Unit of Assessment: 10 Mathematical Sciences

1. Unit context and structure, research and impact strategy

a. Overview

The period since REF2014 has seen a transformation in the mathematical sciences at Lancaster University in terms of the size and quality of the research base, and its levels of user engagement. Building on its 5th placing in REF2014, and after substantial investment, Lancaster now hosts two of the UK's largest groups within pure mathematics (24.7 FTE, up from 14.3 FTE) and statistics (25.3 FTE, up from 19.2 FTE). This growth (total increase in FTE of 50%) has been achieved whilst enhancing the vitality of the research environment, as evidenced by:

Research Capture of £2.6M per annum, up from £1.1M per annum; with Lancaster currently having the fourth largest EPSRC Mathematical Sciences grant portfolio of any university, and the largest within Statistics and Applied Probability.

Recognition of staff through the award of prizes of the Royal Statistical Society (Wadsworth, Eckley and Tawn) and the European Network for Business and Industrial Statistics (Killick); Eckley being elected a Fellow of the Learned Society of Wales; and the award of nine fellowships (including 3 EPSRC, 2 EU and 2 NIHR).

Key features of the research environment include:

Impactful, interdisciplinary and user-engaged research: Our long-held ethos is that fundamental research is often best performed in collaborations where applications motivate and benefit from new mathematical ideas. During the assessment period we have greatly expanded the range of academic and non-academic collaborators: we have had research projects involving 70 non-academic partners, with direct funding of over £3.5M, and doubled the number of publications co-authored with non-academic partners.

Leadership of large-scale, multi-institutional projects: We currently lead four multi-million pound UKRI grants that bring together large multi-institutional teams with a range of project partners to tackle important open research challenges – see Table 2 in Section 3. These projects address new statistical approaches for health, environment and telecommunications.

Vibrant community of research students and PDRAs: We have greatly increased the numbers of PhD students (from 13 FTE students starting PhDs in 2013/14 compared to an average of 26 FTE per annum since 2018) and PDRAs (rising from 7 to 23 FTE). We have a leading role in PGR provision in the UK, with bespoke training that has been commended by EPSRC (see Section 2); and a proactive approach to developing future research leaders with a particular emphasis on researchers engaged in collaborating with end-users.

Strong, collaborative research groupings: We have strengthened the research group structure of the department (see Table 1). Management of staff is now aligned to research groups, and we have increased support for activities to encourage interaction within and between groups. Collaboration between pure mathematics and statistics has been enhanced by establishing new research groups in Probability and Statistical Learning.



Table 1: Research Groups at census date. Each staff member is listed in their primary group.Due to the strong inter-disciplinary nature of his research, Francis has been submitted to UoA18.

Group	Composition	Research Area and Highlights
Bayesian & Computational Statistics	Costain, Fearnhead, Lee, Lunagomez, Ridall, Sherlock, 3 PDRAs, 6 PhD Students.	Breakthroughs on non-reversible and continuous- time MCMC and scalable Bayesian methods, including a paper read to the RSS in 2020 and two highly cited papers in the Annals of Statistics. Leading the £3M EPSRC Bayes4Health grant.
Changepoints & Time Series	Eckley, Fokianos, Gibberd, Killick, Mukherjee, Sykulski, 4 PDRAs, 18 PhD Students	Novel changepoint and anomaly detection algorithms developed and used widely by end-users. Leading the £2.8M StatScale programme grant, and statistics lead on a Prosperity Partnership with BT.
Extreme Value Statistics	Eastoe, Jonathan, Park, Tawn, Wadsworth, 2 PDRAs, 16 PhD Students	Approaches to multivariate and spatial extremes. Strong collaborative projects have led to research informing design of UK flood defence, and of offshore structures.
Medical & Social Statistics	Francis, Jaki, Mitra, Mozgunov, Titman and Wan, 4 PDRAs, 11 PhD Students.	Methods for clinical and observational studies for health and society. Coordination of EU funded training network. Members awarded 4 fellowships. Contributing to international activities around COVID- 19 therapeutics.
Statistical Learning	Battiston, Grunewalder, Khaleghi, Leslie, Nemeth, 7 PDRAs, 13 PhD Students	Advances in the theory and application of bandit algorithms and scalable inference, including 4 publications in JMLR, 3 at NeurIPS and 2 at ICML. Collaboration and impact through Heilbronn and with a range of Tech firms. Leading £2.7M EPSRC Data Science for the Natural Environment, awarded an EPSRC innovation fellowship.
Algebra & Geometry	Elek, Evans, J Grabowski, L Grabowski, Lazarev, Levy, MacDonald, Mazza, Pauksztello, Towers, 3 PDRAs, 2 PhD students.	Notable results in differential geometry, group theory and representation theory. Publications in: Inventiones, Annals of Math, JAMS, AiM, Selecta, TAMS. Funding includes a Marie Curie Individual Fellowship, EPSRC standard grant, ERC starter grant.
Analysis	Belton, Blower, Choi, Dales, Elton, Hillier, Laustsen, Lindsay, 6 PhD Students.	Published around 80 papers covering theoretical analysis and substantial applications to mathematical physics. Activities have been supported by grants from the Leverhulme Trust, EPSRC and the LMS.
Probability	Blitvic, Korshunov, Turner, Zeindler, 2 PhD Students	Research in probability and applications in mathematical biology; grants awarded from EPSRC and the LMS; hosted the UK Easter Probability Meeting in 2016, and annual Lancaster Probability Days workshops.
Discrete Maths & Geometric Rigidity	Kitson, Nixon, Prendiville, Power, Schulze, 1 PDRA, 2 PhD students.	Advances in geometric and combinatorial rigidity, arithmetic combinatorics and number theory, including publications in JEMS, PLMS, Crelle's Journal, JCTB, and IMRN. Awarded 3 EPSRC grants, and knowledge exchange funding from Heilbronn. Organised workshops at AIM, BIRS, ESI, ICERM and ICMS.

b. Achievement of REF2014 Research Objectives.

The focus of the Department's research strategy has been to further strengthen our position as a world class centre for Mathematics and Statistics. Below we detail how this has been achieved through meeting our objectives from REF2014 around the key themes of sustainability, vitality, interdisciplinarity and impact.

Sustainability

Establish strong research groups in Probability and Geometric Rigidity. We have established a new research group in Probability, with a core of 4 people, and this group has strong links with Analysis (with which it has recently merged), Statistical Learning and Extreme Value Statistics. Members of the group participate in many international collaborative projects: Korshunov was a Guest Professor at the University of Augsburg in 2017 and Turner is a Guest Professor at Geneva University. The leading UK conference on probability was brought to Lancaster in 2016, and a series of annual workshops that have a focus on intra-disciplinary research, organised jointly across Probability, Analysis and Statistical Learning, was inaugurated in and has run since 2017. Since 2014 we have built the UK's leading group in Geometric Rigidity with extensive and expanding international activities. The success of the group is evidenced by: a Heilbronn fellowship to Nixon starting in 2020; EPSRC grants to Schulze, Power and Kitson; the organisation of major international conferences (see Table 1); and annual International workshops at Lancaster since 2015.

Being at the forefront of research that tackles the challenges of fitting complex models to large data. Growth and activity in statistics has been driven by challenges associated with big data: We have established a Statistical Learning group at the interface of statistics and machine learning; helped establish Lancaster's Data Science Institute (described in more detail below); and lead four collaborative EPSRC grants (total value approx. £11M; see Table 2 in Section 3) developing new statistical approaches to address challenges from health, environment and digital Infrastructure.

Vitality

Enhancing opportunities and support for visitors to Lancaster. Departmental and University funding for visitor activities has increased substantially since 2014, enhancing the vibrancy of the research environment. We now have a range of visitor schemes catering for short-term and long-term visits to or from Lancaster for staff, PDRAs and PhD students and support for specialist workshops, with, on average, funds of £50K available per year. These are supplemented by strategic partnerships with leading international institutions, with UC Dublin, MIT and U Washington added as partners since 2014. These offer opportunities for joint PhD supervision as well as supporting collaborative research visits (see Section 4).

To consolidate our reputation for excellence in PGR provision. Evidence of the quality and reputation of our PGR provision include: EPSRC rating the STOR-i CDT as excellent, and STOR-i being the only CDT in the mathematical sciences to be funded at three consecutive funding rounds; successful renewal of an ESRC-funded CDT in which we contribute significantly to the Social Statistics theme; and EU-funding for the IDEAS PhD network (see Section 2).

Interdisciplinarity

The above objectives demonstrate our pro-active approach to support interdisciplinary research. Key exemplars include:

An inter-disciplinary PGR programme. We have mechanisms that support research with industry, through the STOR-i CDT, with social sciences, through an ESRC-funded CDT, with



pharmaceuticals, through the IDEAS PhD network, and with health and environment through studentships linked to some of our large-scale research projects – with over 80 starting PhD students supported through one of these schemes during the assessment period. We aim to train the next generation of researchers in the mathematical sciences to be motivated by research that can have an impact across other areas of science, industry and society, and have the skills to interact with a range of people from other disciplines.

Data Science Institute. The Statistics group has played a leading role in the establishment of Lancaster's flagship Data Science Institute (founding co-director, Eckley; founding theme lead Leslie; and deputy theme-lead Nemeth). The Institute brings together over 300 members, drawn from 15 different academic departments, and has developed a range of mechanisms to support interdisciplinary research, from workshops to research retreats and business engagement. Our strong engagement with the Data Science Institute has led to a number of important new inter-disciplinary projects including strategic programmes at the interface of statistics and the environment and across statistics, computing and engineering (see Table 2 in Section 3).

Geometric Rigidity: Establishing the Geometric Rigidity Group has led to collaborative projects both with cross-disciplinary and intra-disciplinary themes. Three recent Lancaster workshops on geometric rigidity included interdisciplinary themes in materials science (2017), chemistry (2018) and formation control (2019); and engagement with applied scientists has led to outputs in these areas. One example is Power's work on classification of crystal nets by isotopy, published in Acta Crystallographica A, which was highlighted by an editor's commentary: "[This] work features an attractive blend of mathematical techniques from geometry, topology and group theory, brought to bear on difficult questions in crystal chemistry."

Impact

To see continued growth in collaborative research with industry. Our collaborative research programme with and funded by industry has flourished since 2014, with increases in the number and range of industrial partners we have. This enables us to work on statistical challenges closely linked to important economic, social and environmental challenges, and has led to substantial impact of our research on statistical methods: see Section 1d for full details.

Broaden impact into new areas: Defence and Security, Big Data, Rigidity and Changepoints. We have seen strong end-user engagement across all these areas. Evidence includes a submitted case study on the impact of our Changepoint research, and substantive interaction with the Heilbronn Institute: Leslie sits on advisory boards and provides consultancy services, Nixon has a 50% secondment from 2020 and they provided support for Nemeth's EPSRC fellowship.

Fund Research Impact Fellowships. Over the period we have funded 7 impact fellows that allow the strongest PhD students time to progress research ideas from their PhD, investigate impact opportunities, and develop research independence. One example of the success of this scheme is Nemeth who used the impact fellowship as a springboard to establish himself as a leading data science researcher with the recent award of an EPSRC Innovation Fellowship.

c. Open Access and Research Integrity

Lancaster University's research culture is driven by a full commitment to the Concordat to Support Research Integrity, and the University is a member of the UK Research Integrity Office. The Department adheres to University-wide research integrity and ethics procedures. This is facilitated by an Ethics officer that checks all dissertation topics, and representation on the Faculty Ethics committee to which empirical PhD proposals and staff research projects are submitted. We provide training to PhD students on ethics and responsible research and innovation.

The Department encourages and supports researchers to ensure research is reproducible. This is particularly relevant within statistics, where access to software is needed to be able to



reproduce statistical analyses. As mentioned below, we routinely make new statistical methods available as packages in suitable languages such as R or Python, and this is supported through a Research Software Engineer and training for PhD students.

Almost all members of staff regularly publish preprints on repositories such as arXiv, and the publications of all staff are represented in the large and active institutional repository (gold and green access).

d. Impact Overview



Figure 1: Word cloud of non-academic partners who have supported research through direct funding, joint PhD projects or as project partners of research grants. Sector shown by colour: health (dark blue); environment (red); tech/analytics (light blue); energy (yellow); retail (orange); financial services (green); and other (black).

Our research is strongly linked to collaborations and knowledge exchange opportunities with a range of new and existing end-users over the assessment period (see Figure 1). The success of our strategy (detailed below) can be seen by indicators such as direct funding from industry of £3.5M, over 60 CASE-like PhD studentships, over 30 PhD student industrial internships, over 100 industrially co-supervised MSc dissertations and 3 Knowledge Transfer Partnerships.

A culture of impact:

We have enhanced the value given to impact, across both recruitment and promotion, and support all staff to engage in impact activity as appropriate for their research. Specific strategies include:

- *Recruiting with impact in mind*: We target recruitment in impactful areas and recruitment materials specify impactful activity as desirable. This has informed areas of growth, with new research groups in Statistical Learning and Geometric Rigidity.
- *Rewarding Impact Activity*. Impact features in promotion criteria, and has been a factor supporting the promotions of Eckley, Fearnhead, Killick, Nemeth and Tawn.
- Introducing an Impact Champion to educate, advise and support colleagues. The Impact Champion inducts new staff into the impact culture of the department, maintains an impact support fund (consisting of cash and, perhaps more importantly, considerable time resource), and carries out a regular audit of impactful activity in the department.



Long term knowledge exchange partnerships:

A key component of our impact strategy has been the close relationship we have with industry and other non-academic end-users. We continually develop links with new partners, and maintain these collaborations over many years. Our long-term partnerships support fundamental research by highlighting important open challenges, and have been particularly fruitful in providing large-scale impact. Furthermore, these partnerships are an integral part of our success in winning large-scale research funding (see Section 3).

Strategic approaches in this area include:

- Support for Impact-focussed, externally-visible, research centres. We have enhanced our support for the Medical and Pharmaceutical Statistics group and the STOR-i CDT, both of which have a strong focus on end-user and impact related activity. We have also been at the forefront of establishing Lancaster's Data Science Institute.
- *Embedding industry in our PGR training*. We have increased the number of PhD projects co-funded and co-supervised with an industrial partner and support other students to take a paid industrial placement during their PhD. Long term industrial partners take an active role in the training of our students. For example, Shell base staff within the department which enables regular interaction with students, and many of our industrial and non-academic contacts have led training events, e.g. around career and leadership.
- *Knowledge Exchange Events*: We run regular knowledge exchange events with existing and new partners, with over 30 one or two day events during the assessment period. End-users include a range of organisations from SMEs (e.g. Prowler.io and Vypr); multinational companies (e.g. AstraZeneca, BT, Shell, RollsRoyce) and public sector organisations (e.g. BBC, the Office for National Statistics, National Resource Wales).
- A wide range of entry points. We have expanded the range of opportunities for potential new partners to interact with our researchers and investigate the possibilities and benefits of collaborative research. These range from visits to Lancaster to discuss research areas of potential overlap; industrial problem solving days (four per year); and MSc Data Science projects with a 3 month industrial placement (increased from a handful in the last REF assessment period to over 100 in this). Staff are supported in establishing and nurturing new and existing collaborations through the Impact Champion, an Industrial Liaison Manager linked to the STOR-i centre, and the faculty Partnership and Business Engagement Team.

This strategy reflects a belief that there are substantial benefits from involving non-academic collaborators at an early stage of the research. This leads to new mathematical developments motivated directly by contemporary and important challenges. An exemplar of this is how our long-standing research collaboration with BT led to involvement in a successful bid for an EPSRC Prosperity Partnership. To date this partnership has developed several novel inference approaches for the real-time detection of anomalies inspired by and applied to the monitoring and management of BT's network infrastructure.

Take-up of statistical methods through software:

Widespread use of new statistical methods and algorithms also occurs if there is freely-available, easy-to-use software. We strongly support the development of such software, often as packages within R or python. We provide training for research students and staff for developing such software, and have established a culture where new statistics papers have associated packages published as the norm. We also have a Research Software Engineer whose role is to facilitate the development of software. During the assessment period our research has led to over 25 packages and 10 papers on statistical software.

Impact case studies

The success of the above strategy can be seen by our impact case studies. Two case studies are around the impact of our research in extremes to on-shore flood risk and defences, and design of off-shore structures. These have arisen from long-term research partnerships with JBA and Shell. Our case study on the impact of methods for detecting changepoints exemplifies the importance of developing open source software in parallel with the research: with publicly



available R code enabling a breadth of impacts and has led to the implementation of our algorithms within commercial libraries (NAG and MATLAB). This case also details impacts that have arisen through knowledge exchange events and through a long-term research partnership with BT. Our final case study describes impact of our Medical and Pharmaceutical Statistics research centre through design of clinical trials for treatments for Covid-19.

e. Future Research and Impact Strategy

Our over-arching aim is to appoint the best staff and to provide an environment that nurtures and enables them to undertake high-quality theoretical and methodological research that pushes disciplinary boundaries. Equality, diversity and inclusion are central to this aim, ensuring the widest possible talent pool, supporting all researchers to maximise their potential, and benefitting from the advantages of a diverse and inclusive department. Mindful of the recent Covid-19 pandemic we are confident of our approach and long-term planning. We will continue to place a strong emphasis on impact-focussed research where applications motivate new mathematical advances and inform core research. Specifically, we will:

Enhance our research capacity, through retaining, developing and recruiting world-leading researchers; and through supporting and expanding our collaborations with leading researchers across the world. We believe growth will be achieved through embedding data science across the university, and we will look to expand into areas of applied mathematics where there are synergies with existing research strengths.

Grow and diversify research income, increasing the proportion of staff with substantial grant funding (through grant mentoring, and maintaining our incentivisation of applications so awards lead to more time for research), leveraging support from our industrial collaborators, and continuing our leadership of large-scale, inter-disciplinary and cross-institutional research projects.

Increase end-user interactions and see significant impact of our research, by building on our extensive network of industrial collaborations and leveraging our reputation in this area. We see new opportunities for impact on health, benefitting from Lancaster's new Health Innovation Campus, Killick's discipline hopping award and the Bayes4Health grant; and on environmental science, building on Lancaster University's strategic investment in the Centre for Excellence in Environmental Data Science and the DSNE project (Table 2).

Improve and develop our vibrant, supportive and externally acclaimed provision for PhD students, using increased EPSRC support for mathematics PhD students to develop a critical mass of students for mini-CDTs across strategically important research areas.

Maintain a vibrant, supportive and inclusive environment, with a diverse body of staff and PhD students, by continuing the practices described below and implementing the action plan of our Athena Swan Bronze Award.

2. People

a. Staffing Strategy and Staff Development

The sustainability and vitality of mathematics at Lancaster has been enhanced by an *ambitious and targeted growth* in independent research active academic staff (from 33.5FTE in 2013 to 50FTE in 2020). New appointments have been targeted at specific areas, and have been made to ensure each research group have appropriate experience and leadership.

As described in Section 1, we have specifically *established new groups* in Geometric Rigidity and Probability; and *significantly strengthened our capacity* in areas of statistics linked to data science. The latter has seen a new Statistical Learning research group at the interface of



statistics and machine learning, and appointments in statistics made as part of establishing Lancaster University's Data Science Institute.

The quality of our new appointments and early career staff can be seen by their record of being awarded competitive fellowships: an EPSRC postdoctoral fellowship to Wadsworth, an EPSRC Innovation fellowship to Nemeth, an EPSRC discipline hopping award to Killick, an ERC starting grant to L. Grabowski, an EU-Marie Sklodowska-Curie Fellowship to Coelho Simões, an NIHR advanced fellowship to Mozgunov, an AXA fellowship to Rohrbeck, and a Biometrika fellowship to Brueckner.

Career development support.

All staff: The department endeavours to support academic staff at all stages in their careers, regardless of gender, ethnicity or other protected characteristics, and whether they are on a permanent or fixed-term post or whether they work full- or part-time. To ensure appropriate attention is given both to an individual's research direction and to their general career development, the department is subdivided into small research groups. Every member of staff belongs to a group, with groups consisting of members of staff. Many line management duties are devolved to research group leads to ensure both more personalized and detailed support, and that advice and mentoring is appropriate for the specifics of the research area of each staff. The group lead is responsible for undertaking an annual Performance and Development occurs throughout the year. Co-ordination between group leads and Head of Department ensures jobs are allocated to support career development and, where appropriate, for staff to have sustained blocks of time dedicated for research.

As detailed in Section 1d, we are particularly active in promoting the importance of impact, and, where appropriate, supporting staff development in this area. Academics are encouraged to work with Business Development Managers to develop contacts with external partners and involve them in grant applications, and are mentored to work in and take advantage of the full range of Departmental engagement structures. Engagement outcomes are explicitly referenced in promotion material and have been a significant component of 5 promotion cases.

The University's Organisation and Educational Development department supports staff professional development and provides a range of development events specifically tailored for research staff. Workshops include Strategic Career Planning and Mentoring for Academics and Researchers, Developing Successful Proposals, Leading Meetings and Recruiting the Best.

We ensure a fair balance across teaching, administration and research for all staff through a workload allocation model, that gives due credit for external research commitments (e.g. funding via research grants) and substantial contributions to the discipline (e.g. major editor roles, involvement in taught course centres such as organizing APTS workshops or giving MAGIC courses). All staff are eligible for, and encouraged to take, sabbatical leave. Sabbatical is accrued at a rate of 1 term of sabbatical for each 7 terms of service. Parental and Adoption leave, and paid sickness absence are counted within this period of service, meaning that staff who are absent for any of these reasons are not penalised in the length of real-time that elapses before they can request sabbatical leave.

During the assessment period 33 academic staff have benefited from a total of just over 13 years of sabbatical leave. One example is Turner whose sabbatical enabled a long-term visit to the University of Geneva to work with Fields Medallist Stanislav Smirnov on random growth. This was successful with the visit extended by a secondment to Geneva, and with it supporting a successful EPSRC grant application.

We provide substantial support, of around £50K per year, for academic staff and PhD students to create new and develop existing research collaborations, to fund workshops at Lancaster in



their research area, or for any activities linked to developing impact. This is on top of departmental QR funding for conference attendance and dissemination of research.

Early career researchers: In addition to the support mechanisms mentioned above, all new academic staff undertake a probationary period of 3 years. During this period, they are assigned a mentor within the department, with whom they are encouraged to meet regularly to discuss progress in all areas, including research direction, grant applications, teaching and training. New early career academic staff are given a reduced teaching and administration load, with a reduction of 50%, 33% then 17% in the first three years. This frees up time for development of their research direction and contacts. New staff are encouraged and supported to apply for research grants, both from their research group lead and from research support officers embedded within the Department (see Section 3).

We encourage and support all staff to take on supervision of PhD students, and establish their own research team as appropriate. The allocation of University studentships favours early-career staff, and such staff receive support to bid for additional students and PDRAs. To ensure quality of supervision, new supervisors attend a University-run training course and have, as co-supervisor, an experienced member of staff who provides scientific input into, and helps oversee, the project.

PDRAs and research fellows: There have been 59 PDRAs and research fellows during the assessment period. To prepare research staff for future academic or professional careers, care is taken to ensure that they develop skills beyond the confines of their particular research project. They are given the opportunity to gain experience in a wide range of teaching and supervisory activities, in all cases with appropriate mentoring and support. There are many opportunities for RAs to engage in events run by industrial partners and to widen their knowledge of relevant career choices. We are committed to the Concordat to Support Career Development of Researchers, and Lancaster has achieved the European Commission's HR Excellence in Research Award.

Lancaster specifically supports the next generation of researchers in the mathematical sciences through its own Impact Fellowship scheme, which offers 1 to 2 years of support to newly completed PhD students. This has supported 7 high-quality fellows over the period; with all who have completed the scheme moving to permanent academic positions.

b. Research Students

Research students are seen as important to the vitality of the Department and consolidating our PGR provision has been one of the strategic aims of the Department. This encompasses providing funding for PhD studentships, recruiting and attracting the best students, and providing them with high-quality subject-relevant training and opportunities to develop transferable skills. We have graduated 110 PhD students during the census period (approx. 16 per year, compared to approx. 8 per year for REF2014), with 141 new PhD registrations.

Studentships and recruitment

We have been pro-active to increase the available funding for research students, and during the assessment period have had the following opportunities in addition to EPSRC DTP studentships:

STOR-i centre for doctoral training in statistics and operational research: This is the only centre in the mathematical sciences to be funded for three successive periods, with two bids for renewed funding being successful within the assessment period. The current funding covers 5 cohorts of students, with 12 PhD studentships per cohort (8 funded by EPSRC and the other 4 funded by Industry and Lancaster University). Up to 80% of studentships are case-like, and all other studentships involve collaboration with leading international academic partners. The centre has been graded excellent in its two mid-term reviews to date.



ESRC funded North West Social Science Doctoral Training Partnership: This is a collaboration across four Universities in the North West of England. Within the social statistics pathway, led by Lancaster, the Department has attracted between two and three studentships a year, funding PhDs that focus on the development of advanced quantitative methods for social science applications and providing specialist training for students at the interface of statistics and social science. Many students have taken the opportunity for internships in government departments or public sector bodies such as the Home Office, the Office for National Statistics and the Scottish Office.

IDEAS European training network: This Lancaster-led network for early career researchers comprised of 8 partners (5 academic and 3 industry) and a number of associated partners from the pharmaceutical industry. It has trained 14 PhD students (3 hosted in Lancaster) using a pan-European, cross-sectorial approach in methods for early phase drug development. The researchers received dedicated training in statistical methodology as well as transferable skills training. Moreover, secondments to complementary partners (i.e. students at academic institutions were seconded to industry and vice versa) were mandatory.

University-funded Studentship: During the census period Lancaster provided one studentship per 2 self-funded students, and routinely supported research grants with studentships. Over the period this has resulted in 26 fully-funded studentships, of which 8 are linked to research grants.

A summary of our growth in PhD studentships over the assessment period is shown in Figure 2. Further substantial growth will occur due to the EPSRC Mathematical Sciences studentship scheme, which will fund 14 studentships for 2020 and 2021. These are being proactively managed, for example to support development of ECRs (six of nine studentships to date have an ECR as a lead supervisor) and to produce a strategic mini-cohort in noncommutative algebra and analysis (5 studentships starting October 2020).



Figure 2: *PhD Studentships by source and year.*

As part of our active recruitment process we run a summer taster programme, in which 12 undergraduates from a wide range of universities come to Lancaster to do 8-week research projects, with a view to giving them experience of PhD study. This has proven successful, with 70% going on to a PhD within the mathematical sciences, including a number of students whose undergraduate background is not mathematics, and who would not naturally make such a choice.

Monitoring and support

The progress of all students is monitored by their Higher Degree Committee. The student is able to discuss any issues with the committee's independent chair outside formal meetings, and the



meetings themselves help prepare students for defending their thesis at viva. Formal appraisal of performance is conducted each year, informed by staff and supervisor progress reports, draft thesis chapters and presentations. In later years students are required to have a written plan for completing, over an appropriate time-scale, against which progress can be assessed, with any problems being flagged early so that support can be given.

Training and opportunities

Lancaster is a major supporter of the taught courses centres, with all PhD students required to take courses put on by APTS, MAGIC or NATCOR. To supplement opportunities available both through these centres and from over 20 postgraduate courses run by the Department, we also run regular masterclass series in statistics and operational research and these are made available to non-Lancaster students, with support for attendance through our STOR-i national associates network.

The scale of our postgraduate community enables us to offer PhD students a bespoke set of training relevant for researchers in the Mathematical Sciences. Examples of this include:

- *Effective Communication*: an annual programme of meetings and workshops (e.g. by BBC journalist Michael Blastland) that focus on the challenges to effective communication faced by researchers;
- *Presentation and Interview skills*: sessions delivered by VoX Coaching and other partners to incorporate personal confidence coaching for self-selecting students;
- Careers & Leadership Talks by academic and industrial researchers that give students a clear idea of career opportunities, and the skills required for success.
- *Mental Health & Well-being*: courses on building resilience run by MIND, tackling the inner critic, and mental health first aid.

We believe that students benefit substantially from experiencing a variety of research environments, and ensure that they have opportunities to do so. We provide a research fund which allows students to make competitive applications for funding to support medium-term visits to leading international research groups. Students on projects co-funded by industry typically spend between 3-6 months with the industrial partner during their PhD.

We support students in finding and taking paid internships: spending 2-6 months with an industrial partner working on a practical problem in an area quite different to that of their PhD. This allows students to gain a more diverse and rounded set of skills. The timing of internships within the study period is carefully managed to minimise disruption to thesis completion. In the period more than 30 students have taken an internship, with an average length of 4 months.

The quality of our students is evidenced by the success at receiving awards. Examples include American Statistical Association best student paper prizes to Park (2014) and Haynes (2015); RSS prizes at RSC2017 to Welding and at RSC2018 to Tickle; an ISCB student award to Urbas (2020), an AISTATS best paper award to Grant (2020), and the OR Society's PhD prize to Morgan (2020).

c. Equality and Diversity

The Department is proud of its promotion of equality, diversity and inclusion (EDI) in all that it does. It has held an Athena Swan Bronze award since November 2016 and is a Registered Supporter of the London Mathematical Society's Good Practice Scheme. Staff and students are supported by the University's EDI team who provide training, advice and support to ensure that EDI is successfully embedded throughout. All staff undertake mandatory Diversity Training at the start of employment, and this is repeated every 3 years. All staff with decision-making responsibilities for REF2021 attended mandatory tailored training on EDI and unconscious bias.

Departmental oversight: The Department has a dedicated Equality, Diversity and Inclusion Committee (EDIC), which meets termly and whose membership includes HoD, Department



Officer, academic and professional staff, PDRAs and students (PGR, PGT and UG). The Department is committed to a sustainable way of increasing diversity in staff and student recruitment, to support staff development, and to uphold the principles of the Athena Swan Charter. The Department's Disability Officer oversees disability-related matters for students and liaises with student disability services. Together with the EDIC Chair, they engage with institutional ED&I, Athena Swan and Disabilities committees.

Department profile, appointments and promotion: The Department has a headcount of 79 indefinite and fixed term academic staff, with 23% female, 22% BAME and 5% with a declared disability. We are committed to increasing the diversity of staff, as per our Athena Swan action plan. The University is a member of the government's Disability Confident Scheme, the Stonewall Global Diversity Champions programme for LGBT equality, and are committed to signing up to the Race Equality Charter in April 2021. All figure prominently on our job adverts. Every permanent academic post is advertised via mailing to the European women in Maths, and we pro-actively advertise positions via networks to ensure as strong and diverse a field of candidates as possible. All recruitment panels have gender diversity, and every member must have attended institutional training on recruitment.

The Department's Promotion committee ensures all staff are considered equally for promotion, encourage staff to apply, and give feedback on setting work priorities so as to strengthen future cases. This is supplemented by support from group leads, who, through yearly performance review exercises, advise each group member regarding academic progression. During the assessment period there have been 35 successful promotions, with 29% for female staff.

Diversifying the academic landscape: Events such as our annual Florence Nightingale Day (run annually since 2013) and the 2019 LMS Perspectives in Mathematics bring generalaudience talks by high-profile mathematicians of varied gender, race and age. The Florence Nightingale Days were cited as an example of good practice when we obtained our Athena Swan Bronze award in 2016, and their popularity has increased year-on-year (from 35 attendees in 2013 to 136 in 2020). Our Outreach Committee engages organised educational activities, showcasing role models of various backgrounds, for secondary schools in the North-West. Speakers at our seminar series and workshops are chosen so as to comply with our gender diversity rules, namely a minimum of 25% female speakers; and we have a fund for our PGR seminar series to support invited external female speakers. At the 2019 British Mathematical Colloquium, held in Lancaster, over 40% of invited speakers were women, including over 50% of the plenary talks.

Research students: Our PGR programme has a track record for its inclusive approach, championing equality and the development of a vibrant, collaborative and people-centred working environment. This has been recognised by e.g. external reviews of our STOR-i CDT. Examples of good practice include (i) a summer taster programme which has been key to recruiting a diverse student community; (ii) a provision of bespoke support, including flexible working arrangements for students with caring responsibilities, disability and other personal circumstances to enable a doctoral training experience tailored for all; and (iii) a peer mentor for each new PhD student. The result is a multicultural community that has formed a highly supportive workplace, welcoming to all diversity groups. Of the PhD students who started during the assessment period, 35% are female, 19% are BAME, and 10% have a declared disability.

Part-time staff: The Department strives to ensure that all members of staff are treated equally. Work-load allocations are made on a pro rata basis through discussions between the HoD, the relevant line manager and the member of staff. All staff are encouraged to take advantage of the University's flexible working policy and this is particularly useful for those with caring responsibilities. For instance, staff may request that their teaching hours do not start early or finish late to enable them to carry out the school run; similarly, we have changed the time of the Statistics colloquia series so that these no longer coincide with the end of the school day.



Parental leave, and supporting return to work: Staff returning from leave receive reduced administration and/or teaching load for a temporary period, to allow a higher proportion of time to be devoted to progressing research activity. Staff have access to the University Maternity and Adoption Research Fund, which is designed to minimise disruption to research during, and after, extended parental leave. In addition, staff returning from family-related leave are encouraged to make use of a £3,000 per year departmental fund to support re-engagement with research. In 2019, the fund was extended to staff members returning from other types of compassionate leave.

Staff well-being: Through the Institution's Safety, Health & Wellbeing committee structure, Staff Wellbeing is firmly on the University's agenda. The recently formed Staff Wellbeing Engagement group has developed the University's new Staff Wellbeing website, providing a single source for staff to access a range of support options and wider well-being. The University pays for staff to be able to access a range of professional support through the Employee Assistance Programme and has selected the Five Ways to Wellbeing framework, used by the Government, charities like Mind, and the NHS, as a basis to provide information and activities to help improve the mental health and wellbeing of its staff.

3. Income, infrastructure and facilities

a. Research Income

There has been a step change in grant capture since 2014. In the assessment period the research grant capture averaged $\pounds 2.6M$ per annum, an approx. 120% increase compared to the previous period. Due to the lag between grant capture and expenditure this is seen in the HESA income data with it rising consistently to $\pounds 2.3M$ in 2019/20, as shown in Figure 3.



Figure 3: Research Spend and Capture by year. To aid visualisation, we show the best fitting linear trend for Research Capture. Capture and Spend averaged £1.1M and £0.9M per year in the REF2014 assessment period.

At the end of the assessment period, Lancaster was ranked fourth in terms of EPSRC funding in the Mathematical Sciences, and top for Statistics and Applied Probability, see Figure 4.

This increase in funding has been the result of the following strategic changes to encourage and support appropriate grant submissions:

Incentivising research grants. We have transparent mechanisms for reducing non-research workload to account for external grant funding and the time spent both managing and performing funded research projects. We also offer seed-corn funding specifically to develop ideas and create academic end-user collaborations linked to potential grant applications.





Figure 4: (left) EPSRC Mathematical Sciences portfolio: area of circle proportional to size of portfolio, colour for framework (blue), strategic (green) and other (grey) universities; (right) Top institutions for size of EPSRC portfolio in Statistics and Applied Probability. Figures screen captured from EPSRC website July 2020.

Increased support for grant writing. The Department has run grant-writing workshops to help all staff, and especially early career staff, to become more effective at securing research funding. Use of our research group structure means an experienced member of staff, working in the same research area is able to give advice from an early stage on grant proposal ideas, appropriate funding sources, and how best to present the research. We have also benefitted from a restructuring of and investment in Research Support at the University, with a dedicated member of Research Support based in the Department who is able to relieve much of the administrative burden of putting together a grant application. Staff have been able to take part in Faculty run courses that support fellowship applications – the latter helping Nemeth and Wadsworth with their successful applications; and we routinely provide support for interview practice and preparation.

Leveraging University and Industrial support. We encourage all PIs to investigate opportunities for enhancing a research proposal through University support or by utilising our range of industrial contacts for financial or in-kind support. Where appropriate staff contact potential industrial collaborators at an early stage to ensure that foundational mathematics and statistics research is of relevance for contemporary and important challenges. The University routinely supports grant applications, often through the provision of PhD studentships, and we have a strong record of substantial financial and in-kind support from non-academic project partners (e.g. see Table 2).

A focus on large-scale, inter-disciplinary and inter-institutional research programmes in statistics. Building on our world-leading research reputation and established collaborations with leading statistics, scientific and end-user groups we have encouraged and supported large-scale grants aimed at tackling key challenges that have arisen as part of the big data revolution. The success and benefits of this is described below.

Diversifying funding sources. We proactively pursue non-standard funding sources, and encourage and support staff to apply to these where appropriate. Building on our involvement in Lancaster's Data Science Institute and our new research group in Statistical Learning we have success with funding from tech firms such as Google, Amazon, Prowlier.io and Rock Services. This is part of a range of industrial partners who support our research (see Figure 1 above), and has enabled us to maintain a sector leading record in industrial funding (see Figure 5).





Figure 5: Research Income Spend per FTE for HESA cost centres UK, EU or Non-EU industry, commerce and public corporations (Lancaster in red; and various mission groups). Comparator data only available to 2018/2019.

As mentioned, an important component of our grant portfolio are long-term, inter-disciplinary, multi-institutional and impact-facing research programmes. We currently lead 4 large-scale collaborative research grants that were awarded during the assessment period:

Table 2: Major EPSRC grants	awarded and	led by Lancaster	⁻ Mathematics	during the
assessment period.				

Grant	Funding	Collaborating Institutions	Project Partners	Research Topic
Statscale (2016-2023) PI: Eckley	£2.7M EPSRC £400K Project Partners	Cambridge	Astra Zeneca, BT, ONS, Shell	Statistical approaches for large-scale streaming data.
Bayes4Health (2018-2023) PI: Fearnhead	£3.0M EPSRC £200K Project Partners	Bristol, Cambridge, Oxford, Warwick	Astra Zeneca, Health Protection Scotland, Public Health England, GSK, Wellcome Trust	Bayesian Data Science methods for the Health Sciences.
DSNE (2018-2023) PI: Leslie	£2.7M EPSRC £540K Project Partners	CEH	Over 20 project partners, including EDF, the Met Office, DEFRA and NCAR.	Data Science for the Natural Environmental.
NG-CDI (2017-2022) Co-PI: Eckley	£2.6M EPSRC £4.5M Project Partners	Bristol, Cambridge, Surrey	A Prosperity Partnership with BT.	Next Generation Converged Digital Infrastructure.

Each of these addresses generic research problems that are motivated by open applied challenges, and has a programme of research that was co-designed either with end-users or with scientists embedded in disciplines such as computing, the environment and health. They exemplify the success of our strategy for inter-disciplinary research/research with end-users (see Sections 1 and 4) and are one pathway for developing substantial impact from our research. In addition to these, we were major partners in EPSRC programme grants, i-like (2013-2018; £2.4M) and CoSInES (2018-2023; £3M), aimed at developing the next generation of computational statistical methods; and a £1.6M EPSRC grant (2020-2024), led by the School of Computing and Communications, aimed at reducing energy demand through digital innovation.



These large-scale, collaborative grants add substantially to the vibrancy of the research environment, through regular research visits of world-leading researchers; organisation of workshops; interaction with end-users and funding for impact related activities; and a strong emphasis on inter-disciplinary research.

b. Infrastructure and Facilities

Physical infrastructure

The Department, housed within one floor of Fylde College, and the adjoining Postgraduate Statistics Centre and Science & Technology Building, enables co-location of all staff, PDRAs and PhD students. It includes an AccessGrid room specifically for advanced courses delivered by the MAGIC consortium. Concurrent with Departmental growth there has been investment in new space:

- A dedicated space for the STOR-i Centre for Doctoral Training, that has allowed colocation of over 50 students, support staff and impact fellows. This incorporates highquality facilities for networking and informal interactions supporting STOR-i's engagement with academic and industrial partners. We believe that this provision has been essential for nurturing the STOR-i culture, developing a group identity, facilitating peer-to-peer learning and integrating students into larger research teams.
- A dedicated open plan office for the EPSRC-funded Data Science of the Natural Environment project, consisting of 16 desk spaces to host project staff and visitors and providing meeting, interaction and seminar space. This space catalyses inter-disciplinary research through bringing together researchers in statistics with those from environmental science.
- All departmental staff associated with Lancaster's Data Science Institute, have access to, and regularly use, the Institute's shared office space to facilitate interdisciplinary and collaborative working.

Operational infrastructure

The primary form of research infrastructure is high-end computing, and the Department invests heavily in this to provide a dedicated, well-used resource that supplements central University provision. Staff have access to the Department's own computer support (2.4FTE computer technicians) and computer cluster (924 computer cores, 5TB of memory; plus 5 virtual machines with a further 288 cores). In addition, all staff and PhD students have access to Lancaster University's High-End Computing cluster (8,800 computer cores, 40TB of memory, 70TB of high performance filestore). The Department invests approx. £50K annually to cover personal machines for PhD students and renewal of machines for staff.

Our excellent support for IT helped us to seamlessly and successfully move to virtual working, and minimised disruptions due to COVID-19. This is evidenced by e.g. less than half our final year EPSRC-funded PhD students requesting any extension to their studentship – substantially below the 92% of students who requested extensions nationally.

Infrastructure supporting impact

Following a review in 2014, the University recruited 2 impact professionals to support impact in the Faculty of Science and Technology, which also has a 14-strong Partnerships, Business and Enterprise team. The Faculty allocates impact funding and distributes EPSRC's Impact Acceleration Account: the Department has benefited from £64K to support 8 projects including collaborative research to develop joint extreme value statistical analyses for the Office for Nuclear Regulation, and a workshop on changepoints with partners including the Office for National Statistics, Tesco and BT which resulted in further developments in our changepoints impact case study. The MSc in Data Science has a dedicated Business Engagement Manager to ensure strong industry and government connections throughout the programme and a ready



supply of externally-sponsored MSc projects, while STORi has a 50% FTE Industrial Liaison Manager to generate industry-sponsored PhD studentships.

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

a. Support for Research Collaborations

We have formal research collaborations, which include co-supervision of PhD students and funding for regular visits, with leading international research centres based at MIT, NorthWestern, UC Dublin, U Oslo and U Washington. Example outputs from these include Rohrbeck's work with Arnoldo Frigessi (Oslo) on spatial monotone regression methods motivated by the problem of predicting water-related insurance claims (papers in Biometrika and Annals of Applied Statistics); and Baker's work with Emily Fox (Washington) on sampling algorithms (papers in Statistics and Computing and at NeurIPS).

There are generous funds for supporting collaborations, with on average £50K per year available for visits of staff to other organisations, visits to Lancaster or to support specialist workshops at Lancaster or similar research activities. As examples of the benefits accruing from this funding from a single year: 2016-17 saw funding over 30 visits to/from Lancaster (including 9 that established new collaborations), 4 workshops and the establishment of a new seminar series in Algebra, Combinatorics and Measure (set-up at the request of then new staff member, L Grabowski and with 25 seminars including 4 with non-UK speakers). These activities led to a successful grant application funding a post-doc, more than 30 publications, and supported the writing of 2 research monographs.

We have a track record of successful collaborations with some of the best statistics groups in the UK. The success of these can be seen by our involvement in and leadership of large-scale grants (see Section 3 and, in particular, Table 2) that include collaborations with nationally leading groups at Bristol, Cambridge, Oxford and Warwick. These research programmes each include funding for a range of cross-institutional interactions, as well as research events with project partners. Examples of their success include ground-breaking work on scalable Monte Carlo: the Zig-Zag algorithm (published in Annals of Statistics) and the ScaLE algorithm (an RSS research section read paper).

Lancaster leads LMS-funded networks on Functor Categories for Groups, and Algebraic Quantum Field Theory. The first network involves Cambridge, RHUL and Lincoln, and has met three times a year since 2017. It brings together researchers representing the various subjects touched by functor categories for groups in order to incentivise future advances and stimulate new collaborations in the UK and abroad and provide a platform for young mathematicians from across the UK to meet, present and discuss their research. From this activity, Mazza is now collaborating with Castellano, Nucinkis and Vera on Mackey functors for profinite groups. The second network was established in 2020, involves Cardiff, Nottingham and York, and will connect researchers across the UK through regular workshops, enhancing scientific exchange and encouraging new collaborations. A particular focus is to give PhD students opportunities to get to know other researchers and to share their research in a relaxed environment.

b. Collaboration with Key Research Users and Contributions to the Economy and Society.

As will have been apparent from earlier sections, collaboration with research users underpins much of the research at Lancaster, and has been central to our strategy for expansion, the growth of our PGR programmes, our success in external grant funding and large research projects, and the breadth of our end-user interaction and impact from research. A long-held ethos at Lancaster has been that the best methodological and theoretical research is motivated by and applied to contemporary challenge.

A small number of exemplars of mechanisms that facilitate impactful research and successful projects are:

STOR-i: Over 80 companies have contributed across three generations of STOR-i, with approximately three-quarters of students on CASE-like projects. Several companies support projects over multiple years and developments from such long-term relationships form the basis of three impact case studies, as detailed in Section 1d. Examples of impact from other STOR-i industrial projects include: Research by Urbas on modelling recruitment to multi-centre clinical trials with AstraZeneca, to analyse recruitment to ongoing trials and decide on interventions to ensure the required sample size is obtained on time. Stubington's optimisation research is being employed in experiment design by Lubrizol, saving them £2-3M in the development of new oilbased products. Spatial and Temporal extremes work by Winter is influencing the Met Office's methods for European heatwave risk assessment. O'Malley's work with the US National Oceanic and Atmospheric Administration has led to improved methods for ocean movement tracking with his software being widely used globally.

Statistics for the natural environment: The Department has a strong cross-disciplinary research focus on environmental data science, building on long-term work of Tawn in applying extreme value statistics to flooding and offshore conditions. Collaborating with the School of Computing and Communication and the Lancaster Environment Centre, we have instigated an environment research theme in Lancaster's Data Science Institute and been key participants in a Memorandum of Understanding between LU and the Centre for Ecology and Hydrology to establish a Centre of Excellence in Environmental Data Science. Consequently, 6 members of the department are funded by the EPSRC project on Data Science of the Natural Environment, along with 10 researchers from other LU departments and 4 from the Centre for Ecology and Hydrology. An example of the collaborative research is recent work developing a spatially indexed extreme value theory method to analyse and predict melt from ice sheets.

Medical and pharmaceutical statistics: Building on long term collaborations with companies including Roche, Janssen, Merck, Quanticate, Novartis and AstraZeneca, we led the EU-funded (\in 3.1M) IDEAS PhD training network. The industrial funding through these collaborations (total in-period contribution approx. £1M) has supported 11.5FTE years of PDRA time and 3 CASE-like PhD students. The reputation, skills and research developed has also resulted in substantial involvement in efforts to find treatments for COVID-19 through the development and deployment of adaptive multi-arm clinical trials. These include involvement in the flagship RECOVERY trial that identified the first COVID-19 treatment shown to reduce mortality.

Consultancy and advisory work: In the assessment period Departmental researchers have provided consultancy and advisory services to entities including the Heilbronn Institute for Mathematical Research, Prowler.io, Hong Kong University, Eurostat, the Bond Review, and the National Flood Resilience Review. The latter review forms a pathway for our extremes research to impact the design of flood defences, while several confidential impacts are currently being achieved through engagement with the Heilbronn Institute.

Public engagement: The Department is committed to engagement with the public and schools. Public engagement activities have included public lectures (recent examples by Sykulski and Tawn) and external speakers, either stand-alone or associated with academic conferences, as well as science fair-type events such as the national Fun Palaces, events held at libraries and community days run by the university or partners such as EDF. We are leading the University's establishment of a specialist maths school, the Lancaster University School of Mathematics, due to open in September 2022, with up to 250 students and significant wider engagement activity. As mentioned in Section 2c we are active with widening participation events, such as running our annual Florence Nightingale Day. The department has also been involved in the university's Campus in the City project since that project began, taking mathematics activity into Lancaster city centre with engagement with over 500 people. Work with schools involves visits by schools and pupils to campus, for example to Royal Institution Masterclasses and Engineering Development Trust Summer Schools, and visits to schools, especially by postgraduate research students. The latter activity helps engage future research leaders into public engagement, and is funded as part of our re-investment of industrial funding (current funding of approx. £100K for



this activity; with an average of 7 PhD students each year, visiting between 5 and 10 schools; and with approx. 800 school students involved to date).

c. Contribution to the Discipline

Awards: Killick is the first UK recipient of the Young Statistician Award of the European Network for Business and Industrial Statistics (2019); Wadsworth, Tawn and Eckley have received awards from the Royal Statistical Society (Inaugural Barnett Award to Tawn and Research Prize to Wadsworth in 2015; Greenfield Industrial Medal to Eckley in 2018). Eckley was elected a fellow of the Learned Society of Wales in 2017.

Fellowships: As summarised previously, Killick, Wadsworth and Nemeth have been awarded EPSRC fellowships, L. Grabowski an ERC starter grant, Coelho Simões a Marie Sklodowska-Curie fellowship, Jaki and Mozgunov NIHR fellowships, Rohrbeck an AXA Fellowship, and Brueckner a Biometrika Fellowship.

PGR Training: Lancaster is a founder member of APTS, MAGIC and NATCOR. We have hosted training courses for APTS and NATCOR and Lancaster staff have given courses across the training programmes. The STOR-I CDT funds and runs a National Associates scheme that opens up many training events to UK-based PhD students at other universities who are working with industrial collaborators, currently this scheme is benefitting 17 PhD students across 12 institutions.

Our leadership in PGR training is further exemplified by Eckley advising on U Newcastle's CDT on Cloud Computing for Big Data, and the Imperial-Oxford CDT on Statistics and Machine Learning; and Tawn sitting on the advisory panel for the Science Foundation Ireland Centre for Research Training in Foundations of Data Science.

Journal Editorships: Fearnhead is editor of Biometrika (2018-), Mukherjee was co-editor of Sankhya, Series A (2008-2015), Lazarev is a managing editor of the LMS Bulletin (2019-) and Fokianos, Grabowski and Towers, and Schulze have been guest editors for Statistics, the Glasgow Mathematical Journal, and Symmetry respectively. Over the period staff have held 25 Associate Editor roles.

Conference Organisation at Lancaster: We have hosted around 40 workshops and conferences at Lancaster during the period, including the 2019 British Mathematical Colloquium, the 2016 Easter Probability Meeting, an annual workshop linked to the STOR-i CDT, and regular workshop series on Geometric Rigidity, Probability, and Statistical Scalability. We are organising and hosting the 2021 International Workshop on Operator Theory and its Applications (postponed from 2020).

External Programme and Conference Organisation: Staff have been organisers of three research programmes at the Isaac Newton Institute: Inference for Change-point and related processes (Jan-Feb 2014); Scalable inference, statistical algorithmic and computational aspects (July 2017); and Statistical Scalability (Jan-Jun 2018); and of the programme on Abstract harmonic analysis, Banach and operator algebras' at the Fields Institute, Toronto, (Jan-Jun, 2014). They have also helped organise over 40 workshops or conferences external to Lancaster.

Learned Body, Research Council Roles and Advisory Board Membership: Involvement with the London Mathematical Society includes or has included membership of: the Publications Committee (Lazarev, Turner); Publishing Nominating Group (Lazarev); the Personnel Committee (Belton); the Development Committee (Dales); the Grants Committee (Lazarev, Turner); the Prizes Committee (Lazarev); the Programme Committee (Leslie, Turner) and the Good Practice Steering Group (Mazza). Dales was vice chair of the EMS ethics committee. Involvement with the *Royal Statistical Society* includes membership of the Research Section (Leslie, Tawn, Wadsworth), Honours Committee (Eckley, Fearnhead), Statistical Computing Committee



(Nemeth, Vice-Chair; and Killick), Chair of the Applied Probability Section (Turner) and membership of the Search Committee for a new JRSS B editor (Wadsworth).

Jaki has been a member of the executive committee of the International Society for Clinical Biostatistics, and its treasurer. Eckley is on ENBIS Committee for the George Box medal. Wadsworth is the UK representative for European Courses in Advanced Statistics. Advisory board membership for APTS, EQUIP and Big Insight (all Eckley); and CRISM and SECURE (Tawn). Eleven staff are EPSRC college members, Nemeth is member of the EPSRC Mathematics Early Career Forum and a member of the UKRI Future Leaders Fellowship Peer Review College, Eckley, J. Grabowski and Nemeth have sat on EPSRC panels. Leslie was a member of the Bond Review Committee and Implementation Group. Jaki is a board member of the MRC Methodology Panel Advisory Group and was a member of the NIHR Efficacy and Mechanism Evaluation Advisory Group. Fearnhead and Jonathan are panel members for REF2021.

Invited Talks at International Conferences: The many hundreds of invited talks at international conferences include BayesComp2020 (Fearnhead keynote talk, Florida 2020); Indian Mathematical Society (Dales, invited plenary, Jammu 2018); Geometry and Approximation (Elek, keynote talk, Dresden 2019); Analysis in Athens (Power, opening plenary speaker, Athens 2017); Conference on Applied Statistics in Ireland (Leslie, 2016); South African Mathematical Society (Dales, Cape Town 2019); Banach Algebras and Application (Choi, Toronto 2015; Choi and Laustsen, Winnipeg 2019); Extreme Value Analysis (Tawn, Wadsworth, Zagreb 2019); the World Statistics Congress (Eckley, Morocco 2017).