Environment template (REF5)

Institution: Bangor and Aberystwyth Universities – Biosciences, Environment and Agriculture Alliance (BEAA)

Unit of assessment: 07 Earth Systems and Environmental Sciences

a) Overview

Bangor and Aberystwyth Universities have a longstanding research partnership, particularly well developed in the natural sciences, where it has been supported by externally funded strategic initiatives. Our staff submitted to UoA7 are grouped within four complementary and overlapping research themes established across the **College of Natural Sciences (CNS)** at Bangor and the **Institute of Biological, Environmental and Rural Sciences (IBERS)** in Aberystwyth, spanning marine, freshwater and terrestrial ecosystems and combining disciplines to provide an effective research environment to tackle pressing and complex challenges facing the world's population, including global environmental change, biodiversity loss and unsustainable use of natural resources:

- **Earth system science and climate change**
- **Integration of catchment and coastal processes**
- **Ecosystem conservation and resource management**
- **Environmental and evolutionary biology**

b) Research strategy

Bangor and Aberystwyth Universities have developed a formal research partnership, built, in part, on our history of collaboration in the natural sciences, including environmental science. Broadly, Bangor has prioritised the Environmental Sciences (UoA 7) and Health (UoA 3), while Aberystwyth has focussed on Agricultural Sciences (UoA 6) and Geography (UoA 17). This has allowed us to develop our own thematic foci and specialised infrastructures, while benefitting from the considerable synergistic potential of inter-institutional and interdisciplinary collaborations. We make joint submissions to UoAs 6 (led by Aberystwyth) and 7 (led by Bangor), returning individual staff to each as appropriate. However, we have not split each universities' research doctoral degrees awarded or income between the two submissions, thus all of Aberystywth's is reported in UoA6 and Bangor's in UoA7. Together the two submissions comprise a substantial cross-institutional and interdisciplinary research grouping supported by major joint strategic capacity-building and research project grants across the entire REF period, extending until at least 2019.

In Bangor, the College of Natural Sciences (CNS) was formed in 2006 to integrate and develop research and education across three cognate academic schools: Ocean Sciences, Biological Sciences, and Environment, Natural Resources & Geography, partly co-located with NERC's Centre for Ecology and Hydrology Bangor lab. In parallel, Aberystwyth University integrated related research groupings in a merger with the BBSRC Institute of Grassland and Environmental Research to form the Institute of Biological, Environmental and Rural Sciences (IBERS). Consolidating both this merger and the Aberystwyth-Bangor partnership, the **Biosciences, Environment and Agriculture Alliance (BEAA)** has received a strategic investment, since 2008, of £55M from the BBSRC, Welsh Government and the two universities. BEAA was built on the success of two joint HEFCW-funded environmental research centres: Centre for Integrated Research in the Rural Environment (CIRRE), and Centre for Catchment and Coastal Research (CCCR), representing £5.5M in staff and infrastructural investment (2006-2012). Looking forward, the partnership is poised to build on this capacity through our joint leadership of the **NEXUS Wales** network, a £7M Welsh Government investment in postgraduate and postdoctoral research in Low Carbon, Energy and the Environment.

Achievement of Strategic Aims

The formation of the College of Natural Sciences in 2006 has helped realise our institutional vision of placing environmental science as one of the strategic research priorities of Bangor University.

Integrating the research strengths of the three schools in the college, and providing an efficient conduit for strategic co-ordination with colleagues in Aberystwyth, the College leadership and organisation has enabled this area of science to flourish with substantial investment in buildings and equipment, alongside strategic staff appointments, partly through facilitating the winning of a series of major research grants.

Bangor's UoA17 submission in RAE 2008 had an interdisciplinary but exclusively marine focus, with a strategic plan emphasising climate change science, novel application of marine materials and sustainable use of marine resources. Since 2008, this has been achieved, but subsumed within a broader, more ambitious environmental science research strategy across CNS and IBERS to encompass terrestrial biogeochemistry, plant genetics/biotechnology, molecular ecology and conservation science, aspects of which were represented in the strategic plans of both institutions in UoA16 in RAE2008.

Indicators of our success in the current REF period, taken across CNS, include: (i) publishing 1456 ISI-listed papers; (ii) increasing by more than 400% the number of papers published by our staff both in Science/Nature-family journals, and in 'second-tier' journals with impact factors >9, to a combined total of 45 papers; (iii) increasing PGR student FTE by 26% to 162 in 2013; (iv) year-on-year increase in research income which doubled from 2008/09 to 2012/13 (REF 4b). Indicators of success of the Bangor-Aberystwyth research collaboration in environmental science are that during 2008-2011, CIRRE and CCCR were awarded £24.5M in research grants for projects that are joint between the two universities. The publications of the two centres had field-weighted citation indices for 2007-2011 that were 97% and 49% above world average respectively.

Our continued success in meeting strategic research aims is attributable to: **recruitment, development and retention of high-calibre senior and early-career researchers**, bringing in 25 new research-active academics including 3 Professors and 21 ECRs (Section C); **investment in state-of-the art research infrastructure** (Section D); **establishment and nurturing of multidisciplinary centres** linking the two institutions. BEAA (above) provides the over-arching co-ordination across all 4 research themes, which will be extended by NEXUS Wales ("future goals" below), while 4 other joint centres play catalytic roles within the themes.

The **Earth system science and climate change** theme aims to integrate new discoveries of past climate change with those of the impacts of contemporary climate change on ecosystems, communities and organisms, investigating potential mitigation through marine renewable energy and enhanced management of terrestrial and coastal environments. For this we draw on expertise in palaeoceanography, sclerochronology, ocean physics, tidal mixing, ocean and terrestrial biogeochemistry, ecology and applied psychology. Research in this theme has been greatly strengthened by the Bangor-led **Climate Change Consortium of Wales (C3W)**, a 10-year, £4M programme launched by HEFCW in 2009. Our research aligns closely to international policy processes, for example, through input to ecosystem carbon stock and flux estimates for the 2013 IPCC assessment. Also aligning with the strategic priorities of NERC, shown by our involvement in 5 programme grants, the Ocean Physics group applies marine turbulence measurement techniques to quantify and parameterize key processes driving fluxes across critical interfaces, leading to improved predictive capacity of global climate models.

Development of interdisciplinary skills across CNS and IBERS has been at the heart of growth of the **Integration of catchment and coastal processes** theme, investigating processes from agricultural ecosystems via catchments to estuarine and coastal environments. This has benefited from the co-location in 2006 of the NERC Centre for Ecology and Hydrology with cognate CNS research groups in the Environment Centre Wales building and by the £2.8M HEFCW interdisciplinary Aberystwyth-Bangor **Centre for Catchment & Coastal Research** programme (2006-2012), focussing on the Dyfi and Conwy rivers and adjoining shelf habitats. Our research in shelf sea processes, including turbulence and vertical mixing, is integral to understanding the land's influence on the biogeochemistry of coastal waters and pelagic primary production. We have strengthened research capacity in dynamic modelling to improve understanding of the atmosphere-land-river-sea linkages of water, sediment, pathogen, macronutrient and greenhouse gas fluxes,

particularly in wetlands and in the river-estuary transition zone, with major NERC support and a range of collaborators.

Ecosystem conservation and resource management integrates fundamental and applied science, with core investment provided by the £2.8M **Centre for Integrated Research in the Rural Environment** (HEFCW-funded, 2006-2012). Marine, wetland, forest and agro-ecologists work with biogeochemists, modellers and social scientists to address threats to biodiversity by climate change, habitat loss, over exploitation and invasive species. Our staff play substantial roles in Wales' £6.2M Axis II Agri-Environment Monitoring Scheme (with CEH) and the NERC Biodiversity and Ecosystem Services Sustainability consortium project on coastal margins. The world-leading **Centre for Evidence-Based Conservation** uses systematic review to provide evidence on environmental management and conservation targeted at the needs of managers and policymakers, including the World Bank/UNEP Global Environment Facility. Notable among our involvement in 5 grants funded by the NERC-ESRC-DFID Ecosystem Services and Poverty Alleviation programme, is our leadership of a new £1.9M consortium project investigating whether capturing the value of providing global ecosystem services can reduce poverty in Madagascar. A major conduit for addressing sustainability issues in the marine environment is the £23.6M **SEACAMS (Sustainable Expansion of the Applied Coastal and Marine Sectors)** programme, led by Bangor and partnered by Swansea and Aberystwyth Universities (EU-funded, 2010-2015) to facilitate collaborative research with the commercial marine sector.

Environmental and evolutionary biology integrates the fields of genomics, physiology and ecology to explore the interactions between populations, species, communities and the broader environment on both contemporary and historical timescales. We address major fundamental questions such as the role of environmental change and ancient hybridisation in the generation of cichlid fish diversity and the energetics of trans-Himalayan bird flight. We also apply our expertise in plant genetics for the sustainable production of biorenewables, in environmental metagenomics to mitigate pollution, in microbial biotechnology to understand major tree diseases and in reptile genomics in developing public health provision of effective anti-venom to treat snakebites. Recent new appointments have strengthened our capacity in bioinformatics, analysis of full genome sequences and ancient DNA. The theme's mix of fundamental and applied research has enabled grant capture since 2008 >£11.5M, notably from RCUK, DEFRA and European Union sources and produced a string of high-profile research papers, often with collaborators from leading research centres in the UK and abroad.

Current and future strategic goals

The staff base, research infrastructure and interdisciplinary collaborative research ethos built up since 2008 place Bangor and Aberystwyth Universities in an excellent position to realise our vision of emerging as an increasingly influential centre of excellence in environmental and agricultural sciences, well-positioned to address the grand environmental challenges of the 21st century. We endeavour to maintain this momentum as joint leaders of the new Welsh Government strategic initiative, **NEXUS Wales** (Natural Resources Network for Wales in Low Carbon, Energy and the Environment), which will provide £7M over the next 5 years to support research targeting the provision of energy, food and water with other ecosystem services. NEXUS is intended to position Wales as a leader in the integrated ecosystems approach to the management of natural resources with a direct impact on policy and enhancement of commercial opportunities. NEXUS Wales will target the interface of NERC and BBSRC science, thus combining the complementary strengths of Bangor and Aberystwyth. It will also incorporate EPSRC areas such as marine engineering and flood risk management, as well as ESRC themes such as public perceptions, economics and welfare impacts of environmental management. We anticipate that the alignment of NEXUS Wales with the priorities of RCUK, TSB and Horizon 2020 will result in leverage of substantial additional income streams throughout the coming REF cycle.

NEXUS Wales will invest heavily in the recruitment of post-doctoral and postgraduate researchers, and will foster pan-Wales research, with extensive national and international linkages, to nurture the expertise, vision and drive required to develop **Laboratory Wales** as a globally unique test-bed integrating scales from genes on through landscape and up to the whole-country level, across air-

land-marine domains. A key component will be the development of new ICT tools to exploit the opportunities of high performance computing and new cloud computing networks in areas such as environmental monitoring and linked process models from molecules to ecosystems. We will integrate ground-breaking work on fundamental environmental process with the four NEXUS themes (impacts and mitigation of climate change and human activity, sustainable intensification, low carbon energy pathways, and developing the bio-economy). For example, development of **population genomics** approaches (statistical analysis of populations of whole genome sequences) in the study of ecological speciation, demographic change and extinction will improve understanding of biotic responses to global environmental change over a range of timescales.

c) People:

i) Staffing strategy and staff development

Rationalisation of staffing structure prior to RAE2008 provided a framework which addressed the drive for excellence in research across CNS and IBERS, while maintaining the highest quality teaching provision. We built on this during the REF period with an investment of almost £4M in new positions targeted at NERC strategic research priorities, matched with appropriate development of facilities and technical support: for example SEACAMS has funded 8 industrial fellows and 5 technical staff. Since 2008, 25 new research-active academic staff have been appointed in UoA7-relevant disciplines, partly through 11 new academic and research posts in Bangor University's 2011 strategic drive to strengthen the mathematical base of the environmental sciences. We have also recruited 1 BBSRC and 5 NERC Research Fellows in this area. This advance will be sustained during the next 5 years through the NEXUS Wales Post-Doctoral Academy with funding for 40 person-years of posts across Wales.

New posts in **earth system science and climate change** include Butler in sclero-climatology, Green in dynamical oceanography (ex-NERC fellow), Lenn in ocean physics (NERC fellow), Neill in numerical modelling and Pienkowski in palaeoceanography, while **integration of catchment and coastal processes** has been strengthened by Patil, a catchment modeller, along with Neill. **Ecosystem conservation and resource management** has been enhanced by the recruitment of Davies and Moore in marine ecology, De Luca in soil carbon (chair, co-funded by NERC), and Skov in mangrove ecology. New appointments in **environmental and evolutionary biology** include De Bruyn in fish phylogeography and ancient DNA, Casewell in venom evolution (NERC fellow), Farrar in plant genomics (BBSRC fellow), Knapp in ancient DNA and McDonald in environmental microbiology. Many new staff work across themes, such as Neill, Davies and Moore.

Career development support. We now have clear career development pathways rewarding excellence in teaching & scholarship, impact & engagement and academic leadership in addition to research excellence, allowing us to nurture outstanding researchers within a supportive collegiate environment that values the range of specialised skills required in a 21st century academic unit. Effective, targeted development for all staff, including those on fixed-term contracts, is facilitated by annual Performance Development Review, carried out by senior staff, critically assessing achievements and plans, identifying obstacles to peak performance, and actioning appropriate responses. Training tailored for researchers includes induction into research support processes, and provision of coaching in grant applications, including for EU consortia, provided by dedicated teams within CNS, IBERS and the central Research and Enterprise Offices. New appointees have additional monitoring of their overall performance by their unit (usually school) head during the 3-year probationary period, and there is a dedicated mentoring group for early career researchers, reporting to the unit staff development committees. Early career staff are given reduced teaching commitments during the first 2 years, with generous start-up packages and priority in competitions for PhD studentships. Established staff are encouraged to take supported study leave every 7 years, with priority based on plausible plans for enhancement of research excellence. Bangor and Aberystwyth are active participants in **Welsh Crucible**, a pan-Wales initiative that supports the development of future research leaders through a series of two-day workshops covering media, policy development, creativity, collaboration, leadership, international collaborations and communication. There are also interdisciplinary pilot research grants. Success in staff development is evidenced by promotions during the REF period of 6 Professors, 3 Readers and 13 Senior

Lecturers/Senior Research Fellows in the environmental sciences.

Both Bangor and Aberystwyth Universities have achieved the Human Resources Excellence in Research award which acknowledges alignment of our policies with the **Research Concordat** to support the career development of researchers. Researcher Concordat Groups oversee the annual review of the Policy Statement and manage the implementation plan. We have utilized both the Careers in Research On-line Survey (CROS) and Principal Investigators and Research Leaders Survey (PIRLS), along with researcher focus groups to ensure that our provision meets the needs of research staff. Bangor is Local Contact Point of the **EURAXESS** network. Both universities are active members of the South West and Wales Vitae Hub.

Staff are **recruited internationally** to maximise our research quality, with new appointments from outside the UK including De Bruyn, De Luca, Green, Knapp, Lenn, Moore, Patil and Pienkowski. We have attracted high profile **sabbatical visitors** including Tom Osborn (Johns Hopkins), Jim O'Donnell (Connecticut), Bob Chant (Rutgers), Dan Murphy (Western Australia), Marvin Hall (Penn State), Paulette Bloomer (Pretoria), Gerd Gäde, (Cape Town) and Bernadette Sloyan (CSIRO).

Development of Women in Science. Bangor University achieved an Athena SWAN Bronze award in 2011 and has an active Athena SWAN Group that is developing interventions to better support women working in the sciences. The University has also developed a new senior academic promotions policy, agreed a new policy to improve gender representation on decision-making groups and is looking at enhanced career break provision for academic staff. The College of Natural Sciences is working on an application for a Departmental award and aims to achieve Silver by 2015. At Aberystwyth, IBERS is playing a leading role in the preparation of the University's Bronze Award submission.

ii) Research students

Postgraduate recruitment. CNS has a well-established Graduate School which recruited an average of 40 post-graduate research students per year (2008-2013). The dominant RCUK sponsor was NERC, which funded an average of 4 new algorithm PhD students annually. In addition, 4 ESRC-NERC interdisciplinary studentships were active over the period. As well as standard methods of PhD funding, Bangor has pioneered 4 major innovations: (i) A joint PhD programme with CATIE, the Tropical Agricultural Research and Higher Education Center, which is the leading institution in land-use environmental research and postgraduate education in Latin America. Since 2008, 7 students have been awarded PhDs on this joint doctoral programme. (ii) An Erasmus Mundus Joint Doctoral Programme "Forests and Nature for Society" (FONASO) of 7 university partners commenced in 2010, supported for 10 years by €6.7M of EU funding. (iii) The use of EU regional development funding for research skills training through industrial PhDs in the £33M Knowledge Economy Skills Scholarship (KESS) programme, led by Bangor. Of the 230 PhD studentships awarded, 29 were in CNS (Bangor) and 11 in IBERS (Aberystwyth) (total value £4.0M). This programme also supported 44 MRes studentships across the two centres. Its success led to Bangor membership of the prestigious European Industrial Doctoral School. (iv) Links with CEFAS have allowed us to co-fund 3 joint PhD studentships working on marine shellfish resources, benefitting from research placements in the CEFAS lab and from courses on advanced analytical methods. Looking to the future, funding secured for the Bangor/Aberystwyth-led NEXUS Wales will support 58 PhD studentships over the next 5 years to join a unique interdisciplinary research and training programme in the areas of environment, bioscience and energy. In November 2013, it was announced that Bangor University will also participate in a **NERC Doctoral Training Partnership,** in collaboration with Lancaster and Nottingham Universities, CEH, the British Geological Survey, Rothamsted Research and 41 other partners. This will fund 12 new PhD studentships per annum for 5 years, ensuring that we will be involved in leading competitively funded PG research training in the Environmental Sciences through the next REF cycle.

Training and support mechanisms. The College of Natural Sciences Graduate School was established in 2007. Development of postgraduate training was driven by the NERC-led 2010 and

2012 reviews of 'Postgraduate and Professional Skills in the Environment Sector'. These reports stressed the need for developing training in multi-disciplinary research with specific skill sets in computer modelling, soil science, microbiology, food supply, energy supply and translating research into practice, all disciplines actively researched in our unit. Our training and progression requirements are frequently reviewed, not least because of our success in obtaining studentships through diverse routes with their own emphases and training needs. A flexible approach to the provision of training maintains a cohesive and integrated postgraduate research body, and ensures consistency in access to high-quality training opportunities and monitoring procedures. Students undertake an annual Training Needs Assessment with their supervisory team, identifying their generalist and specialist development needs, to generate a personal development plan which provides an individualised and tailored pathway through the training landscape. Students review their plan as they progress, meaning that training need not be front-loaded, but is continued throughout the PhD as the students' requirements change (e.g. students initially need to develop their understanding of risk, ethics and intellectual property; towards the end of their doctorate, they may benefit from developing fellowship applications). The Bangor University Graduate School oversees College provision and runs its own quality-assured courses as well as welcome events, postgraduate conferences and access to a range of personal development programmes across the University's Graduate Skills Programme. Regular multidisciplinary conferences provide organised intellectual and social contact between students of different disciplines and from many different backgrounds and countries. Parallel developments in Aberystwyth are clarified in UoA 6 REF 5, and NEXUS Wales will enhance inter-institutional integration.

The core of student training is organised through the Supervisory Committee, consisting of 1 or more principal supervisors, an internal academic reviewer and an impartial Chair. Supervisors are expected to undertake workshops in research student supervision and a mentoring scheme for staff new to PhD supervision is in place. Formalised compulsory training for PhD students includes: (i) Health, safety and statistics; (ii) Transferable skills and project preparation, and evidence of immersion in College-wide research culture. Research presentations are required at School/College level in years 1, 2 and 3. The Academic Development Unit offers specialist research training modules including GIS, statistical analysis, Matlab and Academic Writing, as well as courses to develop career management skills and other domains of the Researcher Development Framework. Students on the KESS programme have additional training through internships with industrial partners and an intensive enterprise programme leading to a Postgraduate Skills Development Award (PSDA). These Business-University partnerships closely match the HEFCE Wilson review recommendation.

Progress monitoring. Monitoring of research student progress takes place at 3 levels, the supervisory committee, the Graduate School and the University. At least fortnightly checks on progress are expected and monthly supervisory meetings are recorded centrally. At months 9, 21 and 30, formally-recorded supervisory committee meetings decide on student progression based on assessment of the student's defence of their progress report, and completion of required training and presentation elements. Reports from all supervisory committees, including feedback from students, are reviewed centrally and issues reported to the Senate Postgraduate Committee. When there are concerns, these are followed up with individual students and Schools by the Senate Committee Chair. The University also participates in the Postgraduate Research Experience Survey (PRES), a report of which is considered by the Quality Assurance and Validation Task Group and Senate Postgraduate Committee.

Two key indicators of the success of our Research Student programme since 2008 are: (i) for NERC students Bangor has a 95% 4-year submission rate (n=19); (ii) Bangor's first destination data for environmental science PhD graduates (n=149) shows that 49% are employed in research, 21% in education, 5% each in government, consultancy and industry respectively, with less than 1% reported as unemployed and the remainder in other or unknown categories.

d) Income, infrastructure and facilities

Funding and provision of specialist infrastructure and facilities: Bangor and Aberystwyth have reciprocal arrangements allowing staff ready access to each other's facilities, many of which were funded by joint programmes. In this Bangor-led UoA 7 submission, we will focus on the facilities at Bangor, clearly stating which facilities are based in Aberystwyth, as these will be covered in more detail in UoA6.

The £8M Bangor University-NERC co-funded **Environment Centre Wales** (completed in 2007) integrates the multi-disciplinary expertise of 60 environmental scientists from the University and NERC Centre for Ecology and Hydrology. It hosts our UoA 7 research in biogeochemistry, soils, microbiology, genomics and molecular ecology across the 4 research themes and cements the ethos of the College by bringing together researchers from all 3 constituent schools. The embedding of the Wales Environment Research Hub within the building provides an effective means for Bangor's environmental scientists to direct their research at addressing major policy issues and disseminate the outcomes to key stakeholders. BEAA has provided further major funding for infrastructure and equipment to both universities including £3.5M to Bangor, mainly for environmental research, in addition to some £20M for new buildings and facilities for Aberystwyth supporting environmental, and mainly agricultural, research.

We have secured substantial infrastructural funding to enhance the **impact** of our research. Current investment includes a new **Marine Innovation Centre** under construction for SEACAMS, designed as a hub to foster collaborative research with the commercial marine sector, providing business access to expertise, laboratory and ship facilities, including space for 10 new business-university collaborative projects. This will mesh with: i) the 2014 completion of the £46M "Pontio" **University Innovation Centre** - providing a base for the arts and community engagement activities as well as an innovation facility for interdisciplinary research; ii) the Welsh Government £10M investment (2013) in the Bangor University **Science Park** focusing on research and development with the low carbon/renewable energy sector, providing facilities to attract and incubate SMEs through co-ordination with the Anglesey Energy Island and Enterprise Zone. These developments will integrate with our research in marine renewable energy and biorenewables. They will also link closely to the Aberystwyth-based **Innovation and Diffusion Campus** focused on the accelerated translation of environmental and biological science research for the primary production and environmental sectors to benefit and help rebalance the UK economy, through new partnerships, companies and collaborations delivering food, fuel, fibre and chemicals.

We have benefitted from major improvements in facilities for **land-use research**. The Wolfson Foundation/Royal Society awarded £550k to establish two major research facilities, the **Wolfson Carbon Capture Laboratory**, providing space and equipment for a dozen scientists to improve scientific understanding of carbon capture and provide estimates of national and global peat carbon sequestration potential, and **Europe's largest rhizotron** for below-ground research focused on carbon storage and turnover in replicated experimental mesocosms. Aberystwyth-led components include a new **Upland Research Platform** for the UK, leasing the Pwllpeirian estate from the Welsh Government, linking this with the Bangor Henfaes Research Centre and creating a chair in Upland Research to address how best to manage upland landscapes for the provision of energy and food while maintaining ecosystem services and biodiversity in the face of environmental and societal change. In parallel Aberystwyth plans to expand its **National Plant Phenomics Centre**, using the latest precision genomic and phenomic technologies to redesign crops for both production of energy, materials and food, and environmental services.

Bangor is one of the UK's best equipped universities for research across the range of aquatic environments from the continental shelf ocean to coastal and freshwater. The multipurpose 35 m **Research Vessel Prince Madog** can sail for 10 days between ports, and has berths for 10 scientists and a crew of 8. Its research capacity was strengthened in 2010 by upgrading the side-scan system to a Cmax CM2 (£25k) and in 2011 with a £310k ship-mounted Reson 7125 dual frequency (200 kHz and 400 kHz) SeaBat Multi-beam system for seafloor mapping.

We have outstanding **plant and animal facilities**. Substantial refurbishment of seawater laboratories and marine aquaria has taken place since 2008. A large new Home Office/CEFAS-approved aquarium is being built by SEACAMS, enabling procedural work on diseased or exotic organisms. Investment of £147k from BEAA in freshwater aquaria in 2010 has allowed an internationally important collection of cichlid fish to be established for evolutionary genetic research. New computer-controlled constant-environment rooms (£98k, 2011) maintain aquatic organisms at precise temperatures (4-35°C) under controlled lighting, facilitating the study of biological rhythms and physiological effects of climate change. BEAA has invested £138k (2010) in new Home Office-approved facilities for housing and studying venomous snakes and other reptiles. Plant growth and analytical facilities have been substantially improved with 3 new controlled-environment rooms equipped to meet containment standards for GM work (£432k, BEAA 2010). New glasshouses constructed as part of the Bangor-Aberystwyth joint Welsh Institute for Sustainable Environments programme (£316k, 2008) complement the agricultural plots available at Henfaes, Bangor's 252 ha field research centre, which includes a range of heathland, woodland and grassland habitats.

Our excellent **laboratory analytical facilities** include HPLC, GC-MS and stable isotope mass spectrometers. Investment of over £250k from BEAA has added a Li-Cor open-path gas analyser coupled with a sonic anemometer to determine ecosystem level fluxes of CO_2 and CH_4, a Lecotruspec analyser to measure C, H, N, O and S in 1-10 mg liquid or solid samples, a Bruker S2-picofox TXRF for solid or liquid elemental analysis, a Columbus Instruments Micro-oxymax multiple-sensor 20-chamber respirometer to measure microbial respiration in environmental soil and water samples, a Metrohm Ion Chromatography system to measure anions and cations reflecting acid rain impacts and nutrient status of peat wetlands, 3 new Varian GCs with a variety of detectors for measurement of CH_4, CO, CO_2, N_2O and various pollutants in environmental samples. Facilities for environmental **microbiology** and human pathogen research have been enhanced by the provision of 3 new fully-equipped level-2 containment laboratories and a microbiological fermentation suite (£740k, BEAA 2010).

A new ancient **DNA laboratory** has been built (BEAA 2012) with a second due in early 2014. Molecular facilities have also been extended by the addition of Real-time PCR detection capabilities and an Agilent Bio-analyser enabling easy access to external next generation sequencing (£48k). In a £305k BEAA investment, a new Zeiss **confocal microscope** has been added, complementing and enhancing the capabilities of the existing inverted confocal system. Bangor and Aberystwyth are partners in **High Performance Computing Wales**, an EU/Welsh Government/Industry-funded collaboration. The machine at Bangor comprises 648 Intel Xeon (Westmere) 2.66 GHz cores, nearly 2 TB of memory and 10 TB of local storage. It is used extensively by environmental science researchers at both universities, facilitated by the competitive award of 3 Fujitsu-funded PhD studentships to develop new models for linking catchment to coast processes, and for assessing the efficiency of tidal turbines and their environmental impacts.

Research funding includes a strong record from NERC totalling over £10M in responsive mode, thematic and consortium funding awarded to Bangor over the REF period, including 8 grants (£2.7M) in ocean physics, 5 in palaeoceanography (£698k), 5 in ocean biogeochemistry (£1.15M), 8 in catchment and coastal processes (£3.4M), 7 in terrestrial biogeochemistry (£1.20M) and 8 in ecosystem conservation, sustainable resource use and environmental biology (£1.18M). In addition, we have been awarded 3 knowledge exchange grants (£223k). Bangor-Aberystwyth collaboration is notable in the river–estuary transition zone (NERC, £929k, 2009-2013) and in global ecosystem service values and poverty reduction (£1.9M, 2013-2016, see international collaborations section below). Several major BBSRC and Leverhulme grants support fundamental research in environmental and evolutionary biology, and a notable new BBSRC award to Bangor funds study of the mechanism of microbial cellulose decomposition (£330k, 2014-2017). Amongst the major BBSRC funding to Aberystwyth is the renewal of its Strategic Programme Grant in Energy Grasses and Biorefining in 2011. Bangor has been awarded £24.9M in grants for 51 projects from the EU in the 2008-13 period. In addition to SEACAMS (see section B above), substantial funding has been won in the areas of sustainable environments (£6.6M), biorefining for

renewable materials (£10.6M) – both joint Aberystwyth-Bangor-Swansea projects – and marine resources (£3.4M to Bangor for 4 projects). Microbial genomics and biotechnology is another significant area of EU funding (details in section E below). UK and Welsh government sources have awarded a total £8.6M to Bangor since 2008. Main foci include £1.15m from the Welsh Government's Academia for Business programme, including a Knowledge Transfer Centre and 5 collaborative projects with industrial partners, and £1.5M from DEFRA. Overseas sponsors have funded 43 projects (£2.3M total) in Bangor.

e) Collaboration and contribution to the discipline or research base

Collaborations within the UK in oceanography and (by both Bangor and Aberystwyth) in marine biology have led to NERC-funded consortia with the Universities of Southampton, Oxford, Leeds, Bristol, Reading, Liverpool, Plymouth, Essex, St Andrews and UCL, along with the National Oceanography Centre, British Antarctic Survey, Scottish Association for Marine Science and the Met Office. Co-location of CNS and CEH staff in the Environment Centre Wales building has fostered work on several collaborative research projects with notable success over the past 2 years, including £1.6M to Bangor University from 2 NERC programmes (Macronutrient Cycles and Biodiversity and Ecosystem Services Sustainability, both 2012-2016) and a Large Grant on dissolved organic matter in freshwater ecosystems (2013-2017); in total these 3 projects were awarded NERC funding of £6.9M.

Active **international collaborations** are evidenced by high levels of research funding in international multi-partner projects. Our microbiologists have secured €1.8M from interdisciplinary EU programmes, co-ordinating the €2.8M MAMBA project (2009-2013), with academic and industrial collaborators in Canada, France, Germany, Italy and Spain that extends from our focus on marine extremophilic microorganisms to drug discovery, cosmetics and synthesis of fine chemicals. Micro-B3, with 32 academic and industrial partners, co-ordinated in Bremen, focusses on marine microbial bioinformatics for ecosystems biology and biotechnology (€10M, 2012-2015). We have also participated in consortia working on the development of microbial resources for bioremediation: MAGICPAH (€2.8M to 2014) based at the Helmholtz Centre for Infection Research in Germany, with 11 scientific teams from 8 different countries and 2 industrial collaborators; the ULIXES consortium consisting of 8 European and 4 non-European partners co-ordinated at the University of Milan (€3M to 2014); Kill-Spill (oil-spills: €10M, FP7, 2013-2016), co-ordinated by the Technical University of Crete with 33 participants including 14 SMEs. Two major Darwin Initiative grants (total £772k) support collaborations with conservation groups on the Cayman and Chagos islands and with Madagascar, while the NERC-ESRC-DFID Ecosystem Services for Poverty Alleviation programme supports 4 conservation projects in East Africa and Madagascar, with many UK and international collaborators (£2.5M, 2013-2016). We co-ordinate the Marie Curie Initial Training Network ARAMACC (€3.1M, 2013-2017) on sclerochronology with academic and industrial partners from Germany, Norway, Croatia, France, Netherlands and Portugal. Bangor is also an active member of key international consortia, including: the Earth Microbiome Project, the Global Soil Biodiversity Initiative, ECOFINDERS and the Consortium for the Barcode of Life.

Interdisciplinary research. The HEFCW-funded joint Bangor-Aberystwyth research centres have been a major focus for interdisciplinary research in the REF period, e.g. the Climate Change Consortium of Wales ranges from physics to psychology. Freeman leads a £1.2M international interdisciplinary project on the implications for public health of rising dissolved organic carbon in drinking water; J Jones works with hydrologists, spatial modellers, economists and sociologists from institutions in many countries on payments for ecosystem services. Neill collaborates with Swansea University engineers to model the environmental impact of marine turbines in a £7M project. The Centre for Evidence-Based Conservation works with London Institute of Education social scientists in a World Bank/UNEP project on the impacts of protected areas on human wellbeing. Two Rural Economy and Land Use projects, involving researchers from multiple disciplines and institutions, assessed the merits of consuming vegetables produced locally and overseas, and how to reduce *E. coli* exposure risk in rural communities.

Among many examples of **collaborations with research users,** we highlight our work with Welsh Water plc addressing profitability and risks to the environment and public health, collaboration with the shellfish industry on projects related to pathogens, pollution and invasive species, engagement with the Forestry Commission and Woodland Heritage leading to a £1.1M Defra programme on the microbiology of acute oak decline, links with UK Met Office to develop improved models for weather forecasting, a £1.9M biofuels project funded by Shell, and joint projects with the UNEP/World Bank Global Environment Facility. Research funded by the NERC Macronutrients and Biodiversity & Ecosystem Services Sustainability Programmes involves major engagement with government agencies, businesses and NGO end users in the UK and overseas.

Roles in external bodies: D Jones, committee member Welsh Government Land Use Climate Change and Defra Biofuel Programme, advisor Bill and Melinda Gates Foundation (improving soil quality in sub-Saharan Africa and SE Asia); **Kennedy**, co-ordinating author Supplement to IPCC Guidelines on National Greenhouse Gas Inventories - Wetlands, president Challenger Society for Marine Science (2012-2014), UK member Scientific Committee on Oceanographic Research; **Pullin**, member Defra review groups on conservation (2011-2012); president European Section, Society for Conservation Biology (2008) and chair Science & Publications Committee (2008-2012); **Scourse**, president Quaternary Research Association, UK national representative International Union for Quaternary Research, UK quaternary science representative International Council for Science (2008-2011), chair NERC Radiocarbon Laboratory Steering Committee (2008-2011) and NERC Integrated Services Review Group (2012); **Thomas**, Chair NERC Arctic Programme Advisory Group (2010-present). *Other contributions:* NSF Review Panel for Climate Change Research (**Freeman**); British Ecological Society Grants Committee (**Hiddink**), Public and Policy Committee (**Pullin**, vice-chair (2008-2012); **J Jones**, member); Marine Studies Group Committee (**Kennedy**); at least 12 staff have served on NERC/BBSRC peer review colleges.

Staff have taken an active and prominent role in **conferences and public events** worldwide with at least half presenting invited keynote lectures. Select examples are: **Freeman**, chair Royal Society Discussion Meeting on *Geoengineering* (2010), keynote Finnish Academy of Sciences (2010); **Golyshin**, keynote 14th *International Biodeterioration and Biodegradation Symposium* (2008); **Jenkins**, keynote *Brazilian Congress of Crustaceans* (2012) and *10th Bioencrustation and Biofouling* (Rio de Janeiro, 2013); **D Jones**, head Scientific Steering Committee of the *Rhizosphere3 International Conference* (Perth, Australia, 2011); **Scourse**, inaugural lecture Cardiff University Public Lecture Series on *Our Changing Climate: Complex Science and Contentious Policy* (2011); **Scourse** and **Richardson**, exhibited at *350th Anniversary Royal Society Summer Science Festival* (2010) and (with **Butler**) organisers *3rd International Sclerochronology Conference* (Bangor, 2013); **Thomas**, chair (2007-2009) *Polar Marine Science Gordon Research Conference*; keynote *Earthwatch Annual Debate* at Royal Geographical Society (London, broadcast on BBC Radio 4, 2008); keynote Mathematical Bioscience Institute *Ocean Ecologies Workshop* (Columbus Ohio, 2011).

Editorships: Over one third of submitted staff (14) have acted as Editors of international journals during 2008-13, including **Freeman**, Guest Editor *Phil. Trans. Royal Society A*, *Climate Research*; **J Jones**, Senior Editor then Associate Editor *J. Applied Ecology*; **Pullin**, Editor *Biological Conservation*, Handling Editor *Conservation Letters*, Editor-in-Chief *Environmental Evidence*; **Scourse**, Executive Editorial Board *J. Quaternary Science*.

Fellowships, awards and prizes: **Butler**, the 2010 Lewis Penny medal of the Quaternary Research Association; **Freeman**, Fellow of the Society of Wetland Scientists (2013); **D Jones**, Senior Visiting Professorship in the Chinese Academy of Sciences (2011); **Scourse**, Royal Society-Leverhulme Trust Senior Research Fellowship (2008-2009); **Simpson**, the Nansen Medal of the European Geosciences Union (2008) which preceded the designation of *Si* the 'Simpson number' used in modelling estuarine processes; **Thomas**, Distinguished Professor of the Academy of Finland (2008-13).