Institution: Queen's University Belfast

Unit of Assessment: 7

a. Overview

The School of Biological Sciences at QUB includes two Research Clusters (Fig. 1): Molecular Biosciences (MB) and Ecology, Evolution, Behaviour and Environmental Economics (EEBEE). **The 26 staff (24.4 FTE) submitted in UOA7 consist of: (1) 21 (19.4 FTE) Ecology, Evolution and Behaviour researchers** in EEBEE, all involved in **Quercus** and working closely with five Gibson Institute environmental economists returned in UOA19; and **(2) five Environmental Microbiologists** in MB, all associated with **QUESTOR**. The School's 36 other staff (33.4 FTE) are in the UOA6 submission.

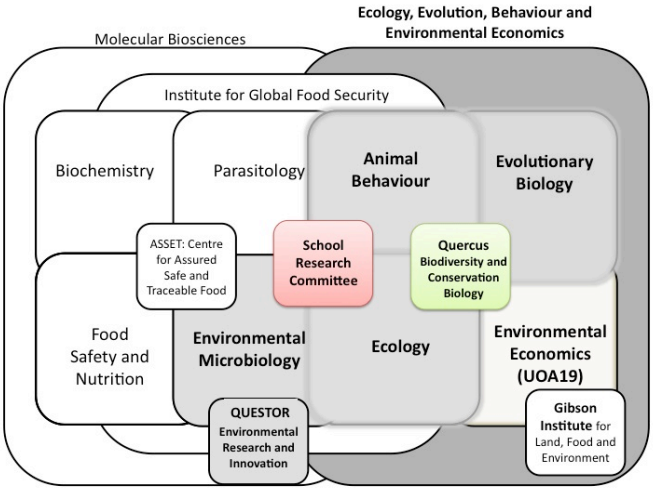

Fig. 1. Structure of School of Biological Sciences **(research included in this unit is shaded)**

b. Research strategy

Achievement of strategic aims during assessment period

Strategic aims laid out in RAE2008 for the Ecology, Evolution and Behaviour Research Cluster and environmental microbiology (in the Molecular Biosciences Research Cluster) were to: **(1) ensure that our conservation research will provide benefits for the environment at local to global scales, by obtaining long-term funding for Quercus; (2) promote interdisciplinary research with environmental economists; (3) encourage fundamental research that is internationally excellent; (4) pursue applied research with environmental/industrial impacts; and (5) respond successfully to changing opportunities and funding priorities.** The research strategy is overseen by the School Research Committee, including Head of School (HoS) and both Cluster Directors of Research (DRs). Our strategic aims have been achieved, incorporating opportunities and funding priorities as below:

(1) In 2008, Quercus (led by **Montgomery**) initiated **the Natural Heritage Research Partnership** (NHRP) funded by the Northern Ireland Environment Agency (NIEA), with core funding of £2M and total annual spend >£400K over 10 years. Quercus/NHRP has successfully combined research and societal impact, resulting in 74 applied conservation projects, 39 Government reports and 42 publications (e.g. papers in *Biological Conservation* on: [1] seabird foraging, [2] endangered freshwater bivalves, and [3] agri-environmental schemes for hares). An international programme of conservation projects has been expanded, in partnership with the Operation Wallacea Trust.

(2) To foster **interdisciplinary synergies between ecologists and environmental economists**, economists were brought into the Research Cluster in 2008. Now, economists lead a ***Quercus*** project on ecosystem services from peat bogs, with input from conservation biologists. ***CIRB*** (2011-2014; EU £2.6M) involves economists to determine costs of invasive riverbank plants. Our NERC consortium project ***CBESS*** (Coastal Biodiversity & Ecosystem Service Sustainability; 2012-2016; £263K to QUB), is a collaboration between ecologists (**Emmerson, O'Connor**) and an economist (Prof. Ric Scarpa). **Cameron** has an Ecosystem Services for Poverty Alleviation (ESPA) project in Madagascar, ***P4GES*** (Can Paying 4 Global Ecosystems Services reduce poverty?). **Cameron** and three environmental economists (Scarpa, Dr Alberto Longo and Prof. George Hutchinson) are members of NERC's ***Valuing Nature Network***. To enhance interactions, new economics appointments Scarpa and Boeri are co-located with ecologists.

(3) To promote **excellent fundamental research**, the unit has adopted a theoretically led focus on important questions in ecology, evolutionary biology, animal behaviour, and environmental microbiology; this has been funded, and resulted in high-profile publications, as exemplified here:

Ecology: Emmerson (appointed 2011) quantified the role of strong and weak interactions in food

web stability (*PNAS*, 2009). **Lennon** (appointed 2012) showed that species–climate associations found by climate envelope methods are no better than chance for 68 of 100 European bird species (*PNAS*, 2008) and provided the first evidence of climate-driven range shifts for an African bird community (*Ecology Letters,* 2013). **Montgomery** established the Centre for Irish Bat Research with University College Dublin (with €500K from National Parks & Wildlife), and discovered evidence of 'invasional meltdown' caused by invasive small mammals (*Biological Invasions*, 2012). **O'Connor** (appointed 2010) showed that losing apparently similar species from marine ecosystems can have drastically different effects (*Global Change Biology*, 2013). **O'Connor** and **Emmerson** developed a new conceptual framework for quantifying multiple forms of stability (*Ecology Letters,* 2013, listed by Faculty of 1000 PRIME). **Rossberg** published (Wiley, 2013) a book describing a theory linking food-web structure, biodiversity and niche space.

Evolution: **Paxton** showed that cryptic plasticity underlies the major evolutionary transition to eusociality in bees (*Current Biology*, 2010); his Insect Pollinators project (BBSRC, £460K) researches emergent honeybee pathogens. **Cotter** (NERC Fellow) addressed the interplay between hormones, reproductive effort and the immune system to discover the evolutionary costs of maintaining and mounting an immune response (*Ecology Letters*, 2010). **Maggs** contributed to the international red algal Tree of Life project by highlighting uncertainties in the tree (*BMC Evol. Biol.,* 2010). **Provan** and **Maggs** demonstrated the importance of rear-edge populations as reservoirs of genetic diversity in seaweeds under immediate threat from global climate change (*Proc. Roy. Soc.*, 2012). **Sigwart** (appointed 2009) focuses on evolution and systematics in marine molluscs – her 2012 *Nature* paper showed definitively that, although living chitons have the same shell form as their ancestors 300 million years ago, the fossils have a radically different body plan.

Animal behaviour: Elwood developed experimental approaches to elucidate decisions by fighting animals (e.g. *Animal Behaviour*, 2009, >100 cites). **Holland** (appointed 2011) showed that bats use the Earth's magnetic field as a compass, calibrated through an interaction with the sunset (*PNAS,* 2010), and obtained a NERC new investigator grant on bat navigation. **Houghton**'s 2010 *Nature* paper on Lévy and Brownian movement patterns of marine predators was ranked by the Faculty of 1000, and listed by US science magazine *Discover* as one of the year's 100 most important scientific studies. **Houghton** and **Montgomery** described temporal switches of foraging behaviour in insectivorous bats (*J. Roy. Soc. Interface,* 2012). **Kunc** provided experimental evidence that changes in animal behaviour in response to environmental change are based on behavioural plasticity rather than evolution (*Am. Nat.,* 2010). **Scantlebury** used a NERC new investigator award to examine energetic constraints associated with foraging ecology and adaptation to the environment of the cheetah, a super-predator (*Biology Letters*, 2013).

Environmental microbiology: **Allen** and a Canadian team showed (*Cretaceous Research*, 2013) that coprolites from extinct marine lizards record ancient microbial environments. **Hallsworth**'s pioneering studies on microbial stress biology and the limits to life identified novel types of solute stress (*PNAS*, 2010). **Kulakov**'s metagenomic investigation of micro-organisms in Lough Neagh is funded by Leverhulme. **Larkin** was funded by BBSRC to develop a novel electron transfer system for oxido-reduction bioprocesses using rhodococci. **Quinn**'s international collaboration on biochemical and genetic aspects of organic phosphorus cycling in the environment elucidated the structure and mechanism of the enzyme phosphonoacetate hydrolase (*Biochemistry*, 2011).

(4) Applied research on ecological management, fisheries, aquaculture, conservation, invasions, animal welfare and environmental microbiology at local and global scales has resulted in many successes, such as the following examples:

Cameron (appointed 2010) influenced the designation of 6% of Madagascar as protected areas, and advises the government on development of a national reforestation policy and the consequences of climate change for biodiversity conservation (*Science,* 2008). **Dick,** with leading invasion ecologists from Canada and South Africa, predicts the ecological impacts of invasive species using comparative functional responses, with funding from NERC and Leverhulme. **Roberts** is developing integrated aquatic resources management with the Loughs Agency and University of Glasgow (IBIS project, £1.2m; 2012-2015). **Farnsworth** has Irish government funding (£900K) for an Ecosystems Approach to Fisheries Management (EAFM), with practical applications, such as projecting outcomes of ecologically oriented fisheries management strategies. **O'Connor** developed marine monitoring tools for the Water Framework Directive; **Rossberg's** work is influencing development and implementation of food-web indicators for the

EU Marine Strategy Framework Directive. **Environmental Microbiologists** benefit from QUESTOR's industrial links and leveraging potential to exploit national and international opportunities in biodegradation, nutrient cycling, biotechnology, bioremediation and microbial stress biology; there are five ongoing interdisciplinary initiatives (**Larkin** is PI for ATWARM and ATBEST) totalling £15M in value.

Vision and strategic plans

Our vision for the future is to build on our expertise and approaches with external guidance from our **International Scientific Advisory Board,** including global research leaders in microbiology, Prof. Rita Colwell and Prof. Lubbert Dijkhuizen, and evolutionary ecologist Prof. Nils Christian Stenseth. Their wide experience is helping to shape our research strategy.

We will: (1) **Exploit new opportunities at the interface of ecology, genomics and bioinformatics** arising from rapid developments in hardware and software, in approaches such as phylogenomics, metagenomics and synthetic biology. A School-wide systematic review early in 2014 will inform options and facilitate decisions about future platforms and investment strategy.
(2) Improve research facilities and infrastructure in Belfast and at QML, in particular **to maximize the value for research of the School's new, £32million (2017) building**, providing a supportive social environment for research alongside excellent laboratory facilities. Shared laboratories with specialist research equipment and nearby interaction space will provide opportunities for synergy.
(3) Foster **fundamental and theoretical novel**, high-quality research in strategic areas of ecology, evolution, animal behaviour, and environmental microbiology; promote synergies between existing staff and strategic new appointments.
(4) Promote **applied research,** delivering impacts at local to global scales.
(5) Exploit **diverse research funding sources** to maximize awards.
(6) Produce **highly educated and skilled future research leaders**.

The strategy will be delivered through the following specific forward research plans:

***Ecology*: Cameron,** to complement conservation work in Madagascar, is developing a program of research in Ireland on the landscape ecology of bioenergy crops, aiming to conserve biodiversity and deliver agro-ecosystem services. **Caruso** (appointed 2013) will establish a soil biodiversity lab, network with established international research groups, and apply for an ERC Consolidator Grant within Horizon 2020. **Farnsworth** will further develop EAFM through EU partnerships and advance information-based understanding of biodiversity. **Houghton** will explore the trophic impact of jellyfish blooms on pelagic ecosystems and exploit jellyfish collagen for biomaterials. **Lennon** will include species traits (e.g. trait richness rather than species richness) to understand the likely impacts of environmental change on ecosystems. **Montgomery** will experimentally investigate the impact at individual to ecosystem levels of species replacements due to multiple invasive species. **O'Connor** will research the effects of multiple stressors on the diversity and functioning of coastal ecosystems, to quantify ecological disturbances and the contribution of primary producers; she is applying for NSF/Ireland funding for marine biofuels. **Dick** will expand his collaborations on invasion ecology research in South Africa, Canada, USA and China.

***Evolution*: Cotter** is seeking grant funding (BBSRC, MRC) for a geometric nutritional modelling approach to assess the nutritional requirements of an ageing immune system, in states of health and parasitism, and to test the micro- vs macro-parasite paradigm in the innate immune response. **Maggs** will use NERC funding for a full scaffold genome sequence to complement next-generation sequencing (NGS) of the sea lettuce *Ulva*. BBSRC funding with India (2014-2017; lead PI: John Bothwell, Durham) will use selective breeding of *Ulva* for biotechnology. Whole (organellar) genome sequencing with Dr Heroen Verbruggen (Melbourne) will explore key innovations in the large red algal family Rhodomelaceae. **Provan** will determine the distribution of genetic diversity across species' ranges (plants, algae), exploiting the potential of new developments in NGS and bioinformatics to assess the potential for natural populations to adapt to current and future global climate change. **Sigwart**'s future work will focus on linkages between environment and evolution, and the diversification dynamics of molluscan body plans at a range of time scales, building on her recent ground-breaking discovery of a novel sense organ in primitive molluscs.

***Behaviour*: Holland** will build on NERC funding to investigate the sensory and cognitive mechanisms of orientation, navigation and migration in bats and birds, and use the annual killifish as a new vertebrate model for ageing and cognition (he is applying for a Wellcome Trust new

investigator grant). **Kunc** will contribute to the emerging field of behavioural conservation – how environmental change affects animal behaviour (reproductive success, population viability, and habitat selection). **Scantlebury** will examine thermoregulation and energy expenditure in *Oryx* in Saudi Arabia ($500K from NSF), developing new approaches to interrogate energetic constraints of mammals and using tri-axial accelerometers to assess movement; he will determine the costs of disease (e.g. bacterial infection, parasitism, diabetes) in models including rats, badgers and cattle.

***Environmental Microbiology*: Allen** and **Larkin** will exploit biocatalysis of oxidoreductases and their directed evolution through synthetic biology, with funding from Almac Biosciences and SynbiCITE, the Innovation and Knowledge Centre in synthetic biology led by Imperial College. **Kulakov** will lead new metagenomic approaches to biocatalyst development. **Quinn** will extend studies of phosphorus metabolism by activated sludge microorganisms to novel routes of microbial organic phosphorus metabolism in the marine environment and soils, using metagenomic and metatranscriptomic approaches. **Hallsworth**'s work on microbial stress biology will be applied to astrobiology and optimization of soil health in arid regions and biofuel yields.

c. People, including:

i. Staffing strategy and staff development

Staffing strategy and infrastructure: The unit's research strategy prior to and since RAE2008 has promoted both fundamental and applied research. EEBEE expanded, with 9 staff appointed during the assessment period. Strengths in biodiversity were enhanced with strategic investments: a new Chair in Biodiversity, **Emmerson**, a senior lectureship in community ecology (**Lennon**), and a lectureship in climate change and mitigation (**Cameron**), all closely linked with the environmental economists returned in UOA19. A new post in animal cognition (**Holland**) links ecology and animal behaviour, and **Cotter** works at the interface between ecology, evolution and physiology. Gap analysis led to the recruitment of soil biologist **Caruso**. Rapid expansion of environmental microbiology in 2005 integrated research in biodegradation, nutrient cycling, biotechnology, bioremediation and microbial stress, with applications in pollution. A suite of adjacent laboratories has excellent research infrastructure including bioreactors for scale-up to pilot plant levels.

To capitalize on our geographical position and historical strengths in marine biology, we have selectively invested in academics with marine interests: **Sigwart**, John Bothwell (moved to Durham 2013), **Houghton**, **O'Connor**, and **Emmerson**. **Sigwart** is Director of the Queen's Marine Laboratory (QML) at Portaferry, and other staff are encouraged to have bases at both QML and in Belfast, using shared offices, to increase cohesion, and provide a better environment for PhD students and PDRAs based at QML.

Support for career development of academics: New academic staff have a 3-year probationary period, complete a Postgraduate Certificate in Higher Education and Teaching, and receive formal training in graduate student supervision. A probation committee of three senior academics monitors progress by annual reports and meetings, with detailed feedback. Each new appointee is assigned a mentor who provides help and advice on research development, at regular formalized meetings. Mentors ensure that new appointees experience a friendly and supportive environment to help guide them towards confirmation in post. All new staff benefit from the provision of essential research facilities, start-up funding, a three-year restriction on teaching load and at least one fully funded PhD studentship. Promotion criteria are discussed during annual appraisals with senior staff, and QUB provides annual promotions workshops.

Implementation of the Concordat to Support the Career Development of Researchers: The principles of the Concordat are fully implemented in our unit as an important element of our SWAN Gold Award action plan. In addition to the range of training and mentoring programmes across the University that help new research and academic staff develop key skills, we provide support at the School level for early stage researchers to develop their careers. Our **Postdoctoral Forum** was established in 2010, with support from the School's SWAN Self-Assessment Team, to provide information to aid career and personal development. Feedback from an anonymous questionnaire to all Postdoctoral staff provided an informed framework, to ensure the aims and objectives of the Forum meet expectations. All contract research staff are members of the Forum and are encouraged to attend its meetings and workshops. The Forum is a platform promoting social interaction, opportunities for career advancement, networking, and general support. It has sessions to provide pertinent career information and support, such as workshops on 'Grants and

Fellowships' (Nov 2012), 'REF, Citations and Research Output' (Jan 2013) and 'Career Management – The How to Guide' (March 2013). The annual reception for New Research Staff provides an ideal setting to network with academic staff, and discuss research/grant opportunities. Postdoctoral representatives sit on the School Board, and can raise any issues or queries from the Forum, ensuring that it is integral to the School and can influence decisions that affect postdocs. Our postdocs generate many excellent ideas for improving their research environment; these are implemented where possible. Full annual appraisal with PIs is strongly encouraged.

Personal research fellowships: Cotter is a NERC Research Fellow appointed to a lectureship in the School; she started the fellowship in October 2010. Prior to appointment at QUB, **O'Connor** held an Irish Environmental Protection Agency Postdoctoral Research Fellowship, 2008-2010; **Caruso** won an Alexander von Humboldt personal research fellowship, 2011-2012.

International staff appointments and international recruitment: We recruited academic staff from Ireland (**Sigwart, O'Connor, Emmerson**) and Germany (**Cameron, Holland, Caruso**). More than half of the postdoctoral staff are international, from the EU and New Zealand, USA, Canada, Russia, Ethiopia and Japan. The quality of applicants we attract is exemplified by **Holland's** NERC-funded post, which had 20 applicants from 6 countries – the appointee was from the Max Planck Society (Germany) and the reserve from Lund University (Sweden). Staff with external international appointments include: **Dick**: Collaborator in Invasion Biology, Stellenbosch, South Africa; **Scantlebury**: Extraordinary Lecturer, Mammal Research Institute, University of Pretoria; **Sigwart**: Visiting Lecturer, University of Washington (Friday Harbor Labs), USA.

Visiting scholars: Prof. Josh Eagle, Professor of Law at the University of South Carolina, was a **Fulbright scholar** visiting QML in 2013. **Cotter** hosted **Science without Borders** research fellow (**F. Silva**); **Roberts** hosted 5 visitors between 2010 and 2012 from the **Centre of Excellence in Marine Biology, Karachi**; **Provan** hosted Dr Jie **Liu** (**Kunming Institute of Botany, China**) for 6 months research. **Dick**, **Emmerson, Maggs** and **Montgomery** have hosted Visiting Research Fellows from Liège, Madrid, McGill, Munich, Padua, Rio de Janeiro and Sydney.

Supporting equalities and diversity: In May 2013 the School achieved a **SWAN Athena Gold award**, one of only three in the UK, and the first in biological sciences. QUB plays a leading role in promoting the role of women in higher education, and Biological Sciences was the first School in QUB to gain a Silver award (2008). Under our SWAN mission, we support equality and diversity. We monitor gender statistics at all levels, from work experience placements to professorial advancement. We have practical measures such as research-only periods for academics returning from maternity leave, and a female lecturer is co-opted to the School Management Board to address the lack of women at higher levels. Our 2008 action plan addressed several gender parity bottlenecks in the academic pipeline, and the School has shown a continued improvement in the proportion of female academics. We attract female applicants for academic positions through rigorous staff recruitment and promotion processes that recognize and reward internationally leading research. Our transparent workload model ensures that females make a fair, but not disproportionate, contribution to teaching and administration. QUB is fully compliant with the Disability Discrimination Act and we provide work experience for young people with disabilities.

ii. Research students

Recruitment: We have a robust, consistent and highly successful approach to recruitment of postgraduate research students. Typically we receive 7-8 Department of Employment and Learning (DEL) quota studentships annually for UOA7 staff. Of these 2-3 are directly allocated; the others are 'leveraged' by large RCUK grants or 50% external industrial or stakeholder co-funding for international places (e.g. student from Mauritius co-supervised by the University of Malaya). Strategic interdisciplinary awards are obtained competitively. Proposals by academics for DEL projects are screened for financial feasibility and scientific merit by both DRs, with priority going to new staff to help them establish quickly. Approved projects are aimed at recruiting the very best PhD students; they are advertised on FindaPhD.com and the School website, with closing dates, interviews and offers in February-March to secure the best applicants. We typically have around 20 applications for each project, often more (c. 200 in 2013 for a Madagascar project). Each year the DRs chair panels of experienced interviewers and ECRs to shortlist and interview applicants using established criteria. This year's successful applicants include Kyriacos Kareklas, whose MSc project was published in *Biology Letters* and widely publicized (Why do fingers wrinkle in water?).

Studentships (3 or 4 years) are also funded from a wide variety of other sources, including government agencies (e.g. NIEA via Quercus, Irish National Development Plan – Beaufort; Teagasc–Walsh; SeaFish; NSERC), industry (e.g. through QUESTOR), EU Interreg (IBIS) and RCUK (e.g. CBESS). Each year we attract 2-5 students making successful applications for priority themes of the NI Department of Agriculture and Rural Development. These other studentships also attract excellent applicants: the CBESS PhD "Testing descriptors for non-market valuation of benefits from biodiversity" is being undertaken by Justin Grainger, who had 20 years' experience in senior financial management and a Marine Biology degree. International PhD students are self-funded or come through schemes such as Brazil's **Science without Borders.** The unit's success is demonstrated in the increasing number of new PhD students: averaging 10 per annum from 2008/9-2009/10, it has risen to c. 20 each year (2012/13: **19** + 4 MPhil; 2013/14: **20** + I MPhil).

Supervision: All students have a minimum of two QUB supervisors; if one is on probation, the other must be a senior academic. The quality of supervision is high: our academics interact closely with their students, limited to a maximum of 6 primary supervisions. Since 2008, **54 postgraduate students have completed doctoral training in the unit,** 44 in EEBEE and 10 in environmental microbiology. During the assessment period, academic staff numbers have increased. Post 2010, strategic appointments have increased the capacity for supervision and this is now reflected in our increased annual intake of PhD students.

Training and support: In their first semester, students participate in the Foundations in Postgraduate Research module, with introductory drinks reception, Health and Safety, and generic Skills Training. In addition, students enrol in a University Researcher Development Programme and undertake a minimum of 30 days training and development activity. The School supports student attendance at bespoke student-led courses and funds at least one international conference. The Staff-Student Consultative Committee meets each semester and provides a forum to identify problems and seek agreeable resolutions in an open and friendly environment. The HoS and Postgraduate Committee Chair also provide support. There are regular events for social and scientific interaction including coffee mornings and journal clubs. Students are strongly encouraged to attend our weekly research seminars given by visiting speakers and staff members.

Progress monitoring: A rigorous monitoring and reporting regime requires each student to complete an Initial Review at 3 months and Differentiation at 6-9 months. Each stage involves an advisory committee of three academics plus supervisors, and reporting forms help the student understand what is required. Following Differentiation, students submit annual reports. In addition to informal supervisor-student interactions, students have six formal meetings with their supervisors each year and give a presentation annually in the research seminar series.

d. Income, infrastructure and facilities

Research facilities in Belfast: EEBEE primarily occupies two floors of the Medical Biology Centre (MBC), recently completely refurbished to provide high-quality laboratory and office space (**Level 6: completed 2007, cost £1.1M; Level 5: completed 2011, cost £1.7M**), supported by a core-funded technician. *Genetics***:** an ABI 3730XL genetic analyzer is used for microsatellite and AFLP genotyping, and DNA sequencing. *Environmental microbiology* has a high-throughput cultivation system for marine microorganisms and facilities for fluorescent microscopy, molecular biology and microbial ecology. Metagenomic methods (including pyrosequencing at NERC's Biomolecular Analysis Facility) and bioinformatics are linked with analytical approaches such as solid-state NMR and mass spectrometry based in QUESTOR. Investment in *NGS technology* is planned, possibly in partnership with industry, supported by the School's recent appointment in bioinformatics (Dr Caroline Meharg). *Ecological Theory and Computational Biology:* Mathematical and computational models of marine food-web and size-structure population dynamics are supported by dedicated computational facilities housing high-performance servers, a bio-mathematics library and relevant software tools. *Fieldwork equipment*: includes 4x4 vehicle, quad bike, small boats, and GPS-guided quadcopters. *Elemental analysis– isotope ratio mass spectrometer* (EA-IMS) (for stable isotopes of C and N), and accelerator mass spectrometer *radiocarbon-dating facilities* are available nearby in the ^{14}CHRONO Centre for Climate, the Environment and Chronology.

New building: In 2017 we will consolidate all Belfast-based research activities into a purpose-built research and teaching facility designed to accommodate significant growth and specifically for our research needs, with large ecology and molecular research laboratories, specialist procedure rooms, multiple CT rooms, seawater supply, and greenhouses. Funds (> £30 M) have been

committed by QUB and planning for the move is at an advanced stage.

Queen's University Marine Laboratory: on Strangford Lough at Portaferry, 50 km from Belfast, QML is a specialist facility for marine sciences providing infrastructure for biological research and a platform for interdisciplinary work (marine renewable energy, coastal defenses) in space shared with the School of Planning, Architecture and Civil Engineering. **Sigwart** directs infrastructure and facilities, reporting to the School Management Board and HoS. A 5-year strategic plan (2010-2015) has improved the use of office and laboratory space, optimizing efficiency and staff communication (**investment of c. £200K from School and QUB Estates**). A guiding principle is to increase engagement by non-resident users, external collaborators and international visitors, who regularly use the teaching laboratory for research, training and field courses. New remotely accessible booking systems and clear costings for key infrastructure (e.g. boats) have improved transparency and therefore usage. Implementation of the strategic plan has increased the user base for QML facilities from approximately 8 to 55 regular users (staff, students and associates).

Infrastructure and facilities: A *flow-through filtered seawater system* (200 tonnes per day) is the primary unique infrastructure, supporting 100 x 45 litre *mesocosms* that are individually temperature controlled to create experimental benthic communities mimicking natural rock pools or shallow subtidal systems. Other facilities include a 120-channel *autoanalyser*; two *research boats* for near-shore work, RV *Cumella* and RV *Bubbles*; HSE-approved *SCUBA* facilities; *Microscopy* for histology and 3D tomographic reconstruction is unique in Britain and Ireland. Specialist facility for large-scale *macroalgal culture*, including seabed license in Strangford Lough for long-line cultivation, one of only three available to UK universities. **Support staff**: Two core-funded technicians with clearly defined roles and responsibilities cover all potential user needs including specialist research facilities, and contribute matched salary costs for Interreg-funded projects.

Research funding portfolio: Overall, research income has been sustained at over £2M per year since 2008/9, increasing to over £2.5M in the last two years. The diversity of sources reflects the success of our strategy of seeking funding for both fundamental and applied research. **RCUK** income increased steadily to nearly £0.5M in 2012/13, more than doubling from 2008/9, tracking our investment in excellent new academic staff. The unit is increasingly successful in NERC and BBSRC grants including consortium, early career and research fellowships. **EU funding**: We have grants from various FP7 funding streams such as Marie Curie and KBBE, and are planning for Horizon 2020. Interreg IV structural funding programmes provide large grants (QML and Belfast), which we will seek to renew. **Government**: five more years' funding by NIEA for Quercus is assured. **Industrial collaboration**: environmental microbiologists have KTPs and Proof of Concept grants with Almac Sciences and are developing them with Whiteford Geoservices and DMAC Engineering. A QUB Proof of Principle award in 2013 will improve commercialization with companies such as Sekisui and Procter & Gamble. The new NI Centre for Advanced Sustainable Energy (CASE) will provide opportunities for funding bio-energy projects. Membership of the SynbiCITE Knowledge and Innovation Centre for synthetic biology will allow bids for industry funding both within the project and externally (e.g. TSB calls).
Consultancies and professional services: Allen, Almac Sciences and DMAC Engineering; **Cameron**, the US Agency for International Development (USAID) for "Integrating Climate Change Adaptation into Biodiversity and Forestry Assessments"; **Paxton**, BASF on wild bees (pesticides).

e. Collaboration or contribution to the discipline or research base

National and international research collaborations: All academics in our unit have extensive international collaborations and more than 50% of our publications have international co-authors. Our collaborations are supported by a range of financial and other measures. These include: (1) sabbatical leave opportunities; (2) endowment support for the New Brunswick/QUB Eaton exchange programme; (3) international funding opportunities e.g. Royal Society circulated regularly by HoS and DR; (4) applications for EU research grants are supported financially, e.g. **InvestNI, Intertrade Ireland**, and logistically – **QUB Research and Enterprise staff**: identify and promote new research funding opportunities; provide expert support and professional guidance to develop applications; co-ordinate development of large-scale or strategic institutional bids; organise training activities such as workshops, networking events, funder events; and engage with major funding organisations and key external stakeholders.

Examples of collaborations include: (1): **Dick**, 3 months Leverhulme-funded sabbatical in 2012 at the Centre of Excellence for Invasion Biology in Stellenbosch, South Africa, resulting in postdoc

exchange and 5 collaborative publications; (2) **Eaton-funded** visits (2010-2013) by Prof Mike Duffy, Dr Tony Einfeldt and two PhD students and (3) **Scantlebury**'s collaboration with Prof N Bennett and Dr Gus Mills on physiological ecology of cheetahs in South Africa, funded by NERC/Royal Society, involved 10 visits over 4 years; **Houghton** had Royal Society funding to visit Dalhousie University, Canada, in 2010, to establish links with Prof. Ron O'Dor (Ocean Tracking Network, Census of Marine Life); **Holland**'s NERC-funded work is a collaboration with the Max Planck Institute for Ornithology and Tel Aviv University's bat research station in Bulgaria.

Interdisciplinary research: Interdisciplinarity is specifically promoted through strategic PhD studentships between Schools and disciplines. Beaufort funding from Ireland (total £2.5 M) led to close collaborations with Mechanical & Aerospace Engineering and Pharmacy. Our membership of SynbiCITE, the synthetic biology Innovation and Knowledge Centre, includes other Schools in QUB. **Caruso** (started 2013) participates in the Terrestrial Antarctic Biocomplexity Survey with scientists from NZ, USA, UK, China, Germany, Spain and South Africa, whose backgrounds range from soil molecular microbiology to large-scale geological and atmospheric systems.

Research collaborations with research users have informed research activities and strategy: Throughout our unit, collaborations with users have been beneficial in informing our research activities and strategies, as described in our impact template and case studies. **Holland**'s research on the mechanisms of migration in birds has extended to the possible role of migration in introducing pathogens to Lough Foyle and Carlingford Lough, funded by the IBIS aquaculture project. In collaboration with Northern Ireland Water and the EPA (RoI) **Quinn** developed a novel process for phosphorus removal from wastewater, with ongoing research on process improvement and the underpinning biochemistry and genetics. Through the IBIS Project and SeaFish grants the shellfish industry's need for improving yield and quality, by reducing stress during transport, led directly to research by **Sigwart** on oxygen physiology of marine invertebrates.

Examples of leadership roles contributing to the discipline

Advisory Board Membership: **Emmerson:** National (Ireland) contact for Diversitas; **Larkin**: Steering Committee, UK Integrated Pollution Management Network (to 2011); **Cameron**: Madagascan National Biodiversity Database. **Rossberg** is UK delegate to ICES and OSPAR.

Research Councils. **Membership of RCUK peer-review panels**: NERC – Bothwell, **Emmerson**, **Houghton**, **Larkin**, **Maggs**, **Provan**, **Quinn**; EPSRC – **Allen**; BBSRC – **Larkin**).

Learned societies: **Elwood**: Treasurer and President, Association for the Study of Animal Behaviour; Convenor and Treasurer of International Council of Ethologists; **Maggs**: Past-President, International Phycological Society; **Paxton**: Vice-President European Bee Research Association.

Conference programme chairs: **Kulakov:** SGM international meeting "Microbial Viruses", 2011; **Maggs:** Organiser, 8th Biennial Systematics Association, 2011; **Montgomery**: Organiser, 11th International Mammalogical Congress, 2013; **Paxton**: Co-Organiser of EurBee 5 conference, Halle, Germany, Sept 2012; **Provan**: Ecological Genetics Group, 2013. **Dick**: Organiser, Freshwater Invasives – Networking for Strategy Conference, Galway, 2013.

Invited plenary lectures: **Cameron**: Government Workshop on Climate Change, Madagascar, Jan 2008; **Cotter**: Co-evolution conference, University of Jyvaskyla, Finland, Oct 2011. **Elwood**: Lab Animals Veterinary Association Conference, Manchester, 2009; **Houghton**: University of Bath Millennium Lecture in 2011. **Sigwart**: World Congress of Malacology, Thailand, 2010.

Membership of the Royal Irish Academy (**the highest academic honour in Ireland**): **Montgomery** (2005), **Elwood** (2008), **Maggs** (2013).

Journal editorships – **Editor-in-Chief:** *European J. Phycology* (**Maggs**); **Associate Editors:** *J. Animal Ecology* (**Cotter, Montgomery**), *Ecological Entomology* (**Cotter**), *Biological Invasions* (**Dick**), *Marine Biology* (**Houghton**); *Applied & Environmental Microbiology* (**Larkin, Quinn**); *J. Applied Ecology* (**Lennon**); *J. Biogeography* (**Maggs**); *Animal Behaviour; BMC Evolutionary Biology* (**Provan**); *American Naturalist* (**Rossberg**); *J. Zoology* (**Scantlebury**); *Marine Biology Research* (**Sigwart**); *Pedobiologia* (**Caruso**).

Awards and prizes: **O'Connor**: 2008 MarBEF (Marine Biodiversity and Ecosystem Functioning – EU Network of Excellence) Award for Excellence; **Holland**: 2011 Grocott award, Royal Institute of Navigation; **Houghton**: 2013 British Science Festival Charles Lyell award.