Institution: University of Essex

Unit of Assessment: 5 - Biological Sciences

a. Overview

The School of Biological Sciences teaches and conducts research on topics ranging from the structure and function of biomolecules to global environmental issues. Given the wide range of research interests and activities across biology, we provide critical mass by assigning our research staff to one of two research groups dependent on the major focus of their research. The **Environmental and Plant Biology** group (**EPB**) conducts research in two main areas: Ecology and Biogeochemistry, and Plant Productivity. The EPB group is led by Mullineaux and includes three other professors (Geider, Raines, Underwood), a reader (McGenity) two senior lecturers (Suggett, Whitby) and three lecturers (Bechtold, Dumbrell, Steinke), two of whom are early career researchers (ECRs), a University-funded Research Fellow (Lawson) and a Leverhulme ECR Fellow (Jones). The group includes 14 post-doctoral researchers, 35 PhD students and is supported by 10 technicians. The **Molecular and Cell Biosciences** group (**MCB**) has two main research foci in the areas of Disease Mechanisms, and the Structure and Function of Molecules. The MCB group is led by Klenova, a reader (Zwacka), two senior lecturers (Mason, Metodiev), and seven lecturers (Brooke, Hough, Kad, Marco, Reeder, Reeves, Worrall), three of whom are ECRs. This group has close interactions with the biophysicist Cooper, who is part of the University's submission to UoA 26. The MCB group includes 4 post-doctoral researchers, 50 PhD students and is supported by a research fellow (Svistunenko) and 7 technicians.

The School Director of Research (DoR) oversees the School's **Research Strategy Group (RSG)**, which is responsible for the development and maintenance of a vibrant research environment, the implementation of the School's research strategy and policies, overseeing mentoring and progression of PhD students and ECRs, administering seedcorn funding, and providing critical support in research proposal preparation and submission. The membership of this group includes the Head of School, the lead professors of the EPB and MCB groups plus one additional member of staff from each group, the Postgraduate Director and the Director of Education. The DoR and RSG are supported by a dedicated research administrator.

b. Research strategy

Our research strategy aims to create a culture and infrastructure that fosters excellence, innovation and academic leadership and enables fundamental and applied research focused on addressing key challenges facing society in the areas of the environmental quality, food security and human health. EPB has a tradition of internationally recognised research excellence in the areas of photosynthesis and plant metabolism with allied molecular genetics applied to plant-environment interactions, marine primary productivity and biogeochemical cycling, coastal ecology, microbial ecology, and biotechnology. MCB's strengths are in protein structure and dynamics, haem proteins and structural bioinformatics. Importantly, MCB is engaged in translational research and has strong links with regional hospitals through the Essex Biomedical Sciences Institute (EBSI), the Director of which is Klenova (Lead for the MCB). EBSI facilitates research by providing access to clinical samples and enables collaboration with clinical research fellows. The complexity of biology demands multidisciplinary approaches, and so a key component of our strategy has been to build strong collaborative links locally with colleagues in the Department of Mathematical Sciences and School of Computer Science and Electronic Engineering, as well as nationally and internationally (see section e.2).

b.1. Strategic Aims & Objectives for 2008-2013: Following the RAE 2008, we developed a strategy to facilitate world leading and internationally excellent research. Our objectives were:

1. To create critical mass by re-organising our research groups and through appointment of additional Category A staff in areas of established excellence.
2. To invest in new equipment to enable innovative and cutting edge research.
3. To improve the research environment of the School including more rigorous procedures for mentoring ECRs and for insuring progression of PhD students.
4. To increase participation in external collaborations and in directed programmes where we could make unique contributions.

We successfully implemented this strategy by consolidating our existing research strengths and by establishing four new research strands, two in EPB (plant signalling in stress and microbial ecology theory) and two in MCB (protein structure and function, and signalling networks in cancer and stem cells). New appointments were made in each of these areas as described in section c1.i below. We also invested in equipment and refurbishment of laboratories (£1,100,000), a microscopy imaging suite (£690,000) and a state-of-the-art proteomics facility (£400,000), and appointed two permanent senior research officers and two permanent research fellows to provide technical expertise for this new equipment. These facilities have been employed in 13 externally-funded projects with a total value of over £3 million and contributed to the delivery of 11 papers for REF2014. The overall success of the 2008-2013 strategy is shown by the quality, focus and range of the papers that we submit in our REF2 entries (highlights of which are briefly summarised in section b.3 below) and by the vibrancy of the research culture and environment that is described in the remainder of this document.

b.2. Research Strategy for 2014-2019: The University has indicated that it wishes to **increase the number of internationally excellent category A staff in Biological Sciences by 50% by 2019**. Our over-riding aim in the period 2014 to 2019 is to at least double our per capita research income and increase substantially the number of 4* papers. To achieve this we will:

1. *Maintain and expand areas of current research excellence.*
2. *Invest in new and developing technologies to enable innovative research and to facilitate novel approaches to pressing questions across the biological remit.*
3. *Ensure wider non-academic impact arises from our research*
4. *Seek internal and external support to facilitate expansion of our infrastructure and facilities.*

The immediate (12-18 months) priorities will be to ensure that our new **ECRs are integrated into the research ethos of the School and are given the best possible opportunities to excel; to increase the capacity of the EPB group** to ensure the excellence in research in this group is sustained and expanded**; to provide internationally excellent leadership to the MCB group;** and to provide support to **enhance the performance of our existing successful staff**.

Over the next REF cycle we will make five new appointments at the professorial level, with additional appointments at lecturer/senior lecturer levels to complement and add critical mass both to our existing areas of excellence and to those areas aspiring to international excellence. Within EPB, these appointments will help to ensure succession and to provide leadership in the areas of **environmental and plant genomics and bioinformatics.** We will make new appointments (one at the professorial level) in **metabolic modelling/synthetic biology** based on plant, algal and bacterial systems that have environmental and biotechnological applications. This strategy will be supported by further investment aimed at strengthening our regional and national links through a newly announced University initiative, the **Eastern ARC** (a research consortium involving the Universities of Essex, East Anglia and Kent) that will support the appointment of Research Fellows and PhD students across the three institutions. This will be initiated in 2014 by the appointment of a Research Fellow and PhD student in Synthetic Biology in each of the institutions.

Within MCB, senior appointments in the area of **genomics/epigenomics and protein structure/ function** will be made to provide leadership to the large number of junior staff in this group and to raise research income and quality of research outputs. Part of this strategy is already being implemented in the form of a **University-funded cross-Faculty genomics initiative**, which complements the ESRC investment of £4 million for links between Essex's Institute for Social and Economic Research (ISER) and the Sanger Institute. The first stage of this has provided **£1,500,000 to appoint five new academic staff** and a laboratory manager in Biological Sciences, to **create purpose built laboratories** and purchase equipment to support the establishment of this facility. This has led to the appointment of a lecturer in 2013 (Marco), and the recruitment of a Professor to lead the group is on-going; with three further academic appointments planned for 2014/15. **Bioinformatics** to underpin both the genomics capability and the ongoing and future research activities across the School will be further developed in the coming year. We have one new appointment in computational biology (Marco), an existing computational chemist (Reynolds, not submitted to this panel), a structural biologist (Hough), a dedicated SRO (Chernukhin) and one further appointment planned for 2014.

The future expansion in Biological Sciences will require additional space for both offices and laboratories and a proposal will be considered for inclusion in the capital building programme early

in 2104 (2014-2018).

b.3. Research achievements 2008-2014: Selected highlights of research achievements of established staff include:

EPB - Plant Biology: *Mullineaux (Plant Cell 2009)* demonstrated the requirement for abscisic acid in activation of high light signalling and acclimation in *Arabidopsis*. *Lawson (J Expt Bot 2013*) developed new methodology and showed the importance to water use efficiency of stomatal responses to light and CO_2.

EPB - Environmental Biology: *Dumbrell (ISME Journal 2010)* produced the first quantification of neutral processes regulating soil microbial communities. *Underwood (PNAS 2013)* identified unifying relationships for predicting regional organic carbon loads in Antarctic and Arctic sea ice based on the physical properties of the ice. *Whitby (ISME Journal 2011)* elucidated a novel naphthenic acid degradation pathway.

MCB - Disease Mechanisms*: Klenova (Clinical Cancer Research 2009*) demonstrated that loss of CTCF poly(ADP-ribosyl)ation is associated with breast tumour development. *Metodiev (Neoplasia 2013)* showed that CD74 increases the invasion and metastasis of breast tumours by deregulating the tumour suppressor Scribble.

MCB - Molecular Structure and Function*: Kad (Mol Cell 2010)* described, for the first time, the physical basis of initiation of nucleotide excision repair. *Reeder (J Am Chem Soc 2012)* showed that tyrosine-based electron flow pathways can be engineered into redox active haem proteins to facilitate their detoxification by antioxidants.

Achievements of **newly appointed staff** include: *Brooke (Cancer Research, 2011)* demonstrated that the RNA-binding protein FUS is a potent repressor of prostate cancer growth. *Marco (Nucleic Acids Res 2013),* showed that genomic clusters of microRNAs emerge as new microRNAs near existing ones rather than from tandem duplications*. Zwacka (Oncogene 2008)* showed that MnSOD gives rise to resistance to TRAIL-induced apoptosis by preventing release of Smac/DIABLO from mitochondria into the cytosol.

b.4. Responsiveness to National and International Priorities & Initiatives 2008-2013: EPB has contributed to RCUK priority areas of *Food Security* and *Living with Environmental Change,* with funded research and impact programmes in the areas of *Increasing Crop Plant Productivity*, *Assessing Biodiversity and Ecosystem Services*, and *Assessing Impacts of Environmental Change on Organisms and Communities*. This was accomplished through participation in eight RCUK thematic programmes or priority themes (see e.2 below), five European Commission-funded projects and networks (see e.2 below), and three other international research programmes (see e.2 below) in addition to holding 27 responsive mode RCUK grants and nine other EC grants during the REF2014 period. MCB has contributed to the RCUK priority in *Lifelong Health and Wellbeing* through responsive mode BBSRC and MRC funding and grants aligned with funding priorities of charities. Recently initiated projects that are responding to national and international priorities include BBSRC- and MRC-funded research on blood substitutes, and Illinois-Gates Foundation and BBSRC funded research on improving photosynthesis to increase crop yields.

b.5. The School provides a vital and sustainable research environment that fosters research excellence: The School is committed to engendering a strong research culture for staff and students. Our research groups meet monthly and hold annual research away-days to discuss staffing, infrastructure requirements and research policy, identify emerging research areas and funding opportunities, and develop innovative research projects. This information feeds back to the School's RSG for use in developing and implementing strategy.

The **School Seminar Programme** provides funds to enable internationally renowned researchers from within the UK and overseas to visit and present their work. To maximise the impact of this seminar programme, visiting speakers meet not only with academic staff but also with our postdoctoral researchers and PhD students. The EPB and MCB groups also run seminar series and host meetings for our academic staff, research officers (ROs) and PhD students to present, discuss and debate their most recent findings.

The School's RSG operates a **formal review of research proposals** to provide feedback to PIs, thus helping to ensure quality and competitiveness. RSG also administers a **Research Fund** that supports feasibility/pilot studies, which are often used to establish new collaborations; funding is awarded on a competitive basis. During the period 2008-2013, approximately £300,000 was used to support 65 projects. All newly appointed staff in Biological Sciences are provided with a

University-funded PhD studentship, which is key to enabling establishment of independent research. We also award studentships to established researchers to provide opportunities to develop new projects. Studentships are awarded competitively through review by RSG and take into account not only the significance, rigour and novelty of the project, but also the quality of the student.

The University is committed to enabling a strong research culture and actively supports a **Research Leave Scheme**. Category A staff are entitled to one term of research leave for every six terms of teaching and service and through this they are expected to develop their research programmes, external profiles and contribute to the School's research excellence and environment. All ECRs are allocated one term's research leave in the first three years after appointment. During the period 2008-2013, 17 members of academic staff have collectively taken 43 terms of research leave under this scheme and this has led to new collaborations, research grant income and REF2014 outputs.

b.6. Multidisciplinary and interdisciplinary development: Important research problems often transcend disciplinary boundaries. For example: *Mullineaux and Bechtold***,** in collaboration with the University of Warwick Systems Biology Centre and the computational and metabolomics groups at the Food and Environment Research Agency, have combined plant physiology with molecular genetics to identify novel genes controlling crop plant yield under stress as part of BBSRC- and EU-funded programmes. *Underwood, Whitby, McGenity and Dumbrell* are undertaking interdisciplinary research at the interface of microbial ecology, biogeochemical processes and landscape management as part of the NERC BESS and Macronutrient Cycles programmes. *Reeves* is a member of an NIH-funded multidisciplinary research team extending across three countries that combines molecular biology and biochemistry, synthetic organic chemistry and solid state NMR to elucidate the activation mechanism of rhodopsin. *Reeder and Cooper* are developing haemoglobin-based blood substitutes by combining biochemical, cell toxicology and molecular biology approaches funded by the BBSRC Super Follow-on Fund and the MRC Developmental Pathway Funding Scheme. *Brooke* has identified novel therapeutics for the treatment of prostate cancer funded by Johnson & Johnson and Abraxis & Sanofi Aventis. *Reeves* and *Reynolds* have combined computational chemistry, experimental mutagenesis and plant GPCR knowledge to understand similarities between class A and class B GPCRs and hence activation of the calcitonin gene-related peptide receptor with BHF funding. *Kad* developed new instrumentation to measure interactions between proteins and DNA at the single molecule level with unprecedented temporal resolution as part of a BBSRC-funded project.

b.7. University Support for Research**:** The University's Research and Enterprise Office (REO) provides unified, comprehensive support for pre- and post-award external research grant activity, and for 'third-stream' research applications including knowledge-exchange and commercialisation. A team of REO managers provides expert advice on sources of funding, support with preparing research proposals, support in providing opportunities for collaborative research brainstorming, training events, some of which are particularly directed towards ECRs, links to external bodies and research funders. Financial support for research is provided to the School in the form of a fraction of the HEFCE QR income it earns, a share of a cross-University Research Promotion Fund and approximately half of the indirect-cost component of research grants won, with a further 10% going directly to the principal investigators. The School invests these funds strategically in order to maximise long-term research capacity. At the School level we have a dedicated research administrator who provides support for staff in identifying sources of funding.

c. People, including:

i. Staffing strategy and staff development

c.i.1. Changes in staffing and relationship of staffing strategy to research strategy and physical infrastructure: Over the REF2014 period of assessment the School has made significant changes in staffing with new appointments to replace retiring staff and as part of our strategy to increase research capacity. Our goal is to **appoint the highest quality applicants** recruited globally, and applicants are judged primarily on the quality of research and fit with existing research in the School. We also aim to ensure that each of our research groups has a **sustainable mix** of senior, mid-career and early career staff. The most radical change to staffing has been in the **MCB group,** which arose from the fusion of the former Biophysics and Molecular Medicine groups. This has involved the appointment of seven lecturers (*Kad, Mason* and *Worrall* in

2007; *Hough* and *Reeder* in 2011; *Brooke* and *Marco* in 2013), a reader (*Zwacka* in 2013) and a research fellow (*Svistuenenko* in 2008). Our strategy to appoint **complementary expertise** into this group has been successful; there are coherent themes running through the group, which now has critical mass in highly competitive areas e.g., Cancer Biology; new collaborations are being established both internally and externally, and funding from BBSRC, Wellcome, and charities including Leverhulme and CRUK is now being won (expenditure from this will not be evident in REF2014). We are providing strong management and mentoring to support this new group to maximise potential.

The School has also used staff turnover to enhance its research activity by recruiting early career researchers into areas of research excellence where they have benefited from mentoring by senior staff. Within EPB these are Environmental Microbiology (Dumbrell mentored by Underwood) and Plant Productivity (Bechtold, Jones mentored by Mullineaux). In addition to making new appointments to ensure the continuity of our research in areas of excellence, the School's staffing strategy to 2020 aims to increase our number of category A staff so as to expand and improve the scope and quality of our research.

c.i.2. Development and support of research staff: In addition to the support provided by research groups, a robust performance review process provides support, insures transparency and is creating a culture of excellence. Within the School, **Annual Personal Development Reviews (PDRs)** are undertaken by the Head of School and DoR with all research active staff in order to review the quality and quantity of research outputs, research grant activity, knowledge transfer/ impact activities and to identify quantifiable objectives for research activity and professional development for the coming year. At the Institutional level, the University's Pro-Vice-Chancellor (Research) monitors the performance of all research active staff across the University on a biannual basis, in discussion with the Faculty Executive Deans, Departmental Heads and Research Directors. Rigorous assessment of research performance, relevance and impact forms a vital part of the probation and promotion processes, with oversight of these processes vested in central University staffing committees.

Mentors are assigned to all probationary lecturers to provide advice on networking, career planning, developing a research profile, developing research ideas and preparing effective research proposals. This mentoring has led to successful PI grants from our ECRs (e.g., Dumbrell from NERC; Mason from Wellcome; Kad from BBSRC; Lawson from BBSRC and NERC).

Teaching and Administrative Load: The School has a transparent workload model, which is used to allocate teaching and administrative loads taking into account research and professional service activities. The school operates a policy to ensure that Lecturers at the start of their careers have reduced teaching and administrative loads to allow time to develop a research programme.

c.i.3. Implementation of the Concordat to Support the Career Development of Researchers: The concordat is fully implemented at University of Essex. Postdoctoral Research Officers (ROs) are supported through their annual PDRs with their supervisors, and ROs are encouraged to take an active role in outlining research objectives and approaches, and identifying training and career development requirements/opportunities. Supervisors work with the University's Human Resource and Research and Enterprise Office teams to ensure on-going professional development, whilst advanced subject-specific training is supported by the School's scientifically-trained Research Administrator. Funds are also provided to attend external courses that aid the development of the ROs' research careers, and encourages and facilitates ROs to participate in School activities and networking (e.g., via giving occasional advanced lectures to undergraduate/postgraduate students, running research group seminar programmes).

c.i.4. Support of equality and diversity: The School, like the University, recognises the value of diversity and is committed to equality of opportunity. The University is a member of Stonewall's Diversity Champions programme, became a 'Two Ticks' employer in 2008, and has recently been given the Athena Swan bronze award, and the School of Biological Sciences is now preparing to apply for the Departmental level Silver Award in 2014. Within the School of Biological Sciences, women hold senior positions including Head of School, Director of Education, Curriculum Director and MCB group lead.

ii. Research students

c. ii. PhD students: We provide a challenging but supportive environment to nurture the

intellectual and personal development of our community of about 85 PhD students from over 31 countries, many holding competitive studentships. We are a member of the recently established NERC EnvEast DTP. PhD students are co-authors on over 150 papers published since 2008, including 30 of the papers submitted to REF2014.

c.ii.1. Doctoral training: The Graduate School has overall responsibility for PhD student training and provides a CPD programme (*Proficio*) that offers training in scientific and generic research skills and professional development. Our School Graduate Director co-ordinates and oversees PhD student training and progress and supervisors provide training in project-specific research skills. The research groups (EPB and MCB) provide opportunities for students to present and discuss their work. Students are also expected to join learned societies and can use School funding to participate in UK and international conferences. Since 2008, over 70 of our students have presented their research in national conference or workshops and over 40 in international venues.

c.ii.2. PhD supervision and progression: In addition to having a supervisor, students are assigned an independent advisor who is involved with monitoring progress throughout the period of study. Student progress is assessed formally at 6-monthly supervisory boards, where they report to their supervisors and their independent advisor. Milestones include production of a project plan (first board), a literature review and an annual report (second board). In the second year, confirmation to the PhD programme is determined at a board with the Graduate Director (Chair), the Director of Research, supervisor and independent advisor. The School's Research Students Progress Committee (Graduate Director and Head of School) formally reviews progress annually and makes recommendations to the University's Graduate School.

c.ii.3. Research student culture: Our PhD students are embedded within the research environment of the School and are integral members of our research groups. To strengthen and support the PhD student community within Biological Sciences, and to facilitate interactions amongst students, we provide a postgraduate research room with desks, printing and internet facilities. Students oversee the functioning of the room and are provided with funds to undertake self-selected activities. An annual graduate forum is organised by the PhD students providing training not only in communication, but also in organisational skills and budget management.

c.iii.4. The School has supervised eight CASE studentships during the REF period in the areas of drought tolerance, peptide antagonists, computational biology, biodegradation of recalcitrant organic compounds, soil nutrient dynamics, and microbial processes.

d. Income, infrastructure and facilities

The School of Biological Sciences attracts research income from a diverse range of external sources. EPB derived its income primarily from NERC, BBSRC and the EC with additional support from charities and corporate sponsors, whilst most of income to MCB came from charities including Wellcome Trust, Leverhulme Trust, Alzheimer's Research UK, Parkinson's UK, Age UK, BHF, Cancer Research UK, Breast Cancer Campaign, Prostate Cancer UK, Retinitis Pigmentosa Fighting Blindness, as well as NHS, Colchester Catalyst Charity, Royal Society, Science and Technology Facilities Council.

d.1. Nature and quality of the research infrastructure and facilities: The School provides a comprehensive range of facilities for modern, multi-disciplinary, biological research within 3,200 m^2 of research laboratory space housing approximately £5 million of equipment. All academic staff are provided with laboratory space sufficient for the size of their research groups and to accommodate undergraduate, MSc and PhD students. The majority of laboratories have been refurbished over the last 10 years and further refurbishment of laboratories to house our genomics staff will be complete this year. Research across the unit is underpinned by School-funded research officers/ fellows (4 FTE) and skilled technicians (17 FTE) who provide continuity of expertise, manage research facilities and equipment, and support research staff and PhD students. Overall management of shared facilities and major pieces of equipment are the responsibility of the DoR and RSG and maintenance, training and access are managed by individual members of academic, research and technical staff.

Major shared facilities include the **Proteomic, Bioimaging and Protein suites.** Our **Proteomics facility** allows genome-scale analysis of protein abundance and post-translational modifications utilising stable isotope labelling and label-free approaches and includes a LTQ/Orbitrap Velis

MS/MS interfaced with a splitless nano-scale liquid chromatography system. **Bioimaging:** we have a significant track record of in-house development of methods, optical instruments and software algorithms for quantification and visualisation of cells and molecules. We use three-dimensional high-velocity (ms) and long-term (d) live cell imaging, highly sensitive single molecule and biosensor-based or label-free physiological imaging. We also have widefield/deconvolution and confocal fluorescence microscopy, total internal reflectance (TIR), oblique angle fluorescence (OAF), darkfield and lightsheet microscopy, optical trapping and in house developed chlorophyll fluorescence imaging. **Protein Production, Purification and Characterisation:** Our protein suite is fully equipped for large scale protein production and purification with three AKTA systems for ion exchange, size-exclusion and affinity chromatography and analytical/preparative HPLC, and a comprehensive mass-spectrometry facility. We have a robotic protein crystallisation facility and access to the Diamond UK and Swiss Light Source Facilities. **Biophysical characterisation** capabilities include equilibrium and kinetic circular dichroism (CD), electron paramagnetic resonance (EPR), stopped-flow fluorescence kinetic analysis, isothermal titration calorimetry (ITC), UV/visible/NIR and fluorescence spectroscopy, surface plasmon resonance (SPR) and molecular modelling/computational chemistry. For research in **Molecular and Cell Biology,** we provide a wide range of equipment including Q-PCR machines, gel documentation systems, centrifuges and plate readers. Dedicated cell/tissue culture rooms are equipped with laminar flow cabinets, controlled-environment incubators and CO_2 incubators. A FACS-Aria flow cytometer is used to characterise and sort cells. Our **Bioinformatics** capabilities include web-server workstations for processing of large datasets, online applications for sequence manipulations and database access, two dedicated multi-processor servers and computer workstations operating both open-source and commercial software such as Mascot Server for proteomics and Bayesian biological network modelling which can be incorporated into workflows using high performance computing resources that are accessed at the National Grid Service. We support our research in **Plant and Algal Physiology** with a wide range of equipment for the analysis of photosynthetic parameters including Fast Repetition Rate and PAM fluorimeters, O_2 electrodes and optodes, infra-red gas analysers and a membrane inlet mass spectrometer to measure O_2 and CO_2 fluxes. In addition to a glass house with GM containment and controlled environment growth facilities, our **Plant Phenomics Facility** enables high throughput screening of model plant species using an automated phenotyping platform for integrated imaging of water use efficiency, photosynthetic efficiency and growth parameters. For research in **Environmental Microbiology and Marine Biology**, we have controlled environmental facilities and a coral reef research aquarium, with replicated CO_2-stat and pH-stat incubation systems. Analytical facilities include GCs with diverse detectors (MS, FID, FPD, ECD), uPLC/MS, and HPLC for measuring trace gases, hydrocarbons and lipids, and equipment for measuring important environmental parameters, such as; nutrient autoanalyzer, ion chromatograph, and a system for measuring dissolved and particulate organic carbon and nitrogen.

d.2. Evidence of cross-HEI shared or collaborative use of research infrastructure: During the REF period, 6 PhD students and 21 other researchers from 27 UK research organisations, as well as 18 overseas PhD students and 39 other overseas researchers from 26 countries undertook collaborative research in Biological Sciences at Essex. These researchers came to access the specialist knowledge and to participate in experiments that employed bespoke instrumentation and facilities including our coral reef research aquaria (**Suggett**), DNA tightrope systems (**Kad**), and leaf imaging systems (**Lawson**).

Our researchers have also taken advantage of shared use facilities within the UK, for example; Biomolecular NMR at UEA (Reeder, Worrall); Light Sources at Harwell (Hough, Kad, Reeder, Worrall); NERC NBAF and isotope Facilities (Lawson, McGenity, Mullineaux, Underwood, Whitby); Small Mars Chamber in Milton Keynes (McGenity); EPSRC LENNF AFM facility in Leeds (Kad); Metabolite Facility in Exeter (Bechtold); UK Field Sites including Defra instrumented catchments (Whitby); Forest Research chronosequence site (Whitby); International Field Sites including Oil Sands Tailing Facility in Alberta Canada (Whitby); Wakatobi Field Research Centre in Indonesia (Underwood); Canadian Polar Research Facility in Nunavat (Underwood).

d.3. Research governance is overseen at the level of the University by REO's Research Governance and Planning Manager, who ensures compliance with legislation and funders' requirements. The School has a robust ethics procedure managed by its Ethics Officer. Graduate

students and contract researchers are primary authors of papers arising from their work and students and technical staff are co-authors on papers to which they have contributed. The University retains ownership of all intellectual property rights generated by its employees in the course of their employment by the University, and REO's Research & Enterprise Managers (REM) enable researchers at all levels to exploit commercial opportunities arising from their research.

e. Collaboration or contribution to the discipline or research base

Researchers within the School have contributed to the discipline and research base by assuming leadership roles and undertaking service activities for professional societies, charities and research councils. All staff participate in the peer review of scientific papers and research proposals. **Raines** is Editor in Chief for *Journal of Experimental Botany,* **Klenova** is Associate Editor for *Cancer Cell & Microenvironment*, and **Kad**, **Marco**, **McGenity**, **Lawson** and **Suggett** are subject editors or Editorial Board members for 9 other journals, whilst **Dumbrell**, **Kad**, **McGenity** and **Whitby** have been Guest Editors for special issues. **Underwood** serves on NERC's Panel of Chairs and NERC's Science and Innovation Strategy Board. **Geider**, **McGenity**, **Mullineaux**, **Raines** and **Suggett** serve on RCUK panels and committees, whilst **Dumbrell**, **Geider**, **Metodiev** and **Raines** have served on EC, ESF or other overseas research council peer-review committees. **Geider**, **Hough**, **Lawson**, **Raines**, **Suggett** and **Underwood** have served on UK Research Council, Learned Society and other national and international boards, committees and working groups.

e.2. Researchers within the School have responded to national and international priorities and initiatives, as shown by our collaborations in directed programmes and research networks.

Nationally, we have participated in two BBSRC programmes; SABR (**Mullineaux**) and 'Enhancing photosynthesis to achieve a step change in photosynthesis' (**Raines**, **Lawson**, **Bechtold**); collaborative research with Rothamsted as members of the Crop Improvement Research Club (**Raines**, **Lawson**), which aims to develop high yielding wheat varieties; six multi-institute NERC programmes investigating nutrient cycles and biodiversity undertaking research that underpins informed assessments of alternative futures of the UK and global environment: QUEST (**Geider**), SOLAS (**Geider**, **Underwood**), Ocean Acidification (**Suggett**, **Lawson**), Macronutrient Cycles (**Whitby**, **Underwood**), BESS (**Underwood**, **Dumbrell**, **McGenity**), Shelf Seas Biogeochemistry **(Suggett**, **Geider**); BBSRC-funded and Leverhulme Trust-funded development of novel non-invasive cell biological tools to measure plant responses to environmental stress and to evaluate the role of the circadian system in modulating stress tolerance (**Mullineaux**, **Jones**).

Internationally, we have participated in six EC projects including FP6 project CARBOOCEAN to assess marine carbon sources and sinks (**Geider**), FP7 PROTOOL to develop automated tools to measure primary productivity in European Seas (**Suggett**, **Geider**), FP7 ABSTRESS to improve the resistance of legume crops to combined abiotic and biotic stress (**Mullineaux**, **Bechtold**, **Lawson**), FP6 HYDRALAB III large scale ice tank investigations (**Underwood**), FP6 project MIST to evaluate the utility of mesenchymal stem cells in novel tumor therapeutic approaches (**Zwacka**), and FP7 programme BioStruct-X to access the EU synchrotron facilities (**Hough**).

Other international collaborations include participation in a BBSRC India Partnership on the analysis of water productivity traits in Indian crops (**Mullineaux**, **Bechtold**); a project with King Abdulaziz University, Saudi Arabia, to investigate extreme abiotic stress tolerance in C_3 desert plants and biotechnological potential of desert microbes (**Mullineaux**, **Bechtold**, **Lawson**, **McGenity**, **Underwood**); a Gates Foundation-funded programme at University of Illinois to improve photosynthetic efficiency of crop plants for developing countries (**Raines**).

e.3. Cross-institutional and international collaborations are facilitated through working visits by academics, research officers and PhD students. Networking is facilitated through provision of School funds for staff and PhD students to attend national and international conferences. The School uses the annual personal development review process to encourage staff to engage with NGOs and professional societies in the promotion and coordination of national and international research activities and programmes. It is also facilitated through participation in PhD training partnerships and networks (EC FP7 Initial Training Network HEXACOM; NERC EnvEast DTP; FP6 EUROCEAN Network of Excellence (ended 2008); FP7 IRES Network ProSymbioCoRe). The University's REMs in the REO help academics link to external bodies, research funders and non-academic users of our research (see Impact Template).