

<b>Institution: Brunel University London</b>
<b>Unit of Assessment: 07 – Earth Systems and Environmental Sciences</b>
<b>1. Unit context and structure, research and impact strategy</b>

### **Achievements, strategic aims and impact during the assessment period**

**Overview:** Brunel University is one of the UK's leading centres for chemical pollution research and this is our third submission to the Earth Systems and Environmental Sciences UoA. The current submission demonstrates a significant expansion in the depth and reach of our research output in the specialisms of environmental risks, environment and health and pollution research. Building on the strong reputation of Brunel ecotoxicologists in endocrine disruptor research and the protection of aquatic environments, we have strengthened our activity in four focal areas of research: 1. Predictive approaches in toxicology, including combined chemical exposures (“cocktail effects”) and *in vitro* – *in vivo* extrapolations; 2. Endocrine disruptor research with an emphasis on test method development; 3. Pollution monitoring, clean-up technologies and chemical analytics; and 4. Evidence synthesis for regulatory decision making and development of new practices and policies for pollution control. These inter-linked areas are all supported by a portfolio of funding from the EU and DEFRA.

Our strategy has been to achieve strength-in-depth in these areas to provide a platform for effective interdisciplinary research that addresses the complex challenges to global and planetary health and sustainability in the 21<sup>st</sup> century. We have broadened our scope to develop solutions for the practical challenges of widespread and ubiquitous chemical pollution and to build capacity in chemical policy and environmental management, especially on resource and waste management systems. This has been enabled and supported by the appointment of several talented junior staff to faculty positions and has driven exciting collaborations across the university (College of Business, Arts and Social Sciences on a Global Challenges undergraduate programme) and internationally on several prestigious high-visibility projects.

These developments have positioned us well to build a broad educational portfolio and to evolve into a **Division of Environmental Sciences** within the new College of Health, Medicine and Life Sciences, with a fully developed undergraduate and post-graduate teaching programme. By establishing this academic unit, we have embedded our research excellence in the College and have achieved financial stability and access to College resources.

We have been extraordinarily successful in securing outside funding, especially from the EU. Over the reporting period, our research income has grown to £6.1 Million. As a result, we have consolidated and expanded our international collaborations, networks, and partnerships. Accordingly, most of our research output has grown out of international collaborations. We have made extensive use of consultancies and professional services as major elements of our funding strategy and were able to secure an additional £1.1 Million to support our research. We have provided intellectual leadership in our specialist area for over a decade. This is demonstrated by the quality of our research output which is in the top 10% of journals in our disciplines. Our work is highly cited (296 peer-reviewed papers which received 5,278 citations) and has had a major impact on chemical policy at the European level (see **impact case studies**). With a knowledge exchange strategy that prioritises disseminating our science in a way that is accessible to generalists, we had 8 papers in the Nature group of journals and Science, many of these as commentary articles.

**Research objectives and future goals:** Our research strategy seeks to address key aspects of chemical pollution and management relevant to human and ecosystem health. The societal needs for the protection of human health and the environment from harmful pollution, and for improved resource efficiency and waste management inform both our research and impact strategies. We strive for depth in key strategic areas of high political relevance but weak scientific underpinning. We aim to advance the scientific foundations for policy decisions. In these areas it is essential to build inter-disciplinary and international collaborations. Our strategy seeks to strengthen existing internal and external links and to build new links to disciplines that enhance the impact of our

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research, especially in the areas of improved chemical regulation, pollution management and prevention, and sustainability. To encourage a high degree of creativity and inter-disciplinary collaborations, we have adopted a flexible structure without rigid group boundaries. Some of the highlights in each of the four focal areas are presented below with reference to key research papers in this submission.

**1. Predictive approaches in toxicology, mixture toxicology:** Our research on the effects of combined chemical exposures has moved the whole field from largely descriptive practices to a systematic predictive approach. The toxic effects of quite complex multi-component mixtures (> 35 components) can be predicted accurately based on the toxicity of its components (Orton 2014 *Tox Appl Pharm* 278, 201). We have expanded this work by establishing the accuracy of prediction concepts for new toxicity endpoints (Ermler 2014 *Arch Toxicol* 88, 799, Gaudriault 2017 *Env Health Perspect* 125, 087004, Thrupp 2018 *Sci Total Env* 619, 1482). We can now tackle complex exposure scenarios in settings relevant to human health and aquatic ecosystems, entirely by modelling. Our work is shaping a new consensus that exposure limits defined for single chemicals are too high and cannot protect against the risks from coincidental mixtures (Kortenkamp and Faust 2018 *Science* 361 (6399), 224). Our track record has allowed us to attract major EU funding in human biomonitoring and exposome research (HBM4EU, ATHLETE) where we lead collaborations with academic and regulatory partners all over Europe.

We have developed ways of predicting developmental and reproductive toxicity in animals based on the outcome of culture dish assays for hormone-disrupting effects (Scholze 2020 *Env Health Perspect* 128, 117005). This work opens the way for the cost-effective prioritisation of chemicals for testing in one of the costliest study formats in regulatory toxicology, reproductive toxicity testing. To facilitate the development of more efficient approaches for the ecotoxicological testing of pharmaceuticals we have engaged in major collaborative efforts with industry and academic partners. We conducted a comprehensive analysis of all regulatory compliant aquatic ecotoxicity data and proposed additional testing for drugs with effects of concern (Gunnarsson 2019 *Env International* 129, 320).

**2. Endocrine disruptor research:** Our work on evaluating the impact of endocrine disrupting chemicals (substances with the capacity to interfere with hormone systems, leading to irreversible harm) has moved from established areas of research (estrogen mimics in fish) into less well researched aspects. We have identified many current-use pesticides as interfering with male sexual development through a new mechanism (Kugathas 2016 *Env Health Perspect* 124, 452). Our work on molluscan endocrinology highlights the need for novel testing strategies to ensure protection of invertebrates from endocrine hazards (Baynes 2019 *Scientific Reports* 9,1). Our expertise and track record in this field has allowed us to attract major EU funding for three projects on test method development for thyroid hormone system disruption (ATHENA), developmental neurotoxicity (ENDPOINTS) and metabolic disorders (GOLIATH).

**3. Pollution monitoring, clean-up technologies and chemical analytics:** We have evaluated the technical and environmental performance of a technique for mitigating the contamination of wastewater with steroidal estrogens, agents we have previously identified as disrupting the development of fish. The technique is based on a peroxidase enzyme replica and is the starting point for cleaning steroids and other pharmaceuticals from waste waters in an effective and environmentally friendly way (Mills 2015 *Scientific Reports* 5, 10511). We are leading the EU-funded demonstration activity INTCATCH that promotes a paradigm shift in the monitoring of surface water quality by using innovative autonomous and radio-controlled boats with sensors, test kits and run-off treatment technologies. The approach will supersede the inefficient, costly and time-consuming routine sampling and analysis procedures currently deployed.

#### 4. Evidence synthesis for regulatory decision making and development of new practices and policies for pollution control:

In a major international collaborative effort, we have developed a framework for the systematic review and integrated assessment of endocrine disruptor tests in a regulatory context which allows us to draw conclusions about the strength of evidence linking exposure to adverse effects (Vandenberg 2016 *Env Health* 15, 74). To further improve the hazard identification of these chemicals we have developed ten key characteristics of endocrine disruptors which can be used to identify and organise mechanistic data when evaluating chemicals for their endocrine disrupting properties (La Merrill 2020 *Nature Rev Endocrinol* 16, 45). Our research facilitated the development of criteria for the identification of endocrine disrupting chemicals at the EU level.

**Achieving impact:** Key issues in chemical pollution management that require better scientific underpinnings directly inform our research strategy. Our impact strategy builds on this by addressing concerns about the usefulness of current emission limits for protecting against risks from combined exposures, and concerns about risks from endocrine disrupting chemicals. In both these policy areas we have achieved substantial policy impact by providing a sound decision-making context for protecting the general population against harm from chemical pollution, at the EU level (DG Environment, DG Research, European Food Safety Authority) and nationally (UK Hazardous Substances Advisory Committee, German Human Biomonitoring Commission, see our **impact case studies on mixtures and on endocrine disruptors**). We have achieved further impact by highlighting institutional and legal barriers that prevent better control of exposures to endocrine disrupting chemicals through our work in support of the EU Endocrine Disruptor Strategy. We also highlighted deficiencies in test methods for the identification of these chemicals and this has shaped research funding activities by the European Commission.

We also actively engage in science communication and translation. Highlights include several features in BBC programmes such as *Horizon* and *Trust me I'm a Doctor*.

**Future strategic aims:** Building on our achievements in these four focal areas, we intend to broaden our research to deliver approaches and solutions that can better manage or even prevent chemical pollution of the environment. We will continue to contribute to public benefit by responding to these societal challenges which directly inform our research strategy. All this requires an inter-disciplinary approach to our research, especially at the interface with social sciences, policy and law which we are eager and ideally placed to pursue.

We are well positioned to evolve our research on chemical mixtures into developing concepts for defining exposure limits that protect against mixture risks, and to identify chemicals that disproportionately contribute to mixture risks. This knowledge will provide the basis for new chemical regulatory strategies that can structure risk management and monitoring efforts. The mixture perspective can also inform the exploration of planetary boundaries for emerging risks and pollution.

Our endocrine disruptor research will continue with a focus on less developed areas (thyroid, developmental neurotoxicity, disruption of lipid metabolism) to develop new test methods that can find entry into regulatory testing. We seek to expand this work into fundamental research of biological processes that can underpin improved testing strategies.

We will further invest in predictive toxicology with a view of developing chemical testing strategies that minimise the use of animals and rely increasingly on *in vitro* cell-based approaches. We have recently appointed new staff in this area (Miller).

Our plan is to diversify funding sources by strengthening our research on the sustainability of value chains, especially in the plastics area, with a view of advancing concepts for necessary changes and policy recommendations. To support this transition, we have made two appointments in this area (Iacovidou and Martin).

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**Supporting interdisciplinary research:** The University has established the Institute of Environment, Health and Societies which we are leading. It is the declared aim of the Institute to foster inter-disciplinary research across the University's Colleges and Departments. The University also stimulates innovative inter-disciplinary research projects by awarding Brunel Research Initiative and Enterprise Fund (BRIEF) of up to £15,000 for endeavours that combine the expertise of two or more researchers from different disciplines and groupings within the university. BRIEF awards are competitive and are allocated through peer review. The unit has attracted BRIEF awards for projects at the interface between pollution research, environmental management, and sustainability. One of the successful BRIEF projects (awarded jointly to Iacovidou and Martin) explores the trade-offs associated with closing the food plastic packaging loop, focusing on the occurrence and lifecycle fate of intentionally and non-intentionally added substances from a systems perspective. This project will challenge the sustainability of closing the material loops and make recommendations to policy makers and industry for changes needed across the plastics value chain.

**Open research environment:** With 100% of our submitted output Green or Gold Open Access, we are going well beyond REF Open Access policy requirements. The university embraces an open research environment, and this unit is actively engaged in research projects (EU-funded ATHENA, ENDPOINTS, GOLIATH, ATHLETE) that oblige us to make data findable, accessible, inter-operable, and to increase data re-use according to the FAIR principles. Our strategy is to use these projects as examples of good practice to drive the development of open research environments in the unit and beyond.

**Research integrity:** We are committed to upholding the Universities UK Concordat to support research integrity. We are nurturing an environment that supports research of the highest standards of rigour and integrity. We ensure adherence to these standards by supervision and annual review of compliance at the level of Colleges, Departments and Divisions, and by a dedicated peer review process of research outputs and grant submissions (see Section 2). Responsibility for creating a stimulating and sound research climate lies with principal researchers. Appropriate training of staff is encouraged, managed, and supervised through the staff appraisal process (Section 2). The needs of inexperienced staff in creating a good research environment are met through mentoring by senior staff. All research ethics matters are overseen by the College Research Ethics Committee which is accountable to the corresponding University Committee. Incidents of research misconduct, witnessed or suspected, are dealt with according to the procedures outlined in the University's Procedures for Investigation of Research Misconduct.

## 2. People

**Staffing and recruitment policy:** Since 2014 we have strategically enhanced our research capacity by nearly 50%, from 9 to 17 staff. We have sharpened the focus of our key research areas in pollution science by appointing several very talented early career researchers (ECR) with a track record in ecotoxicology and endocrine disruptor research (Baynes, Margiotta-Casaluci) and evidence synthesis and cumulative chemical risks (Martin) to full faculty positions. We have strengthened our predictive toxicology focus with a new appointment (Miller). The realisation that improved chemical pollution risk assessment itself does not provide pathways to solutions has led us to invest in research of the sustainability of management options. Accordingly, we have appointed a specialist in sustainability assessment of resource recovery systems (Iacovidou), with the intention of further expanding this area.

As a result, we have reached critical mass in pollution research. The effectiveness of our recruitment strategy is evidenced by the success of our junior staff (Baynes, Margiotta-Casaluci, Martin) in producing high-quality research outputs and in significant contributions to grant income. Baynes and Margiotta-Casaluci joined the unit as PhD students and have now grown to be independent academics with an impressive research portfolio.

All our eligible staff are on open-ended contracts. Many of our staff are actively involved in more than one of our focus areas and are engaged in internal collaborations. The age profile is balanced, with 29% below the age of 40. With 43% of our staff female, we have nearly achieved gender parity. Within the next 5 years we expect to refill 4 posts which fall vacant through retirement of senior staff. As distinguished emeritus academics, these staff members will continue to contribute to the unit's vitality through their experience, connections and ambassadorial roles.

**Staff development strategy:** In 2015, the University introduced a new appraisal system which requires all staff to submit their research plans, to formulate targets for their future activities in research, teaching, administrative activities and external engagement, and to reflect on their achievements in the previous period. To encourage the development of high quality and high impact research portfolios, staff are invited to review their achievements and to agree on new targets during once-yearly appraisal meetings with senior staff. This process identifies training needs, pinpoints readiness for promotion and ensures that the allocation of teaching and administrative duties is commensurate with individual research targets. By prompting conscious planning, this process has proved effective in structuring and enhancing staffs' research activities. This is evidenced by an increase in grant submissions and research output from all staff over the last few years.

The University has also implemented clear and transparent promotion criteria which reward research excellence as well as good teaching and collegiality. There is a stepped system in which promotion criteria become increasingly demanding with seniority of the post. Under this system, **newly appointed Lecturers who pass all probation criteria are automatically promoted to Senior Lecturer**. During the present assessment period, 2 staff were promoted from Lecturer to Senior Lecturer (Silva, Russell). Several very talented post-doctoral research fellows (PDRF) and ECRs were promoted to Lecturer (Baynes, Margiotta-Casaluci, Martin).

The unit's staff development strategy aims to increase the quality and quantity of staffs' research output, both in terms of grant applications and publications, and to enhance the vitality of the research environment. In 2014 we set up an ambitious **training and mentoring programme** to support all staff (including ECRs, PDRFs and PDRAs) in increasing the quality of their grant submissions and publications. This involved peer-to-peer mentoring and regular workshop-style staff retreats. The success of these then relatively unfamiliar practices was palpable by precipitating an increase in the number and quality of grant applications, increases in the number of submitting staff, improved scores on failed grants and higher success rate. Post 2014, we have extended and refined these measures by introducing a peer-support system for grant applications. Well before the submission deadline this begins with a session in which staff pitch their idea to a forum of colleagues. A grant "buddy" is then partnered with the applicant to monitor all the milestones to submission of the proposal. This process is valued by staff, has increased the vitality of the research environment, and has led to several successful grant applications (see section 3).

To support staff in the development of novel ideas and transformative research projects the University offers small grants of up to £10,000. These funds are intended to enable staff to gather preliminary data that puts them in a position to build up competitive grant applications. The award of these grants is through a competitive application process.

To improve the quality of publication output by all staff we have run several workshop-style 2-day **retreats with a professional science writer** in which staff worked on their own papers. Not only has this instilled an understanding of quality, but it has also increased the quality of feedback during the peer review of publications which is mandatory before submission.

To support staff below Reader and Professor level in building an international profile, increase their visibility and catalyse collaborative research links, the University offers financial support of up to £2,500 to attend (or host) a national or international conference, workshop, or seminar to present their research, or to deepen networks of contacts. The granting of support is **merit-based** and administered through a **competitive application process**.

All staff are encouraged to engage with development opportunities provided by the university, such as our management training for early career researchers, ASPIRE.

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We continue to invite mid-level and senior staff to take on research leadership roles with responsibility for mentoring younger staff and for supporting their development in all aspects.

**Policy for research, KT leave, sabbatical leave:** To enable academic staff to concentrate on a programme of work that will lead to identifiable and measurable outcomes towards the University's key performance indicators, a scheme for sabbatical and knowledge transfer leave is in operation. The duration of the leave is determined by the nature of the project but does not exceed 6 months. Decisions to grant leave are made by evaluating staff needs, and applications are considered by using strategic criteria that deliver identified research outputs.

**Support for staff at the beginning of their career, including PDRF and PDRA:** To integrate newly appointed and junior academic staff into the research culture of the unit, they are paired with senior staff members who act as a mentor in all career aspects. During the first three years of their appointment, their teaching load is limited to enable them to develop a high-quality research portfolio. To further encourage junior staff to pump-prime their research, the university competitively awards funds (BRIEF awards) of up to £15,000. These funds are used to develop small scale projects and to increase the visibility of junior staff at international meetings. This practice has put several staff in a position to submit competitive applications to research councils and to win sizeable grants.

The mentoring programme also includes all PDRF and PDRA who are encouraged to become involved with teaching activities in areas of their expertise to enhance their experience and portfolio.

**The unit's implementation of the Concordat:** The University implements the Concordat in its Forward Action Plan. Within our unit, the Concordat is implemented by ensuring that: all researchers have an effective introduction to the unit and the University, have annual professional development review meetings with interim follow-up and a personal development plan, are assigned to a mentor who actively supports their development, and have access to all staff development opportunities.

**Support mechanisms for PGR students:** Since 2014 we have enhanced our support and development of postgraduate researchers to ensure excellence in supervision and successful progression to completion of PhD projects. We are supported by an active Graduate School who have implemented a dedicated programme of workshops, the Brunel 3D researcher development tool. This programme aims to ensure the future employability of PGRs and is structured in three domains: Development of skills to conduct research, skills to disseminate research, and skills to develop research and career. There are also workshops by sub-categories of the Vitae Researcher Development Framework which bring postgraduate researchers across disciplines together to foster an inclusive research culture. Postgraduate researchers' progress is monitored at regular intervals. Apart from the primary supervisor, our supervisory teams consist of two academics with subject/methods expertise and a Research Development Advisor with specific responsibility for working with the postgraduate researcher in identifying and addressing training needs and to offer broader support in terms of career planning. During review meetings, progress is discussed, and any shortcomings of supervision are flagged, obstacles to progression identified and managed.

It is our strategic priority to develop and cultivate the research culture for postgraduate researchers and to ensure they are fully part of the life of the unit, the College and the wider University. All are aligned to the research theme/centre of their supervisor and have access to a research fund to support their studies. They can apply for institutional competitive internal funding to attend conferences to present their work and develop their professional networks. We support an annual College level student-led and organised research conference to which our PGRs contribute. There is also a University level postgraduate researcher conference. Regular research seminars hosted by the research institutes and research centres are scheduled for students to

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present their work and receive feedback from their peers and staff in a supportive environment. Postgraduate researchers are represented on the Student Experience Committee of the College of Health and Life Sciences. Their contributions have made positive changes to the University Code of Practice for Research Degrees.

Since 2014 we have been part of the London NERC Doctoral Training Partnership (DTP) with University College London, Queen Mary, Birkbeck, Natural History Museum, King's College and Royal Holloway. The focus of the Brunel partnership is on chemical pollution and biological hazards, and 4 studentships have been awarded to PGRs in these areas. Since 2014, 20 students have registered as postgraduate researchers. Many of these students came from overseas countries including Oman, Nigeria, Pakistan, Saudi Arabia, Malaysia, and Ghana. On graduation our postgraduate researchers followed a variety of different career paths including in industry, university research. Most of our overseas students went back to their countries of origin to take up positions in government or governmental agencies engaged with public health or the protection of the environment. Several of our home students continued with a career in science, as post-doctoral researchers. Others took up positions with the UK Environment Agency, local authorities, and DEFRA. Yet others embarked on careers in industry, including Syngenta or specialist water companies such as Aqua Technologies.

Staff are incentivised to seek PhD funding from a range of sources as the College will match fund where staff can raise 50% of the stipends and fees.

**Equality and diversity:** Of our eligible staff, 56% are UK citizens, 39% are from the European Union and 6% are from overseas.

Brunel prides itself in an undergraduate student population that is more diverse than that of most other providers. An integral part of our equality and diversity strategy is to ensure that our unit is representative of UK society and mirrors the diversity of the undergraduate student population. Accordingly, we actively promote equality and diversity in our recruitment strategy for postgraduates and postgraduate researchers. The success of this approach is reflected in our demographics: 94% of our postgraduate students are female, 20% are Asian and 3% black, 20% come from non-EU countries and 3% from EU Member States. During this assessment period we have achieved gender parity among our postgraduate researchers (53% female) and have maintained a good ethnic diversity (23.5% black, 8.58% Asian and 4.75% other origins). We have seen an increase in the proportion of disabled postgraduate researchers, from around 5% in 2013 – 2016 to 20% now. To maintain this diversity in the future, we continue to build up a recruiting pipeline for postgraduate students and postgraduate researchers through our undergraduate and Master's degree programmes.

Brunel sponsors **Daphne Jackson Fellowships** to support researchers who wish to return to a research career after a break for a family, health, or caring reason. Staff in the unit (Kortenkamp) has developed a personalised training programme for a fellowship candidate, together with a research programme on combined exposures to chemicals. The candidate (Mousumi Chatterjee) was granted a fellowship and has taken up their position with Kortenkamp, funded by the College.

To support **recruitment of women to leadership roles** we support **Aurora training** which is a key element of Brunel's Athena SWAN action plan and equality and diversity strategy. One staff member (Silva) who has participated in Aurora training is now leading the Division of Biosciences in the Department.

To support a positive work life balance, and to help staff balance their work with priorities such as caring responsibilities, education and training, health and wellbeing or voluntary and charity work, Brunel has a **flexible working policy**. All staff are eligible to apply to flexible working and their requests are considered on a case-by-case basis. Arrangements for flexible working patterns include annualised hours, compressed hours, job sharing and remote working (working from home).

The unit has stimulated collaborations with industry (Astra-Zeneca) through **secondments** and **staff exchanges** (Margiotta-Casaluci, Sumpster) to advance the development of alternative

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test methods in fish. Several staff (Baynes, Jobling, Kanda, Kortenkamp, Scrimshaw) have strong working relationships with the Environment Agency and support their chemical monitoring strategies. We engage with environmental advocacy and volunteer organisations such as Thames 21.

Brunel, as a research-intensive university, is submitting 100% of eligible academic staff. We followed the processes set out in our Code of Practice for the fair and transparent identification of independent researchers and to ensure that the submitted outputs provided a balanced and unbiased representation of the work of our diverse academic community, their characteristics, and contractual positions (age, disability, race, sex, part-time workers and fixed-term employees). Output selection was monitored through regular Equality Impact Assessments.

Our Equality Impact Assessment indicates that the outputs submitted for UoA 7 are a well-balanced representation of the protected characteristics and contractual positions of staff. Our submission has a high proportion of outputs selected for female staff (39% female staff contributing 59% of the outputs) and the 6% of staff with declared disabilities are fairly represented contributing 8% of the outputs.

### 3. Income, infrastructure and facilities

The success of our research strategy, which aims for depth in key strategic areas of importance to society, has become evident with the acquisition of several high visibility grants from the European Commission and UK funding bodies. We have achieved these successes by strengthening our national and international collaborations. Our staff recruitment strategy has fed into this overall strategy by facilitating competitive research grant applications in our focal research areas. As a result, our research income has grown to £6.1 Million, including £580k from UK Research Councils, £500k from private foundations, £520k from UK and EU member state government agencies, £3.48 Million from the European Commission, £580k from industry and £1.1 Million for consultancy work and Service Contracts.

**Major and prestigious grant awards:** Highlights include large multi-centre EU-funded project grants in water pollution monitoring and management (INTCATCH, SOLUTIONS), assessing combined chemical exposures with a focus on human biomonitoring (HBM4EU, ATHLETE), and endocrine disruptor testing methods (ATHENA, GOLIATH, ENDPOINTS). Two of these projects (INTCATCH and ATHENA) are coordinated by our staff (Scrimshaw, Kortenkamp). The acquisition of these projects has allowed us to recruit several talented post-doctoral researchers and PhD students. This success illustrates the effectiveness of our research strategy with collective strengths in key areas of pollution science which also allowed us to bid successfully for projects in predictive toxicology (PANDA, JANUS funded by the Danish government), mixture toxicology in the aquatic environment (funded by Mistra, Sweden's foundation for strategic environmental research and NERC) and several Service Contracts (£1.1 Million), for example with the European Commission (in support of the EU Endocrine Disruptor Strategy), the Norwegian Environmental Protection Agency and the European Food Standards Agency. Recently, we have won a grant from the UKRI Global Challenges Research Fund (£3.5 Million) for a project on reducing plastic waste in Indonesian societies (Jobling).

**Strategies for generating income:** Our strategy for generating income derives from our research strategy which focuses on key issues in chemical control and pollution managements which require better scientific underpinnings. Our track record and international collaborative links in these areas has enabled us to secure funding in these areas, to lead on two significant projects (INTCATCH, ATHENA) and to be major contributors in others. We strive to raise income to support our research vision by:

- Peer-to-peer mentoring and rigorous internal review of all grant proposals prior to submission. This process is fully supported by the University.



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- Utilising university-internal funding schemes to build the portfolio and track record of junior staff so they become competitive for grant submissions to outside funders.
- Encouraging experienced senior staff to share their networks with more junior staff.
- Keeping abreast of new research initiatives via postings from the University's Research Support and Development Office (RSDO). RSDO provides support for the costing and preparation of research grants and organises mock interviews for big grant submissions.

**Links between funding and high-quality research output and impact:** Our funded research has produced impact through a number of papers reported in September 2020 as "highly cited" by Web of Science (**papers in the top 1% in their field**), and all these papers have arisen through internal and/or international collaborations:

- With funding from the Swedish Mistra we engaged in a major internal collaboration (Sumpter, Scholze, Kortenkamp) to demonstrate that five steroidal pharmaceuticals can block egg production in fish at low concentrations, and that their joint effect can be predicted by modelling (Thrupp et al. 2018, *Sci Total Env* 619, 1482; 47 citations).
- Based on our funded research and long-standing experience in mixture toxicology we made substantial contributions to a Guidance Document of the European Food Safety Authority on risk assessment of combined exposures to multiple chemicals (More et al. 2019, *EFSA Journal* 17, 5634; 26 citations) which will shape policy in this area.
- Our research on the impact of endocrine disruptors has allowed us to contribute to an international effort to estimate the disease burden and costs associated with such chemicals (Trasande et al. 2015, *J Clin Endo Metabol* 100, 1245; 157 citations).
- We have contributed to a landmark paper in *Nature Reviews Endocrinology* authored by international experts in which we define key characteristics of endocrine disrupting chemicals as a basis for hazard identification (La Merrill et al. 2020, *Nature Rev Endocrinol* 16, 45, 30 citations).
- Kortenkamp developed a strategy for addressing the question which chemicals should be grouped together to assess risks to male reproductive health (Kortenkamp 2020, *Mol Cell Endocrinol* 499, 110581; 6 citations).
- In a key paper emanating from the EU-funded SOLUTIONS project we developed a vision for dealing with pollutant mixtures in water resource management (Altenburger et al. 2015, *Sci Total Env*, 512, 540, 161 citations).

There are further examples of high-quality papers in top journals, all from funded research in collaborative teams:

- We contributed to a whole genome analysis of a schistosomiasis-transmitting snail (Adema et al. 2017, *Nature Communications*, 8, 15451; 76 citations),
- Demonstrated that populations of cyprinid fish are self-sustaining despite wide-spread exposure to feminising chemicals (Hamilton et al. 2014, *BMC Biology* 12, 1; 45 citations),
- Developed a method for the removal of highly ecotoxic substances that relies on synthetic peroxidase mimics (Mills et al. 2015, *Scientific Reports* 5, 10511; 21 citations),
- Developed a quantitative adverse outcome pathway for the prediction of adverse effects of glucocorticoids in fish, published in (Margiotta-Casaluci et al. 2016, *Scientific Reports* 6, 21978; 11 citations)

**Infrastructure supporting research and impact:** We have well-equipped and well-maintained labs which are the predominant, although not exclusive, domain of research groups. Our work is supported by 4 technical staff. The University has been supportive in providing funding for capital equipment purchases, including chromatographic equipment (£150k). In the next two years the unit

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will benefit from a move and upgrade of the laboratory facilities and offices into another building which will ensure better interaction with, and access to, the existing life sciences infrastructure.

**Equality and diversity issues in relation to support for acquiring funding:** An issue we have begun to address is to find ways of allowing more staff the time required for preparing research grant submissions. To avoid unconscious bias in the allocation of tasks that lead away from such activities, we have developed a **workload allocation model** that ensures a fair distribution of responsibilities and at the same time safeguards equality in support for submitting grants and research output. We achieve fair and equal **access to internal funds** through a merit-based, competitive application procedure with peer review and support (see above staff development strategy). Peer review is also used to ensure that everybody has a fair chance of submitting grants to funding schemes that operate grant rationing.

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

**Research collaborations, networks and partnerships:** Collaboration at the national and international levels is key to realising our research strategy. We therefore systematically encourage staff to work together and to engage in external collaborations. This is aided by the openness and willingness of our more senior, experienced staff to share their collaborative networks. As a result of this approach, almost all our staff are involved with University-internal, national, and international collaborations. More than 30% of the submitted outputs are from collaborations with scientists from national and international HEIs. We are well embedded in international collaborative networks which has enabled us to win several high-visibility EU-funded grants. Highlights of collaborative efforts include:

- Engagement and leadership in international efforts regarding research into endocrine disrupting chemicals and associated risks. During a decade-long effort we have built a leading international network of endocrine disruptor scientists interested in shaping the regulation of these chemicals. This has resulted in several EU-funded projects (ATHENA, GOLIATH, ENDPOINTS) and Service Contracts to support the EU's Endocrine Disruptor Strategy. There is a series of collaborative papers and commentaries that has emanated from this work (see **impact case study endocrine disruptors**).
- Engagement and leadership in international efforts of researching the consequences of combined chemical exposures. We have contributed to a network of international scientists engaged in researching the consequences of combined exposures to multiple chemicals. These collaborative links have been organised through several EU-funded projects (SOLUTIONS, HBM4EU, ATHLETE) and have led to high-impact research papers and commentaries (see Section 3 and **impact case study mixtures**).
- We are engaging in collaborations with NERC CEH Wallingford on researching chemical risk from mixtures (Sumpter)
- Our staff (Ermler, Kortenkamp, Scholze) contribute to University-wide collaborative efforts, such as the Centre for Health Effects of Radiological and Chemical Agents (CHRC) which is funded by the Nuclear Community Charity Fund and is dedicated to researching the genomic health of the British nuclear test veteran community.

**Support for research collaborations:** Our approach to supporting research collaborations follows on from our research strategy and our strategy for developing research income. The University incentivises internal collaborations through internal funding (BRIEF awards etc). The NERC-funded DTP provides a platform for staff to foster collaborations with other universities and this has spawned an exciting project with the Zoological Society London on pollution in cetaceans (Jobling). Senior staff (Jobling, Kortenkamp, Sumpter) have shared their contacts to enable more junior colleagues (e.g. Baynes, Ermler, Margiotta-Casaluci, Martin, Scholze) to develop independent roles in prestigious international collaborative efforts such as SOLUTIONS, ATHENA, ENDPOINTS, GOLIATH.

**Relationships with research users to develop impact:** Our expertise in chemical pollution research and environmental management supports the work of several national and international governmental bodies. Sumpter is a member of the **UK Hazardous Substances Advisory Committee** which advises the UK government on chemical pollution policy where he contributes his expertise in ecotoxicology. Kortenkamp sits on the **German Human Biomonitoring Commission** which derives health-based guidance values. He contributes his expertise on human health and mixture toxicology. He has also taken part as external expert in several working groups of the **European Food Safety Authority**, most recently in one formulating Guidance on assessing risks from combined chemical exposures. He sat on the Chronic Hazard Advisory Panel of the **US Consumer Product Safety Commission** to produce recommendations on the regulation of plasticiser chemicals (phthalates). Kortenkamp, Jobling, Routledge and Baynes have advised the **European Commission** on their **Endocrine Disruptor Strategy**. Baynes and Routledge have researched disruption of the retinoid hormone system which was instrumental for an **OECD** extended review document on developing better test systems for the detection of endocrine disrupting chemicals.

Jobling, Baynes, Margiotta-Casaluci and Kortenkamp have advised the **UK Environment Agency** on their chemical monitoring programmes. Martin serves on the **European Chemical Agency Management Board**, on the Scientific Advisory Board of the **Food Packaging Forum** and in communities of practice for the **UN Environment Programme Strategic Approach to International Chemicals Management (SAICM)**.

**Contribution to the sustainability of the discipline:** Our staff make a significant contribution to learned societies, advisory boards, and others, as follows:

Conference leadership: **Jobling** chaired the 2016 Gordon Research Conference on Environmental Endocrine Disruptors; **Kortenkamp** co-developed the programme of a Royal Society of Medicine conference on Bradford Hill criteria (2017).

Editorships: **Iacovidou**, Associate Editor of Circular Economy Frontiers in Sustainability; **Routledge**, editorial board of Toxics;

Learned societies: **Ermler**, Society of Environmental Toxicology and Chemistry; **Iacovidou**, co-founder and Head of Strategy of the Society of Circular, Regenerative and Sustainable Systems (CRES); **Kanda**, Fellow of Royal Society of Chemistry; **Martin**, Royal Society of Chemistry; **Scrimshaw**, Chartered Institution of Water and Environmental Management; **Routledge**, Fellow of the Society of Biology; **Scholze**, International Biometric Society; **Sumpter**, Fellow of the Society of Environmental Toxicology and Chemistry;

Advisory boards: **Ermler**, Joint Expert Group for Food Contact Materials (FCMJEG) of the UK Committee on Toxicity of Chemicals in Food, Consumer Products, and the Environment (COT); **Kanda**, Scientific advisory board of Pyrocore; **Martin**, OECD Issue Team on Sustainable Chemistry, Food Standards Agency Scientific Advisory Committee on Toxicity, European Chemical Agency Management Board, **Kortenkamp**, various European Food Safety Authority working groups, member of the German Human Biomonitoring Commission, **Sumpter**, Hazardous Substances Advisory Committee

Grant reviewing: **Jobling**, **Routledge**, NERC grant review committees; **Kortenkamp**, NERC college, MRC, Swedish FORMAS; **Silva**, Evaluation Panel for the French National Research Agency (ANR);

**Indicators of wider influence:** In 2016, building on the Queen's award for Research Excellence which we received during the previous reporting period, **Sumpter received an OBE** for excellence in research services to ecotoxicology in the aquatic environment. As an indication of our research leadership in chemical pollution research, staff have received **invitations for opinion articles in high-impact journals**. Sumpter is the senior author of an article in *Science* that considers the future of chemicals in the environment (Johnson et al. 2020, *Science* 367 (6476), 384).

**Unit-level environment template (REF5b)**

Kortenkamp was invited to contribute a paper in *Science* on options for regulating chemical mixture risks (Kortenkamp and Faust 2018, *Science* 361 (6399), 224). He has also produced several commentaries and opinion pieces on endocrine disruptor regulation in *Nature Reviews Endocrinology*, and *Lancet Diabetes Endocrinology* (Kortenkamp 2017, *Nature Reviews Endocrinology* 13 (1), 6; Kortenkamp (2016) *Lancet Diabetes Endocrinology* 4 (8), 649).