Institution: Newcastle University (NU)

Unit of Assessment: 7 Earth Systems and Environmental Sciences

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

Vision: Global environmental change is arguably humanity's greatest challenge. Our research addresses fundamental impacts from rapid climate change and extreme environments through to accelerating biodiversity and habitat loss. Pressures on food, water, energy, raw materials and infrastructure, with their inherent links to human systems, are reflected in our research portfolio. These inform our drive to develop mitigations and policy grounded in an understanding of the anthropogenic drivers of environmental and socio-economic interactions.

Context: Clear interdisciplinary support frameworks enabling action through global consensus are central to success. Our research across multiple disciplines contributes to, and is informed by, the Sustainable Development Goals (SDGs) of the *UN 2030 Agenda for Sustainable Development* and linked UN initiatives (*Decade on Ecosystem Restoration 2021-2030*; *Decade of Ocean Science for Sustainable Development 2021-2030*). Specifically, we target SDGs 7 and 12-15 (Affordable and Clean Energy, Responsible Consumption and Production, Climate Action, Life Below Water and Life on Land). Our research is interwoven with the work of the University's Sustainability Team and SDG committee, providing collective leadership on our commitment to environmental sustainability. We benefit from unique infrastructure, including coastal research stations, farms, bespoke surface water and deep-sea research vessels, and a geothermal well on campus.

Structures and Governance

To facilitate the interdisciplinary working that is essential for our vision, since 2014 UoA7 researchers have consolidated in the School of Natural and Environmental Sciences (SNES, formed in 2017 when the *Faculty of Science, Agriculture and Engineering* consolidated from 10 to 4 Schools, combining strengths in environmental, life, agricultural and chemical sciences). A key driver for the faculty restructure was to improve quality of decision-making, breakdown of artificial discipline boundaries and increased investment in staffing and infrastructure evidenced here. Key collaborations across Faculties culminated in 2020 in our leadership of a Newcastle University Centre of Research Excellence (NUCoRE, Ref5a 2.2.1) in Climate & Environmental Resilience, drawing on challenge-led collaborations with institutional, local, national and international partners (academic/research institutes; industry; government; NGOs).

Our submission represents contributions from **37 independent research active staff** (33.2 FTE)**:** (32.2 in SNES; 1 in the School of Mathematics, Statistics and Physics), an **increase of 8.6 FTE since REF2014**, including 16 Professors (14.8 FTE; two Emeritus), 3 Readers, 11 Senior Lecturers (10.2 FTE), 7 Lecturers (10 FTE) and one Research Fellow (1 FTE). **Fourteen new appointments since REF2014** are included, while 9 staff left NU, 2 moved to other UoAs, and 3 reduced their FTE contribution. UoA7 academics work with ~30 PDRAs, 40 PhD students, and 12 Research Technicians.

All academics, PDRAs and PGRs are managed through primary membership of an *Academic Group*, led by experienced, research-active academics. Secondary group affiliations are encouraged to foster cross-disciplinarity. Academic Group members are proactive in jointly scoping funding opportunities and optimizing research outputs. Group leads report to a Director of Expertise (DoE), with oversight of research and related training and teaching within broad solution-focussed School Directorates (BioEconomy, UoA6; Ecosystems, UoA7; Applied Social Sciences, UoAs6/13; Chemistry, UoA8). Activity is co-ordinated across the Directorates through a *School Research & Innovation Committee*, *School Executive Board*

(DoEs are members) and across all disciplines through the *Faculty* and *University Research and Innovation Committees* and NU Centres of Research Excellence (NUCoREs).

Interdisciplinary Research/Academic Groups

Research Topics: Topic modeling of 2014-2019 research outputs (Figure 1) illustrates the breadth of SNES research and interdisciplinarity across Academic Groups through interlinked key research themes. UoA7 research spans three component *Academic Groups*:

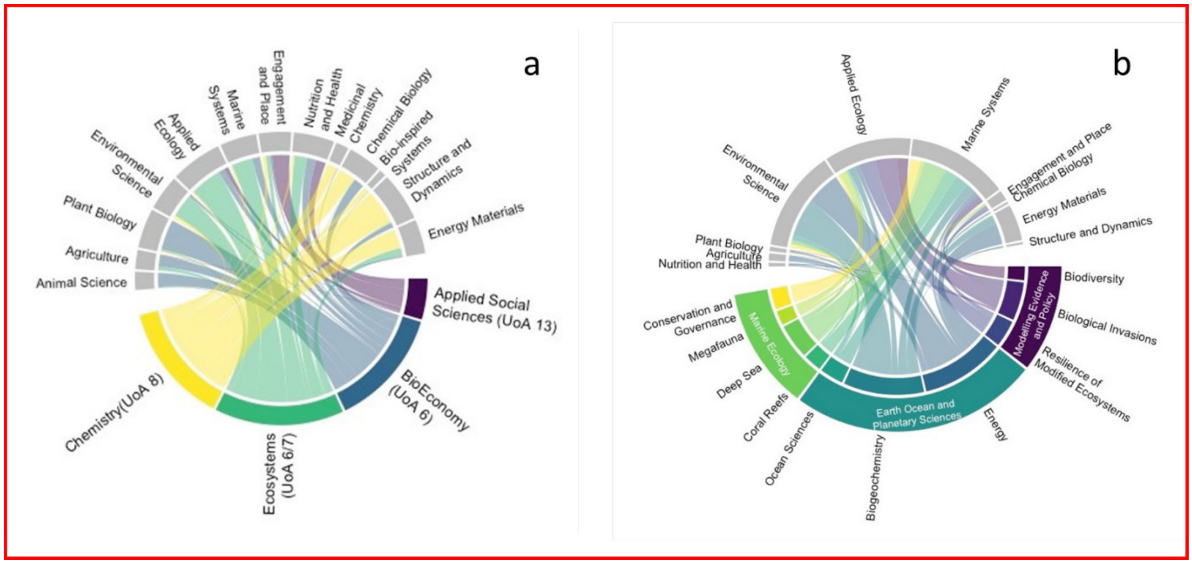

Figure 1. Research activity and links derived from topic modelling of publications, 2014-2020: a; SNES, b; UoA7. Grey perimeter segments (top) are research themes. Coloured perimeter segments (bottom) are: Expertise Areas/UoA (SNES, a), and Academic Groups (UoA7, b). Link widths indicate relative activity levels.

i) Modelling, Evidence and Policy (MEP): This Group brings together conservation ecologists, modellers and policy experts to study health and function of complex biological and socio-ecological systems to support policy development and ecosystem management locally, nationally (e.g. IFCAs, Natural England, DEFRA: ***Fitzsimmons***) and globally (e.g. IUCN, IPBES: ***McGowan, Robertson***).

Collectively, we benefit from diverse funding (UKRI; EU; Royal Society; RAE; RGS; Gilchrist Educational Trust; Heritage Lottery Fund; National Geographic Society; Leverhulme Trust; UK Government/agencies (Natural England; MMO; DEFRA; JNCC)). UKRI PhD CASE partners include conservation NGOs (IUCN Sustain; Reforest Africa; Northumbrian Water; Natural England).

We work closely with Government/NGO partners (e.g. Tanzania Agricultural Research Institute; Tanzania Forest Service Agency; World Agroforestry Centre, ICRAF). International collaborations include: GCRF, Tanzania, Kenya; Royal Society, South Africa; NERC, Brunei; ARC, Australia (***Pfeifer***); GCRF, Colombia, EU, Defra; JNCC and EU, Caribbean states (***Fitzsimmons, Robertson***); COST actions (***Mill***); IUCN specialisms (***McGowan, Robertson***); wildlife and zoonotic diseases (***Mill***); biological invasions (***Mill, Pattison, Robertson***); biodiversity-ecosystem services-human health (***McGowan, Pfeifer, Fitzsimmons***); and pristine and impacted landscape management (***Pfeifer, Fitzsimmons***).

Our diverse portfolio of research outputs (65% internationally co-authored (to 2018) vs 31% in REF2014) involves 252 colleagues and 167 outside UK. We draw on skills from across NU in engineering, remote sensing, ecology, molecular biology, and mathematics, and actively promote PGR/ECR engagement. Hosting Associate Members (e.g. Animal Plant

Health Agency, Natural England, MMO, GN Non-native Species Secretariat) enhances our research and ECR training.

Policy impact is maximized via models co-developed with stakeholders (e.g. web-based apps) and provision of scientific advice (e.g. NatureScot: Parliamentary Environmental Audit Committee evidence (***Mill, Robertson***)). Informing the science-policy interface includes: Earth Observation Intergovernmental Group (***Pfeifer***); IUCN Conventions on Biological Diversity and International Trade in Endangered Species; Intergovernmental Science-Policy Platform, Biodiversity and Ecosystem Services (***Mill, Robertson, McGowan*)**.

Optimized data synthesis addresses information gaps via biostatistical/stochastic simulations (***Pfeifer, Fitzsimmons:*** BBSRC, EPSRC, NERC, MRC, NC3Rs, NHS, NIHR). Numerical, statistical and mixed-qualitative models address: species conservation (***McGowan***); forest restoration, fisheries, and sustainable food production (***Pfeifer, Gaulton*** (UoA12)**,** ***Fitzsimmons***); human-wildlife conflicts including disease risk and spread (**Mill; Rushton,** ***Budge*** **(**UoA6)); and invasive species management (***Mill, Robertson***). PGR and ECR demonstrators share computer coding skills with UGs and developed a coding group that became a 120-member R-Ladies chapter involving industry, government and academics from across all 3 University Faculties.

MEP's work is delivered in three integrated themes:

Biodiversity Science and Policy (McGowan, Mill, Robertson): The Convention on Biological Diversity (CBD) identifies priorities for global species targets. We have led on Aichi Biodiversity Target 12, which was highlighted as a concern by the Convention at mid-term review in 2014. For this we analyzed conservation planning research (***McGowan, Mill, Robertson***: Mair et al., *Biol. Cons,* 2019), identified challenges in aligning researcher and official targets (***McGowan***: Mair et al., *Conserv. Soc.* in press), predicting 2.9-4.2 times elevated bird and mammal extinctions without implementation during the Convention's duration (***McGowan***: Bolam et al., *Cons Lett,* 2020), contributing to the CBD's Global Biodiversity Outlook 5. We evaluated progress in conservation of wild relatives of livestock (***McGowan*** et al., *Cons. Lett*. 2019), promoted opportunities for species-orientated conventions (***McGowan***: Kuunal et al., *Conserv. Sci. Prac.* 2020), and appraised risk assessment within the Convention on International Trade in Endangered Species (***McGowan***: Ridley et al., *Biol. Cons*. 2019), clarifying the contribution of ex-situ management (e.g. extinction avoidance: ***McGowan*** et al., *Cons. Lett*. 2017; Farhadinia et al., *Cons. Biol*. 2020). We assessed protected area conformity to biodiversity outcomes, finding evidence of habitat and species inadequacy (Clark et al., *PLOS One,* Mallari et al., *Env. Manage.* 2013). Our case study to assess compliance with Aichi Target 11 demonstrated that the Philippines failed to fulfil key aspects of Aichi Target 11 regarding protected areas for conservation (***McGowan***: Mallari et al., *Ambio,* 2016), but identified that protected areas are the last refuge for some species (***McGowan***: Boakes et al., *Cons Lett.* 2019).

Biological invasions (Mill, Robertson, Pattison): We inform solution-based adaptive management of biological invasions (***Pattison*** et al. *Appl. Veg. Sci.* 2017; Seeny et al., *Biol Inv*. 2019; ***Robertson*****,** REF2021 Impact Case Study: ***Mill*****;** Richardson et al. *Mam. Rev.* 2020; Cowan et al., *Mam. Rev*. 2020; Jaric et al., *Front. Ecol. Env.* 2020). We determine potential loss of biological diversity, food and water security and inform problematic invader management (UN SDG target 6.6; Aichi Target 9). Our habitat (terrestrial/freshwater/marine), plant, and animal modelling predict a 36% increase in non-native species by 2050, with aquatic invasions occurring first (***Pattison***: Seebens et al. *Glob. Change Biol.,* 2020). We contribute to large-scale UK (***Mill, Robertson*** chair Nature Scotland Advisory Groups) and EU (***Robertson*** et al., *Biol. Inv.* 2015) control programmes. ***Mill*** led modelling and analysis for *Red Squirrels United* (EU LIFE-funded), defining challenges and effective management across invasion stages (***Mill*** et al., *Mam. Rev.* 2020). We develop UK/European frameworks for species prioritisation across taxa and environments (***Mill, Robertson:*** Booy et al., *Biol.*

Inv. 2017; *Glob. Change Biol.* 2020). ***Robertson*** and ***Mill*** advised prioritising UK and UKOT invasive species surveillance and management (2019 Invasive Species Environmental Audit). Our species listing guidance (European Regulations) is now UK policy and global (CBD) best practice applied worldwide (e.g. USA, UKOTs, Australia). Moreover, our partnerships have set national/international invasive species policy and management (UK Non-native Species Secretariat, Animal and Plant Health Agency, Scottish Natural Heritage, UK Environmental Audit Committee, European Commission, International Union for Nature Conservation, CBD).

Health and resilience in modified ecosystems (Fitzsimmons, Mill, Pattison, Pfeifer): We evaluate global landscape/seascape changes impacting biodiversity, ecosystems, and human well-being, identifying healthy forest contributions to stable microclimates (***Pfeifer*****:** Hardwick et al., *Agric. Forest Meteor.* 2015; ***Pfeifer*** et al., *Peer J.* 2019), ecosystem processes (***Pfeifer:*** Ewers et al., *Nat. Comms.* 2015; Rolo, et al., *Forest Ecol. Man.* 2018), and local community livelihoods (***Pfeifer***: Cuni-Sanchez et al., *Ecosys. Serv*. 2016; *Clim. Dev.* 2018). Novel forest health mapping (***Pfeifer*** et al., *Rem. Sens. Environ*. 2016; Jucker et al., *Biogeosci.* 2018) predicted biodiversity responses to external forcing (***Pfeifer*** et al., *Nature* 2017*;* Watling, et al., *Ecol. Lett.* 2020). We lobbied for increased forest resilience research (***Pfeifer*****:** Reyer et al., *J. Ecol.* 2015), devising a framework for forest restoration through regrowth (***Pfeifer:*** Marshall et al., *Front. Forests Glob. Change* 2020) and highlighted the potential of forest restoration/conservation for biodiversity and climate change mitigation (Deere et al., *J. Appl. Ecol.* 2018) as well as pathways for landscape-scale anthropogenic manipulation of forest health (***Pattinson, Pfeifer:*** Da Silva et al., *Forest. Ecol. Man.* 2020).

Social network and futures analyses clarified coral reef resource exploitation (***Fitzsimmons***: Turner et al., *GEC* 2014; *Cons. Lett.* 2020, *Env. Cons.* 2020), identifying drivers of degradation, to advise governments and regional initiatives, e.g. CARICOM. UK Government Agency partnerships (***Fitzsimmons, Mill*** with ***Polunin***: Natural England, NIFCA, CEFAS) provided evidence of the impact of fishing intensity on temperate reefs, identifying fishing-habitat quality relationships (Stephenson et al., *ICES J. Mar. Sci.* 2017), and socio-economic, technological and environmental drivers (Stephenson et al., *Mar. Pol*. 2018). ***Fitzsimmons, Mill, Robertson*** (with ***Polunin***) developed novel species tracking (Skerritt et al., *MEPS* 2015) and modelling/validation of natural (Lees et al., *Animal Biotelem.* 2016) and fished (Lees et al., *MEPS* 2020) species responses resulting in advice to fisheries managers ; ***Fitzsimmons*** and ***Polunin*** (Skerritt et al., *Fish. Mgt. Ecol.* 2020). ***Fitzsimmons*** (with ***Delany***) developed intertidal fisheries management models (Tinlin-Mackenzie et al., *Mar. Pol.* 2019), delivering the first rapid detection of large-scale marine ecosystem change (Lightfoot, *Aq. Cons 2020; Mar. Fresh Ecosys.* 2020). Our mapping underpins major initiatives, e.g. designating UK marine conservation zones (CEFAS, DEFRA), advice to the Department of Disaster Management (UKCOTs) on developing coral reef maps pre- and post- hurricane (JNCC, DEFRA, UKHO). We are integrating ecological knowledge with remote sensing to identify and monitor UK and UKOT marine ecosystem services (Natural England, Environment Agency, DEFRA Darwin/UKHO), and support marine spatial planning (Colombia: Royal Academy of Engineering). ***Fitzsimmons*** (Brennan et al., *Mar. Pol.* 2014) informed the development of novel ecosystem health indicators by the European Maritime and Fisheries Fund (via MMO). These are now part of the Marine Strategy Framework Directive.

ii) Earth, Ocean, and Planetary Sciences (EOPS): EOPS focuses on Earth System processes sustaining the environment, from fundamental biogeochemistry to energy and food production. Research highlights reflect our combination of geology, marine science and biology that brings comprehensive understanding of interactions between diverse Earth surface processes. Our work spans the spatio-temporal spectrum (seconds to millennia; molecular to planetary), the living system-environment interface, and the wide-ranging implications of resource exploitation. Our collaborations amongst academics, industrialists

and policymakers nationally and internationally aid predictions and drive innovative, sustainable resource use (spanning UN SDGs 7, 12, and 15).

Highlights include: our work leading to downward revision of the size of the Atlantic Ocean anthropogenic CO_2 sink (***Upstill-Goddard:*** Pereira et al. *Nat.Geosci.* 2018); the first demonstration of urban soil CO_2 fixation by authigenic carbonates (***Manning:*** Washbourne *et al., Env.Sci.Technol.* 2015); re-evaluation of the contribution of tropical soils to the global carbon budget *(**Teh:*** Riutta *et al. Glob.Chan.Biol.* 2018*)*; identification of marine plastic accumulation at the surface ("garbage patches") and the deep ocean (***Morales-Maqueda:*** Mountford *et al., J.Geophys.Res*. 2019, ***Jamieson:*** Jamieson *et al., Nat.Ecol.Evol.* 2017); comprehensive benefit-impact analysis of UK shale gas exploitation (***Davies:*** REFINE); identification of mineral replacements for fossil-fuel dependent fertilizers (***Manning:*** Manning *Nat.Resour.Res.* 2018); discovery of sub-glacial (and potentially Martian) microbial life driven by mechano-chemically generated hydrogen (***Telling:*** Telling *Nat.Geosci.* 2015); anthropogenic impacts on the deep biosphere and microbial succession associated with petroleum extraction (***Head:*** Vigneron *et al., The ISME J.* 2017).

We have hosted significant national and international conferences (*UK Astrobiology*; *UK Challenger Society for Marine Science;* and, with Engineering, *International Symposium on Microbial Electrochemistry & Technology*). We host/participate in national/international workshops and working groups (e.g. Scientific Committee on Oceanic Research, SCOR; Ocean Carbon & Biogeochemistry, OCB; EMBRAPA (Brazil Rochagem Conference Series); Association for Tropical Biology and Conservation; European Society for Tropical Biology).

Funders include: UKRI; EU; charities (e.g. Leverhulme Trust); industry; UK/ non-UK agencies. Partners include: British Geological Survey; National Oceanography Centre; Plymouth Marine Laboratory; Centre for Ecology and Hydrology; DEFRA; UK Space Agency; Natural History Museum; Northumbrian Water; Malaysian and Sarawak Palm Oil Boards; Terrativa SA, Brazil; Shell Global solutions; BP; Saudi Aramco; Carnegie Institution for Science; Sabah Forestry Department; Southeast Asia Rainforest Research Partnership; UK universities (Aberdeen, Bristol, Cambridge, Cranfield, Edinburgh, Exeter; Imperial, Lancaster, Leicester, Liverpool, Manchester, Oxford, Royal Holloway, Southampton, York); non-UK universities (Calgary, Campinas, Miami, Oldenburg, Sao Paulo, Hawaii, Uppsala).

EOPS work falls into three integrated themes, strengthened by recent investment in Staff (e.g. ***Teh***, ***Ireland***) and facilities (£2M Houston OnePlanet lab):

Energy and Natural Resources (Davies, Gray, Head, Ireland, Jones, Manning, van der Land): our focus is growing resources with minimal environmental impact, e.g. reducing energy from fossil fuels, whilst maintaining them as raw materials (e.g fertilizers, steel) during the post-carbon transition. We are collaboratively exploring alternative energy and carbon mitigation, e.g. interim methane-sourced hydrogen fuel and associated storage issues during the transition to net zero carbon. The *REFINE* project (led by ***Davies***) appraised UK shale gas exploitation and informed the fracking moratorium (Wilson et al., *Mar. Pet. Geol*. 2015) by objective linkage of commercial and environmental concerns with policy development for this contentious economic issue. ***Ireland's*** appointment (2019) augments energy sector decarbonization expertise, and consolidates our geothermal energy research (unique >£1.6m EPSRC/LEP funded NU Helix geothermal well: ***Manning***, ***Ireland***: Younger et al., *QJ Eng. Geol.* 2016).

Advances in microbial fuel cells and CO_2 reduction for organic compound and fuel production (***Head:*** Izadi *et al., npj Biofilm.Microbiom.* 2020) encompass energy and carbon capture within the circular economy (NERC, EPSRC). Building on close collaboration with engineers, we showed trace metal waste enhancement of microbial activity during biogas production (***Gray:*** Shamurad et al., *J Env Man*. 2020), and assessed seam swelling-related, coal maceral geo-mechanical properties during CO_2 sequestration (***van der Land, Jones***: Fender

et al., *Int. J. Coal. Geol*. 2020). Current NERC-funded studies (***Gray***) are developing organic and mineral waste co-digestion for enhanced biogas production and resource recovery from anaerobic digestors.

Studies at the microbiology - petroleum geology interface have demonstrated subsurface microbial community development in active petroleum reservoirs following seawater injection (***Head***: Vigneron et al., *ISME* 2017), and implications for steel infrastructure of mitigating sulfide reservoir souring by stimulation of nitrate-reducing bacteria. Our petroleum systems microbiology research (***Head***: Lahme et al., *Env. Microbiol.* 2020; Sherry et al., *Microbial Biotech.* 2017) has in addition, defined physicochemical limits of microbial communities in petroleum systems (***Gray:*** Sierra-Garcia et al., *Sci Tot. Env*. 2020). Work on oil/gas production infrastructure and developments in microbial fuel cells link directly to resource recovery from waste.

Studies of soil processes link to carbon capture and crop nutrition and the science underpinning soil organic matter stability (***Manning*** and Theodoro, *Extr. Ind. Soc*. 2020), identifying agricultural carbon emissions during future intensive food production. The work of ***Manning*** was also the first to show carbonate mineral formation in urban soils (Washbourne et al., *Env Sci. Technol.* 2015).

Biogeochemistry and the Environment (Abbott, Acikalin, Flynn, Gray, Jones, Teh, Telling, van der Land)*:* We study molecular to global-scale biosphere-environment links through geologic time, leading to better understanding of biogeochemical cycling via microbial-animal-higher plant systems (***Teh***: Riutta et al., *Glob. Change Biol*. 2018; Ashton et al., *Science* 2019).

We develop innovative biomarkers to understand Earth surface/subsurface processes, including petroleum migration and biodegradation (***Jones***: Coffinet et al., *Geochim. Cosmochim. Acta* 2017; Aitken et al., *J. Chromatog. A*. 2018). Using Diamondoid biomarkers we were the first to identify the sub-delta Cretaceous as a major oil source (Niger Delta; ***Jones***: Esegbue et al., *AAPG Bull*. 2020), with implications for assessing hydrocarbon exploration risk. We are also developing bio-electrochemical systems to monitor water quality and for resource recovery (with Northumbrian Water Group and Welsh Water. ***Head:*** Spurr et al., *Env. Sci. Wat. Res. Tech*. 2020).

Organic pollutant fate and bioremediation studies (Oriaku and ***Jones***, *J. Bioremediat. Biodegrad*. 9, 2018) revealed the stimulatory effect of Ni on oil spill bioremediation, clarifying mineralogical limits to biological nutrient provision (***Jones***: Mejeha et al., C*hemosphere 237,* 2019). We are assessing environmental impacts of petroleum production and aqueous by-product mining (***Flynn***: He et al., *Wat. Res*. 2017; von Gunten et al., *Can. J. Earth Sci.* 2018). By evaluating biogeochemical drivers of environmental radionuclide fate, we are improving source to sink models of transport/immobilization for nuclear legacy waste management (***Gray:*** *Fuller et al., Chemosphere* 2020*; Ray et al., Sci Tot. Env*. 2020).

Work on the Cretaceous-Paleogene boundary provides unique insight into the drivers of mass extinctions (***Acikalin*** et al., *Cretac. Res*. 2015). Monitoring benthic organisms and water column phytoplankton traced subsequent ecological recovery (***Acikalin***: Vellekoop et al., *Biogeosci.* 2017) and revealed local tectonic control of late Cretaceous oceanography (***Acikalin*** et al., *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 2016). Our work on modern coastal sabkha elucidated microbial polygon development and preservation, with implications for paleo-environmental reconstruction (***van der Land***: Lokier et al., *Depos. Rec*. 2017). We developed new insights into microbial biogeochemistry in cold terrestrial and extraterrestrial environments (***Telling:*** Safi et al., *Sci. Rep*. 2019; ***Teh***: Hermans et al., *Mires Peat*, 2019). Our organic geochemistry expertise aids fundamental understanding of carbon turnover in peats and organic-rich soils/Arctic sediments, and the origin of fossil bone organics (***Abbott***: Schellekens et al., *Geochim. Cosmochim. Acta*, 2015; Saitta et al., *eLife* 2019; Stevenson

and ***Abbott***, *JAAP* 2019; ***Teh: Manning*** et al., *Front. Forest Glob. Change*, 2019). Work on boreal peatland and tropical forest element cycling has informed management of oil palm plantations and human-modified tropical forests and catchment- to regional-scale IPCC element cycling estimates (***Teh;*** Diem et al., *Biogeosci*. 2017; ***Manning*** et al., *Front. Forest. Glob. Change,* 2019;).

Ocean Sciences **(*Morales-Maqueda, Upstill-Goddard, Willmott*)**: With NU and external partners we contribute to SDG 14 and the *UN Decade of Ocean Science for Sustainable Development*. By studying biological and geophysical controls of air-sea trace-gas exchange we target sea surface microlayer (SML) structure and function and dissolved organics photochemistry. We measure and model large-scale ocean dynamics (circulation, sea surface height) and marine particle 3-D pathways (e.g. plastics; SDG 14.1). We were first to unequivocally demonstrate CO_2 air-sea exchange suppression by natural SML surfactants in coastal and oceanic waters (***Upstill-Goddard:*** Pereira et al., *Biogeosci.* 2016, *Nat. Geosci*. 2018; Sabbaghzadeh et al., *Geophys. Res. Lett*. 2017). Subsequently this was designated a research priority through international SCOR WG141 *Sea Surface Microlayers* (***Upstill-Goddard:*** Engel et al., *Front. Mar. Sci.* 2017). Our quantification of climate-active trace gas production, removal and air-sea exchange informs regional/global-scale evaluations and international agenda setting (SCOR WG143 *Towards global ocean N_2O and CH_4 time series*) through coordinating fieldwork and data calibration/reporting (***Upstill-Goddard***: Wilson et al., *Biogeosci.* 2018; Bange et al., *Front. Mar. Sci.* 2019). Our development of GNSS-Wave Gliders (NERC) has advanced understanding of sea surface dynamics, storm surge and tsunami warning (***Morales-Maqueda*** et al., *J. Atmos. Ocean. Tech.* 2016; Penna et al., *Geophys. Res. Lett.* 2017). Surface and deep/abyssal circulation climate responses have implications for carbon and nutrient dynamics, marine productivity, and climate feedbacks. Quantifying and measuring these, ***Morales-Maqueda*** co-led one of NERC's largest consortium awards (OSCAR). Hydrothermally driven, regional-to-global abyssal circulation was assessed seismically (Tang et al., *Nat. Comms.* 2019). State-of-the-art ocean models (e.g. NEMO) predict thermohaline circulation impacts on physics and biogeochemistry in climate-sensitive polar seas (***Morales-Maqueda:*** Sansiviero et al., *J. Mar. Sys.* 2016), and have elucidated global plastic transport (SCOR WG153 *Floating Litter: Oceanic TranSport Analysis & Modelling (FLOTSAM))* (van Sebille et al., *Env. Res. Lett*. 2020). ***Willmott*** and ***Morales-Maqueda*** have developed predictive capacity through models and autonomous observations (CAMPUS: *Combining Autonomous observations and Models for Predicting & Understanding Shelf Seas* (Mountford and ***Morales-Maqueda***, *J. Geophys. Res.* 2019)). Understanding the Arctic ocean response and loss of sea ice, is critical for predicting wider climate responses; through international collaboration, ***Morales Maqueda*** and ***Willmott*** study Arctic topographic steering of steady, barotropic, planetary and geostrophic circulation, (Gavilan Pascual-Ahuir et al., *J. Geophys. Res*. 2020; Bassom and ***Willmott***, *Tellus* 2019; ***Willmott*** and Gavilan Pascual-Ahuir, *J. Phys. Oceanog*. 47, 2017).

iii) Marine Ecology (ME): This Group studies marine conservation and management, addressing the *UN Ocean Decade* and SDG 14, developing key indicators and cost-effective monitoring through observation. Strengths include: coral and temperate reef ecology**;** state-of-the-art exploration of extreme environments; marine megafauna conservation**;** evaluating zooplankton impacts on fisheries, conservation and human health using marine time series; promoting marine stewardship through citizen science.

Marine Ecology interacts in a wider UoA7/UoA6 SNES Ecology Group (terrestrial ecologists in UoA6), facilitating coordinated interdisciplinary objectives, e.g. marine and terrestrial restoration ecology via common protected area management. In 2019, we hosted the *Marine Biological Association ECR Conference.* We have grown partnerships to enhance discovery and applied science, e.g. sustainable management advice to the Chilean and Peruvian kelp fishery (NERC Newton Fund: ***Moore***, £800k); acoustic recorder networks for marine mammal monitoring (NERC: ***Berggren,*** £353k); low-cost solutions to cetacean bycatch (NOAA;

Berggren*;** US$198k), Marine Mammal Commission (Berggren*,** US$91k); and Offshore Wind Energy and the Environment (Aura CDT 2019-2027; £560k to Newcastle).

Marine Ecology has <u>five research themes:</u>

Tropical and Temperate Reef Ecology (***Bythell, Edwards, Guest, Moore, Polunin***): Coral reefs provide trillions of pounds in ecosystem goods and services, with their decline resulting from climate and land use change and overfishing. Coral reef management and solution-based approaches to restoration ecology (e.g. achieving ongoing impact from REF2014 ICSs for which NU UoA7 ranked second nationally; ***Edwards, Guest***), seeks knowledge to combat coral disease (***Bythell*** et al., *Biol. Rev*. 2018; Sweet and ***Bythell*** *Molecular Ecol.* 2015; Sweet et al., *Proc. R. Soc. B.* 2014). Despite global average declines, we identified high coral cover "oases" (***Guest*** et al., *J. Appl. Ecol.* 2018) and individual reef responses, e.g. to temperature and urbanization (***Guest*** et al., *Sci. Rep.* 2016). Attracting a €2M ERC Consolidator Grant (2017-2022) and two NERC DTP studentships (2019-), our studies of heat tolerance from immunological, physiological, microbial, proteomic and hereditary perspectives informed innovative interventions to aid coral survival (Coralassist laboratory; Darling et al., *Nat. Ecol. Evol.* 2019), including selectively breeding heat-tolerant corals (***Guest:*** Chamberland et al., *Sci Rep*. 2017). To support global research on reproduction timing and synchrony in reef recovery, ***Guest*** and ***Edwards*** developed a NU-based, interactive, coral spawning open resource (Keith et al., *Proc. Roy. Soc.* B, 2016; Baird et al., *Sci. Data* 2021).

Kelp forests, among the most productive ecosystems, are susceptible to ocean warming, over-exploitation, and pollution (UN Ocean Decade; SDG 14.2). We interrogated decadal and shorter (marine heatwave) warming impacts (***Moore****:* Smale et al., *Nat. Clim. Change,* 2019), evidencing genetic diversity loss in trailing edges (***Moore***: King et al., *ICES J. Mar. Sci*., 2020) and potentially in range centres (***Moore***: King et al., *J. Exp. Mar. Biol*. *Ecol*. 2019; *Ecography* 2017). We predicted future reductions in detrital production that could compromise food web dynamics and carbon sequestration (***Moore***: Pessarrodona et al., *Glob. Change Biol*. 2018). Our ecosystem management advice informs kelp harvesting sustainability (£1M: NERC and Newton Fund). Outreach activities have enhanced dissemination of our research impact in this area ('Science Uncovered' national museums, British Science Week, school/public lectures (e.g. Palau, Micronesia).

Deep-Sea Ecology (***Jamieson, Wigham***): We design and construct cutting-edge deep-submergence technologies to study biodiversity and ecological responses to anthropogenic forcing in the deep abyssal ocean (45% of the ocean; chemosynthetic habitats) (UN Ocean Decade; SDG 14.2)(***Jamieson*** *Deep Sea Res. II,* 2018). ***Jamieson*** participated in the $50M trans-global Five Deeps (chief scientist 2018-2019) and Pacific Ring of Fire (2019-) expeditions. This work provided the first documentation of anthropogenic contamination of the deepest ocean trenches (***Jamieson*** et al., *Nature Ecol. Evol.* 2017), informing policy roadmaps for long-term marine stewardship (e.g. reversing the marine plastics problem: ***Jamieson***: Forrest et al., *Front. Mar. Sci.* 2019). It also identified new species (Gerringer et al., *Zootaxa* 2017); established physiological depth limits for major taxa (Yansey et al., PNAS 111, 2014); elucidated community structure and diversity (Lacey et al., *Deep Sea Res.* 2014), and evolutionary adaptations (Richie et al., *Deep Sea Res.* 2018); evidenced global genetic connectivity; devised ecology-based deep-sea sampling strategies (Danovaro et al., *Science*, 2017, *Nature Ecol. Evol.* 2020); and provided ecological data underpinning mineral exploration (***Wigham***: Copley et al., *Sci. Rep.* 2016).

Marine Megafauna Conservation Biology/Ecology* (*Berggren*)**: Targeting the UN Ocean Decade and SDGs 14.2, 14.4 and 15.5, we evaluate: bycatch threats to biodiversity and ecosystem resilience (Temple et al., *Rev. Fish Biol. Fish.* 2018; Brownell et al., *ESR* 2019); exploitation/extinction risks to tropical species (Sharpe and ***Berggren *Aq. Cons*. *Mar. Fresh. Ecosys*. 2019); drivers of genetic structure, demography, species connectivity (***Berggren:***

Viricel et al., *Mar. Biol.* 2016; Pirog et al., *Eco. Evol.* 2019); and socio-economic implications for small-scale developing fisheries of under-reporting of catch/bycatch (***Berggren:*** Barrowclift-Mahon et al., *Mar. Policy* 2017; Temple et al., *Biol. Cons.* 2019). High profile outputs include new species discovery (***Berggren*** and Temple, *Conversation* 2020; Weigmann et al., *PLoS ONE*, 2020) and the description of seal communication (***Berggren:*** Hocking et al., *Mar. Mam. Sci.* 2020; CNN.com, March 2020). We are developing low-cost alarms/acoustic reflectors to minimise mammal bycatch (US NOAA; MMC) with potential global application and assessing anthropogenic noise impacts (***Berggren:*** Yang et al., *PLoS ONE* 2020; NERC Innovation Grant £353k), including windfarm impacts on small cetacean occurrence and behaviour (***Berggren:*** Temple et al., Rept. EDF-Renewables, 2019). We also evaluate anthropogenically compromised immunity (dolphins: ***Berggren:*** Van Bressem et al., *Mar. Mamm. Sci*. 2018) and develop algorithms classifying underwater sounds for mammal monitoring (***Berggren:*** Song et al., and Yang et al., *JASA* 2017). NU are Aura CDT partners 2019-2027 (Offshore Wind Energy and Environment: £5.5M, University of Hull lead; £560k to NU).

Marine Biotechnology* (*Burgess, Clare, Caldwell*):** With industry we are co-developing benign solutions to biofouling and associated hydrodynamic drag (SDG 14.1 Marine Pollution). These include strongly hydrated and multidimensional polymers, and non-stick, ultra-repellent surfaces, for practical coatings (Clare:*** Aldred et al., *Biofouling,* 2019; Kardela et al., *ACS Appl. Mat. Int.* 2019). We are deriving novel antifouling and bioactive compounds from marine bacteria (***Burgess***: Al-Naamani et al., *Chemosphere* 2017; Brunt and ***Burgess*** *Int. J. Cosmetic Sci*. 2018; Zhang and **Burgess** *PLoS ONE*, 2017) and promote low-cost, sustainable seaweeds for food and fuel (***Caldwell***: Nor et al., *J. Appl. Phycol.* 2016; Gao et al., *Aquaculture* 2017*; Algal Res.* 2019; *Food Chem.* 2018; Zhang et al., *IET Renew. Power Gen* 2019*; J. Env. Chem.* 2019), and microalgae for biotechnology applications such as biofuels, food additives, and nutritional supplements (***Caldwell***: Alkarawi et al. *Algal Res.* 2018; Brain and ***Caldwell***: Patent US20180155401, 2018). We elucidate chemical defence in marine microbes (***Burgess, Bythell***: Morales-Garcia et al., *Biofilms Microbiomes* 2018) and marine fermentation and bioprocessing / biotechnological applications of microbial nucleases (***Burgess:*** Basle et al. *Nucleic Acids Res.* 2018*)*. An example of the wide-reaching potential impact of our work is the use of our anti-fouling technology in Arial washing powder (***Burgess:*** REF2021 Impact Case Study).

Coastal Conservation and Governance (Polunin, Delany, Moore, Fitzsimmons)*:** multi-decadal data sets aid understanding complex ecosystem responses to environmental change. Dove Time-Series data (1969-) reveal zooplankton trend-linked climate, fisheries, and human health changes, with conservation implications (UN Ocean Decade; SDG14). This allows evaluation of historical micro-plastic accumulation by zooplankton. Intertidal ecosystems times series are revealing temperature-driven range modification for key indicator species (Delany:*** Vye et al., *Divers. Distrib.*2020), reference their recovery (***Polunin:*** MacNeil et al., *Nature* 2015). We contribute to the largest intertidal spatio-temporal climate change indicator time series that predicts species range (***Delany***: Vye *et al., Divers. Distrib.* 2020), and we are developing biomimetic loggers of internal body temperature deviations from microhabitats. Relationships between mobile consumers and seabed habitats (temperate and tropical) are being revealed (***Polunin***, with ***Mill, Fitzsimmons,*** (MEPS): Stephenson et al., *ICES J. Mar. Sci*. 2017; Newman et al., *J. Animal Ecol.* 2015). We also analyze fish assemblage responses to Marine Protected Areas (MPA) initiatives (***Polunin***, with ***Mill, Fitzsimmons***: Stephenson et al., *Mar. Policy* 2018). We evaluate threats to intertidal and benthic habitats, and commercial fisheries (***Polunin*** *with* ***Fitzsimmons***: Skerritt et al., *MEPS*, 2015; Stephenson et al., *Mar. Policy* 2018 Stephenson et al., *Mar. Policy* 2018), informing national/international marine governance. We interrogate productivity drivers of temperate and tropical fish stocks, evaluate trophic transfer efficiency and changes in fish and food-web trophodynamics (Ocean Decade; SDG 14.4, e.g. ***Polunin, Mill***: Skinner

et al., *J. Animal Ecol.* 2019) and examine benthic/pelagic fishery target species and fish stock variability (***Polunin, Mill***: Duffill-Telsnig et al., *J. Animal Ecol.* 2019).

National/international stakeholder engagement is clarifying marine resource governance, management, and environmental health (UN Ocean Decade; SDG14) through enhanced understanding of socio-economic and environmental drivers (***Fitzsimmons***: Forster et al., *Mar. Policy* 2017; Stephenson *Mar Policy* 2018). This aids management and governance (***Fitzsimmons***: Turner et al., *GEC* 2014, *Cons. Letts.* 2020), identifying barriers to eco-engineering solutions (***Moore:*** Evans et al., *Mar. Policy* 2017; Evan et al, *Env. Sci. Policy* 2019).

Research Strategy

Achievements since REF2014*:** in REF2014 we addressed challenges of Energy Supply, Climate Change and Sustainability, via *Research Clusters* in Geochemistry, Biodiversity and Biotechnology. Successful operation of these clusters across multiple Schools and disciplines was facilitated by the *Newcastle Institute for Research on Sustainability* (2014-17) (e.g. Blake et al., *Waste Man*. 2017; Carrillo-Barragan et al., *Front Microbiol* 2019; Ventura et al., *Biofouling* 2017, Galhenage *ACS App. Mat. Interface* 2016; ***McGowan et al., *Conserv. Lett.* 2017). In 2017, UoA7-relevant groups consolidated in SNES (see section 1), forming *Academic Groups* that have broadened our remit, through 14 appointments and staff transfers. Our remit now encompasses environmental science, biology, chemistry, natural and human geography, archaeology, mathematics, and computing. Doctoral training has also consolidated on UoA7 themes through new NERC DTPs (OnePlanet; IAPETUS2), GeoNetZero CDT (50% funded by NEO Energy), and Aura CDT.

In addition to Group consolidation, our infrastructure has developed (section 3) through serial investment. Highlights include: the geothermal research well on the Helix campus, complementing NERCs £31M Geoenergy Observatories; upgrades to marine research capacity (*RV Princess Royal*, Blyth Marine Station (£2.5M; £0.5M dockside upgrade 2019); Dove Marine Laboratory dedicated marine plastics laboratory); £2M research space refurbishment (Drummond Building: *Energy and Natural Resources, Biogeochemistry and the Environment* including the £0.6M Houston Laboratory, PG/UG teaching/research project space which benefited from a £0.25M philanthropic donation); shared Molecular Diagnostics Facility (£0.5M modernised growth rooms, pathology, sequencing: Oxford Nanopore).

Prestigious funding includes: 1x ERC Consolidator; 12x NERC; 1x EPSRC/BGS; 1x Darwin Initiative; 1x DEFRA; 1x University Ghent; 1x Scottish Government; 2x Malaysian Palm Oil Board; 1x H2020. Larger grants include: NERC Highlight, *Global Methane Budget Closure* (***Teh***: £4M); Malaysian Palm Oil Board, *GHGs from Malaysian oil palms* (***Teh***: £1.4M); NERC Resource Recovery from Waste (***Head***: £1.2M), EPSRC LifesCO_2R (***Head***: £1.9M) GCRF Agri-Systems, *Multi-functional agro-forestry systems* (***Pfeifer*** : £577K; NERC, *Biodiversity and Land-use Impacts in human-modified forest* (***Teh***: £5.2M, consortium); ERC Consolidator (***Guest***, coral reef restoration, €2M).

These projects have driven UK/international fracking policy and led to our co-ordination of *Unconventional Hydrocarbons (*NERC: £8M; ***Davies***, ***Manning***). The industry-funded *REFINE* project, flagged in REF2014, now includes decarbonisation (EPSRC *Decarbonising Heating and Cooling*: ***Manning, Ireland,*** £1.7M). New interdisciplinary research includes agro-forestry landscape research (***Pfeifer***), sustainable management/restoration of rainforests (***Teh, Pfeifer***), greenhouse gas management in peatlands (***Teh***), geologically-sourced nutrients (***Manning***), and biodiversity conservation and sustainability in developing nations (***Teh***, ***Pfeifer, Moore***).

Future Vision: We are directing our research on fundamental ecosystem function to develop responses to global change, framed by the UN SDGs, consistent with NU's core values of social and environmental justice. NU's "one university, without walls" institutional philosophy

and the resulting recent formation of a cross-university NU Centre of Research Excellence (NUCoRE) in Climate & Environmental Resilience, comprising over 100 researchers across all 3 NU Faculties, will facilitate further reach across disciplines. Building upon institutional and national/international links, supported by NU's Global Challenges Academy (Ref5a 2.2.5), we will enable wider societal benefits. We will expand our engagement with policymakers through NU's Policy Academy (Ref 5a 2.2.5), to improve governance structures and regulation. Parallel expansion of research-informed teaching will generate future scientific cohorts and national/international policymakers.

Post-REF2021priorities include:

- *Nurturing inter- and multi-disciplinary research:* Will be fostered in our NUCoREs. Historical research strengths (data modelling, molecular ecology, biogeochemistry etc.) will feed into cognate research on climate change and societal adaptation through our Climate and Environmental Resilience NUCoRE, strengthening connections with data scientists, engineers, geographers, political scientists and economists. An early example is the FarmZero initiative (with UoA6 and UoA12), promoting multi-disciplinary sustainable agro-ecosystems-energy research using NU's research farms.
- *Promoting equitable collaboration:* SNES resources and HEIF/QR-SPF funds will be used to promote cross-sectoral, SDG-focussed, global collaboration and knowledge exchange (e.g. agroforestry, forest restoration and resilience; human-wildlife interactions; infrastructure and biodiversity), engaging academics and stakeholders nationally and internationally.
- *Strategic staff appointments:* NU's strategic ambition is to grow research income by 35% in 5 years and increase researcher capacity by 20% in 10 years. This expansion, underpinned by the Newcastle University Academic Track (NUAcT) Fellowship initiative to support 100 transition-to-independence fellows (see Ref5a 3.2.4) alongside succession planning, will enable new strategic appointments. Specifically, targeted appointments will strengthen environmental microbiology and its links to Biology, Biogeochemistry, and Agriculture to address key environmental processes underpinning sustainable resource management.
- *Growing and adapting staff and student skills*: We will develop sectoral and geographical mobility and skills at all career stages e.g. through our internal Peer Review College to help colleagues target funders, *Research Masterclasses* providing advice and guidance (e.g. *Building Consortia with Government,* 2020), expand DTP activity and engage in industry-funded initiatives (e.g. *Energy Geoscience*).
- *Influencing national/international research agendas*: We will encourage staff to serve on national /international committees, research councils, learned societies and professional bodies.

Impact Strategy

Societal and economic impact is intertwined with our research strategy. Our second place impact ranking in REF2014 was facilitated by strong external collaboration (e.g. ***Edwards*** co-wrote IUCN Coral Reef Guidelines). External partner/stakeholder collaborations continue (e.g. ***Guest***: ERC Fellowship). Our two additional highly ranked REF2014 ICS were built on strong collaboration with the energy sector and a current ICS has strong industry links (Proctor and Gamble).

Highlights of ongoing research with impact include:

- *Invasive Alien Species:* major global extinctions cost €9.6 billion p.a. Research (£30M+) underpins UK, EU, USA, Australia policy; IAS global target delivery (IUCN/ CBD).

- *Global Species Conservation:* assessing CBD (2011-2020) Strategic Plan; formulated post-2020 global biodiversity framework; protected areas and biodiversity conservation; anti-extinction conservation; informed global species targets.
- *Marine Biofouling*: invasive species translocation (cost: $150 billion p.a); environmentally benign solutions via interdisciplinary consortia with industry R&D; antifouling technologies commercialised (AkzoNobel, Nanocyl, Adaptive Surface Technologies); spinouts formed (Sharklet Technologies, Naturecoat).
- *Marine Protected Areas (MPAs):* informed UK fisheries policy; eight MPA designations; methodology adopted nationally/internationally.
- *Bacterial Biofilms*: biofilm disrupting enzyme; first incorporation of a new enzyme into market leading laundry detergent (Arial) in 20 years.
- *Oil Palm Management*: "best-practice" informing Malaysia Palm Oil Board; relevance to national and ASEAN policy, and IPCC through "GHG emissions factors".
- *Climate-Smart European Rice*: managing rice GHG emissions (Paris Accords); transferability to other temperate/sub-tropical systems.
- *Rock Dust for Soil Fertility*: pioneered as agricultural fertilizer in Brazil, is now a Brazilian federal regulation).

Open Research

We support research impact through an institutional open dissemination policy, with "on request" data availability post-publication being expected, notwithstanding ethics, consent, or intellectual property issues. Open access of *all* published work is on-line (MyImpact): author typeset accepted manuscripts become "green" (embargo-dependent open access). New internal policies have increased compliance from 83.7% (2016) to 93.2% (2019). An open access team manages UKRI and COAF block grants, supporting Gold Open Access, and where the publisher does not offer green access (see Ref5a 2.3.3). We enhance impact and visibility through data management, facilitating originator-user collaborations via our *Research Data Service* repository, which archives and publishes open datasets linked to outputs, where funder-specified or discipline-specific repositories do not exist. The Data Service supports data management plan preparation in line with the *FAIR* data archive philosophy (Findable, Accessible, Interoperable, Re-useable) with 10 years minimum open access.

Research integrity and ethics

We align with NU commitment, policies and processes (Ref5a 2.3). All research proposals (externally or internally funded) are subject to initial ethics screening via an on-line procedure that identifies whether a proposal requires formal review by a Research Ethics Committee. All researchers are made aware of the University Code of Good Practice in Research, which clarifies expectations relating to integrity, research misconduct, leadership and cooperation, and professional standards and advice. Training is tailored to disciplinary needs and is obligatory for those involved in projects requiring formal ethical approval. Academic Groups encourage open discussion of current research, fostering values of integrity and ethical research practice from post-graduate research students through all career stages to our most senior professors.

2. People

Staffing strategy and staff development

We support the UK goal of growing R&D spending through HEI research, recruiting the most talented staff and freeing-up additional research time to deliver on our strengths and vision.

Staff Turnover and New Appointments: We have used the opportunity of staff turnover to enhance the inter-disciplinarity within our Academic Groups. Staff leaving during the REF period (***11 FTE***; Professor: ***Bentley; Larter; Stead; Wagner****;* Reader: ***Talbot; Hubert, Wolff***. Senior Lecturer: ***Maerz;*** Lecturer: ***Tosh*****)** were replaced (***14 new*** appointments: 4 Professors; 5 Senior Lecturers; 5 Lecturers; plus 1 Independent Research Fellow), evidencing our commitment to research growth and increasing our FTE return (33.2, REF2021; 24.6, REF2014). New appointments include: geology, ***Acikalin*** (2016); geo-energy/petroleum, ***Davies*** (Chair, 2014), ***Ireland*** (2019); soil science, ***Teh*** (Chair, 2019); geochemistry/geomicrobiology, ***Telling*** (2016), ***Flynn*** (2017); microbial systematics, functional (meta)genomics, ***Montero-Calasanz*** (2015); coral reef resilience, ***Guest*** (ERC Fellow, 2018); invasive species/ecological change, ***Robertson*** (2014), ***Pattison*** (2019); ecosystem function and services, ***Pfeifer*** **(**2016); coastal ecology and conservation, ***Moore*** (2020). New research areas that have emerged: physical oceanography/ global ocean modelling, ***Willmott*** (Chair, 2014), ***Morales-Maqueda*** (2015); deep sea ecology ***Jamieson*** (2016).

Staff Support: A robust workload allocation model ensures a research-focused workload distribution and strategic staff appointments are made to optimise academic research direction and workloads. New lecturers receive a start-up package and all academics receive personal travel budgets. Shared strategic budgets (Faculty, School and Academic Group level) support multi-user equipment purchase/upgrade/maintenance, workshop participation for initiating new partnerships, and support for grant applications and ECR and PGR development.

New staff pursue the *Postgraduate Certificate in Advanced Studies in Academic Practice* (CASAP): within 'Pathways to Recognition', NU's Continuing Professional Development Scheme. Staff mentoring optimises academic potential and ECR transition to independence. New staff have reduced teaching and administration duties to facilitate development of their research programmes. Academic Groups nurture interaction, supporting career development for all colleagues. Annual one-to-one reviews optimize individual staff strengths and set realistic, aspirational targets to develop potential, with NU courses (e.g. IP training, grant-writing, science communication, engagement, and outreach) supporting this. School seminars (external speakers) are scheduled biweekly, with Academic Groups hosting informal seminars from PDRAs and PGRs and research and teaching away-days attended by all staff including technicians. Peer mentoring and review provides critical evaluation and constructive feedback for grant/fellowship applications, mock interviews are organized as appropriate.

Academic Promotions: eleven UoA7 staff promotions during the REF period (1 Professor; 1 Reader; 7 Senior Lecturer, 2 Lecturer), illustrate our commitment to career development, recognising staff achievement.

Gender Balance: UoA7 returns 29 male and 8 female staff. Twenty two percent of staff are female, representing 23% of returned FTE, an improvement over 11% in REF 2014 (27 male and 3 female staff returned).

Equality, Diversity, and Inclusion*:* EDI is embedded in our activities, maximizing equal opportunity. Full inclusivity ensures equitable, cross-society staff/student recruitment and retention. We increasingly use anonymized longlisting in recruitment campaigns (e.g. for our flagship NUAcT Fellowships) Membership of all panels/committees is structured to ensure representation of staff diversity, we encourage all minority group applications, promote outreach activities, EDI awareness, training, and development. Routine provision includes: EDI advisors and funds; training (e.g. unconscious bias); return-to-research and career re-entry fellowships; Stonewall Diversity Champions programme; staff-run support networks (e.g. BAME; carers; parents; disabled colleagues; NU Women). All provide fora for shared identities and interests in related issues. In recognition of the demands on colleagues, during the first Covid-19 lockdown NU activity was managed to provide the opportunity for flexible, quiet time on Fridays. SNES continues to encourage "Low Email Fridays". NU is among few UK HEIs holding an Institutional Athena Swan Silver award. SNES (currently Bronze) is pursuing

initiatives to achieve silver by 2022 and gold by 2025. We support all staff re-establishing their research after career breaks; UoA7 pioneered support for return from extended periods of leave, including maternity leave, a model being adopted Faculty-wide. Case-by-case extended leave planning helps returning staff regain research momentum (e.g. continued teaching cover; reduced administrative tasks: enhanced travel budgets). We have enabled six maternity/paternity leaves since REF2014. We support staff experiencing challenges in their home life by providing teaching and administrative cover as appropriate, and promote part-time employment to help achieve better work-life balance. In 2020 16.7% of all academic staff and ECRs were part-time, a 23% increase on REF2014. We equally support ECRs and established staff in repositioning their research, by appropriately reallocating duties, supported through Academic Groups, Degree Programme Directors and Directors of Expertise, by deploying additional research funds, and by aiding childcare costs for conference attendance, and additionally as necessary.

***Technical Support*:** technical staff are managed at Faculty level to facilitate flexible, support for changing academic priorities on main campus and at the outstations/ research vessel in line with evolving SNES business plans and Faculty strategy. Clear accountability ensures professional development for technical staff and maximises career progression opportunities. A dedicated technical staff network (NUTechnet) enables meetings and communication, optimising knowledge transfer, best practice and championing EDI among the technical staff cohort. Through NUTechNet, the University jointly hosted the 2020 Technician Partnership Conference, with the National Technician Development Centre and Northern Universities N8 group. Technical staff attend Academic Group meetings to support research and strategic equipment needs, and laboratory/field activity. A Faculty Technical Training Co-ordinator promotes the institutional commitment to career and professional development, emphasising visibility, recognition, sustainability, and impact, and supporting professional registration. In conjunction with the National Technician Development Centre (NTDC, 2019) technical staff development needs have been identified at all levels and are being addressed in conjunction with NU's Organisational Development team.

***Administrative and Professional Services support**:* Faculty managed *Professional Services* supports academic excellence and student experience, meeting School research and teaching needs: technical provision; administration; PA/secretarial; business development and corporate partnership; communications, media; estates; finance/accounting; HR; IT; marketing; procurement; quality assurance.

Postgraduate training

Changes to PhD registrations partly reflect staff reassignment during Faculty restructuring in 2017. Subsequent growth reflects our achievable aspiration of >30 PhDs per year by 2022, a goal which is facilitated by recent DTPs partnering with non-HEIs: the IAPETUS2 DTP (NERC) stipulates >30% CASE studentships and the OnePlanet DTP (NERC) anticipate 40% CASE. Growing our MPhil/MRes cohort was a major post-REF2014 aim which has been met. Current focus is increased PhDs in a supportive, stimulating, multidisciplinary environment that realizes full potential. Our PGR on-time completion rate was >95% in 2019.

PGR Training, Support, and Academic and Personal Progress: All PGRs have primary and secondary supervisors, with twenty credits induction and 80 credits training support provided in years 1-2 (research skills, ethics, H&S). New PGRs sign a joint Learning Agreement with supervisors detailing expectations and responsibilities. Project approval (months 1-2) comprises: a 1000-word Project Plan; timeline/key milestones (Gantt Chart); ethical approval; financial budget; Training Needs Analysis Checklist (project-specific and career development training organised by the Faculty Graduate School). A Progression Panel (supervisor-nominated subject specialist and a PGR Director-nominated EDI representative) provides impartial support, ensures research viability, quality and impact and assesses the student's academic progression. Student progression reports/forward plans are submitted electronically

(*e-portfolio;* 9, 21, 33, 42 months) and are discussed in formal meetings, with recommendations closely monitored by the Graduate School Director.

Postgraduate experience:

Discipline-specific PGR conferences and themed seminars ensure exposure to cutting-edge research and include faculty and SNES trans-disciplinary PGR Conferences where all PGRs contribute either poster (Stage1) or oral (Stage 2+) presentations. Academic Groups provide additional presentation opportunities, with a monthly PGR Newsletter detailing events, research and training opportunities and School/University policies.

PGRs control consumables budgets with supervisory guidance, supporting development of research management skills. An annual £500 allowance supports international/national meeting attendance (77 PhD attendances during REF period at international conferences, e.g.: AAPG; AGU; AGU Ocean Science; Anaerobic Digestion Technology; EGU; FEMS Microbiology Congress; Gas Transfer at Water Surfaces; ISME Microbiology; Liege Ocean Dynamics; Microbiology and Nuclear Wastes; Sustainable Bioenergy; World Congress, Geology and Soils Science).

PGRs have received prestigious awards: *Macgregor* (2016/2017), best paper, Royal Entomological Society, Wallace Award, best thesis; *Moss* (2017), RES PG conference best talk; *Byrne* (2018), best student poster, Ecological Society Annual Conference. In addition PGR students participating in international placements (industrial/academic/ international fieldwork) include: *Chiwona* (Geological Survey Malawi); *Kendry*, *McGhee* (Canada, Congo fan); *Walker* (Cuadrilla); *Sabbaghzadeh* (Atlantic Meridional Transect: 2014, 2015; SOLAS summer School 2015); *Rickard* (GEOMAR, Germany); *Shamurad* (Analysing microbial population structures, Woods Hole, 2018).

Leaver data show high demand for our PhD graduates. Examples: *Orrell* (2017), Royal Society Edinburgh Enterprise Fellowship; *Macgregor* (2017), PDRA, Univ. York; *Sabbaghzadeh* (2018), PDRA, Leibniz Institute for Baltic Sea Research; *Al-Wahaibi* (2019) PDRA, Sultan Qaboos Univ., Oman; *Malm* (2020), PDRA, Umeå Univ., Sweden. In addition, PhDs (and PDRAs) have secured academic positions world-wide (e.g. *Hiron*, Swedish Univ. Agric. Science; *Littlewood* (2019), SRUC, Edinburgh; *Oldekop* (2017), Univ. Manchester; *Washbourne*, UCL; *Goddard*, Northumbria University; *Jorat*, Abertay; *Renforth*, Cardiff then Heriot Watt); *Mejeha* (2016), Federal University of Technology, Nigeria.

3. Income, infrastructure, and facilities:

***Research Spend*:** external research income has increased (Table 1) and reflects diverse funding sources (Figure 2).

Table 1: UoA7 research income during the reporting period (2019/20 was artefactually reduced by Covid-19 pandemic)

	13/14	14/15	15/16	16/17	17/18	18/19	19/20
Research Income: £1000's	2243	2623	2266	2271	2517	2529	2222

Infrastructure, Facilities and Future Strategy: SNES research facilities are Faculty 'owned', facilitating interdisciplinary cross-School, cross-Academic Group, and cross-Faculty collaborations. Unique, externally-funded specialist facilities have been developed (e.g. Marine Biotechnology laboratory suite; research aquarium; NERC/Leverhulme air-sea exchange tank), and we routinely access centrally managed research facilities in other Schools/Faculties (e.g. SEM; XRD; EPSRC Surface Analysis Laboratory; IC, ICP-AES, ICP-MS). Facilities for UoA7 research include unique off-campus assets; e.g. Dove Marine Laboratory, the only such HEI facility on the UK east coast, which together with the research vessel *Princess Royal* and Blyth Marine Station has greatly enhanced our capability in studying coastal ecosystems and global change (e.g. micro-plastic accumulation via dedicated plastics laboratory). NU contributed (£125k) to the £500k Coastal Communities Fund to upgrade the docks at Blyth Marine Station, improving the safety and provisioning of the *Princess Royal*.

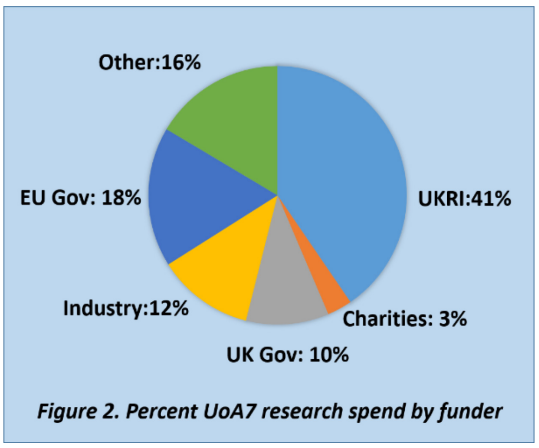

Figure 2. Percent UoA7 research spend by funder

On the city centre campus (Ref5a 4.2), a programme to collocate cognate disciplines and facilities has been undertaken. The Drummond Building refurbishment (£2M, 2019), housing most EOPS research and the One Planet DTP hub, provides state-of-the-art class 2 containment facilities (PGR and taught students), and enhanced preparation and experimental facilities, e.g. unique controlled environment system mimicking sub-glacial and Martian conditions. An example outcome is our lead, as one of only three institutions world-wide, in analysis of hopanepolyol lipids (unique indicators of bacterial processes). The Drummond building also supports researchers from the School of *Engineering* and *Geography, History, Classics and Archaeology*. This has cross fertilised ideas: 20% of Drummond-based UoA7 PGRs and research grants are joint with non SNES staff (e.g. *Decarbonising Heating and Cooling*: EPSRC; £1.3M; ***Manning, Ireland***, with Law, Engineering). A £2.8M refurbishment in the nearby Devonshire Building established a microbiological hub alongside biotechnologists/synthetic biologists. Analytical facilities (e.g. HPLC suite including HPLC-MS for innovative biomarker research) are now co-located in the Bedson Building (£0.6M investment), optimising technical support and updating/rationalising instrumentation.

At Newcastle Helix campus (Ref5a 4.2.1) we have a deep "green" geothermal well and community-used Carbon Capture Gardens (NERC Engagement /EPSRC SUCCESS funding, ***Manning***). Collaboration with *Groundwork* (cross-UK charities federation) is enabling community action on poverty and the environment.

In the region, we use the BeWISE facility (£1.2M EPSRC; £ 0.5M NU /Northumbrian Water Group), the largest European facility examining microbial behaviour during sewage treatment, to develop electrochemical sensors (***Head***).

Nationally, we were major partners in the £31M UK Geoenergy Observatories, exploiting our experience of deep (>2km) research borehole drilling: ***Manning*** is a 20% FTE, NERC Senior Science User.

Capability will expand post- REF 2021 through ongoing/planned improvements to facilities, by encouraging co-habitation with related disciplines, continued development of industrial links, and via shared services with local businesses.

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

Table 2 provides a summary which is exemplified below.

Table 2: UoA7 REF2021 collaborations and contributions to the research base, economy, and society.

Invited External Presentations	Workshops Organised	External Panels	International Partners	Incoming Visitors	Lead PhD supervisions	PhDs co-supervised with other HEIs
47	**21**	**26**	**41**	**11**	**72**	**15**

PhD co-authorships	Awards, Prizes etc.	Editorial Boards	Grants >£1M	Spinouts/ Patents	Collaboration Agreements	Esteem Indicators
136 of 314	**6**	**28**	**24**	**2**	**21**	**54**

National Scale policy and other national impacts:

- House of Commons: UK Soil Health Inquiry 2015 (***Gray***)
- *REFINE;* UK shale gas exploitation appraisal/ fracking moratorium (***Davies***)
- Invasive species policy/management (UK Non-native Species Secretariat, Animal and Plant Health Agency (***Robertson***)
- Policy advice, Natural England, DEFRA (***Fitzsimmons***)
- Chairs: Nature Scotland Advisory Groups (***Mill, Robertson)***
- Environmental Audit Committee Evidence, NatureScot, 2019 Invasive Species Audit Committee, UK/UKOT (***Mill, Robertson*)**
- Coral degradation and MPA advice, Natural England, NIFCA, Cefas (**Fitzsimmons, *Mill, Polunin***)
- REMIN (Scotland): soil carbon capture (***Manning***)
- *Capturing our Coast*, public "ownership" and stewardship (***Delany***)

International policy contributions and science collaborations:

- Chair: IUCN SSC Post-2020 Biodiversity Targets Task Force (21 international members: post-2020 Global Biodiversity Framework (***McGowan***).
- Co-chair: 2016-17 Policy Committee, IUCN Species Survival Commission (IUCN SSC 10,000-member global network (***McGowan***).
- IUCN representative: CBD (2016-); IPBES (2012-); IPBES Capacity Building Task Force (2017-) (***McGowan***)
- IUCN delegation, Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES; 2021), resource agent, IPBES Capacity Building Task Force, 2017-2019 (***McGowan***).
- CBD workshop: decadal plan, Global Biodiversity Outlook 5 (***McGowan***)
- UNEP-World Conservation Monitoring workshop (2015): impacts of illegal wildlife trade; report, UN Environment Assembly and Earth Commission Post-2020 Global Biodiversity Framework (2020); briefing, CBD Subsidiary Body on Science, Technology and Technological Advice 24 (***McGowan***)
- UN High Level Political Forum: Setting Science-Based Targets for Biodiversity in the Context of UN SDGs: July 2020 (***McGowan***)

- World Bank Environment, Natural Resources and Blue Economy Global Practice, Coalition on Private Investment in Conservation, 2020 (***McGowan***).
- Co-chair, Association of Commonwealth Universities, "HE and SDG networks" (***McGowan***).
- Chair: Technical Steering Committee, GEF/World Bank Capturing Coral Reef Ecosystems (***Edwards***).
- Earth Observation intergovernmental group (***Pfeifer***).
- Evidence: European Maritime and Fisheries Fund (MMO); ecosystem health indicators (***Fitzsimmons***).
- Invasive species best practice; USA, Australia (***Robertson, Mill***)
- Invited contribution: *The Prokaryotes*; highly regarded reference work (***Head, Gray***).
- Invited contribution: *Ocean-Atmosphere Interactions of Gases and Particles;* state-of-the-art reference (***Upstill-Goddard***).
- SCOR WGs: Sea Surface Microlayers; Marine trace gases; Marine Carbon (USA 2018): international agenda setting ***(Upstill-Goddard***).
- Helmholtz International Ocean-Atmosphere Network, Kiel, 2018 (***Upstill-Goddard***). Key output: Engel et al., *Front. Mar. Sci.* 2017.
- NERC GHG Removal (***Manning*** with Aberdeen). Key output: Lefebvre et al., 2019. LCA for enhanced weathering, Ministry of Mines & Energy Brasilia.

Collaboration Agreements: METU-Turkey, Max-Planck-Institut für Chemie-Germany; INGV-Italy **(*Acikalin*);** AkzoNobel (***Clare***); IFAPA/Univ. Almeria, Spain ***(Montero Calasanz***); Banyan Tree Global Foundation, IPB Indonesia (***Polunin***); Cuadrilla (***van der Land***).

Plenary, Keynote and Invited External Presentations: Royal Society 2017; Brazilian Critical Zone Symposium, São Paulo, 2019; Plenary, 29th British Organic Geochemical Society Conference, Bristol 2018: Keynote, 56th BSRG Annual Conference, 2017; UN Climate Change Conference of the Parties COP 25, Madrid 2019 (***Abbott***); Keynote,11th International Symposium on Marine Engineering, 2017 Japan, Keynote, Japan Adhesion Biology Society 2017; Keynote, *Bridging the gap between academia and industry - a collaborative enterprise*, 2016 France (***Clare***); Goldschmidt 2019 (***Flynn***); ICABB 2019 India; ACMIS 2018 Mongolia; CABCBEB 2018 Chile; Servier Pharmaceuticals 2014 France (***Goodfellow***); CONTASAD, 2015 (***Jones***); Keynote, Society for Environmental Geochemistry & Health, 2019; Ministry of Mines and Energy Brasilia, 2018 (***Manning***); Utrecht 2019 (***Morales-Maqueda***); Impact of atmospheric warming on SW Greenland ecology, 2017; SE Asia Rainforest Research Partnership 2014, Malaysian Palm Oil Board 2018, Univ. Malaysia Sabah 2018 (***Teh***), Manchester, Stirling, Edinburgh (***Telling***); marine biogas international workshop, Los Angeles 2018; Helmholtz International Ocean- Atmosphere Network, Kiel, 2018 (***Upstill-Goddard***);

Awards/Scholarships etc: Visiting Professor Toulon University (***Clare***); Leverhulme Emeritus Fellowship (***Goodfellow)***, Fellow, American Academy of Microbiology (***Goodfellow, Head***); European Academy of Microbiology (***Head***), Fellow of the Royal Society of Biology (***Head***) "*Deep Sea Hero 2020":* ECO magazine/ Schmidt Ocean Institute/ National Oceanography Centre; Chief Scientist, *Five Deeps Expedition* (2018-19); "'Expedition of the Year" award 2020, Explorers Club, NY (***Jamieson***); Web of Science highly cited researcher (cross-field) 2018, 2019, 2020 (***Moore***); Fellow, International Coral Reef Society, Royal Society of Biology, MBA (***Polunin***); University Tasmania Senior Research Fellowship (***Willmott***).

Conference and Workshop Organisation and Hosting*:* UK Challenger Society for Marine Science biennial conference (2018: 300+ delegates; high profile international keynotes); 8th Astrobiology Society of Britain Conference (2019); 16th Marine Biological Association PGR conference (2019); British Sedimentology Research Group (2017); 2nd International Workshop on Alternative Potash (2017); European Federation of Geologists workshop (2015); NERC LORISE consortium (2016); International Symposium on Microbial Electrochemistry & Technology (2018).

External Advisory Panels (examples)*:** Review Board, Leibniz Institute for Baltic Sea Research, Chair, Comité International Permanent pour la Recherche sur la Préservation des Matériaux en Milieu Marin (COIPM) (Clare***); National Oceanography Centre Association Steering Board (***Clare, Upstill-Goddard***); Scientific Advisory Board, SECORE International, (***Edwards***); EPSRC Energy Science Advisory Committee, NERC Senior Science User, UK Geoenergy Observatories, EPSRC IDRIC Panel, BBSRC GGR Demonstrator Panel, NSF-NERC Sensors in the Soil Panel, NERC-FAPESP Sustainable Gas Futures panel chair (***Manning***); UK Geomicrobiology Network, Astrobiology Society UK, Greenland and Kangerlussuaq International Research Networks (***Telling***); External Review Group, National Oceanography Centre, Belgian Science Policy Office Evaluation Panel, Belgian Research Action- Interdisciplinary Networks, Kiel/GEOMAR Cluster of Excellence and Future Ocean sustainability, SCOR National Committee, Hong Kong University Grants Committee Research Assessment Exercise, Norwegian Research Council Centres of Excellence, EUROFLEETS2 - integrating the European Research Fleet (***Upstill-Goddard***); Defra/DECC Met. Office Science Review Group, Philip Leverhulme Prizes Panel, Canadian Excellence Research Chairs Panel, Plymouth Marine Laboratory Science Advisory Council (***Willmott***).

Editorships/Editorial boards (examples): *J. Mar Sci. Eng.* (***Clare*** (Chief Editor), ***Upstill-Goddard***); The ISME Journal (***Head*** (Chief Editor 2014-2020)); *Restoration Ecol.* (***Edwards***, Coordinating Editor); *Org. Geochem., Mar. Pet. Geol*. (***Abbott***); *Antonie van Leeuwenhoek* (***Goodfellow***); *Coral Reefs, Plos One* (***Guest***); *Sci. Reps*. (***Moore***); *J. Ocean Clim.* (***Morales-Maqueda***); *Env. Conserv.* (***Polunin***, Chief Editor); *Ann. Appl. Biol.* (***Port***); *Ecol. Evol., Plant Ecol. Div., Front. Forests Glob. Change* (***Teh***); *Arctic, Antarctic Alpine Res*. (***Telling***); *JMBA* (***Wigham***).

Learned Societies (examples): ***Upstill-Goddard:*** President, UK Challenger Society for Marine Science (2018-2020); ***Manning:*** President, Geological Society of London (2014-2016); ***Moore****:* Council Member, British Phycological Society.

Engagement: ***Jamieson***: deep-sea ecology on *Blue Planet II* (BBC) and *Deep Ocean: Mariana Trench* (NHK/Discovery TV), advice to Filmic Art, 3D *Deep Ocean Experience* DVD, NHK 2017 documentary *Deep Ocean: Descent into the Mariana Trench*, lander featured in *Blue Planet 2;* ***Gray*:** co-author, "Understanding drivers of antibiotic resistance genes in High Arctic soil ecosystems"; *Envir. Int* (2019); coverage in >400 international media outlets (e.g. Washington Post; BBC World News); ***Upstill-Goddard***: co-author, "Reduced air–sea CO_2 exchange in the Atlantic Ocean due to biological surfactants (2018); coverage in major newspapers and BBC World News; Bolam et al., 2020 on extinctions avoidance received widespread publicity (e.g. *Guardian, New York Times*) and CBD media team metrics indicated 200 outlets (lead story in GB05 launch); ***Mill, Fitzsimmons:*** Great North Museum science engagement; climate change and invasive species (107,944 public visits in 6 weeks).