) award for most promising solution, chosen from >1000 submissions (2017).
- Life-time Achievement Award for contributions to 'Radar Entomology' (International Radar Aeroecology Conference, Zhenzhou, China, 2019) (**Reynolds**).
- 'Hind Rattan' (translates to 'Jewel of India') Award for outstanding contributions to research by a non-residential Indian recognising contribution in REF period (**Gowda**).
- Winner, Swiss Malaria Group's #EndMalaria video competition (2017) with "Living with Malaria" (**Hawkes**).
- Outstanding Alumna Award University College Dublin, Ireland 2020 (**Grace**).