Institution: University of Leeds

Unit of assessment: UOA14

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

1A. CONTEXT

Integrated expertise from the School of Geography (SoG) and the Social and Political Transport Science group of the Institute for Transport Studies (ITS) positions Leeds as a world-leading centre for geographical research. We aspire to advance knowledge and solutions to profound global-scale challenges, including: climate change and transitions to net zero; inclusive, just and healthy societies; advancing technologies for environmental management; securing healthy soils and freshwater supply, and ecosystem protection. Collaboration on research, impact and postgraduate/postdoctoral researcher (PGR/PDR) training is underpinned by shared facilities and administrative support as part of the Faculty of Environment (FoE). Directors of Research & Innovation represent SoG and ITS in a cohesive faculty research committee, strengthening interdisciplinary strategy development and management alongside UOA6 (Food Sciences), UOA7 (Earth & Environment) and UOA12 (Engineering) colleagues. Significant developments since REF2014 (Table 1) include:

- Strategic hires and professional development have expanded expertise in climate change adaptation, urban analytics and food security, strengthening our ability to lead research on major global challenges.
- Increased PhD awards/yr with current PGR numbers >166FTE (232 PhD and MA/MSc by Research (MbR) students including cross-UOA co-supervision), producing graduates who will lead future scientific and societal advances.
- A >5-fold rise in REF2 outputs in Nature/Science group journals (with >3-fold increase for *Nature/Science* core journals), more monographs, and increases in PGR/PDR-led nominations.
- Average Income/FTE/yr increased 26%, with >£12M new awards in 2019/2020. These successes contributed to >£25M of new office, laboratory and field facilities since 2014, enhancing our inspiring and vibrant environment.
- Athena Swan silver award (2019), and new UOA-led BAME and LGBTQ+ initiatives, recognising equality in structures and cultures are key to maintaining high-quality research, impact and training.

Table 1: Indicators of UOA development

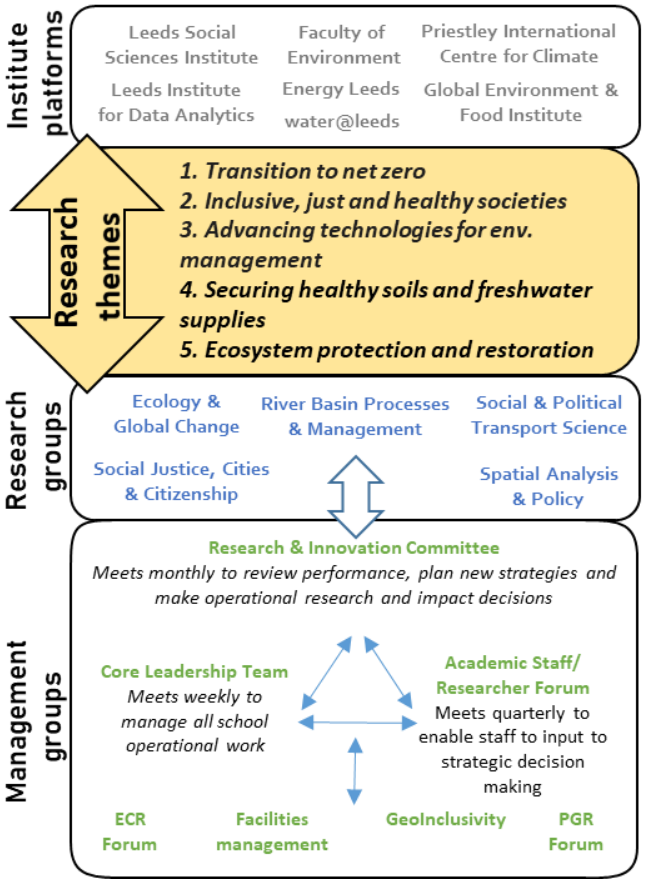
	REF2014	**REF2021**
Staffing		
Cat-A submitted	48.9FTE	60.85FTE
PhD awards (avg/yr)	64.7 (12.9/yr)	123.6 (17.6/yr)
REF2 outputs		
Nature/Science group	8 (4%)	43 (28%)
Nature/*Science*	4 (2%)	15 (10%)
Monographs	1 (<1%)	5 (3.3%)
PGR/PDR led	17 (10%)	28 (18%)
International co-authors	68 (38%)	96 (63%)
Non-academic co-authors	36 (20%)	52 (34%)
Income		
Total research income (avg/yr)	£16.6M (£3.3M/yr)	£31.5M (£4.5M/yr)
Avg. income/FTE/yr	£69,386 (2011-13)	£87,435 (2018-20)

Addressing global challenges requires interdisciplinary research, and we combine staff expertise and PGR mentoring in the natural sciences, social sciences, computer science and arts & humanities. Leadership of major research centres and projects positions us centrally in international, national and regional networks, enabling two-way dialogue with industry, government, NGO's, public groups and other academics. These allow us to understand and respond quickly to emerging research needs and provide evidence to underpin decision-making. Strategically-directed impact pathways are supported by professional support staff and funded

knowledge-exchange projects, generating benefits for environmental protection, public health and the economy.

1B. UNIT STRUCTURE

The distinctiveness of Leeds geography lies in our five research themes (Fig. 1). These themes span our research group expertise to focus inter-disciplinary thinking, while positioning the unit centrally in numerous external networks (Section 4) and cross-institute research platforms (see REF 5a).



← Fig. 1. UOA structure. UOA ***research themes*** (highlighted) ensure our ***research groups*** play leading roles in interdisciplinary ***institute platforms***. Delivery is supported by ***management groups*** interacting efficiently and effectively (arrows) via staff with roles spanning committees.

Research and impact management is led by Research and Innovation Committee (RIC), with research group leaders and two research/impact managers supporting SoG and ITS Directors of Research & Innovation with operational and strategic decision-making. RIC is part of a broader management structure (Fig. 1) which enables two-way dialogue and professional support between management groups and all staff. This connectivity allows researchers' voices to be channelled to leaders, and decisions fed back via the same routes, to inform operations and further iterations.

The unit comprises five research groups: ***Ecology & Global Change (EGC)*** determines the dynamics of ecosystem patterns and processes in space and time**.** ***River Basin Processes & Management (RBPM)*** researches processes and fluxes and their impacts on the environment and society in freshwater, soil, alluvium, ice and marine environments. ***Social Justice, Cities & Citizenship (SJCC)*** analyses the complexities of social (in)justice and citizenship and contributes towards achieving a radically fairer world. ***Social & Political Transport Science (SPTS)*** studies mobility and transport systems to deliver effective, fair and environmentally sustainable mobility systems. ***Spatial Analysis & Policy (SAP)*** develops and applies cutting-edge methods to enhance understanding of society, business, and the environment. SoG-ITS integration was consolidated with Manley's chair, four University Academic Fellows (UAF; Heinen, Ge, Lovelace, Pangbourne) and two UKRI fellows (Pangbourne, Philips). Research groups organise meetings (including inter-group theme-based meetings) for peer support, discussing outputs, planning/reviewing proposals, training and developing impact activities. All staff, PGRs, PDRs and visiting-researchers are members of at least one group, to maximise inclusivity in debates and decision making. We support affiliations with multiple groups to further develop our interdisciplinary expertise.

Our research themes align with globally recognised geographical challenges. For example, 13/17 UN Sustainable Development Goals relate directly to our research and impact activity, most notably climate action, sustainable cities, gender equality, health and wellbeing, clean water, and life on land. Four themes are relevant to World Economic Forum major challenges (food security, inclusive growth, climate change, gender equality), and we work in 4/7 EU priority areas (climate action, health and wellbeing, societal engagement, sustainable food/farming). New research and

impact initiatives are supported through competitive faculty-level internationalisation funds (£20k/yr), school-level priming funds (up to £10k/yr), university-level strategic initiatives (e.g. UAF £50K start-up), and seedcorn funding from the White Rose Consortium (Leeds-York-Sheffield; (£11K/yr) or N8-Agrifood partnership of research intensive Universities across Northern England (up to £30K).

Institute platforms (REF5a) build directly on the work of our research groups given our strategic focus on interdisciplinary global-challenge themes (Fig. 1)**.** We lead water@leeds (Holden & Tillotson [directors]) and Leeds Institute for Data Analytics (LIDA) including the Alan Turing Institute Urban Analytics theme (Birkin [director]). We hold leadership roles within the Priestley International Centre for Climate (Chatterton, Ford, Gloor), Leeds Social Sciences Institute (Waite [deputy director], Lomax, Routledge), Global Food and Environment Institute (Carter, Chapman, Ziv), Energy Leeds (Lovett, Marsden) and Culture (Bell). These platforms enable us to lead the development of collaborations, partnerships and PGR training, cross-fertilising ideas with internal and external partners (Section 4).

1C. RESEARCH AND IMPACT: EVIDENCE FOR STRATEGY DELIVERY

After successfully implementing our REF2014 plans, RIC mapped major international research needs/challenges to our research excellence. This underpinned a revitalised strategy that aims to extend our previous plans with increased research quality and further growth of our position as international leaders. Four **key objectives** are:

(1) Continue to produce world-leading outputs and develop solutions to global challenges by increasing our leadership of collaborative partnerships internationally and nationally.
(2) Enhance research quality, innovation strengths and staff diversity through retention and strategic hiring, and growing doctoral/postdoctoral excellence alongside expansion of our MbR programme.
(3) Further expand the breadth, depth and diversity of our research portfolio with more large-grant income, to enhance our environment, outputs and impact.
(4) Increase the depth and breadth of relationships with businesses, regulators, NGOs and civil society, to further identify research user needs and deliver relevant knowledge.

Our achievements and future plans under each of these objectives are detailed in sections 1-4, respectively, of this document.

Since REF2014, our researchers delivered >1300 outputs and played a role in >360 funded projects. Improved outputs quality is fertilising ever more fruitful collaborations and partnerships. *Five research themes have developed to focus and grow interdisciplinary innovation both within and between research groups, and with external collaborators and users*. For each theme, evidence for major research and impact achievements, and ongoing initiatives to strengthen further, are presented with parentheses illustrating key examples from our REF2 and REF3 submissions.

Theme 1. Transition to net zero. Climate change is the most pressing environmental problem of our generation. A key focus of our research is on continental-global consequences and responses to climate change, with large grant funding from NERC, Gordon & Betty Moore Foundation and the EU, leading to global impact with international governments. Key achievements have been advanced understanding of carbon-cycle processes in Amazonian (UOA14-4239) and African forests (UOA14-4171), high-latitude peatlands (UOA14-2437) and the Southern Ocean (UOA14-2307), and quantifying global Methane budgets as part of the NERC MOYA consortium (Gloor; UOA14-1820). We led a major new conceptualisation of the 'Anthropocene' linking ecology and 'human geology' (UOA14-1295), and developed new climate-social science insights to support government policies for adaptation (UOA14-4157; 4187).

A second area of strength focuses on emission reductions drawing on expertise from the social sciences, engineering and environmental studies. We are a focal point for the transport carbon-reduction agenda nationally, leading mobility themes within multi-partner centres DEMAND, CREDS, UKERC and UKRI's Energy programme Decarbon8 with >20 businesses and

government groups. We developed expertise on transport-sector planning to address climate targets (UOA14-1504; 1507), relationships between multimodality and emissions (UOA14-3138) and reducing emissions from heavy-goods transport (UOA14-4204). Our researchers have pioneered sustainable societal transitions, with funding from ESRC and EPSRC advancing understanding of low-impact housing and transformational urban environmental development (Chatterton, UOA14-1543, REF3 UOA14-3), and demand management to drive sustainable water use (UOA14-4176).

Our work is influential for international decision-makers and society, including IPCC assessment invitations and commissions to synthesise and communicate the effects of global change (1.5˚C SR, SROCC, AR6 and SRCC reports; Ford, Brown). We have developed partnerships with governments in S. America and Africa to protect major C stocks in peatlands (REF3 UOA14-2), and led the Commission on Travel Demand used by the UK government's Committee on Climate Change (Marsden).

Theme 2. Inclusive, just and healthy societies. The world is increasingly urban but inequalities are widening within and between cities and rural areas. Covid-19 has focused government and public attention to these issues, and our expertise positions us to lead on responses. Understanding and managing the movement of human populations is a significant component of our research, as a core partner in the JPI/ESRC Urban Public Administration and ServiceS project (UPASS, with Amsterdam, Zhejiang and Beijing Jiaotong), and the UKRI Urban Living Partnership. Research links sociology expertise with urban transport planning in relation to governance of sustainable mobility (UOA14-4068), and for increasing physical activity, especially walking and cycling (UOA14-3136). Research linking human behaviour with transport network analysis transformed UK cycle infrastructure planning, including pandemic-driven pop-up cycle lanes (REF3 UOA14-4). The Transport, Travel and Social Adaptation Study (TRANSAS; Marsden) funded by UKRI, Department for Transport (DfT), Transport Scotland, Transport for the North and Liverpool City Region was also developed to direct Covid-19 responses. We have advanced links between sociology and population movements due to forced labour, exploitation and asylum (UOA14-4155; 4232), economic circuits of migration control (UOA14-2875) and healthcare (UOA14-1849).

A second focus develops new understanding towards safeguarding human rights, with theoretical and methodological innovations in critically-engaged scholar-activism as distinctive strengths (UOA14-1544; 4695). Research on the effects of, and responses to, social exclusion has strengthened considerably since 2014 through roles in the EU Contested Cities network (9 partners in Europe/S. America), the EU Contested Territory project (19 partners), and McQuaid's UKRI Future Leaders Fellowship. Research has highlighted serious inequalities in energy justice (UOA14-4154), air-quality exposure (UOA14-4293) and sexual-orientation legislation (UOA14-1793). Our work includes a strong focus on neoliberal political and economic drivers of inequality, in particular improving understanding of housing affordability, displacement and safety problems associated with privatisation including Grenfell (UOA14-4387; 4613), energy poverty (UOA14-2180), health effects of urban deprivation (UOA14-804) and ongoing ESRC funded work on financialisation of the European migration crisis (Garelli).

Impact has arisen from commissioned inputs to the UN High Commissioner for Human Rights (McQuaid, Hodkinson), and Mullen's role in the European Social Policy Network underpinned improvements in access to essential services for low income people. We produced two commissioned reports (UK Chief Medical Officer, Natural England) on environmental inequalities (Mitchell) influencing the Guys and St Thomas' Charity £30M health effects of air quality programme. We provided advice to the DfT on travel behaviour (REF3: UOA14-4) and testimonies to UK parliamentary committees on modern slavery (Waite) and transport planning (Marsden). Further impact is developing from AHRC-funded Queer memorials work and ESRC IAA funded work promoting LGBTQ+ inclusive fieldwork (Zebracki). Gonzalez's ongoing ESRC traditional retail markets research emphasizes innovative alternatives toward social inclusivity, apprising Parliamentary committees and directly informing Covid-19 high street retail responses.

Theme 3. Advancing technologies for environmental management. Large-scale datasets and analytical advances are revolutionising our understanding of human-environmental system processes, in terms of data volume, velocity and variety. Our strengths build on leadership of the LIDA, the Alan Turing Institute Urban Analytics theme, hosting four Turing fellows, and leading the ESRC's Consumer Data Research Centre (CDRC) and Consumer Data Research Support Service (CDRSS). Theoretical data science develops computer science advances to enhance understanding of geographical patterns and processes (UOA14-34*;* 939; 3710). These fundamental advances allow us to develop leading urban analytics advances from massive datasets spanning healthcare, social media and travel/retail smartcards. Partnerships with governments inform understanding of social phenomena including prosperity, healthy-living, transport and crime, and we work with major businesses to maintain economic competitiveness. Leadership of the CDRC underpinned our development of new insights into socio-economic systems using 'big data' from businesses, such as mobile phone records (UOA14-4071), travel behaviour (UOA14-4070) and smart meters (UOA14-2481). Our data science has significantly advanced urban planning knowledge, including internal migration patterns (UOA14-4207), economic drivers of urban form (UOA14-4231) and property-market dynamics (UOA14-4230).

A second strength is developing and applying methods for remote sensing to inform management of environmental change, utilising hydrology, geomorphology and ecology data from networks of sensors, satellites, drones, scanners and photogrammetry. Our work developed new methodological advances in structure-from-motion (SfM) photogrammetry to minimise 3D uncertainty in drone-derived data (UOA14-2715), and protocols for using SfM in extreme environments where direct measurements are dangerous or impossible (UOA14-4159; 4203). Other strengths in developing remotely-sensed spatial data have created methods to compare high-resolution data with historical imagery, improve land cover classification, and quantify glacier surface properties using laser scanners (UOA14-938; 4238). We pioneered satellite technology applications in ecology, advancing estimates of forest biomass (UOA14-4220), identifying 4.67M km^2 of dryland forest never previously reported (UOA14-219) and quantifying acceleration of Amazon secondary forest loss for the first time (UOA14-4173).

Our distinctive strengths are recognised internationally, including Comber's role as the UK representative on the UN Global Earth Observation land cover validation panel, Ziv's work on the GEO-BON Ecosystem Services working-group, and Phillips as a core member of the European Space Agency's (ESA) Climate Change Initiative Biomass project. Scientific excellence enables our academics to influence policy-making: urban analytics research on real-time behavioural responses to major weather events contributed to a session at the International Transport Forum OECD, and we hold advisory roles for the Office for National Statistics (Lomax, Norman).

Theme 4. Securing healthy soils and freshwater supplies. Soils and water are critical for human wellbeing, food systems and environmental health. Our catchment-science strengths incorporate socio-economic, behavioural and biophysical perspectives to guide decisions about agricultural land-use change, soil sustainability, and water quantity/quality in aquatic systems, with co-ordination roles in major EU (BESTMAP, Euro-FLOW) and UK (NERC integrated catchment solutions programme iCASP) networks. We lead continental-global scale soil science advances, explaining the genesis of global peat development from new catalogues of radiocarbon dates (UOA14-4216), agricultural-zone shifts with climate change (UOA14-1147) and biome-scale nitrogen fixation (UOA14-3229). At regional scales we have advanced understanding of tropical soil carbon storage (UOA14-4133; 4229), water supply hotspots from peatlands (UOA14-4235) and links between policy and land management (UOA14-999). A growing focus is on contaminants of emerging concern, developing leading expertise on pharmaceutical chemistry in food crops (UOA14-3845) and the aquatic environment (UOA14-1810), and developing new insights to anti-microbial resistance (Carter, NERC UK-India Tackling AMR).

Our research has developed widespread understanding of aquatic systems in rapidly changing environments, including the first full water transfer inventories and footprints for China (UOA14-4176), significant advances in malaria-risk mapping across the while of Africa incorporating

hydrological modelling (UOA14-4167), and improved understanding of aquatic foodweb response to extreme events using network science (UOA14-1811). Studying emissions from thousands of floodplain trees closed the Amazon methane budget, demonstrating that they emit as much methane as all Earth's oceans combined (UOA14-1820). We make significant advances in understanding the global consequences of cryosphere change for the environment and society, advancing understanding of glacier and ice-cap recession rates (UOA14-1842; 2609), and developing knowledge of the implications of ice loss for: permafrost carbon storage (UOA14-4228); societal change by connecting Indigenous knowledge and science across the entire Arctic zone (UOA14-4186), and; mountain river biodiversity based on >1.2M invertebrate observations from mountain ranges globally (UOA14-4234).

Our expertise is recognised via advisory roles with groups such as the UN-FAO (Grainger), NASA's High Mountain Asia panel (Quincey) and the UK's technical advisory group for the EU Water Framework Directive (WFD) (Klaar). We advised the UK government Agriculture Action Group taskforce and two Royal Society Global Environmental Research Committees (Holden, Lewis). Multiple impacts are developing from leadership of the NERC iCASP centre (2017-22) on themes including reducing flood and drought risk, water quality, and sustainable agriculture (Klaar, Chapman, Kay).

Theme 5. Ecosystem protection and restoration. Ecosystem services underpin human wellbeing, but human activities have pushed the planet into its sixth mass-extinction event. We quantify changes in biodiversity and ecosystem functional processes in forest, soil, freshwater and marine ecosystems and use our expertise to inform protection and restoration solutions via changes in land management, rewilding and policy interventions.

World-leading research on tropical forests is built around founding and leading Forestplots.net, the meta-network of people and plots connecting >2300 researchers and fostering analysis of biodiversity and ecosystem function datasets from >4500 plots (44 countries). We led funding of this network via multiple large grants by originating collaborations including RAINFOR (S. America), T-FORCES (Asia) and the African tropical rainforest network (AfriTRON). Phillips' research leadership led to his induction as a Fellow of the Royal Society. We lead multiple advances understanding forest ecology, including establishing thermal-sensitivities of forest carbon cycling with 225 researchers from 178 institutes (UOA14-4172), drought effects on carbon cycling (UOA14-420; 4236) and tree mortality (UOA14-2610), and relationships between functional processes and facets of diversity, including biodiversity (UOA14-1297), phylodiversity (UOA14-4178) and dominance (UOA14-4240). Nottingham's appointment expanded our expertise in soil microbiology, developing new understanding of below and above-ground tropical forest diversity and functioning (UOA14-4132; 4133).

A second ecosystem strength focuses on peatlands, with major advances in understanding carbon storage in the tropics including potentially the world's largest tropical peat complex in the Congo (UOA14-1296; 2643). Pan-European research has identified significant concerns about widespread drying (UOA14-4177) and erosion (UOA14-4237) and produced methodological advances for modelling frameworks (e.g. DigiBog, SD-TOPMODEL) to facilitate advances in peatland land-use planning and restoration (e.g. UOA14-4153; 4210). Clarivate Analytics analysis of our outputs and citations in Web of Knowledge showed that we are one of the world's most productive institutes for peatland research.

Our ecosystem expertise informed protected area designations in S. America and Africa (REF3 UOA14-2) and we worked with Defra to inform government agriculture and environmental (carbon) protection plans. Carver's rewilding research (REF3 UOA14-1) led to his appointment as joint-chair of the International Union for Conservation of Nature (IUCN) Commission on Ecological Management Rewilding Task Force, mandated to develop a framework for protecting and restoring wildland ecosystems that informs IUCN policy and guidelines for 1300 members and 14,500 global experts.

1D. ONGOING STRATEGY DEVELOPMENT

We will continue to challenge and improve knowledge by combining fundamental advances with applied research, to generate adaptive solutions among scientists, policy-makers, businesses and society. A strategic growth area underpinned by the initiation of a cross-faculty group on *Climate Change Adaptation and Vulnerability* will link our work across Theme 1 & 2, strengthening collaborations across the Priestley Centre via Ford's leadership of the UKRI COVID Observatories (2020-22) project understanding interacting Covid-19, climate & food system risks among Indigenous peoples. McQuaid's FLF (2020-25) will further expand understanding of how the arts can help marginalised African communities engage with climate change decision-makers. Lovett's leadership of the Royal Society/DfiD African *Clean Energy Research* alliance (2016-21) and the EPSRC Resilient Sustainable Micro-Grids project (2018-21) will further enhance the role of geographical expertise in low-carbon energy solutions under Theme 1. Additional strengthening between SoG-ITS will allow the development of novel *Transport Solutions for People and Planet* spanning Themes 1 & 2, with leadership of DecarboN8 already advancing place-based research to accelerate decarbonisation, and new micro-mobility solutions building from ELEVATE (Heinen 2020-24). International leadership will strengthen via a Canada-UK AI initiative (2020-23; Manley) on Responsible Automation for Inclusive Mobility.

Building on the successes of Theme 3, we aim to strengthen our data analytics leadership via holding/sharing data, and training and analysis. We seek to grow expertise in *health and population analytics*, as part of the SIPHER medical sciences consortium (2019-24), work on automation and mobility (ESRC 2020-23) and leading the ongoing CDRC (2020-24). We will build on urgency research to increase societal understanding of the global responses to Covid-19, advancing understanding of transmission (Manley MRC, EPSRC), effects on crime rates (Malleson, ESRC) and travel adaptations (Marsden, EPSRC). This research will ensure Leeds' key role in post-crisis economic and societal recovery, and allow diversification of funding streams towards MRC/healthcare providers. We plan to build on LIDA expertise and facilities to grow capacity for *environmental data analytics*. For example, ongoing work with ESA is informing satellite data solutions to uncover forest structural and functional characteristics, 'smart agriculture' expertise under Themes 3/4 is developing from £3.2M investment in soil, hydrological and meteorological sensor networks and analytics expertise (Section 3B), and our research under Theme 5 will expand intercontinental ecosystem knowledge utilising molecular (omics) techniques. *Agricultural sustainability* expertise will further develop new links between Theme 4 and 5, building on expertise leading BESTMAP (Ziv, EU 2019-2023), Carter's UKRI FLF on contaminants in agricultural systems (2020-25), and Chapman/Holden's work to understand soil carbon formation, transformation and loss (NERC Locked-Up, 2019-23). To sustain this growing agricultural expertise, we aim to expand BBSRC and agro-industrial funding.

1E. OPEN RESEARCH

Increasing open outputs, data and collaborations has been supported with three staff in SoG/ITS, institute-level staff, and via initiatives such as ReproducibiliTEA led by library staff. Outputs are archived in the White Rose Repository (WRR), with a ten-fold growth in deposits since 2014 and >450,000 downloads (Table 2). Open access PGR thesis availability has tripled since 2014, with a nine-fold increase in downloads. Access to outputs is enhanced further by UOA researchers' use of Research Gate (>50% Cat. A staff), pre-print servers (e.g. arXiv, bioRXiv) and funding for Gold open access (119 papers in 2020; 51 in 2014; total since 2014 = 674 [~50% of outputs]).

Table 2. WRR deposits and downloads

	Years	Deposits	Downloads
Outputs	To 2014	141	60,068
	To 2020	1455	456,492
Theses	To 2014	59	10,405
	To 2020	174	97,601

Orcid ID used by all staff aids cross-referencing of our activity. 95% of in-scope nominated outputs and >94% of total outputs in the REF period are open-access compliant. Reproducibility is

supported with data and code archives, facilitated through Research Data Leeds (>100 datasets deposited from UOA members since 2015 launch), external repositories, and our own DOI minting (ForestPlots.net). By originating and developing the ForestPlots platform (NERC, EU, Royal Society), we support researchers worldwide to access data, and contributed to the development of the global plant-traits database 'TRY'. A second open platform (PeatDataHub.net) that we lead has been developed since 2020 with QR strategic-priorities funding.

We promote accessible science through *open and reproducible code, publications, tools and software* via external roles and collaborations: (1) Comber is co-Chair of the Association of Geographic Information Laboratories in Europe, a forum on open and reproducible research; (2) *Geocomputation with R* (Lovelace) was the first completely open source and publicly accessible online geographic textbook from an established publisher, and we hold editorial roles for open access journals (e.g. Brown - *Frontiers in Environmental Science*); (3) Many staff use GitHub, encouraging community engagement and collaborative input plus transparent review; (4) We actively promote the R statistical computing platform, including textbooks (Comber, Lovelace), techniques/practical exercises using RPubs, and package development (BiomasaFP; cyclestreets; OpenTripPlanner, pct, stats19; stplanr; >150,000 downloads combined); (5) CDRC provides open outputs (maps, case study data) with >200,000 downloads; (6) We lead co-production initiatives to deliver public services in equal and reciprocal relationships, steering the Leeds Open Data Institute innovation group (Chatterton), and leading >40 iCASP co-production workshops with businesses, government and NGOs. Open research supports our strategy aims by fostering broader collaborations and enabling end-user uptake of outputs to develop impact. For example, R package 'stplanr' now underpins a web portal for UK MPs working on road safety, and the iCASP Derwent Data Finder facilitates Environment Agency planning for monitoring water quality.

1F. RESEARCH INTEGRITY

The Concordat to Support Research Integrity is implemented at the institution level for all researchers. Policies on General Data Protection Regulations, professional integrity, whistleblowing, research misconduct, harassment, and bullying are continually enacted and monitored by SoG/ITS management teams. A pre-application risk review, where necessary, initiates ethics, H&S and high-risk travel reviews. Ethical review for all research involving human subjects or substantial environmental impacts is overseen by FoE Research Ethics Committee with UOA representation (Mullen). Authorship policy follows the Committee on Publication Ethics. Implementation is supported with UOA initiatives including training for PGRs and staff (e.g. ethics, plagiarism, conflicts of interest), open research growth, and enhanced laboratory sample tracking procedures. These approaches improve design, analysis and interpretation of all projects.

Section 2. People

2A. STAFFING STRATEGY

Staffing is central to Objective 2, and our profile has increased in seniority, quality and diversity since 2014. Returned FTE increases are accompanied by enhanced quality of outputs, impact case studies and income/FTE. The UOA draws on the expertise of >140 staff, including cross-faculty professionals: Category A (submitted) is 59 academics and 5 independent fellowship holders (60.85 FTE; 56.85FTE on permanent contracts). Cross-department appointments promote interdisciplinarity (e.g. Tillotson with Engineering, Ford with Earth & Environment, McQuaid with English). Five emeritus staff and 35 postdoctoral associates bolster our research strengths.

At the unit level, SoG and ITS employ two dedicated Research and Impact Support Managers, providing bespoke assistance to academics for research and impact planning, complex bid development and administration (Section 4B). In addition, research networks that SoG/ITS lead employ >10 co-ordinators, and facilities are managed by 10 technical staff. Two dedicated administrative officers provide travel planning, purchasing, and workshop/conference organisation. At Faculty level we developed an integrated approach to research support, to draw on the expertise of >20 shared professional staff who advance skills, knowledge and strategy

development. This includes a Faculty Research Office supporting grant administration from project conception to completion, and eight staff supporting doctoral training, marketing, outreach and media activity, enabling researchers to maximise their productivity in a fast-changing environment.

We strongly encourage *visiting-researcher exchanges* to/from the UoA, with formal policies underpinning incoming application reviews by Research and Innovation Committee. Since 2014 we supported >100 visitors (including PGR) from 27 countries, spanning academic, governmental and NGO organisations (Fig. 2a). Through the EU funded Contested Cities network we hosted >30 visitors from Europe and Latin America. Four visiting-researchers benefitted from prestigious Cheney Fellowships funded by alumni endowments, and we hosted visitors from India and Ghana funded by Commonwealth Fellowships, four British Council academics from South America, and two Chinese Scholarship Council recipients. Other visitors have been supported by Royal Society, British Academy and Marie Curie funding. Our academics have held visiting-researcher positions at e.g. Colorado (Gloor), Brisbane (Lomax, Heinen) and Beijing (Tillotson, Grainger). These prestigious linkages maintain our international standing with network building, co-supervising projects, research dissemination and impact generation.

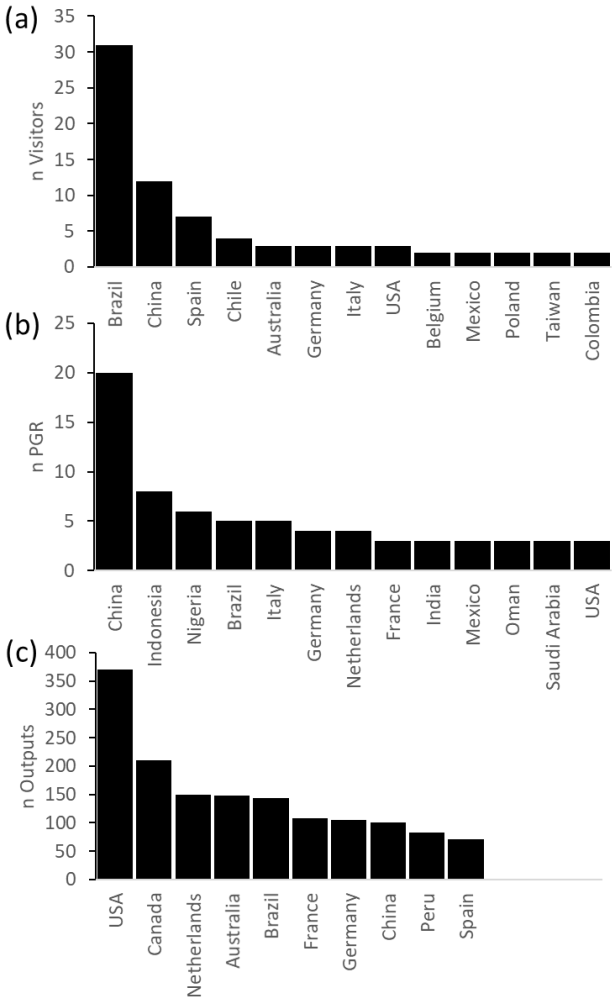


Fig. 2. Top ten countries (excluding UK) for (a) incoming visiting-researchers, (b) PGR recruitment and (c) joint-authored outputs →

2B. STAFF DEVELOPMENT

We ensure UOA vitality is sustained with staff development and succession planning linked to structured training, mentoring and promotion schemes in line with the Concordat to Support the Career Development of Researchers. A multi-pronged approach includes ECRs and postdoctoral researchers: (1) *Coaching and mentoring* (mandatory for probationers) expands personal effectiveness and career progression. Annual staff review and development meetings with a senior academic enable constructive two-way discussion of achievements and setting realistic, achievable and prioritised personal/school objectives. (2) Annual Academic Meeting (AAM) *appraisals* for all staff with Heads of School and Directors of Research & Innovation review successes and strategically plan future priorities including professional development. (3) Internal funding allocations from grant overheads to personal development funds supports training and networking. (4) *ECRs are supported* further via a specific forum, with the leader representing staff on faculty and school level research and innovation committees. (5) *Secondments* to promote development of staff expertise, networks and impact (e.g. Lovett - Kew Gardens 2015-17; Birkin - Alan Turing Institute ongoing). In support of our equality and inclusivity strategy, (6) *female staff* are encouraged to develop leadership skills and maximise their potential through Aurora and Springboard programmes, and (7) all academic leadership roles are advertised openly providing *equal opportunities for career development*. (8) Staff benefit from *a continuous research and impact workload allocation (20% pro-rata)* plus *sabbatical period (up to 6 months every 5 years or upon completion of major leadership roles)* to develop grant proposals, outputs, and/or impact thus enabling continuity of high-quality innovations. (9) *Non-academic staff* are supported through coaching/mentoring, annual staff

review meetings with line managers, and with core school funding for training course attendance and following National Technician Development Centre best practice.

Annual *recognition and reward* nominations by team leaders allow us to value staff expertise for both research, impact and academic leadership activity, and enhance retention. Our valuing of staff contributions has seen promotions of eight staff to Associate Professor, and ten to Professor since 2014. We replace departing academics and support-staff in key areas to maintain strengths, and recruit new staff to expand into emerging strategic areas. Eight appointments have been made to 5-year tenure-track UAFs (Batterman, Carter, Heinen, Klaar, Lomax, Lovelace, Ge, Pangbourne), plus four lecturers (McQuaid, Morris, Garelli, Nottingham) and three chairs: climate adaptation (Ford), environmental analytics (Comber) and urban analytics (Manley). Our academic *demographic profile* (Table 3) reflects the success of our recruitment and development programmes, with more Professorial staff and a balanced F:M profile at Lecturer/Research fellow (reflecting the even gender balance of new hires). For succession planning we closely mentor early-career fellowship applicants, with >20 successes since REF2014 (Section 4E).

Table 3. Submission profile (%) with female/male breakdown (n)

Role	REF2014	REF2021
Professor	24% (F: 0; M: 13)	38% (F: 4; M:20)
Associate Professor	32% (F: 5; M: 12)	24% (F: 4; M: 12)
Lecturer/research fellow	44% (F: 7; M: 17)	38% (F: 12; M; 12)

2C. RESEARCH STUDENTS

An intellectually stimulating and rigorous PGR training environment is core to Objective 2. We achieve this by developing innovative and exciting projects at the forefront of our five themes, and integrate PGRs into funded-project teams whenever possible. PGRs are valued members of research groups and institute-level platforms, exposing them to interdisciplinary ideas. PGRs are key players in strategy delivery, through high-quality publications (Table 1) and central roles in many collaborations with academic and non-academic partners.

PGR recruitment spans >40 countries (Fig. 2b) and averages >30 starters annually, supporting capacity building and knowledge advancement in our five research themes. Our international standing is particularly strong in S. America linked to our Amazon monitoring networks (Section 3B) with international co-supervision supporting >30 Brazilian visitors (mostly PGRs). Since 2015 SoG has promoted a MbR for a shorter research degree or to combine research with employment, growing to 7 students (2020). Applications are judged on a candidate narrative to identify students with high potential, taking into account life-experiences as well as academic achievements. Shortlisted PGRs are interviewed by at least two staff who undertake unconscious bias and protected-characteristics training, ensuring fair and equitable processes. Degrees are offered full-time or part-time to allow flexibility for diverse circumstances. The Leeds/FoE graduate boards established criteria for consideration of potential academic achievement in PGR admissions, raise awareness of PhD opportunities through advertising on BBSTEM, and established summer placements for BAME students to experience research opportunities. The ESRC White Rose DTP also developed a partnership with the Stuart Hall Foundation to ring-fence two scholarships for black British students.

PGR funding is sustained from research councils, industry and internal competitions (Fig. 3). UKRI awards are predominantly ESRC (White Rose DTP, Turing scholarships and Data Analytics and Society CDT) and NERC (SPHERES 2014-18 and PANORAMA 2019-27 DTPs; SENSE CDT 2020-26). We diversified funding by obtaining eligibility for AHRC studentships through the White Rose College of Arts and Humanities and the EPSRC Water-Wiser CDT (2019-27). Large proportions of self-funded and international government-funded PhDs highlight our reputation as a leading PGR training institute.

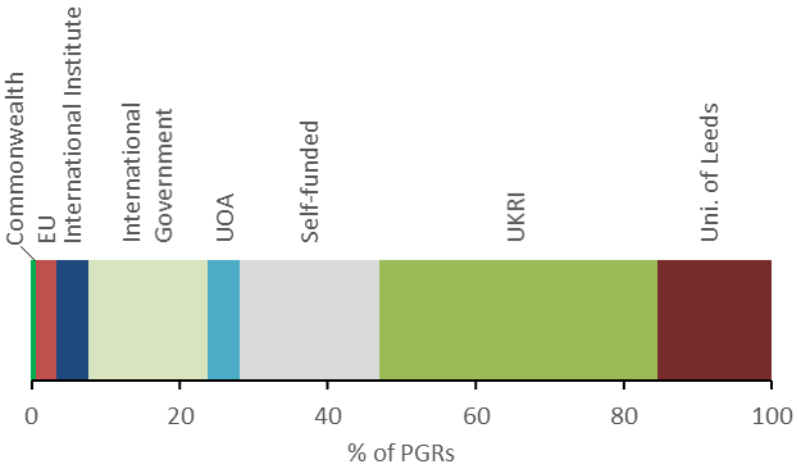


Fig. 3. PGR funding sources since 2014.

Building from strong end-user linkages (Section 4), we held 16 CASE/collaborative studentships from NERC/ESRC since 2014, 5 via competitive open-CASE schemes. We have also received studentships from industry (Yorkshire Water), strategic partnerships (e.g. the Alan Turing Institute, China Scholarship Council), large grants (e.g. Marie Curie Euro-FLOW and ERC DUST) and international businesses (e.g. Malaysian Rubber Board, Ghana Petroleum Corp.). To expand funding, a dual-PhD programme has been initiated with Beijing Jiaotong University, and we aim to develop this model with other partners. Further diversification is originating from a Leverhulme training programme in Extinction Studies starting 2021, and annual bursaries for two MbR students studying flood management funded by the Environment Agency, National Trust and other partners.

PGR Monitoring and Support is led by two supervisors per PGR (monthly meetings), reporting to an independent support group (two members) to review progress/offer advice. Pastoral care is overseen by Director of PGR Studies to enhance support/networking. PGR Forum reports to Research and Innovation Committee, and PGRs participate further in faculty/university initiatives to support their development (e.g. water@leeds forum; Leeds Social Science Institute, Priestley Climate Scholars). Professional and personal development is supported within research groups, and cross-group theme engagement is strongly encouraged. Group meetings allow PGRs to participate in decision-making and present ideas and research. PGRs receive a Research Training Support Grant for external training and conference attendance to further develop their skills and networks. SoG's Culture Enhancement Fund for PGR-led initiatives enabled a Science/Art Collaboration in Climate Studies conference, and training in virtual reality to enhance outreach. Our strategy has supported a >94% PhD submission rate, almost 50% increase in PhD completions/yr compared to REF2014 (Table 1 & 4), plus 16 MbR completions.

Table 4. Doctoral degrees awarded

	2014	2015	2016	2017	2018	2019	2020	Total
Professional research doctorates	0	0	0	0	0	0	0	0
Other doctoral degrees	18.19	17.11	11.93	12.5	18.66	25.98	19.24	123.61

A *Training and Career Preparation* analysis (month 1) is reviewed and updated regularly with each PGR's support group. Meeting records, training and progression are monitored online using a system (GRAD) developed by SoG and now used across the University. PGRs develop generic and interdisciplinary skills (including transferable skills) following the Vitae Researcher Development Framework, coordinated by the Leeds Doctoral College (see REF5a).

Training prepares PGRs for work in environments in and beyond academia. Human geography training is from an MA Social Research, and the White Rose DTP interdisciplinary social-sciences programme including Leeds-developed pathways (Wood: Cities, Environment and Liveability

pathway director; Malleson: AQM group). PGRs in the ESRC Data Analytics and Society CDT undertake a 4-yr integrated PhD/MSc with social sciences, computing, mathematics and natural sciences training. Physical geography PGRs undertake training through DTP/CDTs. Residential training schools build team-working and networking skills, and modelling, programming and statistical analysis training are core provisions. Optional training develops field and laboratory, impact planning, publishing and enterprise skills. Our expertise and standing allowed us to develop novel international PGR training courses with UFZ, Germany, and The National Socio-Environmental Synthesis Center, USA, funded initially from a Leeds International Research Collaboration Award. We co-ordinated 6 workshops (8-10 PGRs each) since 2014, developing collaborative skills and joint publications.

Publications are a key route to enhancing PGR communication skills and employability, and since REF2014 14x PGRs defended a new PhD by publications. Our PGRs led major outputs since 2014 including papers in *Nature* (UOA14-1296), *Trans. Inst. British Geographers* (UOA14-4230), *Nature Sustainability* (UOA14-4235, 4169), *Nature Communications* (UOA14-4240) and *Nature Ecology* (UOA14-4178). Two PGRs subsequently won fellowships at Leeds (Philips: ESRC; Draper: Marie Curie), and others won positions at prestigious institutes including Arizona, Beijing, Birmingham, Cambridge, Chinese Academy of Science, Exeter, Glasgow, Humboldt-Berlin, Imperial, Leeds, Ningbo, Oxford, Singapore, Texas, Yale and Zhejiang, extending our academic network of influence.

We encourage PGR secondments to gain hands-on experience and build collaborative links. Examples include LIDA internships, and collaborative award opportunities with non-academic CASE partners, academic collaborators, learned society schemes, or temporary employment (e.g. van-Leeuwen, Calderdale Council). PGRs are supported to take leaderships roles in scholarly networks (e.g. O'Kerry RGS-IBG Gender and Feminist Geographies; Philips RGS Transport Geography). These approaches recognise that PGRs undertake a range of careers, enabling self-directed experiences to enhance their employability. Former PGRs have established careers in major organisations including Capita, the European Centre for Medium-Range Weather Forecasts, Environment Agency, National Transit Agency Ecuador, Ministry of Land Ghana, Natural England, Oman Ministry of Defence, Indonesian Ministry of Planning, Taipei government, Walmart and the World Bank. A dedicated Professional Development Manager maintains alumni links, allowing us to grow research, impact and training with their organisations.

2D. EQUALITY & DIVERSITY

We promote diversity, equality and inclusivity (E&I) among all UOA members, to attract, develop and retain excellent people from diverse social and cultural backgrounds. UOA members take core roles in University- and sector-wide initiatives, including Aurora and Women Rising, and a faculty team which won an **Athena Swan Silver award** with a clear action plan for achieving Gold. Our E&I ethos is supported by the SJCC and SPTS groups who are internationally recognised on equality and diversity research, exemplified by hosting Feminist and Women's Studies Association, and Impact in Sexualities and Queer Research conference. EGC group create multi-lingual conference presentations and outputs that enhance collaborations with tropical nation researchers.

We developed *our GeoInclusive task force (replacing E&I Committee) to ensure an inclusive and welcoming workplace* spanning all staff and all aspects of their work, regardless of status based on protected characteristics. Head of School plays a key role, with E&I expertise included from all research groups. Our UOA management structure provides pathways for all staff to voice problems, challenge decision-making and find solutions (Section 1B; Fig. 1). Post-2014 strategy has been underpinned by: equalities and unconscious bias training (all staff); mentoring and review; promotion workshops; return to work and post-maternity/adoption/surrogacy protocols; female writing and impact case study retreats. A LGBTQ+ geography forum provides a space to meet and provide mutual support. We recognise BAME researchers are under-represented, and are working to address this. SoG supported the first 'Decolonising the Curriculum' event at Leeds

(2019), and initiated a Black and Student of Colour Forum (inc. PGRs) to share experiences and support, directed by Loyola-Hernández (Racial Justice Network trustee).

We are committed to fairness in HR and staff development. Staff returning from *periods of unplanned leave are supported with phased returns*, and *flexible/remote working options* are available to staff with personal or dependant health/caring needs. *Career pathways for part-time and fixed-term staff* are the same as for all staff, using a carefully monitored workload model and promotion criteria 'calibrated' for fairness. We offer the potential for sharing leadership roles, enabling part-time staff to hold roles including Deputy Head of School and Director of Student Education in SoG. Staff benefit from institutional support including Occupational Health Services *wellbeing*, and we undertake *workplace adjustments for researchers with disabilities* via assistive equipment and/or support workers, enabling a productive working environment. We allow researchers to request *childcare costs for conference attendance* from research group funds or external funded projects where appropriate.

E&I considerations underpinned REF planning, with the submission team comprising balanced F:M membership, and output/ICS reviews discussed openly to aid staff development. Consensus decision-making on expected scores underpinned output and ICS selection. An optimum outputs profile was modelled anonymously based on expected scores, then summarised by staff group (Table 5). We recognised that work was needed to address gender imbalances and have taken positive steps through structured training, mentoring and promotions. As a result, leader roles for 3/5 research groups, 6/8 UAF awards and 50% new lectureships are held by females. Female FTE has risen from 20% to 32% since REF2014, the UOA now hosts four female professors (REF2014 = 0), and more income is attributed to female staff (section 3A).

Table 5. Output and FTE distribution by staff groups

Group	Outputs (%)	FTE (%)
Female:Male	25:75	32:68
Professor:Associate Prof.:Lecturer:Researcher:Former	45:27:16:06:06	36:35:09:20:N/A
Human:Physical	47:53	64:36

Section 3. Income, infrastructure and facilities

3A. INCOME

Strategy Objective 3 focuses on enhancing income from diverse funders, and REF4b/c show income grew significantly during the REF period to >£5M/year in 2018-20. Awards are from >50 sponsors, more diverse than 2014, and with enhanced EU and UKRI income (Fig. 4). Staff development successes include awards to female researchers (3% in 2014 up to 31/35% in 2019/2020) now being in line with FTE (32%), and overall enhanced income/FTE (Table 1). These successes allowed us to develop world-leading research outputs and facilities, maximise societal impact, and further grow non-academic networks.

Income generation has been boosted through our focus on awards >£1M. We successfully led or were partners in >20 large grants since 2014 across all five themes. These include leading major UKRI programmes such as ESRC's Consumer Data Research Support Service (CDRSS) and the Consumer Data Research Centre (CDRC; combined >£16M; £4.1M to Leeds), and NERC's £5M iCASP. Three NERC large grants on tropical ecosystems totalled >£8.5M (£4.1M to Leeds; CongoPeat, BIORED and ARBOLES). Four EPSRC grants totalling £7.8M (£2M to Leeds) included ELEVATE, DEMAND, DecarboN8 and Sustainable Microgrids. We also hold major co-investigator positions in EPSRC's Centre for Research into Energy Demand Solutions (CREDS) and UK Energy Research Centre Phase 4.

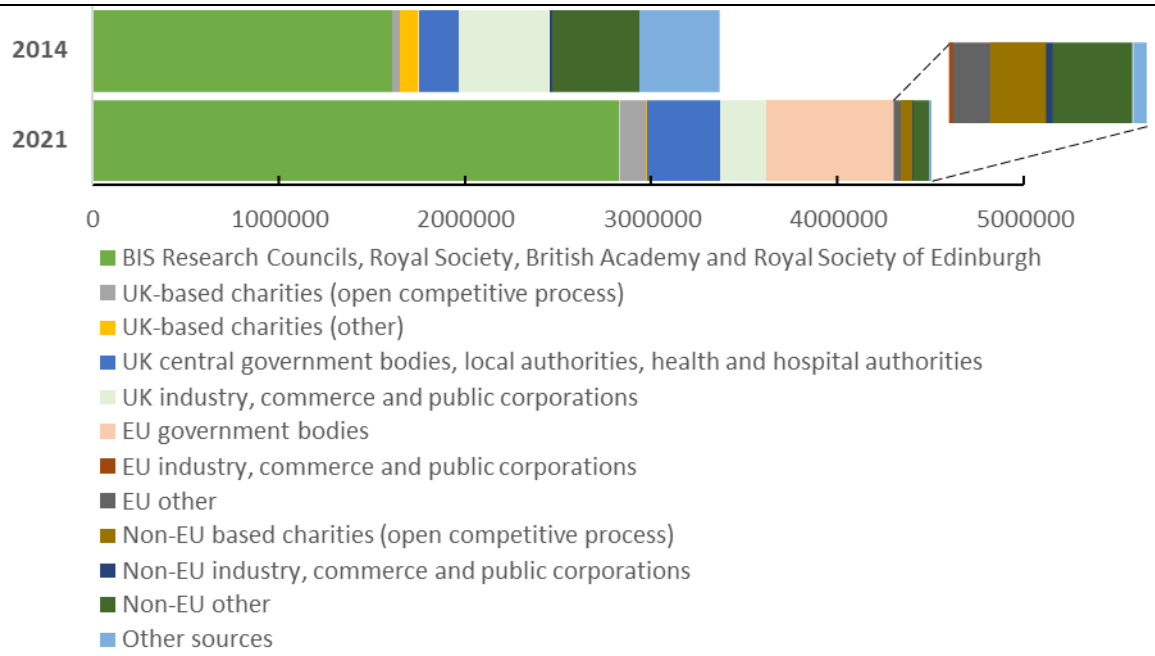


Fig. 4. Annual average research funding, REF2014/2021

We have successfully grown EU funding, with five co-ordinator roles (>£13M total; £3.8M to Leeds): Euro-FLOW, BESTMAP, CONTESTED TERRITORIES, DUST and EMPOWER. We also won partner roles in >£20M EU projects including CONSOLE, CONTESTED CITIES, ECOPOTENTIAL, and RECARE. Additional large-grant successes were from the UKRI-MRC Prevention Research Partnership as part of the Systems Science in Public Health and Health Economics Research consortium (SIPHER) (£1.1M), a £1.2M Royal Society award to study solar treatment of biomass for power generation, and support for the Amazon Forest Inventory Network (RAINFOR) in Peru (Moore Foundation, £1.2M). Research income will be sustained post REF2021 with >£12M new awards in 2019-20 combined, reinforcing our world-leading expertise and enabling further advances across our research themes.

Key to income growth is *organisational support.* Large applications and fellowships are primed through structured workshops supported by university Research and Innovation Services and interdisciplinary platforms, funding for external planning meetings, cross-faculty reviews, and interview training. Pre-application support occurs within research groups and via Directors of Research, who pre-review applications via a project initiation procedure which alerts internal reviewers plus technical support (laboratories, IT, HR), then maintains oversight of reviews to ensure only competitive ideas are submitted. Our processes are continually informed by staff participation in, and learning from, funding panels and peer-review colleges. Faculty Research Office supports researchers with application financial planning, risk management, online submission and post-award management. In addition to strategic planning, staff remain agile to rapidly emerging opportunities via core workload-model allocations for research; notable awards include Covid-19 responses (Ford, Malleson, Manley, Marsden), NERC Urgency (Brown, Klaar, Smith), and NERC Highlights (Brown, Chapman, Holden).

3B. INFRASTRUCTURE AND FACILITIES

Repurposed facilities have been developed for SoG (£14.3M in 2015, plus £4M for LIDA in 2014) and ITS (£3.9M; 2017) providing modern space to enhance collaborations between students, staff and external partners. We offer 15 rooms with 56” screens for visualisation and teleconferencing, and two rooms can function as private space for parents with children or for wellbeing. A technical services committee, coordinated by deputy heads of school, manages facilities. A faculty-level committee ensures efficiencies in purchasing, maintenance and sharing excellence. Library collections span >2 million titles, with dedicated UOA funding for new additions, and open access systems (data, outputs) maximising societal access to our work (see Section 1).

IT infrastructure is overseen by Directors of Research, who interface with institute IT leaders. Infrastructure supporting efficient remote-working has been upgraded significantly both before and during the Covid-19 pandemic, including desktop anywhere via Microsoft remote desktop client and Pulse Secure VPN, incorporating full Microsoft Office 365 software. Modern servers support off-site intensive simulation work. All students and researchers benefit from SharePoint technology and enhanced visualisation capabilities for spatial analysis and simulation. High Performance Computing (HPC) equivalent to 12,000 computers can be accessed free at point-of-use, funded through central overheads and a £1M biennial university-level investment, as part of the N8 universities *collaborative regional facility.* Staff and researchers benefit from direct access to IT support, annual software updates, and 3-5yrs hardware renewal.

LIDA provides further specialist computing facilities and a 5-person support team, free at the point-of-use. Integrated data analysis expertise across the University and with external partners forms a key infrastructure element linking research and impact for strategy Theme 3. Notably, this forms part of the *UK data analytics strategic infrastructure*, and Lomax sits on the governance board for the Data and Analytics Facility for National Infrastructure supporting long-term UK planning and investment. LIDA houses >200 workstations, with 80 dedicated to training. The highest standards of data access and protection are provided (ISO/IEC 27001:2013) plus NHS information governance toolkit compliance. Controlled data input/output provides confidence for external funders and users, with inward investments to date supporting >90 major projects.

Analytical laboratories have a dedicated manager who leads training and supervision of technicians. SoG laboratories offer colorimetric auto-analysis, elemental thermal oxidation, gas chromatography-mass spectrometry, ion chromatography, laser particle sizing, optical-emission spectrophotometry, UV-vis spectrophotometry, a microscopy facility and walk-in climate-controlled chambers. Defra licensing allows the import/storage of non-EU samples. We work with N8 universities to maintain efficiencies/collaborations through equipment sharing. Laboratory use, including basic consumables, is free to access funded via SoG core finances, allowing all researchers equal opportunities to develop high-quality research.

We lead specialist fieldwork facilities including *state-of-the-art global forest monitoring networks* RAINFOR, AfriTRON and Protected areas of Peru (MonANPe). Infrastructure includes >4500 plots in 44 nations tracking tree and soil ecology/biogeochemistry, with selected sites augmented by temperature-controlled greenhouses and canopy towers (>£120K NERC, Royal Society), hydrological monitoring and digital herbaria ($50K; Moore Foundation), plant physiology equipment (>£100k) and Unmanned Aerial Vehicles (UAV) (£35k; British Council). Laboratory facilities enable advanced tree-ring width and isotopic analysis (>£27K NERC). Cyberinfrastructure hosted and developed entirely at Leeds (ForestPlots.net) allows us to collaboratively manage, share and analyse complex data including those of partner networks. These facilities allowed us to develop significant, wide-reaching impact case studies (REF2014/21) with data underpinning national submissions for Paris Agreement Forest Reference Emission Levels, plus >100 world-leading outputs including >15 in Nature/Science group since 2014 with >1000 collaborators.

A £3.2M university investment in the GFEI (2019), and NERC/BBSRC awards (>£750K to Leeds), provided a *UK-leading baseline capability in integrated environmental and agricultural sensing and observation* at the university farm, underpinning our soil science leadership in the N8-Agrifood consortium. Infrastructure includes three multi-parameter stations (£111K) with eddy-covariance CO_2 analysers, 3D ultrasonic anemometers, net radiometers, plus temperature, humidity, soil moisture, water potential and heat-flux sensors. Hyprop2 moisture analysers and a WP4C Dewpoint potentiometer (£33K) support laboratory analysis. A Haldrup F-55 harvester (£155K) enables precision harvesting of crops. A £125K Nano-Hyperspec VNIR (400-1000nm) is hosted on a DJI UAV with GPS/INS and LiDAR Integration. Two smaller UAVs with high-resolution cameras further allow the collection of imagery and SfM photogrammetry. Two SoG staff hold Civil Aviation Authority UAV pilot licenses. These investments have enabled our researchers to

win >£1.3M NERC funding since 2015 (Critical Zone Science, SoilBioHedge, LOCKEDUP), to underpin growth of our agricultural research over the next decade.

Fieldwork is supported by three vehicles and equipment including ground-penetrating radar, Leica GPS-Total Stations, a Reigl terrestrial laser scanner, water quality probes, a LiCor portable CO_2 analyzer, multiple dataloggers including telemetry for meteorological and hydrological research, and a variety of coring and ecology equipment. This high-quality equipment, funded via annual allocations of core funds and informed by staff-suggested priorities, allows researchers to maintain our reputation at the forefront of physical geography research.

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

4A. ARRANGEMENTS AND SUPPORT FOR RESEARCH COLLABORATIONS, NETWORKS AND PARTNERSHIPS

We effectively lead large collaborations allowing us to secure funding (further supporting strategy Objective 3) and we engage proactively with businesses, regulators, the third sector and policy-makers to identify and cultivate impact (Objective 4).

Investment in the best people and facilities allows us to develop and maintain a reputation for leading research and societal impact via *active collaborations* with UK and overseas scientists. *Internationally,* the school leads numerous networks (see Section 1C & 3A) spanning our five research themes, creating direct two-way linkages to rapidly disseminate research findings/ideas and gain timely information about emerging opportunities. *Nationally*, LIDA links us to >90 research centres, programmes and projects with infrastructure supporting >£50 million of research, making it a major powerhouse for civic engagement and business growth. water@leeds has grown rapidly from its initial core strengths in our RBPM group to now be a world-recognised centre. SoG benefitted substantially from this investment, leading to our principle role in the NERC iCASP project. *Regionally*, Leeds is a member of the N8, developed specifically to increase collaboration and drive economic growth with end users. The EPSRC DecarboN8 network led by Marsden brings together 23 industry, civil society and community partners including Transport for the North, to collaboratively seek solutions for decarbonising transport systems.

Success of our collaborative networking is illustrated by >80% of REF2 outputs having co-authors external to Leeds (63% international). Our collaborative reach has doubled over the REF period with outputs written with researchers from >120 nations; REF2 nominations include co-authors from 95 of these nations (46 in 2014), in line with our strategy of developing international partnerships and engaging with global challenges. Additional to our long-standing strengths in Europe and the Americas (Fig. 2c), we are growing Chinese collaborations (2014: x5 outputs; 2020: x22).

PGR supervision enables collaboration externally, including the White Rose social sciences DTP linking Leeds, Sheffield, York, Sheffield Hallam, Hull, Bradford and Manchester Metropolitan. Our staff lead projects in three CDTs, with Liverpool, Manchester and Sheffield (ESRC Data Analytics and Society), Edinburgh, British Antarctic Survey and National Oceanography Centre (NERC Centre for Satellite Data in Environmental Science (SENSE)), and Loughborough and Cranfield (EPSRC WaterWISER CDT). The NERC DTP PANORAMA led by Leeds offers further research integration with York and Hull. These provide staff and PGRs with 3-4 year collaborations, which sustain the production of novel outputs, impacts and proposals.

4B. RELATIONSHIPS WITH KEY RESEARCH USERS, BENEFICIARIES OR AUDIENCES

Dissemination and impact training, planning and support for researchers is supported by SoG's Impact Support Manager (ISM), and ITS's Research Support Manager. Support and access to priming funds, including institute-level impact accelerator accounts, allow staff to develop relationships with research users and audiences. Training and support is provided centrally via ODP&L (REF5a) and through workshops led by ISM. Non-academic collaborations with new and

existing partners support two-way exchange of knowledge, underpinning impact planning and a case-study portfolio across all research themes.

A briefing-note series developed in 2019 provides staff with opportunities to translate research outputs so non-specialists quickly understand new findings, and our staff contribute to POST notes (e.g. 537, 603) to reach UK parliamentarians. These approaches seed potential future collaborations and impact. Media training and press releases enable our work to reach wider audiences and influence public discourse via television, radio and in written articles/social media. A diverse array of social media streams at the level of individual staff, research groups and for both SoG/ITS (combined followers >8000) further enable public engagement with research. Proactive use of social media, LinkedIn and Altmetrics enables ISM to effectively develop and track pathways to impact among research users; for example, Lewis published a top 50 Altmetric paper in 2019 creating >5000 interactions including new links to policy sources. Events such as the annual CDRC Data Partner Forum, LIDA Showcase, LIDA intern scheme (30 projects since 2016), and iCASP funded projects (>40 since 2017) provide pioneering examples of industry engagement supporting strategy Objectives 1 and 4. As an example of our collaborative successes, 34% of REF2 outputs were co-authored with non-academics who enabled rapid adoption of new research recommendations.

Baseline research and impact workload allocations (Section 2A), coupled with increased research income that allows us to employ *support staff in project management roles*, provide time for researchers to engage quickly with, and lead, emerging opportunities with a range of audiences. Our rounded impact strategy includes a focus on government organisations and businesses who can drive impact from the 'top-down', as well as civil society and campaigning NGOs who push for impact 'bottom-up'. These relationships are strategically directed at different scales: engagement with major international organisations allows us to hold a position at the forefront of global research challenges, whilst national end-user engagements ensure our strong UK standing.

To be recognised as a world-leading research institute (strategy Objective 1), we support staff to develop relationships with major *international organisations*. For example, multiple roles link to the UN, including Grainger as advisor to the FAO Forest and Land Restoration Mechanism, the Convention to Combat Desertification Science-Policy Interface, and the Global Forest Resources Assessment. Additionally, Comber is the UK's Global Earth Observation land cover validation panel representative, and Ziv leads the Biodiversity Observation Network working-group in the Intergovernmental Group on Earth Observations. Phillips was invited to showcase research at the UN Framework Convention on Climate Change COP21 (Paris, 2015). Other international contributions include malaria planning advice to the Zambia Chief Medical Officer (Smith), informing WWF's International policy on Forest Carbon Finance (Phillips), and commissioned reports for the European Social Policy Network (Mullen).

A major focus for impact is *government and policy makers*, who enable our work to permeate multiple sectors. We inform future transport solutions working directly with local authorities and Sustrans.org. (Heinen, Lovelace, Mullen), Marsden sits on the Leeds City Council Expert Advisory Panel on transport, and Philips works with Transport for Greater Manchester. We hosted the DfT Strategy Executive in 2018/19, including a researcher-led course for their professional development. Marsden also led the Commission on Travel Demand cited in the Committee on Climate Change's 2018 report to Parliament, resulting in further work with the DfT, Transport for London, the Committee on Climate Change, the Transport Economists' Group and a commissioned report for the European Parliament.

Our quantitative human geography strengths are recognised with national commissions and roles, such as with the Foreign and Commonwealth Office (Birkin), Government Office for Science (Marsden), Depts. for Education (Gould), Health (Norman, Heppenstall), Communities & Local Government (Chatterton) and the All Party Parliamentary Group on Modern Working (Waite). The Office for National Statistics (ONS) employ Lomax as an expert advisor for National Population Projections and a panel member on Modernising the Census, and Norman sits on their Population

Theme committee. Predictive policing research (Malleson, Heppenstall) has developed partnerships with South Yorkshire Police and Ordnance Survey. In response to the Covid-19 pandemic, Birkin was selected to be Task Leader for Urban Analytics on the Royal Society's Rapid Assistance in Modelling the Pandemic steering group, he sits on the Isaac Newton Institute's Infectious Dynamics of Pandemics steering board, and Heppenstall is a Data Science Advisor for the UK government Joint Biosecurity Centre, guiding local and national decision-making.

Physical geography end-user linkages have grown from a NERC impact fellowship (Viki Hirst) on Water Framework Directive (WFD) projects with the Environment Agency, which laid foundations for iCASP. We contributed to Environment Agency decision-making on Natural Flood Management (NFM) funding allocations (Brown), and work with Leeds City and Calderdale Councils, the National Trust, Forestry Commission and the Construction Industry Research and Information Association (CIRIA) developing flooding solutions (Klaar, Smith). Our external standing has strengthened with roles on Natural England's Science Advisory Committee (Lovett), the UK government/UKWIR Agriculture Action Group taskforce (Holden) and the WFD UK Technical Advisory Group (Klaar). Defra commissioned the first full carbon and greenhouse gas budgets for lowland peatland systems in GB (Baird, Holden, Chapman), evaluation of new ecological time-series methods (Comber), and they appointed Ziv to their Environmental Land Management modelling expert panel to ensure the quality, rigour and relevance of research contributing to post-Brexit policy.

4C. WIDER CONTRIBUTIONS TO THE ECONOMY AND SOCIETY

A strong economy is critical for the UK, and we work with *businesses* to inform decision-making and investment. The iCASP programme aims to lever £50M of economic benefits in the Yorkshire region, so far funding projects with businesses such as JBA Consulting, ARUP Ltd, Thomas Mackay and umbrella organisations such as the National Farmers Union. The CDRC and CDRSS projects link to >150 commercial partners such as Zoopla and ao.com to optimise mapping work, and with retailers ASDA and Sainsbury's planning store locations to reflect seasonal population dynamics. During the Covid-19 pandemic, LIDA led a new data alliance with Rolls Royce to find faster ways of supporting the response and subsequent recovery, using our secure infrastructure, expertise and global networks. The alliance includes IBM, Google, Microsoft, The Data City, Truata and Whitespace. The National Market Traders Federation utilised Gonzalez's findings on retail-market users and providers to develop a practical guide for recovering and re-establishing businesses post-lockdown. Green economic growth is supported through Holden chairing the Shetland Windfarm Advisory group overseeing Viking Energy's conservation and monitoring measures, and an advisory board role with SSE Renewables.

Research use by the *water industry* has developed over multiple RAE/REF cycles. For example, NERC research (2003-09; Chapman) linking soil recovery from acidification to rising raw-water colour has recently driven R&I investment by Yorkshire Water (YW), Scottish Water, United Utilities and Welsh Water, alongside NERC funding (climate resilience programme) with CEH and Glasgow. YW are also a major partner for our Theme 4 work, funding >£1.4M research since 2014, most notably to enhance understanding of peatland hydrology and chemistry to inform land management. Our human geography expertise is utilised by Thames and South West Water, in partnership with the ONS, to understand water demand linked to population dynamics. Moody's UKRI Industrial Innovation Fellowship has expanded expertise in water colour and carbon cycling processes across Europe. Building from a YW funded PhD studying environmental flows furthermore allowed us to develop and lead the Euro-FLOW consortium, with 23 European partners including hydropower and water companies. We have expanded our water research reach into Africa (knowledge-exchange hub with the Global Water Partnership Tanzania), and in China Tillotson's research enabled his Visiting Chair at Beijing Forestry University (2015-18) and collaborations with SUSTech, Hohai and Shandong. This expertise directly supports commercial ventures, with Tillotson sitting on the Technology Advisory Group of G_2O Water Technologies Ltd, as well as supporting 3x water science innovators from Thailand and Vietnam as a mentor for the Royal Academy of Engineering Leaders in Innovation programme.

We engage with an array of *civic groups*, particularly via strategy Themes 1/2 linking us to diverse communities. Chatterton for example established the Antipode Foundation public charity which disperses £200,000/yr in scholar-activist awards, and he has further supported the work of Kirkstall Valley Development Trust and Leeds Community Homes, and been seconded to developer Sustainable Britain, to advise on affordable low-carbon housing. The foundations of this work were funded by the N8, ESRC and Leeds Impact Accelerator Accounts which developed a methodology for co-production, then EPSRC funding for a detailed Urban Living Pilot (the TRUE project). This work provided support to >100 community-led groups (REF3 UOA14-3). Furthermore, Zebracki's co-founder role in Queer Pride Gent, Belgium, informed debates, performances, and the fulfilment of a LGBTQ+ monument following his #LHBTMonumntGent activist work.

Working with *Artists* is a key route for research dissemination. Leverhulme artist-in-residence Trudi Entwhistle created landscape installations inspired by our water research along the 2014 Tour de France route, and an Arts Council artist-in-residence, Dr Joanna Brown, collaborates with Zebracki via water@leeds on cultural perceptions of flooding. Zebracki's research was also showcased at a monument unveiling in Eindhoven, Netherlands, and via co-curation of RGS Artistic events. Additionally, McQuaid led six research-arts events in Uganda (2015-19) on sexual health, barriers to girls' education, and urban sustainability, reaching >500 teachers, parents, NGOs, police and religious leaders with participant-stakeholder focus-groups facilitated to develop solutions.

We have expertise organising *public workshops* such as Loyola-Hernandez's *British Academy Rising Star Engagement Award* #resistance:Exploring digital protest by marginalised groups, merging global online-participation with in-person presentations/discussion. Quincey's NERC Everdrill project was communicated to >50 people from Namche Bazaar, Nepal, via discussions, virtual-reality films of Everest and physical glacier models. Keynote contributions to *prestigious outreach events* included the Royal Society Café Scientifique (Phillips, 2014) and a Royal Institution Christmas Lecture (Baird, 2020).

4D. CO-OPERATION AND COLLABORATIVE ARRANGEMENTS FOR PGR TRAINING

We played major roles in three international PGR training networks: (1) as co-ordinators of Euro-FLOW, we developed five advanced training courses and multiple PGR secondments with regulators, large businesses and SMOs including Engadiner Kraftwerk, Swiss National Park, Environment Agency, Yorkshire Water, ARUP, CBEC Ltd and USGS; (2) The EU Contested Cities network supported the exchange of ~20 PGRs, and this will be extended with; (3) our role in the EU Contested Territories network (2020-2024). We contribute to six UKRI training programmes as leaders or by hosting formal PGR training (Section 2C), and the CDRC offers numerous courses to PGRs and professionals including QGIS, R and Python. PGR training is further enhanced through co-supervision with multiple end-users (Section 2C).

4E. CONTRIBUTION TO THE SUSTAINABILITY OF THE DISCIPLINE

We actively promote collaboration with organisations within and beyond higher education, to drive the global research agenda, co-develop and disseminate our research, and influence policy development. We hold *scientific advisory positions* for >10 institutes, including IGB-Berlin (Holden), Chinese University Hong Kong (Stillwell), Housing Associations' Charitable Trust (Chatterton), ArcticNet Canada (Ford) and both MS-Amlin and SSE Renewables (Holden). In addition to multiple peer-review college roles, our staff hold/held roles on *grant decision-making committees*, notably ESRC (Waite, Heppenstall, Stillwell), EPSRC (Marsden), NERC (Holden, Mitchell, Kay, Woulds), UKRI FLF (Birkin), USA NSF (Gould), Dutch Research Council (Comber), Portuguese STF (Heinen) and the Irish Research Council (McQuaid). We make substantial contributions to *professional/learned societies* with >30 leadership and/or trustee roles including American Association of Geographers (AAG) Feminist Geographies (Conlon), British Society for Geomorphology (Smith), Institute of Environmental Management and Assessment (Mitchell), International Geocomputation Committee (Heppenstall), several RGS groups (Lomax, Pangbourne, Vanderbeck, Zebracki) and Society of Environmental Toxicology & Chemistry (Carter). Our staff *edit international journals* including senior Editorial Board roles for African

Journal of Ecology (Lovett), Transport Policy (Marsden), Applied Spatial Analysis and Policy (Norman, Stillwell), Geology Today (Carrivick) and Regional Env. Change (Ford). Overall, our staff held >50 Editorial Board/Associate Editor positions and edited >15 special issues since 2014.

Leadership of >20 international conferences has maintained the vitality of the discipline, with nine major conferences at Leeds including RC21 Urban and Regional Development of the International Sociological Association (2017, Gonzalez) and the 7th International Conference on Flood Management (2017; Holden, Tillotson). We lead the triennial World Conference on Transport Research Society (Marsden, Heinen, since 2016). We played major roles organising international meetings, such as UNFCCC COP20 Biodiversity and Climate Change, Lima (2014; Baker), International Symposium on Ecohydraulics (Klaar, 2014-2020) and World Wilderness Congress (2019/20; Carver). We regularly lead sessions at the AAG, World Conference of Transport Research, American and European Geophysical Union, and GIScience meetings.

Translating new research to education benefits underpins the future sustainability of geography, with our Professional Development Manager co-ordinating activity with schools/colleges. We contributed to the Geography A-level Content Advisory Board (Chapman), British Council's Global Water Initiative (Grainger), Netherlands Universities QA (Comber), and have developed CPD courses for the National Centre for Research Methods (Newing), DfT (Marsden, Pangbourne, Heinen) and Highways England (Lovelace). Lovett pioneered MOOC development at Leeds with the Environmental Challenges course (FutureLearn platform) reaching >80,000 people (170 countries).

Recognition of the success of our strategy and work to maintain the vitality and sustainability of Geography is evident from prestigious *fellowships and prizes* (Table 6).

Table 6. Notable awards received (*impact prize, +PGR prize)

Award(s)	**Recipient**
AAG James Blair Award for scholar-activism (2016)	Routledge
Academy of Social Sciences Fellow (2018) RGS Murchison Award for pioneering urban-analytics research (2019)	Birkin
British Diatom Group Carter Prize (2017)+	Fell
Cycle Planning Awards Best Innovation (2016)*	Lovelace
Foundation for Sociology of Health & Illness book prize (2020)	Bell
Society for Computational Economics prize for outstanding computational statistics (2020)	Heppenstall
RGS Gill Award for outstanding ECR (2018)	Malleson
RGS-IBG Ambassador Certificate of Achievement (2018/19)+	Tether
Royal Society Fellow (2020)	Phillips
Royal Society of Chemistry emerging investigator (2019)	Carter
Thompson-Reuters highly-cited (2013-2020)	Lewis, Phillips
Thompson-Reuters highly-cited (2018)	Galbraith

Since 2014 we hosted >20 competitively awarded fellowships (Section 2), including 9x UKRI (2x future leaders), 4x Marie Curie incoming and 4x Alan Turing Institute fellowships. Overall, the variety of our contributions and achievements attests to the outstanding strength of Geography at Leeds, and thus a continued world-leading research and impact role throughout the next assessment cycle.