Institution: University of Birmingham

Unit of Assessment: 7 – Earth Systems and Environmental Sciences

1. Unit context and structure, research and impact strategy

1.1. Overview

UoA7 research at Birmingham sits within the School of Geography, Earth & Environmental Sciences (GEES), one of four constituent Schools within the College of Life & Environmental Sciences; GEES also includes UoA14 (Geography & Environmental Studies). There are significant synergies between the two UoAs, including shared facilities, research initiatives, staff training, and focus on inclusivity. Our collaborative ethos and breadth of expertise together drive our emphasis on interdisciplinary research examining the processes affecting our planet and its people. Our activity cuts across the natural and anthropogenic, operating at scales from the nano to the global. The strength, impact and vitality of UoA7 (30.8 FTE) research since 2014 is demonstrated by:

- Receiving and renewing an Athena SWAN bronze award, with new recruitment policies driving major increases in staff applications from and appointments of women, including three in Earth Sciences, which had no female staff at REF2014.
- >1000 Scopus-listed research publications, attracting >20,000 citations, representing ~50% per FTE average increase in annual output from REF2014.
- ~78% of our research publications include international collaborations, involving researchers in more than 70 countries.
- Leadership of the new £30m Birmingham Institute for Forest Research (BIFoR) [REF5a 4.2.3], including the northern hemisphere's only free air carbon enrichment experiment.
- Creating the Birmingham Environmental Research Facility, with ~£5m internal and external investment, including a new flume mesocosm facility (EcoLaboratory), new air quality supersite, meteorological facilities, and new controlled environmental chambers. [(REF5a) 4.2.3]
- Leading two scheduled and one completed major international marine expeditions with involvement in 13 others, worth ~£15m in direct and indirect funding.
- £27.2m of research income, including ~£23.9m from EU and UKRI, ranging from early career fellowships and doctoral training to leadership of international programmes. Examples include:
  - Co-leading, with UoA14 researchers, the joint-largest NERC Doctoral Training Partnership (CENTA2; £8.1m), expanded by 50% at renewal in 2019.
  - Winning a Leverhulme Doctoral Scholarships programme (Forest Edge; £1m).
  - Leading the £5m NERC West Midlands Air Quality Improvement Programme, as part of substantial impact activity in environmental pollution.
  - Leading a £3.7m NERC large grant to study carbon and nutrient dynamics in temperate forests.
  - Winning three European Research Council grants in nanoparticle pollution, tree mortality and deep time diversity changes together worth €5.3m.
- Scientific leadership of the £2.7m redevelopment of the Lapworth Museum of Geology, shortlisted for the largest museum prize in the world in 2017, and underpinning our programme of impact through public engagement and education[REF5a 4.3].

There has been major **institutional and external investment in UoA7** since 2014, including **>£55m facilities investment** and a **50% increase in the number of eligible academic staff** within the two research groups that now comprise UoA7. **We have achieved sustained increases in annual research income**, from £3.38m in 2013/14 to £4.13m in 2019/20. This represents an average 53% increase per FTE from our research income for 2008–2013.

Our research in UoA7 is structured in two groups (Table 1): **Environmental Health Sciences** (**EHS**) and **Earth Sciences** (**ES**). Research themes within these groups are shaped by bottom-up discussion; group members are responsible for establishing their research priorities within the

overall School research strategy. Many of our researchers explicitly sit across themes or groups, facilitating interdisciplinarity. Research groups feed into School-level research strategy via the School Research Committee.

Table 1. Breakdown of career stages of UoA7 submitted staff.

	Professor	Reader	Senior Lecturer/Senior Research Fellow	Lecturer	Birmingham Fellow	Independent Research Fellow
EHS (13 FTE)	8	1	1	3		
ES (17.8 FTE)	2	2	8	3	0.8	2

Environmental Health Sciences excels in atmospheric chemistry, biosphere-atmosphere interactions, air pollution, environmental nanoscience and persistent organic pollutants. Research combines the pursuit of fundamental process-based understanding alongside the development of research applications with impact, utilising our advanced instrumentation and facilities. There has been substantial investment and growth in research facilities since 2014 (Section 3.3). Research highlights include:

- Quantitative understanding of the sources and processes leading to chronic air pollution problems in global megacities, driving policy measures to improve air quality and wellbeing for tens of millions of people;
- Enhanced insights into how chemicals from consumer products are transferred through the environment and, by dermal absorption, to humans, leading to changes in international environmental regulations;
- Systems-level understanding of the impacts of manufactured nanomaterials on the environment, and leading Europe-wide research with industry into reduction of impacts by particle design;
- Globally unique large-scale experiments (BIFoR FACE) [REF5a 4.2.3] and modelling to improve future carbon sequestration projections and evaluate climate change risks to forest ecosystems and their services.

Earth Sciences excels in tectonics, palaeoclimatology and palaeobiology. Cross-cutting themes address the co-evolution of life and the planet, with particular focus on links between tectonics and climate, changes in biodiversity, and natural hazards. The ground-breaking nature of this research is evidenced by high-profile publications with substantial media coverage (e.g. reach of 72m people and advertising value equivalent of £1.38m for research on dinosaur evolution). Research highlights include:

- Experimental evidence of how the first continents formed from oceanic crust four billion years ago;
- Development of fundamental new theories and models of continental breakup and seafloor spreading;
- Novel deep Earth modelling showing that sustained magmatism caused Earth's largest quantifiable CO_2 emission burst;
- New modelling of the global methane cycle unlocking the significance of trace gas climate forcing for warm intervals through deep time;
- Cutting-edge imaging and biomechanics revealing the fundamental role miniaturization played in the evolution of the mammalian body plan;
- Innovative macroevolutionary analyses demonstrating that space, not time, primarily controls Phanerozoic marine diversity.

Staff development is a key priority. Current UoA7 staff include three externally-funded early career staff (two Leverhulme Early Career Fellows, one Royal Society Dorothy Hodgkin Fellow), five staff formerly funded (in this cycle) by externally-awarded independent fellowships, and five staff recruited through the Birmingham Fellowships scheme, an internally funded programme

providing a permanent academic position and protected research time for outstanding early-career academics [REF5a 3.4.1]. Our proactive career support is reflected through promotions, notably five to chair since 2014. Our staff have been our key priority through COVID-19 (Section 2.1).

Equality, Diversity & Inclusivity (EDI) is a priority for the School, which achieved **Athena SWAN Bronze status in 2014 and 2019,** and we strive to be inclusive in all aspects of School life. The EDI Committee covers all protected characteristics and comprises academic and professional services staff and postgraduate researchers. **EDI is embedded in all operational and decision-making activities and is a standing item on all School Committees**. Our staff initiate and **lead grassroots EDI initiatives** with national and international reach: examples include work on inclusive education, developing a primer about toilet stops for field-based teaching that has been implemented internationally (Greene, Edgar, Giles); and work on issues of bias against underrepresented groups in PhD recruitment (Greene, Giles; see Section 2.2.1).

Our investment and growth has been maintained since the start of COVID-19, with new appointments (including Esquivel Muelbert) being made, promotions processes operating as normal (but taking COVID-19 impacts into account), and capital spend on facilities such as the Molecular Sciences building (see Section 1.2.1) continuing, albeit with minor delays.

1.2. Research objectives

1.2.1. Achieving our 2014–2021 research strategy

At REF2014 our goals were to: (i) enhance our research power, through recruitment, infrastructure investment, building international partnerships, and staff mentoring; (ii) sustain our financial strength and use it to build activity in key strategic areas; (iii) support enhanced impact and engagement activities; and (iv) to be the institution of choice for students and staff. Building on REF2014 feedback, as well as the broader Birmingham 2026 strategy of the University [REF5a 2.1], we refined and expanded our goals, underpinned by a reorganisation of research group structures. This led to activity being guided by five core objectives, all with embedded EDI considerations.

1) **Enhance interdisciplinary collaborations**. Our interdisciplinary research strategy (Section 1.4) has increased collaborations between research groups, between UoA7 and UoA14, and across the College and beyond, underpinned by interdisciplinary initiatives and infrastructure such as BIFoR [REF5a 4.2.3] and strategic appointments of new staff working across research groups and UoAs (e.g. Hopcroft, spanning ES and EHS; Pugh and Esquivel Muelbert, crossing into UoA5 and UoA14 research within the University).

2) **Invest in areas of strength and critical mass**. Our College-recognised research 'hot spots' (Environmental Sciences, BIFoR) have received significant investment including unique new facilities such as BIFoR FACE, the Birmingham Air Quality Supersite and Wolfson Glasshouses environmental chambers (Section 3.3), accompanied by three new academic staff (Section 2.1). Earth Sciences investment includes recruitment of six new academic staff (Section 2.1) and the redevelopment of the Lapworth Museum (Section 3.3).

3) **Develop high quality international collaborations**. We have led or contributed to 16 completed or scheduled international marine geology expeditions worth >£15m of direct and in-kind income (Section 4.1). We have expanded our strategic international partnerships in Brazil, India, China, North America, the EU, Chile and East Africa (Section 4.1). We have been highly successful in obtaining major funding, including ~£11.3m in EU income, to support those collaborations (Section 3.1).

4) **Enable our staff to achieve their potential.** We have focused on mentoring, development and promotion of our early and mid-career staff (Section 2.1) and embedding EDI in our research culture. We have reorganised teaching to facilitate

research leave, increased internal pump-priming funding, and improved pre-submission review of grant applications (Section 3.2). This has led to substantial increases in income/FTE from a highly diverse range of funders (Section 3.1), as well as the hosting of NERC, Royal Society, Leverhulme and Marie Curie fellows. Our growing influence and leadership is evidenced through wider esteem and prestige, exemplified by major awards (e.g. Harrison – Elected Fellow, Royal Society; Valsami-Jones – Wolfson Fellowship, Royal Society; Section 4).

5) **Increase support for high-quality impact and engagement**. We have increased funding for impact acceleration and hold regular events facilitating cultural changes needed to realise influence (Section 1.3). Our environmental science work has led to changes in environmental pollution policy and practice from local to international levels, ranging from air pollution to persistent organic pollutant and nanomaterials regulations. Public engagement and education has been driven by the redevelopment of the Lapworth Museum, led by our researchers and now attracting over 60,000 visitors per year [REF5a 4.3], and our involvement in the NERC Engaging Environments Programme, NERC's flagship public engagement investment. We have instigated new academic engagement with a poorly served sector of UK industry (forest management), initiating the process that secured the £14.5m Future of UK Treescapes programme (NERC) and engaging the Defra Chief Plant Health Officer as a Director of BIFoR to support engagement.

1.2.1. 2021–2026 research strategy

Our significant growth and successes since 2014 will enable us to address the increasingly challenge-led research agenda to 2026 and beyond, whilst supporting genuinely research-intensive teaching across our educational portfolio. This aligns with the wider University of Birmingham strategy [REF5a 2.1] to undertake 'research that matters'; significantly increasing the quality of research outputs, delivery of impact and enabling research income as we emerge from the uncertainties of COVID-19. To achieve these aspirations, we aim to:

1) **Grow our research activity and influence**. We will focus upon areas of demonstrable excellence and critical mass, as well as areas of emerging significance, through targeted staff and facilities investment. For example, we will build on the success of BIFoR through a new commitment of £5m charitable and £5m matched internal investment, covering the period 2023–2027, beyond the £30m investment to date. Our rising profile in deep time evolutionary research will be supported by the transformation of our palaeobiology laboratories. This will continue our strong trajectory of growth in research income/FTE.

2) **Expand our leadership of interdisciplinary programmes within the University and beyond.** Key emerging areas that we aim to develop include collaborations between our palaeobiologists and researchers in social science and humanities to address palaeontological ethics, geoconservation, and science communication; leadership of themes (Clean Air, Resilient Cities, Pollution Solutions) within the University's Institute of Global Innovation (Section 1.4); a coherent body of research, teaching, and continuing professional development to link air pollution and urban planning practice; and environmental toxicology research involving collaborations with bioscientists.

3) **Fully exploit opportunities for new lab space and instrumentation provided by the forthcoming Molecular Sciences building.** This new £80m facility (groundworks underway, delivery slightly delayed due to COVID-19) [REF5a 4.2.1], joint between the GEES and the School of Chemistry, will include space for ~10 UoA7 academic staff, and ~90 associated postdocs and doctoral researchers from GEES. UoA7 staff have provided senior-level academic direction to the building design, with interdisciplinary challenge-led environmental research one of four underpinning research foci, expanding capacity and facilitating new research (and training) collaborations.

4) **Develop our community networks, industry and third sector engagement**. We will use sector-facing projects such as WM-Air, BIFoR and Engaging Environments (Section 1.3) to build and expand our partnerships with a diverse range of groups and organisations outside of higher education. We will use the University's new city centre building, The Exchange [REF5a 4.2.2], as a catalyst for a range of city and community activities, initially around the theme 'The Air We Breathe'.

5) **Build on Equality & Diversity progress made during this REF cycle, and increase staff numbers from underrepresented groups**. In particular, we will use proactive recruitment policies, mentoring, and support for promotion applications increase our overall proportion of female and BAME researchers, and their representation at senior levels. We are implementing our Athena SWAN Bronze action plan, and aim to achieve a Silver award.

1.3. Impact strategy

1.3.1. Leadership. Impact continues to be of central importance to our research culture. In 2014 we appointed a dedicated Director of Impact and Innovation to support UoA7 and UoA14 (Chapman, returned to UoA14). Chapman has also served as a member of the NERC Innovation Advisory Board and is College Deputy Director of Research and Knowledge Transfer. He has oversight and responsibility for impact across the College, supported by a College-based team of research facilitators, a research planning partner, a charitable funding partner and a business engagement partner [REF5a 2.1.3].

1.3.2. Training. We provide impact training to staff via dedicated sessions at bespoke workshops as well as regular sessions at school meetings and away days. A variety of mechanisms are used to develop new partnerships, ranging from Discovery Days on campus to tailored visits to individual organisations. The approach is successful, with researchers engaging actively with >400 different end users and organisations from across the private, public, charity and NGO sectors during the period 2014–2020 and is evidenced by ~8% of our research publications with academic-corporate collaborations.

1.3.3. Pump-priming. Our researchers access Impact Acceleration Accounts held centrally at the University as well as School- and College-level pump priming funds to facilitate face-to-face meetings with partners (with an "always open" rapid turnaround mechanism). For example, Jones used pump priming funding to meet with industrial seismic imaging contractors, leading to an InnovateUK grant on applications of machine learning to seismic datasets for natural resource exploration. Consultancy work, managed by University of Birmingham Enterprise [REF5a 4.1], provides a means to kickstart impactful relationships with end-users; each staff member is permitted 30 days annually (examples include work with Merlin Energy, ION Geophysical, and the Environment Agency). Overall, by making relationships with end users central to our grant application process, we have an impact pipeline to achieve mutually beneficial long-term relationships.

1.3.4. Embedding impact in postgraduate research training. CENTA2 exemplifies our approach: led by Birmingham, it involves 19 external partners ranging from industry to NGOs and governmental agencies, supporting a coordinated approach to end-user input and benefit. These partners contributed to the strategic development of CENTA2 and provide an in-kind contribution of ~£3m. Their contributions range from project and student selection, co-supervision and training delivery, to supporting individual studentships through CASE awards (~20% of all studentships) and placements to provide experience outside academia.

1.3.5. Impact examples. An outstanding example of our approach is the £5m **West Midlands Air Quality Improvement Programme (WM-Air)**, secured through the NERC Regional Science of the Environment (RISE) innovation scheme, which runs 2019–2023. UoA7 lead this initiative which applies environmental science expertise to improve air quality and human health across the West Midlands. The project involves over 20 formal partners committing over £1.4m in

additional support, ranging from political bodies (e.g. West Midlands Combined Authority, Birmingham and Coventry city councils) through to infrastructure organisations (e.g. HS2, Transport for West Midlands, Network Rail), public services (e.g. Birmingham & Solihull NHS STP), consultancies (e.g. Arup, Amey), and SMEs.

Our involvement in transformative and cutting-edge engagement practice is demonstrated by our role in NERC's flagship **Engaging Environments programme**, which runs 2019–2022. This public engagement investment (£1.3M) involves a national consortium of partners including five universities, charities and environmental science organisations. This brings together storytelling, community centred citizen science and community organising to share learning, create tools and connect environmental science with citizens. We are working with Citizens UK to combine environmental science with social justice issues (such as air quality, crime, transport, housing) and have been actively engaged in local community leadership around health, the Birmingham 2022 Commonwealth Games, and employment opportunities for young people.

1.4. Interdisciplinary research

1.4.1. School-level. Interdisciplinary research is nurtured strategically through institutes and facilities such as BIFoR and EcoLaboratory, pump-priming support, and education links alongside organic initiatives between individual staff. To increase interdisciplinary activity, a School-level seminar series features speakers who span our research groups in UoA7 and UoA14: in 2014–2020 >50 speakers from 10 countries gave seminars, with gender balance of speakers achieved from 2018 onwards. Two key examples exemplify our approach:

BIFoR is a key focus for interdisciplinary research: led by UoA7 together with UoA5 researchers it integrates >50 researchers across GEES and Biosciences and the wider University, and hosts five BIFoR Interdisciplinary Leadership Fellows spanning climatology, ecocriticism, water sciences, atmospheric science, and history. The Leverhulme Forest Edge doctoral training programme linked to BIFoR, and led by UoA7, involves collaborations across the physical, biological and social sciences, as well as the humanities.

The Urban Initiative (UI) generates original and transformative research and creative thinking through interdisciplinary collaborations in urban planning, environmental, ecological and health sciences. A virtual centre bringing together GEES researchers across UoA7 and UoA14, it currently comprises over 50 academic members, doctoral and postdoctoral researchers and involves international partnerships in countries such as Brazil, India, China, Australia and Mexico. The UI has been a catalyst for interdisciplinary collaborations in the area of environmental changes. For example, we lead the **ASAP project** (A Systems Approach to Air Pollution; funded by DFID 2017–2020), which brings together >20 UK and East African experts in air pollution, urban planning, economic geography, public health, social sciences and development studies to provide a framework for improved air quality management in cities in Kenya, Ethiopia and Uganda.

1.4.2. College-level. Within the College, links with Biosciences (UoA5) are of particular importance. Examples include sequencing proteins in pollen and their modification by air pollution, and ecotoxicology where collaborations have developed around the Environmental Omics Sequencing Facility and use of the keystone species *Daphnia magna* (waterflea). This work has generated new understanding of the role of proteins and other macromolecules in mediating nanoparticle uptake by and impact on biological systems.

1.4.3. Institutional-level. At University level, the **Institute of Advanced Studies (IAS)** promotes bottom-up interdisciplinary research by combining expertise to address cross-cutting themes that are important, relevant and timely [REF5a 2.3.2]. Our researchers led three IAS workshops in 2014–2020 on synchrotron scanning, the BIFoR project, and plant-pathogen-environment interactions, and IAS supported six distinguished visiting fellows to BIFoR. The **Institute for Global Innovation (IGI)** also actively supports researchers to build challenge-led multi-disciplinary collaborations around four main and four emerging themes, especially with

Low- and Middle-Income Countries, through provision of seed funding, convening of workshops and sandpits, and support for travel and logistics [REF5a, 2.3.3]. We lead the Environmental Pollution Solutions emerging theme which draws together Birmingham researchers from Environmental Sciences, Economics, Civil Engineering, Law and Social Work & Social Care, among others. Our researchers also contribute significantly to two other key themes (Resilient Cities, Water Challenges), as well as leading the latest emerging theme, Clean Air.

1.5. Open Research

Our researchers are active leaders in the opening up of the research process: for example, leading a major European Union funded programme to create a community structure for **reproducible science** in the nanoscience area (Lynch), or **publishing community standards** and recommendations for maximising open data in digital studies of biological morphology (Lautenschlager). Other specific actions include:

(1) **Maximising Open Access to our publications** by mandating Green self-archiving of all research outputs on our institutional repository PURE [REF5a 2.2] (100% compliance for outputs submitted to REF2021), strongly encouraging Gold open access where feasible, and encouraging posting of pre-prints in appropriate subject-specific repositories such as bioRxiv;
(2) Training our staff on how to **openly share data** in a citeable form via subject-specific repositories (e.g. Dryad, Zenodo) and the University's Research Portal [REF5a 2.2]; how to manage data in line with the Concordat on Open Research Data; and making data from facilities such as BIFoR FACE open after a specified period;
(3) **Enhancing understanding of Open Research** among our staff, via training opportunities at staff away days and School meetings, as well as highlighting examples of staff engagement with Open Research via our internal School bulletin. Doctoral researchers are trained in Open Research practices and their intersections with research integrity, producing mandatory data management plans at an early stage in their studies.

1.6. Research integrity

Research integrity and ethical practice are central to all our research activity. All new research projects/grants and postgraduate research projects, and all research involving human subjects or other potential ethical issues (e.g. work with animals), must pass a robust ethical review, in line with the central University Code of Practice for Research [REF5a 2.2]. Undergraduate and taught postgraduate research projects all undergo ethical review at School level. Doctoral researchers are provided with extensive guidance and training opportunities: for example, our NERC CENTA doctoral researchers attend a '*Research Integrity*' training day.

Research involving the use of chemical or biological materials, manual handling, or fieldwork all require hazard and risk assessments to be completed, checked, and held centrally. Ethics review and monitoring ensures, for example, that field samples (e.g. fossil, geological) are collected following local and international guidelines and regulations on land access, sampling and custodianship of natural heritage. Where appropriate, such samples are subsequently accessioned into the Lapworth Museum of Geology, ensuring future public and scientific access to them.

2. People

2.1. Staffing strategy and overview

Our staffing strategy focuses on:
(i) Strategic recruitment in areas of critical mass and where our expertise is globally recognised;
(ii) Ensuring development, retention and promotion of existing talent;
(iii) Enhancing female and BAME staff numbers in all roles through recruitment strategies and tackling barriers to career development and promotion;

(iv) Increasing our population of independently funded research fellows.

Our **significant strategic staffing investments** in UoA7 since 2014 (4F, 6M) have focused on building and enhancing areas of research strength, with four new academic staff in EHS (Abdallah, Esquivel Muelbert, Pugh, Pfrang) and six in ES (Edgar, Giles, Greene, Hopcroft, Lautenschlager, Maffione). To recruit Hopcroft, we used the University's Birmingham Fellows scheme [REF5a 3.4.1]. Although appointed prior to 2014, four other current UoA7 staff (Butler, Dunkley Jones, Pope, Shi) also held Birmingham Fellowships and benefited from enhanced support during this REF cycle, with three promoted to Chair by 2020. These investments have boosted research in areas including vertebrate palaeobiology, palaeoclimates, tectonics, persistent organic pollutants, atmospheric chemistry and pollution, and forest ecology.

GEES was awarded Athena SWAN Bronze status in 2014, renewed in 2019. Policies put in place as part of this have ensured that shortlisting and appointment panels pay enhanced regard to EDI questions. This includes:

- Targeting female, BAME and other underrepresented candidates through subject networks;
- Use of gender-neutral language;
- Contextualising outputs/achievements in relation to career breaks during shortlisting and interviews;
- Only approving shortlists if there is realistic gender balance;
- Unconscious bias training for panel members;
- Adding an EDI statement to all job adverts, including a named female staff member to contact informally.

The University is a signatory to the San Francisco Declaration on Research Assessment (DORA) [REF5a 2.2], and we follow its principles in our assessment of academic job applicants. At School level, these new policies resulted in a doubling in applications from and shortlisting of women since 2015 (gender parity reached 2017), and 320% increase in women appointed. Our proportion of women (19% of submitted staff) and BAME (6% of staff) researchers remains low, and improving in these areas is a key priority for the School and the Unit.

We have also **increased our successful support of externally funded independent fellowships** (e.g. Halliday, Clements, Leverhulme Early Career Fellows in Palaeobiology; Giles, Royal Society Dorothy Hodgkin Fellow and proleptic Senior Research Fellow in Palaeobiology). **Staff retention has been high** since 2014, evidencing our attractive research environment. 94% of our submitted staff are employed on open-ended contracts.

97% of our submitted staff are employed full-time. The career pathways for **part-time staff** are equivalent to full-time staff. Promotions panels evaluate the quality of the inputs/outputs of staff and quantity only in relation to their working hours.

Staff on **parental and adoption leave** remain on mailing and School bulletin lists (without expectation of messages being read) and use 'keep in touch' days to attend research events and specific meetings. Tailored support is provided for career progression of academic staff returning from leave, and long-term changes can be made to working hours to accommodate caring responsibilities.

Wherever possible, we provide opportunities for **flexible and remote working**, and have improved information to staff about these options. We schedule core meetings and research seminars within core working hours. We survey staff annually to collect flexible working requests that may affect timetabling of lectures. In 2018/19 and 2019/20, all such requests (7 and 9) from UoA7 staff were supported.

EDI training opportunities used by our staff have included training on unconscious bias, inclusive development, chairing inclusive meetings and being an LGBTQ+ ally. The weekly School bulletin has highlighted positive role models around work/life balance and caring, and information on events such as Women in Science, Black History Month and staff LGBT and

BAME networks [REF5a 3.4.5]. Regular EDI events involving UoA7 and UoA14 staff have included topics such as International Women's Day and Equality and Justice in a Changing World. In 2020, ES staff, postdocs and doctoral researchers established an anti-racism reading group, which has played a key role in driving EDI actions at School level.

We provided extensive support for our staff and doctoral researchers through the COVID-19 pandemic, including reduced workload expectations for those with caring responsibilities (principle of 'best endeavours'), explicitly taking impacts into account in annual performance reviews and promotions, and maintaining a sense of community through online seminars, doctoral supervisions, online away days, virtual meetings and coffee breaks, many organised organically at research group level.

2.1.1. Staff development strategy. We provide our staff with a comprehensive system of induction, probation, annual appraisal, mentoring and training. Academic probation is typically three years, and comprises a Personal Development Plan outlining agreed objectives, ongoing mentoring, and an annual Performance Development Review (PDR) with the Head of School [REF5a 3.4.3]. Our researchers can achieve promotion while still in the probationary period and/or complete probation early when progress is exceptional (4 staff in 2014–2020). We have revised the annual PDR process since 2014 to include discussions of personal development, research leave, career breaks, and promotion.

We offer **mentoring and coaching** to all staff, including compulsory probationary mentoring, peer-to-peer mentoring, and coaching, the latter being provided by the University's central People & Organisational Development team. Four UoA7 staff benefited from coaching in 2014–2020.

Diverse **training opportunities** are enthusiastically embraced by our researchers. We developed a **new induction programme** to support our academics: this model has now been adopted as a model of best practice for the wider College. This programme aims to build a cohort identity and provides a focused introduction to the current Higher Education landscape, alongside personal development skills. All those with teaching responsibilities complete the Postgraduate Certificate in Higher Education (PGCHE). Our researchers use continuing professional development opportunities [REF5a 3.4.4] including the cross-University Research Leaders' Programme (5 staff in 2014–2020), Emerging and Senior Leadership programmes (6), and the Aurora Leadership Programme for early-career female academics (1), as well as the College-level Rising Stars Programme (1). Our staff are encouraged to take on broader leadership roles outside of the School, with three holding such roles since 2014 (e.g. Sansom, College Director of Education).

We have nurtured **disciplinary leadership** throughout this cycle with promotions to Chair (Bloss, Butler, Lynch, Pope, Shi), Reader (Pugh), and Senior Lecturer/Senior Research Fellow (Dunkley-Jones, Edgar, Giles, Stevenson, Watt). Our proportions of both BAME staff and senior female staff remain relatively low (e.g. ~18% of chairs within UoA7 are women, falling below the national benchmark of 24%). We have introduced specific actions to address this including: changes to recruitment policies (see above); improving the PDR process to include explicit discussion of promotion criteria; enhanced guidance on promotions processes through dedicated workshops; proactive Head of School encouragement of female and BAME promotion candidates; mandatory EDI and unconscious bias training for promotions panels; appointment of an EDI representative to the School promotions panel. Future promotions will also account for COVID-19 impacts on research and other activity.

These changes have led to increases in this REF cycle in female applicants and success rates for promotion. Across the School, female staff have been disproportionately (positively) represented in successful promotion applications through 2014–2020, with 69% success rates for women versus 54% for men. We recognise that we have more to do in this area. Increasing our proportion of BAME and female research staff, particularly at senior levels, is a priority for the next five years, and embedded in our Athena SWAN action plan.

2.1.2. Early-career researchers (ECRs). We have a vibrant community of ECRs (Table 2). Independent research fellows are treated as academic staff and receive training and mentoring as part of induction and probation (Section 2.1.1). Where possible, we support research fellows into open-ended staff positions, with eight making this transition in 2014–2020. Full promotion opportunities are available to research fellows (e.g. Giles to Senior Research Fellow). ECRs are involved in School governance via explicit representation on Research and other committees.

Table 2. Counts of internally and externally funded research fellows/PDRAs, 2014–2020

	UoA7
Birmingham Fellows	6
Leverhulme Early Career Fellows	3
Royal Society Dorothy Hodgkin Fellows	3
NERC Independent Fellows	4
Marie Curie Fellows	12
PDRAs	78

The College PERCAT (Postdoctoral and Early Researcher Career Development and Training) initiative [REF5a 3.3] is led in the School by ECR representatives and provides our ECRs with training courses, career advice, funding opportunities, workshops and seminars. PERCAT provided 48 such events in 2014–2020.

2.1.3. Research leave policy. Wherever possible, we concentrate an individual's teaching into a single semester to reduce time fragmentation. Our researchers also have access to a formal **research leave programme** [REF5a 3.4.3] to provide up to one semester to develop their research profile (taken up by 8 staff in 2014–2020). Applications are particularly encouraged where staff with significant caring or other responsibilities wish to enhance their research activity. For example, Bendle used his research leave to build collaborations in the USA leading to joint grant applications and fieldwork in the USA, Vietnam and Laos.

2.1.4. Recognition for staff delivering research and impact. Our workload model calculates research, impact, teaching and administrative load, using weightings based on best practice elsewhere in the UK. Data are gathered on an ongoing basis and inform discussions in PDR meetings. **Our workload philosophy with respect to research is that where new grant or impact activity has been secured, teaching and admin roles are redistributed accordingly**. In doing so, we acknowledge the particular strengths of the individual to provide ring-fenced time for both research and impact activities. The model also includes a standard tariff for citizenship duties and implicit FTE-adjustments for part-time staff, and is monitored annually for gender bias. Data show that, since the introduction of this model, **there is an equitable workload gender balance**.

In line with the Knowledge Exchange Concordat, **impact has equal importance to frontier research in recognition and reward and is reflected in promotion criteria** [REF5a 3.4.6]. We acknowledge the need for continuous improvement in this area and so to assist staff development in impact, we provide training in public engagement, policy and commercialisation.

2.1.5. Supporting staff and postgraduate researcher wellbeing. Our staff have access to the Employee Advice and Listening Service, as well as counselling, harassment advice, and disability support and mediation services [REF5a 3.4.5]. Postgraduate researchers have access to equivalent services provided via the Student Hub. An annual workplace wellbeing week is held to raise awareness of these centrally provided services. Our researchers have received bespoke training on mental health support during fieldwork.

Our researchers use a dedicated **Equalities Travel Support Fund**, launched by the College in 2019, which covers costs related to childcare or caring responsibilities incurred when travelling for research or impact, or when hosting incoming researchers. Up to £500 can be applied for each year by an individual staff member (two awarded to UoA7 in first year of operation).

2.2. Research students

2.2.1. Recruitment and funding. Our postgraduate researchers (PGRs) are funded through six primary pathways: UKRI-funded doctoral training partnerships (DTPs) and Centres for Doctoral Training (CDTs); a Leverhulme Trust doctoral scholarships grant (Forest Edge); Marie Curie training networks; funded positions within major research grants and fellowships; overseas scholarships; and self-funding.

Three primary DTPs/CDTs fund UoA7 students: NERC CENTA DTP; NERC Oil & Gas CDT; and ESRC-NERC Big Data and Risk (DREAM). During the 2014–2020 period, 100 PGRs completed their doctoral studies in UoA7. This represents a 50% increase in PGR completions/year compared to the last REF cycle. NERC CENTA is led by the School, with UoA7 researcher Bendle acting as Director throughout the first funding cycle.

All staff advertise externally for self-funded students or those with externally awarded scholarships, and PGR recruitment is also supported via the University's international office, with focused activity in China, India and Brazil. PhD funding is also provided through College-level resources, including match-funding for DTPs and strong strategic cases, and University schemes such as Elite Overseas Scholarships and Global Challenges Studentships.

We have seen **increased female representation of PGR students since 2015** (current numbers: 41% female; 59% male), and across UoA7 exceed the HESA benchmark (37% female; 63% male). Male PGR applicants substantially exceed female applicants, although female applicants are more likely to receive and accept offers of places. UoA7 researchers (Giles, Greene) have been leading work to assess the EDI impact of the approaches used by DTPs/CDTs in recruiting students from marginalised and underrepresented groups across the UK higher education sector, including an open letter to UKRI in 2020. This work contributed to a radical overhaul of the CENTA2 recruitment processes to improve diversity (e.g. ringfenced BAME studentships) in 2020.

2.2.2. Monitoring and support mechanisms. Students complete a Development Needs Analysis form annually to identify skills gaps and training opportunities. Supervisions take place at least monthly with a formal record of progress and agreed actions logged. Twice annually PGRs have a formal review meeting with the PGR lead for their research group, their mentor and supervisory team. These meetings ensure that the project is on track and that the supervisory team is working effectively and in the interest of the PGR. Non-completion rates for PGR degrees are very low (less than 5%).

This support continued throughout the COVID-19 pandemic, with supervisory meetings and Postgraduate Boards taking place online. Impacts of COVID-19 on research progress were recorded on a monthly basis, in order to build cases for studentship extensions where possible and appropriate. PGRs also engaged extensively with, and in many cases led the organisation of, social support structures through this interval (see Section 2.1).

2.2.3. Skills and career development. Training needs are fulfilled through courses running both on campus and regional courses made available via DTPs. Campus-based courses are curated by the University Graduate School [REF5a 3.2], and include generic skills training, such as communicating research, transferrable and employability skills. Support for international students is provided by the International Students Advisory Service, the Counselling and Guidance Centre, and English skills through the Birmingham International Academy.

Our **PGRs use College-level funds** to organise internal workshops, and a travel fund for conference attendance. In addition, our PGRs organise an annual School-level postgraduate conference, where in year 1 they give a poster presentation, in year 2 an oral presentation and in year 3 chair a session. This enhances interdisciplinary interactions amongst and between the PGR and staff communities.

2.3. Approach to EDI in construction of the REF submission

We have prioritised consideration of Equality, Diversity and Inclusivity issues in constructing our REF submission, following the University's Code of Practice for REF2021, including the use of equality impact assessments in both the process of identifying staff who are independent researchers and in the final selection of submitted outputs. Equality impact assessments, overseen by the Head of School and Head of Research, compared the contributions of staff with protected characteristics and at different career stages to the submitted output portfolio with their representation in the Unit as a whole. Our submission reflects the diversity of our research Unit, and our equality impact assessments show no evidence of biases with respect to any particular cohort or combinations of protected characteristics. All submitted staff have seen and have had several opportunities to comment on the environment template.

3. Income, infrastructure and facilities

3.1. Research income

Crucial to our research grants strategy has been focusing resources within centres of excellence and strengthening our interdisciplinary and international links. Support for funding bids has been provided by an integrated research support office at College-level which helps identify opportunities, assists in drafting applications, works with the University's Business Engagement and Development and Alumni Relations teams [REF5a 4.1] to bring external partners on board and organises mock panel interviews for larger consortium grants. This technical support works together with a rigorous system introduced during this REF period of **mentoring and internal peer review of applications undertaken at research group level**.

The success of this strategy is demonstrated by **major increases in research income**. Research income for UoA7 researchers at REF2014 was £11.53m between 2007/2008 and 2012/2013. Our total research income was £27.24m during 2013/2014 to 2019/2020, representing an absolute annual increase of 67%, and an average 53% increase per FTE. Income data show sustained increases, from £3.3m in 2013/2014 to £4.13m in 2019/2020.

This income was generated from >60 different funders, including €11.3m from European funders and £12.6m from UKRI (primarily NERC). Selected major awards include the West Midlands Air Quality Improvement Programme (NERC, £5m), the QUINTUS project on carbon and nutrient dynamics in temperate forests (NERC, £3.7m), and three European Research Council grants (€5.38m in total).

Additional significant research-linked income includes:

- £15m donation by the JABBS Foundation (with matched internal resource) to inaugurate the Birmingham Institute of Forest Research (BIFoR);
- ~£3.5m income-in-kind from access to NERC and other national facilities;
- ~£15m of direct and income-in-kind for international ocean research expeditions;
- £1.6m income-in-kind for structural geology software (MOVE);
- Involvement in £1.3m funding for public engagement through the NERC Engaging Environments Programme;
- ~£3.4m from Heritage Lottery Fund, Arts Council England, DCMS, Wolfson, University alumni, Research England Museums Fund and National Archives to redevelop the Lapworth Museum and provide subsequent support for enhanced public engagement and research activity.

Since 2014, our improved processes have helped increase the success rate of research grant applications led by women, leading to **substantial increases in total and average annual research grant awards to our female staff**.

3.2. Infrastructure supporting research and impact

New internal processes to support excellence in research and a vibrant research culture were introduced following a strategic review of the outcomes of REF2014. Rigorous **internal grant peer-review** is now the norm. A pitch-to-peers ~4–6 months pre-deadline critiques proposals,

and a 'mock panel' meeting ~6 weeks out assesses full proposals. Bids over £250k typically require formal peer review within research themes, ensuring quality control. The College Research Support Office [REF5a 4.1] provides high quality support aiding these activities. Better outputs are also enabled via **research leave** to address specific deliverables (see Section 2.1.3).

A School **pump-priming fund** initiated in 2015 allocates funds (£2–5k) to proof-of-concept research and translational activity (11 UoA7 staff received funding). We have also provided an **annual research allocation** of £500 per staff member to support activity. Furthermore, our staff, ECRs and PGRs actively use a diverse range of University- and College-level **international networking and research funding**, including for targeted activities in India, China and Brazil, as well as through the Institute for Advanced Studies and Institute for Global Innovation (Section 1.4) [REF5a 2.3]. Ten staff benefited from such internal funding (totalling ~£17k) since 2014. We also use institutional funding schemes that target specific strategic partners [REF5a 2.1.8] such as the BRIDGE initiative with the University of Illinois Urbana Champaign (5 staff benefited from funding totalling ~£30k) or the Universitas 21 network of universities (4 ECRs received funding to visit research partners in Canada, Australia and China) [REF5a 2.1.8]. Our **Equalities Travel Support Fund** supports research-related travel for those with caring responsibilities (Section 2.1.5).

Our researchers make active use of **dedicated School, College and University-level impact and enterprise funds** (Section 1.3). Our researchers are actively involved in the internal panels for this activity. All our submitted impact case studies benefited from these funds. Dedicated professional services support for impact activity is available and includes a College-based Research Communications officer and a Business Engagement Partner. Broader support for impact at an institutional level covers activity ranging from Public Engagement to Enterprise.

Individual research groups run weekly **seminar series** with internal and external speakers, and additional seminar series and discussion groups are organised at subtheme level. These continued remotely through the COVID-19 pandemic, with an increased number of international speakers. This is in addition to fortnightly evening lectures organised by our researchers through the Lapworth Museum bringing in leading Earth Scientists (10 per year) to present research to the public.

We host **numerous international research visitors**: >155 during this REF cycle from >20 countries, particularly China and India. Our research visitors are often in receipt of prestigious external funding (e.g. Sageman, Fulbright Scholar Award, 2019), and we also use internal funding such as the University's Brazilian Visiting Fellows scheme.

3.3. Facilities and investment

We have leveraged >£55m of facilities investment through this REF cycle (including our share of the Molecular Sciences building [REF5a 4.2.1] – groundworks underway), through internal (e.g. annual College-level fund for equipment, alumni campaigns) and external sources. Investment has been targeted to support our key objectives (Section 1.2) of enhancing interdisciplinary collaborations and growing our key areas of research strength and critical mass. Details of our key facilities (Fig. 1) are provided below.

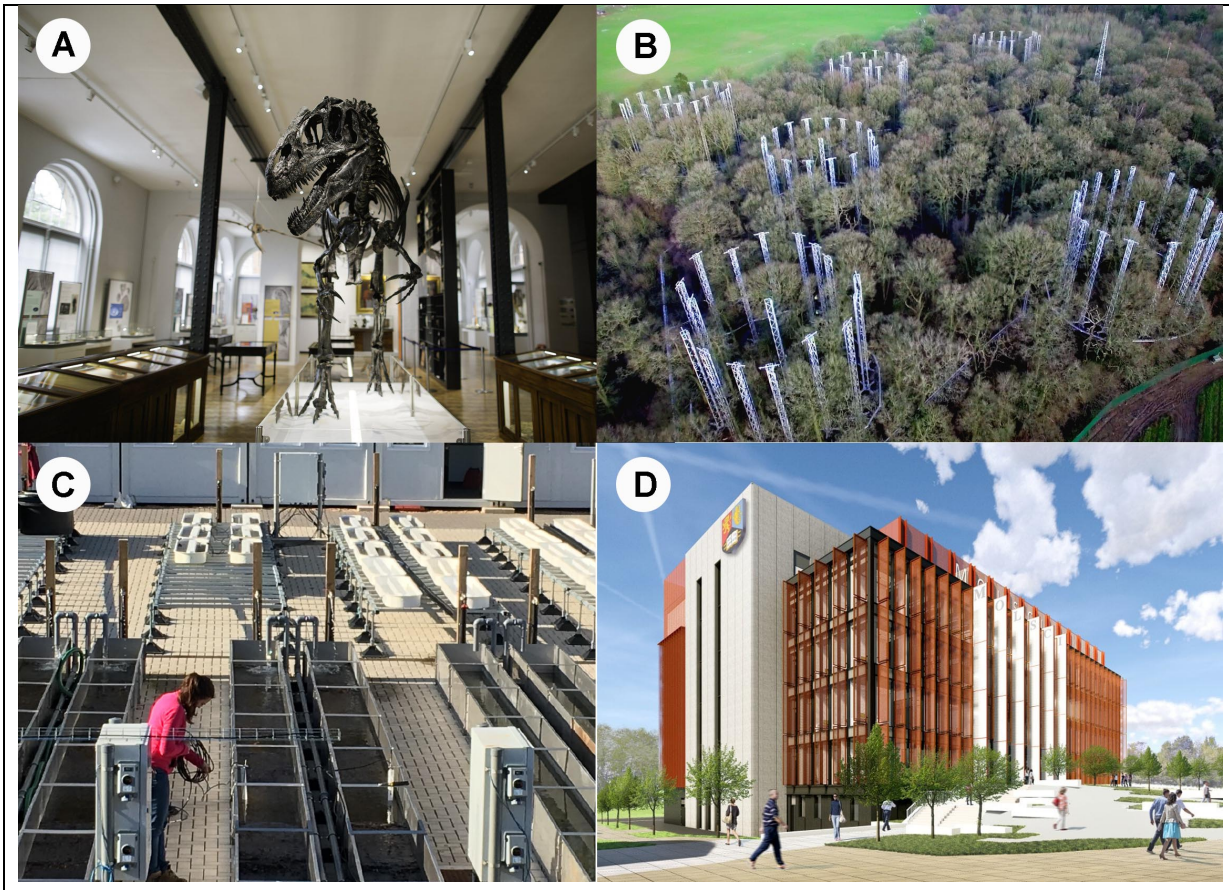

Fig. 1. Some key existing and forthcoming UoA7 facilities. A, Lapworth Museum of Geology. B, BIFoR FACE. C, EcoLaboratory. D, under-development Molecular Sciences building.

The **Birmingham Institute of Forest Research (BIFoR)** was established in late 2013 as an interdisciplinary unit providing a step-change in UK forest research. BIFoR's flagship facility is a **Free Air Carbon Enrichment (FACE) experiment**, which came on-stream in 2017 supported by a £15m donation from the JABBS Foundation, matched by in-kind investment of >£15m by the University. BIFoR FACE is only the second such facility worldwide, and the only one in the Northern Hemisphere. It is set in mature, unmanaged, temperate woodland to assess the impact of rising CO_2 levels on forest ecosystems. BIFoR is led by UoA7 researcher MacKenzie and supports >50 ongoing research projects including involvement of ~15 academics plus postdocs and doctoral researchers from UoA7, as well as UoA14, UoA5, and numerous external institutions, including the Met Office, Earthwatch Institute, and ~15 European universities. Interdisciplinary research cuts across UoA7 and UoA14, as well as into the College of Arts and Law and Schools of Biosciences and Psychology. This is evidenced by the **£1.04m Forest Edge initiative** providing Leverhulme Doctoral Scholarships funding to 20 doctoral researchers across physical, biological and social sciences and humanities. BIFoR has generated £2.5m in further philanthropic donations and >£8m in UKRI funding, including a **£3.7m NERC research grant** (QUINTUS) to study carbon and nutrient dynamics in temperate forests to understand the implications for carbon sequestration in a high carbon dioxide world.

The **Lapworth Museum of Geology** [REF5a 4.3] (see submitted Impact Case Study) has collections and archives including c. 300,000 objects internationally renowned for their scientific significance: the entire collection is designated as 'outstanding' by Arts Council England, and receives Research England funding to help it support the research community. The collections are used extensively by UoA7 researchers, particularly within Palaeobiology, and provide an outstanding venue to engage the public with research. A £2.7 million redevelopment of the Lapworth from 2014–2016 tripled visitor numbers to >60,000/year, as well as receiving international recognition via shortlisting for Art Fund Museum of the Year, the world's largest museum prize. Our research is showcased in the permanent galleries of the museum as well as

in temporary exhibitions, including on changing scientific and artistic depictions of dinosaurs, and the International Ocean Discovery Project and climate change. The Lapworth is a key venue for EDI activity, for example hosting the 2017 exhibition *Raising Horizons*, showcasing key historical and modern women in geology and palaeontology (including UoA7 staff and PGRs).

The **Birmingham Environmental Research Facility** [REF5a 4.2.3] was created during this REF cycle, comprising the Environmental Change Outdoor Laboratory (EcoLaboratory), the Birmingham Air Quality Supersite, the Wolfson Glasshouses environmental chamber facility and the Meteorological Observatory, all co-located on the University campus close to the main GEES buildings. **EcoLaboratory** is a new £1.2m investment by the University into experimental water environments, comprising over 100 parallel flume, open-air mesocosms that allow high replication and real-time monitoring. The facility provides environmentally relevant conditions for assessing the impacts of nanomaterials and microplastics. It is used by our researchers including Lynch, and has facilitated £2.5m of external funding across UoA7 and UoA14.

The **Birmingham Air Quality Supersite (BAQS)** is one of three national air quality research supersites, developed through >£1m of NERC investment (alongside c. £100k support from the University). UoA7 staff lead BAQS, which includes advanced instruments to characterise gaseous and particulate components of the urban atmosphere, and identify anticipated and unexpected trends in atmospheric composition. Data from BAQS is open access, fed into the national supersite network repository, made locally available via the University website, and contributes to Birmingham City Council's monitoring network. The site also hosts instruments operated by external partners (including Cambridge and York universities and sensor development companies). Adjacent to the BAQS site, our **Meteorological Observatory** is integrated into the UK Met Office network. The BAQS facility has directly facilitated >£500k of additional external funding to date, and supports the £5m WM-Air Programme.

The **Wolfson Glasshouses environmental chamber facility**, due to reopen in 2021 (delayed from 2020 by COVID-19) following a £1m Wolfson Foundation award as part of a total £2.7m investment, will provide controlled environmental chambers to study the interactions of plants and biological systems with environmental stressors, such as enhanced CO_2 levels or the presence of new plant pathogens. The facility represents a collaboration between UoA7 researchers and the School of Biosciences (UoA5).

We have conducted pioneering work with **aerial robotics**. From 2013–2018, our academics led NERC Summer School training in the use of mini- and micro-unmanned aerial systems. We have deployed ultra-light drones to conduct aerial photogrammetry, but also pushed the technological envelope through much larger platforms for in-situ sensing of greenhouse gases above the trade-wind inversion, within volcanic plumes, and for the first deployments of a spectrometer to measure solar-induced fluorescence from photosynthesis. Our research on the miniaturisation of environmental sensors includes deployment of meteorological payloads on birds for measurements in settings unsuitable for drones. As a direct result of our scoping work, our researchers participated in NERC-funded research using the world's largest aerial robot, the NASA Global Hawk.

Instrumentation within EHS has been enhanced since 2014, including: a 2-Dimensional Gas Chromatography linked with a Time-of-Flight Mass Spectrometer (ERC funded), one of only two in the UK used in atmospheric science applications, which has allowed elucidation of the chemical composition of diesel exhaust particulate matter in unprecedented detail; a Chemical Ionisation-Atmospheric Pressure Inlet-Time-of-Flight Mass Spectrometer (NERC funded), also one of only two in the UK, which has underpinned the identification of a novel mechanism of new particle formation within the Antarctic atmosphere; a quantum cascade laser system for monitoring atmospheric gases (NERC funded); an organic and elemental carbon analyser for atmospheric particles (NERC funded); and two high resolution proton transfer reaction mass spectrometers (JABBS and University funded). **New instrument development** is a focus of activity, including systems to measure *in situ* atmospheric ozone production rates, halogen atoms, and atmospheric total organic reactivity (all three NERC funded).

The **Facility for Environmental Nanoscience Analysis and Characterisation (FENAC)** was originally established as a NERC facility to support environmental nanoscience and nanotoxicology research, and from April 2020 has been run as a self-sustaining independent facility. The facility has supported >30 research projects including involvement of ~23 academics as well as postdocs and doctoral researchers from UoA7, UoA14, UoA5, and numerous external institutions, including the British Geological Survey, Centre for Ecology & Hydrology and ~18 UK universities.

Other facilities include an industry-standard 3D seismic processing, interpretation, and reconstruction facility and a stable isotope laboratory, providing state-of-the-art continuous-flow isotope-ratio mass spectrometry for the investigation of environmental, biological and geological samples. The **Paleomagnetic Unit and Magnetic Anisotropy (PUMA)** facility was relaunched in 2017 and is equipped with instruments for palaeomagnetic and magnetic fabric analysis. Under development are plans for a new integrated **Palaeobiology Laboratory** that will include wet and dry fossil preparation and processing spaces, state-of-the-art microscope facilities, high-power workstations for virtual fossil visualisation, and 3D scanning and printing facilities.

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

4.1. Research collaborations

Our focus on challenge-led interdisciplinary research inherently recognises that key, outstanding issues to be addressed in the Earth and Environmental Sciences are global in nature, may require access to specialised facilities or infrastructure not present in the UK and that many of the challenges and topics we address operate across international boundaries. In addition to flagship examples of leadership in regional and national collaborations (see section 1.3), we therefore also have extensive leadership of international networks, as evidenced by **co-authored publications with researchers from more than 70 different countries** (Fig. 2). We have also sought to take advantage of specific opportunities afforded by the strategic University goal of strengthening links with Brazil, China, India, and North America [REF5a 2.1.8]. Each has a dedicated University team responsible for promoting engagement alongside central schemes to pump prime activity (Section 3.2), including a hub in Brussels to ensure strong engagement with European partners. Some specific highlights are illustrated below.

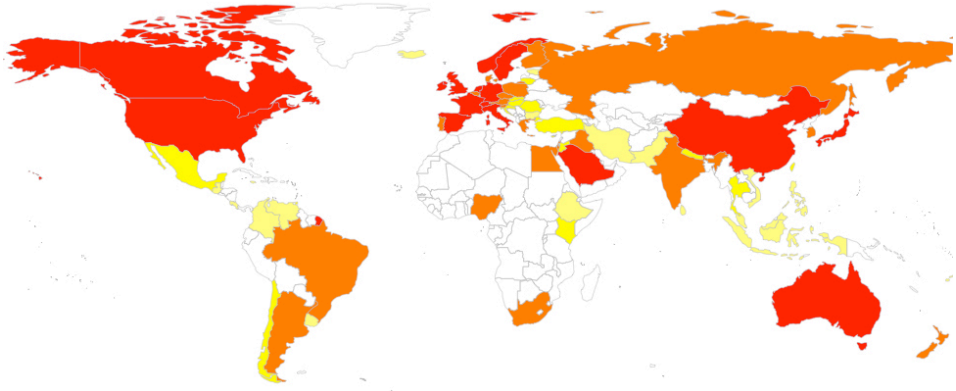

Fig. 2. Our UoA7 academics co-authored papers with researchers from 73 overseas countries and territories from 2014–2020 (warmer colours = more collaborations). The largest numbers of collaborations were with the USA, Germany, China, Saudi Arabia, Spain, France and Australia (data from SciVal).

Environmental challenges do not respect borders hence policy needs to operate at an international scale. For example, in regards to the threat from persistent organic pollutants, Harrad has shown exceptional leadership with numerous partners worldwide by co-ordination of three major EU-funded Marie Curie Initial Training Networks and two Marie Curie International Research Staff Exchange Scheme projects. These collaborations have led to changes in international regulations on halogenated flame retardants and other pollutants. Likewise, Valsami-Jones and Lynch are international leaders in the field of nanotoxicology and play a

leading role in the translation of scientific advances towards the global regulation of nano-enabled products by bringing together teams of researchers, as evidenced by their coordination of or participation in eight major EU (FP7 and Horizon2020) funded projects.

Another key driver of our international collaborations has been through unique facilities essential for tackling global issues that cannot be constrained to a single laboratory or field site. This is perhaps best evidenced by our role in international marine expeditions. We have led NERC expedition JC132 to the Mid-Atlantic Ridge, been involved in five other NERC or similar cruises (each costing ~£1m), participated in or been involved in eight International Ocean Discovery Program (IODP) expeditions, and currently lead IODP Expedition 388 and IODP Proposal 943, awaiting re-scheduling/scheduling respectively.

Finally, our international collaborations are always undertaken with regard to building meaningful two-way partnerships that will grow and develop over time. This has been a key strength of the Air Pollution team who have led multiple projects with partners across China, India and East Africa (e.g. £2m Air Pollution Sources in Beijing project, overall science coordination for the APHH-China programme, leadership of the £1.5m Sources of Air Pollutants in Delhi project, £1m DFID-funded project ASAP-Africa and the £1.6m NERC Highlight Topic project SEANA). For example, the ASAP project (Section 1.4) has the goal of co-creating and producing innovative solutions to East African air pollution (focused on Addis Ababa, Kampala and Nairobi) that build local social networks based on trust and collaboration. The new knowledge generated will spur the development of these coalitions and furnish them with the information required to understand, regulate, monitor, and manage air pollution for the long term.

4.2. Contribution to the discipline

UoA7 researchers have organised or hosted >15 academic conferences in Birmingham in 2014–2020. We also organised numerous symposia at external professional meetings, including key international conferences such as the American Geophysical Union, European Geosciences Union, and Goldschmidt, and two consecutive Faraday Discussions on Air Pollution. In 2017 the Lapworth Museum hosted the *Embodied Geographies* symposium, organised by and involving UoA14 and UoA7 researchers, which explored and developed learning about how EDI issues and questions of fairness work through the academic disciplines within the School. Furthermore, to help inspire the next generation of scientists we hosted the 2019 Earth Science Teachers' Association annual meeting at the Lapworth, showcasing our research activity and sharing new teaching resources.

UoA7 researchers have been extensively involved in committee and leadership roles in 14 key professional societies covering all our subject areas, including the Royal Society, Royal Society of Chemistry, Royal Meteorological Society, Aerosol Society, Geological Society, Micropalaeontological Society, Palaeontological Association, Society of Vertebrate Palaeontology, Volcanic and Magmatic Studies Group, University Geoscience UK, and the Solid Earth Geophysics Forum.

4.3. Wider influence and esteem

UoA7 researchers serve on multiple NERC panels, including the Advisory Network, Peer Review College, Discovery Science Grant panels, International Opportunities Fund panel, and Large Grants panel. Other externally significant roles held by UoA7 researchers include:

- Steering Committee and Grants Panel for the UK Prevention Research Partnership of the Medical Research Council, member (Harrison);
- EU Clean Air Prize, evaluator (Harrison);
- Defra Air Quality Expert Group, member (Harrison);
- Department of Health committees on Medical Effects of Air Pollutants and Toxicity, member (Harrison);
- Advisory Committee for the NIHR Programme Human Health Aspects of Chemical Hazards, chair (Harrison);

- Community of Experts of the European Science Foundation, member (MacKenzie);
- NERC Strategic Programme Advisory Committee and Joint Capital Advisory Group, member (MacKenzie);
- NERC Advisory Network (Mackenzie, Shi);
- Evaluation Panel for the EU's Marie Skłodowska Curie individual fellowships, vice-chair 2014–2017 (Harrad);
- Clean Air Advisory Panel for Wales, member (Bloss);
- National Isotope Facility panel, chair (Fairchild);
- Stratigraphic Commissions for the Precambrian (Cryogenian) and Quaternary (Anthropocene), member (Fairchild);
- IODP-Laboratory Working Group, member (Edgar);
- TALENT Policy Commission, assessing higher education sector's future need for technical talent, member (Edgar);
- Paleobiology Database, executive committee (Butler).

Significant external prizes awarded in this REF cycle include:

- Elected Fellow, Royal Society (Harrison);
- Wolfson Fellowship, Royal Society (Valsami-Jones);
- John Jeyes Award, Royal Society of Chemistry (Lynch);
- Environment Prize, Royal Society of Chemistry (Harrison);
- Coke Medal (Fairchild), Murchison Fund (Watt) and Lyell Fund (Giles), Geological Society of London;
- Arne Richter Award for Outstanding Young Scientists, European Geosciences Union (Watt);
- Stensio Award, International Symposium on Early and Lower Vertebrates (Giles);
- Distinguished Lecturer Award, Mineralogical Society (Valsami-Jones);
- Distinguished Lecturer/Medallist, Royal Society of Chemistry (Valsami-Jones);
- Exceptional Lecturer Award, Palaeontological Association (Lautenschlager).

UoA7 researchers served on the editorial boards of 30 journals covering all our subject areas from atmospheric chemistry (e.g. *Atmospheric Chemistry and Physics*) to palaeobiology (e.g. *Journal of Vertebrate Palaeontology*). Key examples include Harrad as Editor-in-Chief of *Emerging Contaminants* (2014–present) and Harrison as joint *Executive Editor of Environmental Technology* (1980–2016) and Editor-in-Chief of the NPG journal *Climate and Atmospheric Science* (2016–present).

Concluding remarks

Our research environment has grown substantially stronger since 2014. We have invested in people, enhancing our vibrant community of researchers through targeted recruitment, and supporting, developing and promoting our staff. We have developed new initiatives focussed at staff induction, study leave, pump priming funds and internal grant review. The success of these measures is evidenced by low staff turnover, high grant capture and increase in independent fellows joining and staying with us. This in turn has allowed us to draw down strategic internal and external investment to underpin flagship initiatives such as BIFoR, Lapworth Museum, BAQS and EcoLaboratory, allowing us to address new and exciting research challenges. We have embedded new processes to recognise and promote diversity throughout our activity, as reflected by our Athena SWAN Bronze awards, but recognise that we still have much work to do going forward. Our increased focus on impact, demonstrated by excellent doctoral training programmes such as CENTA2, has greatly increased our influence beyond higher education. All of this has allowed us to deliver on and exceed our REF2014 ambitions. With the £80m Molecular Sciences building due to open in 2023, our research environment is set to deliver world-leading research that matters, now and into the future.