

<p>Institution: University of Essex</p>
<p>Unit of Assessment: 5 – Biological Sciences</p>
<p>1. Unit context and structure, research and impact strategy</p> <p>1a) Context and structure</p> <p>The School of Life Sciences (SoLS) initiated a transformative growth trajectory following REF2014 [1b] that will lead to achieving our goal of being a globally recognised centre of intensive and excellent biosciences research. Our philosophy is to deliver research across all levels of biological organisation, from genes and cells through to communities and ecosystems, and our expansion and continued growth has provided a sustainable platform supporting this research vitality [1d]. Our investment in the people behind this research generated a 57% increase in Category A staff since REF2014, leading to an 18% increase in research income (average £1.98M yr⁻¹ to £2.33M yr⁻¹) and supported a >450% increase (from 9 to 52) in the publication of research in the most influential journals (Nature Publishing Group, <i>Science</i> (AAAS), <i>PNAS</i> and <i>CELL</i>). The SoLS produces all Biological Sciences research returned in UoA5 for the University of Essex, and currently comprises (FTEs) 48.7 academics, 46.1 researchers and technicians, 10 professional services staff, 47 PhD students, 86 Masters and 768 UG students, who as a community deliver on our dual-intensive mission of ‘<i>Excellence in Research</i>’, and ‘<i>Excellence in Education</i>’. Research activity is organised into groups [1d], namely Ecology and Environmental Microbiology, Genomics and Computational Biology, Plant Productivity, and Protein Structure and Mechanisms of Disease. In addition, researchers from the SoLS are integrated into several multidisciplinary research institutes and centres. These include: the Essex Plant Innovation Centre (EPIC), and the Essex Biomedical Sciences Centre (EBSC) led from within the SoLS, alongside the Centre for the Environment and Society (CES), and the Institute for Analytics and Data Science (IADS). Through these University-wide cross-disciplinary institutes and centres, we provide a strategic platform to capitalise on our University’s unique combination of research strengths, comprising additional pillars of excellence in Social Sciences, Computer Sciences and Humanities. Since REF2014, academics from the SoLS held principal roles (Deputy VC – Pretty; PVC for Research – Raines; Executive Dean – Underwood; Deputy Dean Post-Graduate Research & Education – Colbeck) within the University Senior Management Team, overseeing strategic management across all the University’s academic activities, ensuring the research needs of the School were recognised and supported through the University’s Research Strategy. Subsequently, we are now ideally placed to tackle the major societal challenges of the future that the UK Government, UKRI and Industry universally acknowledge require closer integration between biologists, data analysts, social scientists, and humanities.</p> <p>1b) Research and impact strategy 2014-2020</p> <p>Our overarching aim is to conduct world-leading research that tackles major societal and scientific challenges with maximum impact, by fostering a collegiate and intellectually stimulating working environment, supported by continued investments in people [2], infrastructure and facilities [3]. Our immediate post-REF2014 priorities were to achieve a 50% increase in Category A staff and to restructure and expand our research groupings to provide a sustainable platform for research and impact growth. We achieved a 57% increase in Category A staff and expanded from two REF2014-UoA5 research groups (Environmental and Plant Biology, and the Molecular and Cell Biosciences groups) to four [1d], and established a parity of research mass across groups. This growth was supported strategically by an expansion in research infrastructure (~1300 m² of new or refurbished laboratories) [3c], sustained investment in facilities and equipment [3d], and the development of a new multidisciplinary centre dedicated to delivering research into impact within the agricultural and horticultural sectors [1d]. The operational objectives (identified in REF2014) and support mechanism behind our growth were (evidence of success is provided in highlighted sections):</p> <p>Obj. 1) maintaining and expanding areas of current research excellence: The School’s Senior Management Team (comprising the Head of School (HoS), Director of Research (DoR), Director of</p>

Impact (DoI), Postgraduate Research Director (PGRD), Director of Education (DoE) and School Manager (SM)) has oversight over recruitment of new academics, investment of School funds in new equipment and facilities and the strategic research direction of School (approved annually by University Steering Group). The Research Strategy Group (RSG), chaired by the DoR and comprising the HoS, DoI, PGRD, four Research Group Convenors (RGC), School Research Manager (SRM) and an ECR representative, identify priority areas for these investments. RSG targets investments in areas with maximum complementarity, identifying areas that benefit the most PIs via an increase in fruitful research collaborations and access to equipment and facilities. We have provided a balanced investment (during 2014-2020) of new academic positions into our research groups [1d], building a critical mass that is nationally and internationally competitive. Our strategy has been highly successful, as evidenced by significant growth in Category A staff [2a], increased research income [3b], and outputs (REF2021: 114 outputs from 100% of Category A staff; REF2014: 77 outputs from 79% of Category A staff), and sustained investment in infrastructure and facilities [3c, d].

Obj. 2) investing in new and developing technologies to enable innovative research: The DoR, in consultation with RSG, identifies new technologies with which to equip our research environment. Funding for these technology-led investments comes from a diverse range of sources [3d], but are primarily supported via competitive applications to the University's Annual Planning Round, PVC-R Capital Investment Funds and from the School's operating budget (see also [Obj.4]), which includes indirect costs returned from grants. We prioritise strategic investment towards technologies with the largest user base, and the greatest potential to increase income and outputs. A key focus of investments (during 2014-2020) has been in genomic technologies and high-performance computing [3d], which are used by researchers from all groups (and externally [3e]). This strategy supported the capture of >£16M of grant income across research groups including multiple ECR grants to new PIs (e.g. 7 Wellcome Trust Seed Awards). Many of these grants underpin emerging impact [3d] and our investments have attracted national and international collaborations and supported research exchanges [3e, 4a].

Obj. 3) ensuring wider non-academic impact arises from our research: The DoI has strategic oversight over all activities aimed at maximising societal and economic impact from our research. During 2014-2020, we facilitated impact activities running parallel to areas of research growth, allowing established research areas to deliver impact and supporting newer research areas to generate future impact [4b]. The success of this strategy is reflected in our Impact Cases, which were chosen from established research areas, Ecology and Environmental Microbiology (2 cases: Underwood; Cameron and Underwood) and Plant Productivity (2 cases: Pretty; Lawson et al.), and align with the strategic foci of these research groups [1d]. In addition to these Impact Cases, all research groups are providing further research-led benefits to the economy and society and developing future Impact Cases [4b]. The strategy and operational support underpinning Objective 3 is provided below [1c].

Obj. 4) seeking internal and external support to facilitate expansion of our infrastructure and facilities: The DoR and SRM, supported by the University's Research and Enterprise Office (REO), identify funding streams for expansion of infrastructure and facilities. Internal funding routes are described previously [Obj. 2] and the Annual Planning Round is used to identify and support infrastructure expansion. Individual PIs are expected to secure external funds for research equipment via both open capital calls (e.g. BBSRC, NERC) and as components of research grants. The University, via the PVC-R, committed to providing 50% funding for equipment worth >£10K on UKRI proposals. This strategy successfully secured >£2M of investment in research infrastructure [3c] and >£1.4M of investment in research equipment [3d], supporting all outputs and impact [3d].

1c) Facilitating Impact (2014-2020)

The DoI ensures that we engage and encourage research with industry, government, and third-sector organisations to translate excellence in academic research into solutions for industry and society. Each research group [1d] addresses strategic impact priorities: these, and evidence of our success in fostering impact, engagement with end-users, and delivering societal benefits are

provided in [4b] and our four Impact Case Studies. Since REF2014, we have:

Widened participation in impact. Impact is now a standing agenda item on all research group and School meetings, and we use annual School 'away days' to focus exclusively on impact. We incentivise and recognise impact activities via inclusions in the Work-Load Model (WLM), research leave [2b], and via annual awards [2b]. Impact activities (including external engagement, diversifying funding, end-user collaborations and patent applications) are included on our promotion and probation criteria.

Increased engagement with industry and knowledge exchange activities: We expanded our industry-targeted marketing to advertise unique expertise and skills, and supported staff to identify and engage with beneficiaries and end-users. For example, we partnered with Agri-Tech East (who represent agricultural innovators, technologists, scientists and farmers) to host events widely attended by the agricultural and horticultural sector, and engaged with the pharmaceutical industry via Royal Society Industry Fellowships (Reynolds). We increased use of social media, press releases, and industry and non-academic publications (e.g. *The Conversation*) to communicate our latest papers, technologies, and capabilities to diverse audiences [4b]. In addition, we have increased KTP and KE applications [4b], consultancy with industry, government, and third-sector organisations, and filed 12 patents.

Increased funding to support impact. We identified and supported applications to funding calls that facilitate impact, including those aimed at the academia-industry interface [4b], and increased grant applications with industry, government, and third-sector organisations as partners [4b]. Targeted funding included: Innovate UK, ERIA, and UKRI and internal business and innovation voucher schemes [4b]. We also discuss in annual PDRs [2b] how staff can secure this funding.

Supported multidisciplinary interactions: We established a large multidisciplinary centre, the Essex Plant Innovation Centre (EPIC), to support impact-focused interactions with colleagues from Computer Science and Electronic Engineering, IADS and the Business School [1d].

1d) Research groupings

Ecology and Environmental Microbiology (EEM) [£7.2M]: Aims to understand the ecological mechanisms behind changes in global biodiversity, and ecosystem functioning, in response to modifications in environmental and climatic conditions. The group address these research aims under four broad themes: *biodiversity* (including microbial); *climate and environmental change*; *(global) biogeochemical cycling*; and *environmental biotechnology*. Research outputs underpin the application of the group's expertise to society's benefit, with a focus on sustainable use of natural (notably marine and coastal) resources, assessment of anthropogenic impacts on the environment, and detection and remediation of (air and environmental) pollution, to provide clear management and policy recommendations allied to these areas [4b]. Three exemplar outputs demonstrated: (1) that changes in the seasonal dynamics of sea ice melt and its released dissolved organic matter modify element recycling and alter microbial evolutionary pathways in the Arctic Ocean (*Underwood, Dumbrell, Nature Climate Change*); (2) a reversal of ecological rules (shallower not steeper mass-abundance scaling and greater not less efficient transfer of biomass through food webs) in response to ecosystems warming (*O'Gorman, Nature Climate Change*); and (3) that mass extinctions and mass radiations are decoupled in time, reversing the long-held belief that post-extinction radiations are the norm (*Hoyal Cuthill, Nature*). Since REF2014, the appointments of *Aldred, Cameron, Clark, Ferguson, Hicks, Hoyal Cuthill, McKew, Nanninga, O'Gorman, Sturrock* and *Taylor* built on established membership (*Dumbrell, Geider, Laissue, McGenity, Smith, Steinke, Underwood* and *Whitby*) to deliver a critical research mass in ecological and environmental microbiology.

Genomics and Computational Biology (GCB) [£0.75M]: Aims to answer one of the most challenging questions in science: how does the genome control the development of complex organisms and their response to an unpredictable environment? We address fundamental questions around how genomes are packaged, organised, modified and regulated to drive

development, and reveal how factors such as environment, disease and ageing affect these epigenetic functions. Research questions are addressed across levels of biological organisation and taxonomic hierarchies, ranging from interactions between the smallest microbes and their hosts within human guts, to cohort-level effects in human society and the emerging trans-discipline focus of socio-genomics [1f – Obj. d]. The creation of the GCB group was a strategic priority detailed in REF2014, and was established soon after to increase our breadth of biological sciences research [1b] and provide a collaborative hub linking all research groups around their common use of genomic and computational biology approaches. Three exemplar outputs showed: (1) depletion of the gut microbiota leads to a global change in histone crotonylation in the colon and that histone crotonylation connects chromatin to the gut microbiota, via short-chain fatty acids and HDACs (Varga-Weisz, **Nature Communications**); (2) nucleosome repositioning links DNA (de)methylation and differential CTCF binding during stem cell development (Teif, **Genome Research**); and (3) the molecular pathways and histone modifications behind Alzheimer's disease neuropathology (Schalkwyk, **Nature Neuroscience**). New appointments supporting a critical mass of research within GCB include: De Navascues, Giotis, Schalkwyk, Skinner, Rallis, Teif, Varga-Weisz, Zabet, and were complemented by existing staff (Marco, Metodiev) joining this group.

Plant Productivity (PP) [£6.4M]: Aims to address the needs for food and fuel of an ever-growing world population, via improving and increasing crop yields without increasing demands for chemicals or water. Members of the PP group (Raines, Lawson, Cavanagh) are part of the internationally renowned RIPE (Realising Increasing Photosynthetic Efficiency) project funded (~\$45M) by the Bill & Melinda Gates Foundation. PP research focuses on whole plant biology with specialisms in stomatal physiology, photosynthesis, and responses to abiotic stress. The group deploys a unique combination of genetics, molecular biology, and physiology to understand and manipulate the fundamental processes that govern plant growth, development, and responses to environmental change. Alongside taking a holistic approach to 'future proofing' crops, the group develops cutting-edge technologies and tools that have been selected by industry for commercialisation (Lawson et al Impact Case) and underpin advancements in our research. Three exemplar outputs demonstrated: (1) a multigene approach to stimulate electron transport and RuBO regeneration can increase plant biomass in both glasshouse and field conditions (Raines, Lawson, **Nature Plants**); (2) the genomic origins of multicellularity and terrestrialisation in plants (Bechtold, **Current Biology**); (3) how direct H₂O₂ transfer from chloroplasts to nuclei, avoiding the cytosol, enables photosynthetic control over gene expression (Mullineaux, **Nature Communications**). Our long-established research strength in plant productivity (Bechtold, Lawson, Mullineaux, Raines) was complemented by one new appointment (Cavanagh).

Protein Structure and Mechanisms of Disease (PSMD) [£4.1M]: Aims to elucidate the structure-function relationships of proteins in the context of physiology, disease, and environmental processes and to provide the technological tools for these investigations. We focus on three key research themes. *Metalloprotein structure and function*: is an internationally recognised research strength, and involves close collaboration with external facilities including Diamond Light Source [3e]. Our expertise in heme and copper proteins underpins translational research in industrial enzymes, as well as human health with key developments in synthetic blood substitutes [4b]; *Signalling cascades within cancer cells*: investigates and validates therapeutic targets (e.g. nuclear receptors and kinases) using our in-house interdisciplinary drug discovery pipeline (cell biology, molecular dynamics, in silico drug screening, computational chemistry, structural biology), and translates findings to the pharmaceutical industry (e.g. Atomwise, Jansen Biotech); *Structural biology of membrane proteins*: addresses research questions ranging from hereditary visual impairment due to rhodopsin mutations, to antibiotic resistance in bacteria and vaccine development. Three exemplar PSMD outputs include discovering: (1) a novel role of lipopolysaccharide O-antigen in antigen presentation and determining the protective qualities of antibody response in bacterial infection (Bavro, **Nature Communications**); (2) the structure and molecular dynamics of the active calcitonin gene-related peptide (CGRP) receptor supporting a major role in sensory neurotransmission (Reynolds, **Nature**); (3) a novel two-stage mechanism for rhodopsin activation (Reeves, **Nature Communications**). New appointments underpinning the growth of research within PSMD, including Bavro, Edwards, Mohr, Prischi, Strange, and Svistunenko, joined existing researchers (Brooke, Hough, Fernandez, Reeder, Reeves, Reynolds,

Worrall, Zwacka) in establishing and expanding this group.

Multidisciplinary research and impact centres: Translating research into impact to address major societal challenges requires cross-disciplinary approaches. Most staff (62%) are members of multidisciplinary centres that facilitate this. These include: **Essex Biomedical Sciences Centre (EBSC)**, which links across biomedical scientists, clinicians, and local NHS Trusts, to translate research in practice; the new (2019) **Essex Plant Innovation Centre (EPIC)**, which consolidates skills, expertise and technologies across the faculty to deliver research solutions to challenges faced by agricultural and horticultural sectors (and secured access to a BBSRC CTP with NIAB-EMR); **the Institute for Analytics and Data Science (IADS)**, which connects academics to end-user organisations, to develop and deploy the latest data analytics (e.g. AI) to address sector-relevant challenges. IADS currently supports two independent research fellows in SoLS (*Clark, Hoyal Cuthill*), who are pioneering data analysis approaches to answer questions in environmental microbiology and evolutionary biology; and the **Centre for Environment and Society (CES)**, which draws on University-wide academic expertise to support impact-focused research underpinning environmental sustainability globally.

1e) Open Research, Research Integrity, Ethics and Governance

Open research, covering open-access, data, tools (methods, code etc) and an open and transparent research environment, is embedded in the shared philosophy of our PIs. We foster an open research environment via developing a culture of engagement based on staff universally recognising the benefits of open research. This is discussed termly in whole School meetings, yearly in our annual 'away days', and on a more regular bases within the research groups; with recommendations distributed to all staff. Routes to open access publishing are promoted via the UKRI Open Access Publishing Fund, and Read and Publish subscriptions (e.g. Wiley), with 27% of submitted outputs achieving Gold Open Access. The majority of our funding originates from UKRI and we follow the UKRI Concordat on Open Research Data. Support in drafting Data Management Plans, including identifying appropriate data repositories, to include with funding applications, or on the commencement of PhD research and discretionary research projects, is provided via the DoR, RM, and Group Convenors. All software and analytical code developed by SoLS is open source and made freely available. 83% of submitted outputs have provided or re-analysed open data, or have contributed to open software and tools.

Expectations related to open research, ethics, regulatory framework, obligations, and professional standards are discussed and outlined in all new research-facing staff (and PhD) inductions, including aspects of research transparency and reproducibility. This is further strengthened via individual laboratory inductions provided by technical managers who outline research practice expected within their laboratories (e.g. transparent and reproducible recording of methods and data generation). The University conforms to the Concordat to Support Research Integrity, and has developed the University Code of Good Research Practice, with overall oversight provided by REO's Research Governance and Planning Manager, who ensures compliance with the code as well as other external 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, and REO's Knowledge Exchange Managers (KEM) enable all researchers to exploit commercial opportunities arising from their research **[4b]**.

1f) Research and impact objectives (2020-2025)

We will build on our growth to become a globally recognised centre of intensive and excellent biosciences research by 2025. Our focus will be on consolidating recent investments in people and infrastructure, and using initiatives that cut across research groups to maximise research and impact opportunities. We will:

- a) *Ensure all research groups are of similar size and effectively interdigitate:*** Each research group will expand to 18 FTEs, providing a critical mass to be internationally competitive. New appointments will be in areas that cut across groups. Examples include: plant virology and immunology (PP-PSMD), environmental epigenomics (EEM-GCB), agricultural genomics (PP-GCB), and environmental controls on antimicrobial resistance (EEM-PSMD).
- b) *Support ECRs in establishing financially independent and sustainable research groups:*** Our investment in new academic staff (32 since REF2014) has yielded a vibrant and productive ECR community. We have supported new staff in establishing their independent research careers [2b], and will continue to mentor them and facilitate funding success (to date all ECRs secured a significant research grant within three years).
- c) *Continue to invest in research infrastructure and facilities:*** Our growth increased the demands for laboratory equipment and infrastructure, and we invested £3.4M to meet demand [3c 3d]. We have recently implemented rolling upgrades and/or replacements of core equipment used across the School and will continue to seek funding to expand further. Our immediate secured investments include a £2.2M upgrade to our EPR spectroscopy, aquatic research laboratories and Controlled Environment Rooms (supporting new PSMD, EEM and PP initiatives by 2022) [3c].
- d) *Grow, and develop new, multidisciplinary centres:*** EPIC is entering its second year and has already secured access to a BBSRC-CTP [1b]. We will expand EPIC by facilitating increased interactions with social scientists and economists, and develop large cross-disciplinary funding proposals. We will establish the Centre for Socio-Genomics that will further support interactions between the Institute for Social and Economic Research and SoLS to examine the genomic impacts of social issues on human health. We will capitalise on opportunities via the Eastern Academic Research Consortium (Arc) of the Universities of East Anglia, Essex and Kent to increase end-user engagement and support networking activities across the region.
- e) *Enhance training and support for impact activities:*** Impact and KE activities will be embedded in all ECR, PhD and UG training. School funds will support research groups to establish an industrial (or wider beneficiary) advisory board, with membership from end-user organisations, to enhance KE, and networking activities. We will curate and expand our databases of external contacts and impact activities, provide on-going assessment of potential impact cases, and help ECRs generate future impact.
- f) *Enhance funding for impact:*** We will fund secondments to partner organisations for individuals with advanced Impact Cases to secure tangible financial, policy or other impact outcomes. We will provide additional funding (from the School budget) to establish impact activities, including supporting new PhDs with direct links to industry, government, and third-sector organisations.

2. People

2a) Staffing strategy

Staffing in relation to research and impact strategy: Our central aim has been to identify and recruit exceptionally talented researchers from a global pool of expertise, embed them within our research groups, and provide them with the investment, support and mentorship required to excel [2b]. This approach has successfully addressed our strategic priority of >50% increase in Category A staff and delivered the first objective of our 2014-2020 strategy [1b]. We are committed to delivering both 'Excellence in Research' and 'Excellence in Education', and our staffing strategy balances these priorities. Research and impact needs are identified via RSG, who consult with the SMG to ensure education requirements are met (outlined in [1b – Obj. 1]). Our strategy focuses most new appointments at the Lecturer level (26 since REF2014), securing talented ECRs with the potential to excel and rise to the level of Professor. For example, *Lawson* and *Dumbrell* were included in REF2014 as a Research Fellow and ECR respectively and are now Professors. Senior

appointments (3 since REF2014) are made in areas identified as requiring leadership or to support new research directions and initiatives; for example, *Schalkwyk* and *Bravo* were recruited to provide leadership in our new GCB and PSMDs groups [1d]. This approach has provided a balanced spread of career stages (42% L, 34% SL, 4% R, 20% P) with depth in leadership and relatively young demographic profile (7% 25-35yrs, 38% 36-45yrs, 32% 46-55yrs, 21% 56-65yrs, 2% >65yr) to support our 2020-2025 research strategy [1e] and beyond.

Recruitment. Academic appointments are made to those individuals who complement our research and impact strategy [2a]. All Category A staff are appointed on permanent contracts with a supportive probationary period [2b]. Our recruitment process aims to attract a diverse and inclusive pool of applicants. Job adverts are drafted based on our University's recruitment templates and job descriptions, with discipline specific modifications that reflect the duties, expectations, remuneration and career pathways for Biological Scientists. Consistent language and terminology clearly articulate research, impact, and education responsibilities help new colleagues to understand the School's values from the moment they apply. Job adverts are distributed widely (via jobs.ac.uk; Nature jobs, Science jobs), including via targeted searches from Research Group Convenors, to ensure we capture the complementary research expertise required to deliver our strategy [1b – Obj. 1, 1e – Obj. a]. Shortlisting panels (comprising ≥5 people, including at least two staff identifying as female) identify candidates for interview who will deliver a School-wide seminar demonstrating their fit to our research groups (interview panels are chaired by the Faculty Dean or their representative and comprises 7 academics (≥2 identifying as female)). For senior staff (SL and Reader) successful applications are reviewed externally to assess they meet the criteria for a senior grade appointment, and for Professors a separate recruitment process chaired by the VC is implemented. Since REF2014, 3 Independent Research Fellows, 26 Lecturers, 1 Senior Lecture, 1 Reader and 1 Professor (M:F 26:6), were appointed, while 10 staff left (3 retirements, 7 moves).

2b) Staff development

New appointments: all new Category A staff are provided with access to state-of-the art facilities, lab space and associated School technician support, an appropriate start-up package to support establishing the research base (typically £30-40K over three years), targeted allocation of School PhD studentships, and significantly reduced teaching loads (~50% during the first 3yrs). Alongside this, the School maintains, within the constraints of our operating budgets, a 50% match-funding policy for PhD studentships for all academics staff who have secured 50% of the award value independently and new appointments have preferential access to these funds. New staff use our supportive 3 year 'Pathway to Permanency' system to ensure a successful transition from probation (100% success rate (13/13) since REF2014) and an independent and self-sustaining research programme (with significant grant capture by ECRs [3b]). Formal mentorship from a senior academic, chosen by the probationer, provides guidance on grant writing, research management and leadership, education, and training needs. Mentors and mentees create a 'Pathway to Permanency' plan with short- and long- term targets. Plans are formally agreed by probationers, mentors, HoS, and Executive Dean of Faculty, and revisited via 18- and 36- month reviews. Probationary staff are granted permanency through the Annual Review process (below) and can apply at any stage of their probation. We place considerable emphasis on preparing probationary staff for their permanent roles, and utilise the support of the University's Organisational Development team who provide Research and Education Staff Inductions and 'Essential Training' on (among others): Computer Safety; Equality, Diversity and Inclusion; Financial Regulations; Fire Safety; Health and Safety; Information Security; Safeguarding; Unconscious Bias; and Research Student Supervision and Examination. In addition, all (100% since REF2014) new academic staff are supported to become Fellows of the Higher Education Academy (FHEA) via the University's CADENZA training programme.

Established academic staff. Key to our overarching aim [1b] is providing staff with adequate time to pursue their research and impact activities (including engagement with industry, government, and third-sector organisations). School Strategic, Area, and Periodic Teaching Reviews during 2014-2020, all revealed fragmented teaching and administrative loads among staff, reducing the amount of contiguously available time for research and impact activities. We addressed this by

compressing teaching into blocks and used our increased numbers of academic staff to redistribute teaching, taking staff workloads from a 20:80 Research:Teaching (R:T) split to 40:60 (R:T). Recent Time Allocation Surveys (TAS) demonstrate these actions are effective (2018-2019 R:T:O 45:51:4). To ensure time remains available for research and impact, teaching, administration, knowledge exchange and other academic contributions are allocated to staff via a transparent Workload Model (WLM), which is reviewed annually. The WLM provides staff a platform to discuss workloads with the SMT, and make appropriate adjustments to allow enough time to pursue research (increases in grant income **[3b]** and high-quality outputs **[1a 1b]** since REF2014 are evidence this is working), and that time allocated to research grants is accounted for. Annual Performance Development Reviews (PDR) between each academic and the HoS provide a supportive framework to discuss career progression, research and impact objectives, funding and output priorities, training (e.g. Leadership Training) needs, ensuring *Essential Training* (detailed above) has been received, and planning applications for promotion and/or other incentives (detailed below). Promotion applications follow a two-step evaluation process, first assessed by the Senior Staff Committees (SSC) in SoLS and then by the University Academic Staffing Committee (ASC; chaired by Deputy VC). The SSC (chaired by HoS) comprises all staff from Senior Lectures to Professors, who evaluate all applications for promotion up to their current grade (i.e. SL, Reader and Professor evaluate applications for SL, but only Professors evaluate application to Professor). The application, along with SSC's evaluation, passes to ASC where, for all applications to SL or above, two independent external peer reviews are also used in making a final decision. Since REF2014, 14 SoLS staff have been awarded promotion, including 10 to SL, and 3 to Professor.

Supporting and Recognising Research and Impact. All academic staff are eligible for, and encouraged to take, Research Leave (entitlement is one term of leave for every 6 terms of employment). Applications are reviewed yearly by RSG and awarded based on a strategically aligned plan for developing research and impact. 21 staff have taken Research Leave since REF2014. In recognition of their performance in securing research income (grants), staff are provided with 20% of the Indirect Costs recovered from their grants (up to £20K per grant) or 2% of the total award value (up to £10K per grant) for charity-funded research not carrying Indirect Costs, to be taken as either: a) salary, b) University-based childcare payments, or c) awarded into their internal Education and Research Incentive Accounts. Since REF2014, all staff chose option 'c' (totalling >£800K) and have invested this money into new equipment, pump-priming future funding applications, additional support for research students, and employing Postdoctoral Research Officers (ROs). The University recognises outstanding achievements via the annual Celebrating Excellence in Research and Impacts Awards, which have been awarded to Lawson (2019), Dumbrell (2019) and Schalkwyk (2020). Further details of how we support staff to generate impact are included elsewhere **[1c, 4b]**.

Research staff (ROs): We have fully implemented the Concordat to Support the Career Development of Researchers at University of Essex, as recognised by retaining our HR Excellence in Research Award (2019) at our four-year review. ROs are supported through their annual PDRs with their supervisors, and take an active role in outlining research objectives, and identifying training and career development requirements/opportunities. ROs are expected to attend and complete the same *Essential Training* as new academic staff (above). Supervisors, supported by HR and REO, ensure both on-going professional development (aligned with *Vitae's* Research Development Framework), and advanced subject-specific training is provided. Funds are provided to attend external courses that aid ROs' career development, and ROs are supported to participate in School activities and networking (e.g., via delivering occasional advanced lectures to students, or running research group seminar programmes). Central to the School's research success is a dedicated team (31 FTE) of Technicians, who manage all laboratories, equipment and facilities **[3c, 3d]**, and support open and transparent research **[1e]**. We are committed to supporting their career development and are signatories of the Technician Commitment. Our recent cross-faculty review identified specific training needs and outlined mechanisms to support Technicians within our professional development frameworks. Technicians use the same PDR process as other research staff.

2c) Research students

Recruitment. To attract a diverse and vibrant community of the highest calibre of postgraduates, we begin recruitment with full details and marketing of opportunities (using inclusive language) on our website, alongside proactively targeting recruitment through PhD advertising sites (e.g. findaphd.com, jobs.ac.uk). Social media platforms like Twitter, Facebook, and LinkedIn are used together with each member of academic staff's network of collaborators. Our approach ensures the widest diversity of applicants is reached in an open and inclusive manner. Candidate selection follows interview procedures (built on UKRI good practice guidelines for EDI, and via inclusive panels mirroring staff recruitment **[2a]**) designed to maximise equality and opportunity, recognising potential as well as prior academic achievement. We typically receive between 150-200 applications yearly (>100 typically for DTP studentships) to join our PhD programmes with ~55-75% from overseas students. 259 postgraduate students were successfully admitted (2014-2020), with the core criteria being the candidate obtained a good degree in a relevant subject (2.i or above). Although not a requirement, most hold postgraduate qualifications as well. The University of Essex is currently 4th in UK for the number of PhD student supervised per FTE academic staff, and recruitment within SoLS has allowed us to be equally well placed, awarding 139 doctorates since REF2014.

Funding: PhDs are supported by the current NERC ARIES DTP (previously EnvEast 2014-2018), the ESRC-BBWR SOC-B CDT (2018-2021), BBSRC Fruit Crop Research CTP (with NIAB-EMR), BBSRC and NERC CASE studentships independent of DTPs (while schemes were active) as well as those aligned to NERC Large Grants: these UKRI DTPs and grants supported 18 students since REF2014. Charities (e.g. Perry Foundation), industry (e.g. Anglian Water) the stakeholder/end-user communities (e.g. CEFAS), School and Faculty Scholarships, International Bursaries, Research Grants, and scholarships from external collaborators (e.g. Diamond Light Source) funded 78 PhDs. The remaining PhDs were self-funded (~62%). The SoLS operates a 50% matched-funds policy, whereby supervisors secure 50% of PhD funds from external sources, the School matches this. This has provided a range of industry-linked PhD that would have otherwise not been possible **[4b]**.

Progress, training and support. The PGRD provides oversight over all progress and training activities for PhDs, and ensures all support mechanisms for successful completion (current completion rates within 4yrs: 94%) and transition into employment are provided. The PGRD acts as a liaison between our PhDs and the Graduate School, which has overall responsibility for PhD student training, and provides a comprehensive professional development programme (*Proficio*). The *Proficio* programme provides every PhD student with £2,500 for attending training courses/workshops and scientific conferences. PhD students, supported by their supervisors, identify training needs upon commencing and throughout their PhD journey, with training logs reviewed by Supervisory Boards (below). PhD students direct the availability of training via their Student Voice Group, leading to new courses being introduced (e.g. *Laboratory Maths*). PhD students are expected to join learned societies and to participate in national and international conferences, and all students are expected to present their research at conferences. In addition to their supervisor, PhD students are assigned an independent advisor who monitors and supports their progress. Progress is assessed formally at 6-monthly Supervisory Boards, where students report to their supervisors and independent advisors. Milestones include production of a project plan (first board), a literature review and an annual report (second board) and in the second year (confirmation board), continuation on the PhD programme is agreed by the PGRD (Chair), the DoR, supervisor and independent advisor. The School's Research Students Progress Committee (PGRD and HoS) formally reviews progress annually and makes recommendations to the University's Graduate School.

2d) Equality and diversity

The School, like the University, recognises the value of diversity and is committed to equality of opportunity. SoLS comprises a diverse research community (40% International, 4% BAME, 37:10 M:F) which reflects our actions in supporting diversity, as does the School's leadership, with the

SMT comprising British (84%), International (16%), identifying as Male (33%), identifying as Female (67%) and LGBT (33%) representation. The University is a signatory of the Race Equality Charter, acts as a Stonewall Diversity Champion, and is consistently ranked in the Stonewall Top 100 employers. Both SoLS and the University held Athena SWAN bronze awards during 2014-2020, with SoLS recently being awarded Athena SWAN Silver (2020). EDI is now starred as a standing agenda item for termly whole-School meetings, and all staff have completed training in Unconscious Biases and EDI Essentials. Staff sitting on any interview panels will have attended additional EDI training associated with that role, and recruitment activities, including wording of adverts, are fully inclusive [2a]. SoLS dedicated Equality, Diversity and Inclusion Committee (EIDC) meets termly and feeds into RSG (among other committees). The EIDC comprises representatives from our ROs, PhDs, Technicians and research support teams, and an Inclusivity Rep. covering the voice of the academic staff. All staff sit on the EDIC on a rolling basis, providing everyone an inclusive opportunity to be involved with the School's voice. The SMT has permanent EDIC membership to ensure decisions are taken to implementation. Our REF submission was prepared by the diverse membership of the SMT (above) and RSG [1b], who paid due regard to equality and diversity at all stages. Selection of outputs followed the University's Code of Practice, was balanced across research groups, and the independent review of outputs was overseen by members of SMT and RSG.

Supporting Staff: Networks and mentorship: We operate the SoLS Peer-Mentorship Programme for all staff (separate to mentorship of probationary staff) to engage with as mentor or mentee. Staff seeking mentorship select mentors who best suit their needs; for example, senior colleagues offering career advice, or colleagues with family commitments offering advice on managing work and childcare. Mentors and mentees meet regularly to discuss these issues. The University provides additional mentoring, via Organisational Development, and formal Coaching (via *Coaching for Success* programme) for staff requesting it, alongside the *Coaching for Manager* sessions, which train line managers as coaches themselves. Support networks within the School and the University to provide staff support tailored to their individual needs, background and circumstances include: the Women in Science Network (as well as being members of the national WISE Campaign); Essex Women's Network; Essex LGBT Alliance; Parents Support Network; and the One-Essex Inclusivity Network.

Families and career breaks: Staff expecting babies are encouraged to meet with Organisational Development, who provide the University's *'Pregnancy, maternity and returning to work'* booklet, and discuss support and return options (e.g. flexible working). The School follows University guidelines on maternity, paternity and adoption leave, and conducts risk and workplace assessments to identify adjustments. The HoS and employee identify cover for teaching and administrative duties. Temporary maternity cover is formally advertised. SoLS Peer-Mentorship Programme connects those planning maternity/paternity leave with those who have recently returned. Staff are encouraged to Keep In Touch (KIT) with the School during their leave via paid KIT days (up to 10 per period), helping staff remain connected with the research environment, training events, new School initiatives and their research/impact projects. Line Managers have a *'How to support pregnant staff'* guide, helping to support them support their staff. All staff on maternity, paternity or adoption leave can apply for a career break to extend their leave. In addition, a parent-and-baby room is available during KIT days and upon their return for breastfeeding and expressing. During leave, staff continue to receive their annual pay increments, and on return meet with line managers to discuss changes to workload or working pattern. For academic staff, this includes a temporary period (6 months) of lower allocated workload (e.g. teaching) to facilitate re-establishing research and impact activities. In addition, the *Returning Parent Career Development Fund* is available to all staff to help with additional caring costs incurred while attending conferences/training/networking events. Staff have priority access with reduced rates for the University weekday (8am-6pm) campus nursery, which was recently rated *'Outstanding'* by Ofsted.

Flexible working and balance: Care leave is available and staff may be granted up to 5 days (pro rata for P/T) of care leave with full pay within any 12-month period on a rolling basis, with an additional entitlement of 5 days unpaid care leave annually. Parents are entitled to a total of 18

weeks' (4 weeks per year) unpaid parental leave per child, which can be taken before their child's 18th birthday. The School provides multiple informal mechanisms to support flexible working, including holding meetings within core hours (10am-4pm) and honouring requests not to schedule teaching at particular times should academics require flexibility. Senior staff lead by example and promote how they make use of this flexibility to others in the School. For example, the SMT encourages academic staff to take one day/week to work on paper and/or grant writing away from the office. The University's *People Supporting Strategy 2015-19* aspires to increase the use of flexible working across the University and the School is committed to helping achieve this by making staff aware of their options.

3. Income, infrastructure and facilities

3a) Operational structure

Securing external funding to support excellence in research, purchase new technologies and equipment, and expand our facilities and infrastructure was essential to delivering on our 2014-2020 strategy [**1b** – **Obj. 1, 2, 4**]. Our main operational mechanisms behind this are provided earlier [**1b**], with evidence of success below [**3b** – **3d**]. The expansion [**1b**] of our four research groups provides vibrant clusters for successful research. Research groups host weekly seminars and meetings open to all staff to develop research and impact ideas. The School complements this with a weekly seminar series hosting external speakers, termly whole-school meetings that discuss and communicate future changes to the funding and impact landscape, research governance, and strategy, and annual 'away days' where staff identify mechanisms to maximise outputs, income and impact. In addition, the DoR works with the University's REO to identify and distribute all open funding calls, industrial funding opportunities, and other sources of external income relevant to the School's PIs. Securing external income to fund postdocs and technicians is the responsibility of each PI, and we have promoted a culture shift to more ambition in seeking external funding and a School policy of at least two substantial grant applications per year per PI. To further support this we provide a stringent grant sift (at least two internal reviewers providing substantial feedback) of all applications worth >£100K which has facilitated successful demand management of NERC Standard Grant submissions. Our support measure drove an overall increase in funding (5yrs of REF2014 (2009-2013): £9.9M; 7yrs of REF2021 (2014-2020): £16.2M; last 5yrs of REF2021 (2016-2020): £13M) with an average year-on-year increase of 11%.

3b) Research income 2014-2020

SoLS secured £16.2M of grant income from 104 sources, with six Medium-to-Large (>£0.6M) grants totalling £5.4M awarded, notable example of which include: three UKRI NERC grants (£1.1M, £0.8M, £0.6M), one MRC grant (£0.7M), one European Commission grant (£0.7M), and our inclusion in the RIPE project (£1.5M from Bill and Melinda Gates Foundation via the University of Illinois). Other funding from a diverse portfolio of sources includes, all relevant UKRI councils (£8.7M, with £0.7M additional in-kind contributions), Wellcome Trust, Leverhulme Trust, and other charities (£2.4M), EU funders (£1.1M), and Industry (£300K). Research income is balanced across groups, after accounting for career stages and composition [**1d**]. Typically, established staff in the EEM and PP groups secured the majority of external income (£7.2M and £6.4M respectively), reflective of their career stages and our long-term track record of these disciplines at Essex. Nevertheless, our newer groups all secured significant funding appropriate to the career stages of their members. For example, 7 ECRs within the GCB and PSMD groups received Wellcome Trust Seed Awards (totalling ~£0.7M). Funding underpins research outputs and impact (52% of outputs were supported by external grant income to SoLS), and the research behind two Impact Cases (*Cameron and Underwood*, *Lawson et al.*) was NERC, BBSRC and Royal Society-funded. The wider contributions of our research to the economy and society are also supported by UKRI and other major funders [**4b**].

3c) Supporting infrastructure

SoLS comprises 6800m² building space, with 3200m² dedicated to research. Since REF2014, we

have significantly invested (>£2M) in refurbishing and creating new laboratory infrastructure. This includes, new genomic laboratories (£1.1M, 187m²), a new computational biology suite (£180K, 80m²), and microbial ecology laboratories with a new analytical and environmental chemistry suite (£800K, 280m²). Moreover, the University completed construction (2018) of a new £18M STEM Centre, which contains >750m² of dedicated biology laboratories solely for the use of SoLS's students. By moving all our educational activities to the new STEM laboratories, we have reallocated >840m² of previous teaching laboratory space for research, supporting our continued expansion. We have secured further investment in new or refurbished infrastructure in the next REF period [1f – Obj. c]. This includes, new glasshouses and control environment growth rooms (£0.4M), aquatic ecology and tropical marine biology laboratories (£1.2M), biophysical spectroscopy laboratories (£0.6M). All laboratory space is managed by dedicated School-funded Technicians (31 FTEs) who provide continuity of expertise, operate research facilities and equipment [3d], and support all researchers within our laboratories.

3d) Research facilities

Investment during the assessment period: We have invested heavily to ensure our major research facilities all contain modern and relevant equipment, providing a well-resourced biological sciences environment to support our growth strategy [1b – Obj. 2, 4]. SoLS has secured >£1.4M in new major research assets since REF2014, including (items with 50%-UKRI or 100%-grant funding are indicated): High Performance Computer Cluster (£55k; with £675k additional University funding); Illumina MiSeq (£95k); Liquid Handling Robots (£110K; 50%-UKRI); high-throughput qPCR (£62k); digital droplet PCR (£108k); 10x Chromium Single Cell (£62k); Agilent ICP-MS (£105k 50%-UKRI); Shimadzu Triple Quad GC-MS (£120K); fieldwork vehicles and boats (£45k); Skalar TOC (£56k); LI-COR automated soil respiration (£75k; 50%-UKRI); and plant photosynthesis and leaf gas exchange equipment (£320K; 100%-grant).

Core facilities: The School operates core facilities available to all researchers that underpinned outputs and impact during 2014-2020. Recent investments (above) expanded and modernised these facilities. **Analytical (environmental) chemistry** [supporting outputs from 15 Category A staff]: Facilities include multiple GCs with diverse detectors (MS, FID, FPD, ECD), ICP-MS, uPLC/MS, and HPLC for measuring trace gases, metals, hydrocarbons and lipids. A new (2017) Autoanalysis suite, and Dionex ion exchange chromatography, for quantifying soil/sediment nutrients. Bespoke systems for measuring sediment oxygen/nutrient flux, with new (2019) multiplex supported Picarro and LI-COR gas exchange equipment to quantify soil/sediment CH₄/CO₂/H₂O fluxes. Using these facilities to monitor local coastal and marine environments has supported grants underpinning Impact Cases (*Underwood; Cameron and Underwood*), and has enabled wider impact in marine and coastal resources and environmental pollution [4b]. **Protein Production, Purification and Characterisation** [supporting outputs from 8 Category A staff]: We are 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. We produce genome-scale analysis of protein abundance and post-translational modifications utilising stable isotope labelling and label-free approaches via LTQ/Orbitrap Velis MS/MS with a splitless nano-scale liquid chromatography system. These facilities support wider impact related to novel breast cancer diagnostic and treatment [4b]. **Biophysical characterisation** [supporting outputs from 10 Category A staff]: Facilities include stopped flow optical/fluorescence and laser flash photolysis set-ups for kinetic analysis of enzyme reactions and ligand binding, extensive facilities for UV/visible/near infra-red and fluorescence spectroscopy from isolated samples and for proteins within cells (Olis instrument). We use a MicroCal Isothermal Titration Calorimeter for deriving the thermodynamics of protein ligand binding, and surface plasmon resonance (SPR) facilities to permit the study of a range of biomolecular interactions. We run specialist facilities for X-band Electron Paramagnetic Resonance (EPR) spectroscopy, including a liquid helium cryostat and apparatus for preparation of rapid-freeze quench samples. A potentiometry set-up is used for measurement of redox potentials by cyclic voltammetry and redox titration. Exemplar wider impact from these facilitated is via our work on artificial blood substitutes [4b]. **High-throughput**

genomics [supporting outputs from 19 Category A staff]: We have extensive specialist facilities for the processing, and next-generation sequencing (NGS) of nucleic acids (DNA, RNA), including high throughput liquid handling platforms (Hamilton, Gilson, BioRad), banks of (regular and LAMP) PCR and qPCR thermal cyclers (with high-throughput capacities) and advanced (with liquid handling support) digital droplet (dd)PCR (BioRad) capabilities for accurate quantification of gene and transcript abundances. Multiple fluorospectrophotometers, spectrophotometers, bioanalysers and automated size-selectors (e.g. Blue Pippin) are used for quality control and preparation of nucleic acid samples for NGS, supported in-house via Illumina and Oxford Nanopore machines. These facilities support wider impact via our work on bioaerosol biomonitoring [4b]. **Controlled environments and growth suites** [supporting outputs from 12 Category A staff]: We maintain ~240m² of computer-controlled glasshouse (with GM containment), and controlled environment growth rooms for plants. Aquatic research is supported via 62 large (>100L) temperature-controlled aquaria, with pH-stating systems and controlled CO₂, simulating tropical or temperate freshwater or marine systems, and replicated external intertidal and freshwater mesocosms (~1300m²). Our microbial (Prokaryote and Eukaryote) growth facilities, comprise constant temperature (and light) growth rooms across a -12°C to +40°C gradient. Wider social benefit from these facilities includes the experimental underpinning of work on restoring degraded coral reefs [4b]. **Plant phenotyping and photophysiology** [supporting outputs from 6 category A staff]: We operate a state-of-the art high throughput automated phenotyping platform for integrated imaging of water use efficiency, photosynthetic efficiency and growth parameters. This is complemented via a range of equipment for the analysis of photosynthetic parameters including Fast Repetition Rate and PAM fluorimeters, O₂ electrodes and optodes, 16 infra-red gas analysers and a membrane inlet mass spectrometer to measure O₂ and CO₂ fluxes. As well thermal imaging equipment to quantify stomatal conductance. These facilities produce our societal impact focused on crop productivity [4b]. **Bioimaging** [supporting outputs from 18 Category A staff]: We have a significant track record of in-house development of methods, optical instruments, software algorithms for quantified image analysis and fluorescent protein biosensor design. We use three-dimensional high-speed (ms) and long-term (d) live fluorescence microscopy, from subcellular to whole organism scales, and biosensor-based or label-free physiological imaging. We have widefield/deconvolution, confocal laser scanning and total internal reflection fluorescence microscopes and in-house developed chlorophyll fluorescence imaging and light-sheet fluorescence and reflectance microscopes. Bioimaging and plant phenotyping facilities underpin the research behind an Impact Case (Lawson et al). **High Performance Computing (HPC)** [supporting outputs from >27 Category A staff]: SoLS kick-started HPC at the University of Essex, with an initial four-node cluster devoted to analysing genomics data. Recent University-level investment expanded this into the CERES cluster, supporting >1000 processors across multiple nodes with 0.5-1.5Tb RAM, and 24 dedicated GPUs. We maintain >12 independent servers (with 56-124 cores and 0.128-0.5Tb RAM each) devoted to specific computational biology tasks (e.g. modelling protein structure, or processing metagenomic data). HPC facilities support all research groups and nearly all researchers, with wider impact via our work modelling GPCRs for enhanced drug design [4b].

3e) Shared or collaborative use of research infrastructure

The SoLS is an active member of the Eastern Arc, sharing access to our core facilities with researchers from the Universities of Kent and East Anglia. >100 external organisations have accessed our facilities since REF2014, including: 15 using genomic facilities (e.g. Universities of Ljubljana, Münster, and Leeds, Imperial College London, Norwegian Institute for Water); 24 using HPC (e.g. Universities of Coventry and Exeter, Queen's University Belfast, Norwegian Institute for Nature Research, National Institute of Health USA, Moscow Institute of Physics and Technology); 26 using EPR spectroscopy (e.g. Universities of Leicester, East Anglia, Sheffield, Reading, Cambridge, Bristol, Leiden, Amsterdam); and 17 using bioimaging (e.g. Universities of Kent, East Anglia, Durham, Southampton, Imperial College London). In turn, we have collaborated with NERC NBAF, Earlham Institute, Diamond Light Source, Swiss Light Source, SACLA X-ray free electron laser (Japan) and UK HEIs to access external facilities.

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

4a) Supporting research collaborations, networks and partnerships

Most substantial (>£100K) grants are collaborative, reflecting national (54%) and international (44%) partnerships and the inclusion of key beneficiaries and end-users (52%; **[4b]**). Subsequently, outputs include national (67%) and/or international (58%) co-authors, and we have published with collaborators from >40 countries since REF2014. Our strategy for supporting collaborative research is based on the principle that robust collaborations form organically from PIs discussing exciting ideas around their shared interests. Thus, we provide time (within the WLM) and space for these interactions to emerge, via our research groups **[1d]**, shared facilities and infrastructure **[3c, d]**, and multidisciplinary centres **[1d]**. Support to identify and secure collaborative (and non-collaborative) research income is provided to all PIs **[3a]**. We run an open policy for hosting visiting PhD students (>30 since REF2014) and PDRAs (10 since REF2014) supporting collaborations with 8 national and 20 international institutes. To facilitate international collaborations, the University has funded, via its International Visiting Fellowship Scheme, SoLS hosting: *Surapipith* (National Astronomical Research Institute of Thailand), *Oyeyemi* (University of Medical Sciences, Nigeria), *Ramamoorthy* (VIT University, India), *Weiner* (Weizmann Institute of Science, Israel) and *Bianco* (University of Rome Tor Vergata, Italy). The University allocates (via open competition) the GCRF awarded via Research England, supporting existing, and new, international collaborations. Examples from SoLS (2014-2020) include: *Ecosystem Management: Building Resilience and Adaptability to Coastal Climate Change Effects* (Underwood, Hicks – South Africa); *Cancer, Biophysics, Gene Regulation & Epigenetics* (Teif – India); *Building an Autism Research Network* (Schalkwyk – Vietnam); and *Effect of Aquatic Trace Gases on Air Quality* (Steinke – Thailand). In addition, since REF2014, 30 external grants have been awarded specifically for networking activities. For example: *BioSkyNet: The First Global Network of Bioaerosols Researchers* (NERC; Ferguson, Dumbrell); *BioAirNet: Indoor/Outdoor Bioaerosols Interface and Relationship Network* (NERC; Whitby, Colbeck); *European Network of Bioadhesions Expertise* (EU COST Action; Aldred); *SeaUnicorn* (EU COST Action; Sturrock, O’Gorman, Taylor, Nanninga).

4b) Fostering Impact from Research

Collaborations both within and outside the HE sector, are central to our research and impact strategy **[1b – Obj. 3, 1c]**, and we promote engagement and knowledge exchange with industry, government, and third-sector organisations.

Developing relationships with key research users, beneficiaries or audiences: To achieve impact from research, engagement with end-users and beneficiaries should be embedded from the outset, and we support this via multiple mechanisms **[1b – Obj. 3, 1c]** including: (i) **working with end-users to secure funding for research and impact:** our significant funding from UKRI strategic programmes (>£4M **[3b]**) has all been secured in collaboration with, and support from (often as project partners) end users and key beneficiaries. We have established multiple (£0.3M) industry-funded projects with partners whose interests align with our four research groups. For example, projects with Bayer Crop Science, BAE Systems, Anglian Water, Colchester Oyster Fishery, The Tollesbury and Mersea Native Oyster Fishery, Royal HaskoningDHV, MARS Inc., are all linked to our wider impact (below). Similarly, funded projects (>£4M) secured from government, and third-sector organisations, for example, Defra, NPL, Kent and Essex IFCA, Prostate Cancer UK, and CEFAS, are all designed from the end-user/beneficiary perspective to facilitate impact. (ii) **using external and internal funding to establish new relationships:** We use multiple approaches to develop new relationships, including securing Knowledge Transfer Partnerships (via Innovate UK and Research Councils) with external organisations (3 KTPs since REF2014). Examples include with ADC Bioscientific, and Wilkin and Sons, aligned to our work on crop productivity. We use Innovation Vouchers (£10K pump prime awards from the University of Essex) to initiate new partnerships (5 since REF2014), for example, with BioConsortia Inc., Isotera Ltd., and RAGT Seeds. As part of Research England’s £4.7M Connecting Capabilities Fund, we access Enabling Innovation: Research to Application (EIRA) R&D grants to springboard commercial

opportunities based on our research (4 since REF2014); for example, developing novel soil biosensors with PES Technologies, and novel therapeutics with Apollo Therapeutics. (iii) **linking PhDs with end-users and beneficiaries:** We have supported 8 CASE studentships since REF2014, and ~22 studentships linked to industry, government, and third-sector organisations. In addition, PhD training opportunities are provided in conjunction with partner organisations [2b], providing a platform for further interactions. (iv) **supporting activities to foster impact:** We have filed (12) research-linked patents that commercial organisations can develop further, and have secured £800K to support the development of protected intellectual property, notably from MRC and EIRA. Patents cover novel diagnostics for breast cancer, artificial human blood substitutes, enzymes that inhibit prostate cancer growth, and genes supporting increased plant productivity. We demonstrated the L-SPI light-sheet microscopy used in our Impact Case (Lawson et al) to national and international HEIs and industry, and provided a NERC Advanced Training (bioimaging) Course (2014-2015) to increase engagement. (v) **using School activities to expand networks:** We provide UG/PG placements with industry, government, and third-sector organisations, providing an additional route for researchers to established working relationships.

Wider contributions to the economy and society: Our research contributes to the economy and society, above and beyond that highlighted in our Impact Cases, with each research group addressing strategic impact priorities: **EEM** – marine and coastal resources, air quality and environmental pollution; **GCB** – Alzheimer’s disease, ulcerative colitis and cancer detection; **PP** – crop productivity; **PSMD** – novel therapeutics, artificial blood substitutes and antimicrobial resistance. Exemplars (in addition to those noted above) of how this strategy has delivered wider societal benefits include, **EEM** research has: 1) underpinned the development of Marine National Parks in low- and middle- income countries and via industrial links with Mars Inc. supported the restoration of degraded coral reefs (Smith); 2) developed non-invasive biosensors for bivalves that can accurately predict spawning within U.K. native oyster populations and working alongside Colchester Oyster Fishery help identify routes to maximising shellfish yields (Steinke, Cameron); and 3) developed molecular approaches to monitor bioaerosols and advised UK agencies (EA, DSTL) on strategies for deploying these as part of the NERC Environmental Microbiology and Human Health programme (Colbeck, Whitby, Dumbrell, Ferguson). **GCB** research has: 1) developed and filed a patent (PCT) for a novel breast cancer diagnostic and treatment aimed at improving detection rates, reducing treatment costs, and providing a platform for drug development (Metodiev); and 2) identified and developed a tool for designing DNazymes that inhibit prostate cancer growth, and are working with our commercialisation team and external biotech companies to develop this further (Marco, Brooks); **PP** research has: 1) demonstrated that over expression of Rieske protein can increase crop biomass in sub-Saharan Africa (part of the RIPE project), and filed patents for future commercial development (Raines); 2) developed new plant-performance instrumentation (with ADC Bioscientific), and worked with RAGT Seeds and Bioconsortia to produce imaging tools for disease screening and crop improvement (Lawson); and 3) increased *HSFA1b* gene expression in *Arabidopsis*, resulting in improved drought tolerance, and filed patents for future commercialisation (Mullineaux, Bechtold); **PSMD** research has: 1) designed and patented artificial blood substitutes, established a spin-out company (Cymblood Ltd) for commercial development, and secured >£1M of additional MRC funds for further optimisation (Reeder); 2) enhanced industrial drug design with Heptares Therapeutics, based on novel Markov state models of GPCRs (Reynolds); and 3) begun development, with Apollo Therapeutics, of inhibitors that prevent *hnRNPA1* mediated therapy resistance in small cell cancer (Prischi).

Engaging diverse communities and publics: We use a range of outreach platforms to communicate our research to diverse communities and the public, and outreach activities are recognised in promotion criteria and on the WLM. These have included, publishing in the popular sciences press via *The Conversation* (18 articles), producing award-winning natural history publications (Pretty – The East Country), and an active social media presence across Category A staff (35 Tweeters). Staff regularly engage with local and national media. We have used science festivals to capture public interest, presenting research at the ‘Big Bang at Essex’ fair (2019), and annually via ‘Pint of Science’ festivals – our 2018 Colchester Pint of Science event sold out the quickest in the UK. Our Outreach Officer organises annual school outreach (including as part of national science week) and we present research at schools and invite school children to attend

talks on campus.

4c) Contribution to the sustainability of the discipline

Advisory boards, committees and learned societies: Many SoLS staff (18) held positions on advisory boards, committees or learned societies, broadening external engagement and further shaping the research base. These include: National Infrastructure Advisory Board (*Cameron*); Essex County Council Air Quality Consortium (*Colbeck*); CCP4 Project Board (*Hough*); Essex County Council – Climate Action Commission (*Pretty, Underwood*); Environment Agency Flood and Coastal committee (*Underwood*); WWF-UK Board (*Pretty*); Academy of Medical Sciences – Health of the Nation 2030 panel (*Pretty*); Presidents of the Society of Experimental Biology (*Raines*); the Aerosol Society (*Colbeck*); and the British Psychological Society (*Underwood*).

Peer review and strategic contributions to research strategy: All staff have contributed to grant peer review, funding panels or committees for UKRI Councils (NERC, BBSRC, MRC, ESRC) and charities (e.g. CRUK). Senior roles supporting UKRI Councils included: *Underwood* (Chair of NERC Science Committee); *McGenity* (NERC Core Panel Member); *Dumbrell, Whitby, Hicks, O’Gorman* (NERC Peer Review College); *Lawson, Mullineaux* (BBSRC Core Panel Member – B). Outside of the UK, four staff have sat on international grant committees, including: German (DFG), Danish (DFF), French (ANR), Polish (NCN), Canadian (NSERC), Czech Republic (CSF) and New Zealand (Royal Society – Marsden), Finland (ASF). Since REF2014, staff have served as Editors-in Chief (*Raines* – Journal of Experimental Botany; *Dumbrell* – Advances in Ecological Research; *Colbeck* – Environment and Health; *Pretty* – International Journal of Agricultural Sustainability) or Associate Editors (*Dumbrell* – Molecular Ecology; Molecular Ecology Resources; *Lawson* - Journal of Experimental Botany; Plant Direct). Staff (15) were also Guest Editors or on Editorial Boards (*Bavro; Cameron; Colbeck; Fernandez, Hough; Lawson; Marco; McGenity, Mohr, O’Gorman; Prischi; Svistunenکو; Taylor, Teif, Zwacka*)

Responsiveness to national and international priorities and initiatives: We have contributed to the development and implementation of national and international research priorities through our roles advising funding councils. *Underwood* has served as the chair of the NERC Strategic Programme Advisory Group (2014-2019) overseeing the formulation of NERC Strategic programmes including the initiation of the Highlight Topics programme. *Underwood* is now Chair of NERC Science Committee (2019-present), which supports the ‘*development and delivery of the UKRI-NERC strategic priorities, investments and policies*’. *Pretty* sat on the BBSRC Food Security Strategy Advisory Panel, helping to formulate the strategy for agriculture and food security. Since REF2014, we have secured >£6.5M of grant income responding to national and internal research priorities and initiatives. **Nationally**, we secured >£2.8M from UKRI strategic research programmes, including: NERC - Environmental Microbiology and Human Health; Emerging Risks of Chemicals in the Environment; Highlight Topics – Urban Soils; Influence of Man-made Structures in the Ecosystem; and BBSRC – NERC Joint Call in Aquaculture; **Internationally**, we have participated in (>£3.7M) strategic programmes including NERC-Newton Fund Wallacea Region - Understanding Biodiversity & Evolutionary Responses to Environmental Change; BBSRC International Wheat Yield Partnership; EC H2020 – Transforming European Industry; EU Interreg – 2 Seas Mers Zeeën; GCRF Global Food Security; and the Realising Increasing Photosynthetic Efficiency project [**1d – PP**].

4d) Additional measures of esteem (fellowships, prizes, awards)

Submitted staff held (since REF2014) MRC Research Leader (*Reynolds*), Royal Society Industrial (*Reynolds*), NERC Independent Research (*O’Gorman*), Eastern Arc (*McKew*), and Institute of Analytics and Data Science (*Clark, Hoyal Cuthill*) fellowships secured in open competition. The following honorary awards were received: ESA sustainability award (*O’Gorman*), NERC 50th Anniversary Award (*O’Gorman*), International Women’s Award (*Whitby*), Hon. Fellow of the Indian Society of Plant Physiology (*Mullineaux*), international Aerosols Fellow (*Colbeck*), Hon. Fellow of the British Naturalist Association (*Cameron*), East Anglian Book of the Year 2018 (*Pretty*), British Science Association Presidential Medal – Agriculture and Food (*Pretty*). Most staff (72%) have

been invited to present at workshops, symposia and national/international conferences since REF2014.