Institution: University of Kent
Unit of Assessment: 10 (Mathematical Sciences)

a. Context This **unit** consists of two groups, **Mathematics** and **Statistics**. Together with the Centre for Actuarial Science, Risk and Investment (CASRI), they form the School of Mathematics, Statistics and Actuarial Science (SMSAS). CASRI is primarily focused on the professional aspects of actuarial science and has strong links with professional bodies and the financial sector.

The unit focuses on the following user groups and beneficiaries: environmental and conservation agencies, health and public services such as weather forecasting, general public (particularly schools), and national and international businesses including pharmaceutical, financial and manufacturing companies. The Mathematics group has grown considerably, with 21 staff submitted compared to 12 in the last RAE. Despite their youth, the research achievements in Algebra, Analysis and Applicable Mathematics (the three main themes of the Mathematics group) have already led to sustained impact on society via public engagement and strong economic impact (Painlevé). The Statistics group is recognised particularly for its work in Statistical Ecology and in Bayesian Statistics. The application of this expertise has led to significant impacts, including those reflected in three case studies: economic impact (Calibration), health impact (DrugAbuse) and impact on the environment (Ecology).

b. Approach to impact The unit's most successful impacts in the period have arisen through three main routes: public engagement, applied and interdisciplinary work, and industrial links. They result from long-term investments by SMSAS to initiate and develop links with a variety of different partners/users, not only via academic staff but also via students and alumni. In order to achieve its ambitions, the unit has been working closely with various other research centres such as the Durrell Institute of Conservation Ecology (DICE), the recently launched Kent Centre for Finance and the Kent node of the National Centre for Statistical Ecology (NCSE) (2005—2015). Institutional support includes the Kent Innovation and Enterprise (KIE) unit which provides professional help in developing business collaborations for the purpose of exploiting research outputs for commercialisation, consultancy and training. In addition, events run by Kent Research Services and KIE provide links with industry (e.g. joint event with the National Institute for Health Research) and support for impact (e.g. staff development events such as **Enterprise and Impact Training** that are attended by unit members). KIE's support has been crucial in the set up and the running of our Calibration case study.

1) Our approach to public engagement and awareness: Our staff members are committed to sharing our research with the public locally, nationally and internationally. To support this ambition, SMSAS coordinates various public outreach activities aimed at raising public awareness of Mathematics and Statistics research at the University of Kent. One of the distinctive features of our outreach programmes is a continuous effort in creating **research-based activities** (mainly aimed at and presented to primary and secondary school pupils). For instance, Hone created a schools activity around his work on Somos sequences and cluster algebras, and Launois developed one on his recent work on Cauchon diagrams and restricted permutations. ECRs are also invited to develop (and have led) similar activities, and benefit from the advice of our **outreach officer** and other experienced staff. All these activities give rise to **credits within our work allocation model**. Examples of sustained **research-led public awareness activities** include: (i) annual Royal Institution Mathematics Masterclasses at the University of Kent; (ii) Nuffield Foundation summer projects, which have allowed sixth-formers the opportunity to experience working on research problems; (iii) regular visits to primary and secondary schools in Kent, but also the invited visit to an isolated primary school on the Isle of Skye, and, as part of an ongoing collaboration with the Lycée Français Charles de Gaulle in London, invited visits by Hone, Launois and Loureiro to present and discuss current mathematical research to pupils starting scientific studies (they met around 150 pupils in 2012 and 2013); (iv) Maths Clubs, e.g. Hone and a local school teacher set up a Maths Club at Queen Elizabeth's Grammar School, Faversham (Kent). This club was a great opportunity for a group of approximately 10 interested pupils to study discrete dynamical systems, including examples from Hone's research, and their applications in physics and biology.

2) Our approach to developing applied and interdisciplinary work: One of the strengths of SMSAS is its diversity, which provides a fertile environment to develop applicable and/or interdisciplinary research programmes. In particular, SMSAS continues to be very strong in both applied statistics research and methodological developments. Applied work is particularly focused on biological and ecological modelling, biostatistics, neuroimaging, shape analysis and time series

and finance and we have good links internally with the School of Biosciences and DICE which offer potential pathways to impact. Impact also stems from more methodological research, as exemplified by our Calibration case study which arises from application of recent research in nonparametric Bayesian methods. In addition to these, we have been developing the following strategies in order to increase the impact of our research in the medium term.

Creation of new interdisciplinary courses: Since RAE2008, SMSAS has developed new vocational programmes that have supported the unit's impact. For instance, the new BSc in *Mathematics and Education* (launched in 2008) is a key ingredient in our future plans for **public engagement** (see Section c.2) as it provides us with privileged connections with secondary Maths teachers. Similarly, several MSc courses have been introduced in order to facilitate and encourage interdisciplinary work, for example *Statistics with Finance* (launched in 2011), and *Mathematics and its Applications* (launched in 2010). The new MSc in *Statistics with Finance* has been designed to encourage interactions between the Statistics group and CASRI. We expect for instance that these interactions will be beneficial to **hedge fund and asset management companies** through the use of complex statistical modelling approaches. On the other hand, the MSc in *Mathematics and its Applications* has been instrumental in encouraging members of the Mathematics group to look for novel applications of their research, especially when developing courses. As expected this led to various high-profile projects with high potential for impact. For instance, a current EPSRC-funded project at Kent, led by Mansfield, is to build missing conservation laws into numerical code that models physical systems. The fact that some of these laws are missing from the models currently in use was, after much work, identified by the **Met Office** as the reason why it famously failed to predict the hurricane experienced by the UK in 1987.

STATDESK: Another tool we have to initiate interdisciplinary collaborations is the STATDESK, a system funded by the University since 1995 through which staff and students can seek statistical advice on research projects. Whilst this often involves addressing basic statistical issues, there are sometimes opportunities for more substantial involvement, leading to joint publications in subject-matter journals. Members of the Statistics group have been co-authors of 4 such papers during the REF period. This work often has considerable potential for impact in the medium term. For example, Ridout has been involved in work on predicting the remaining lifespan of terminally ill patients using data collected routinely on entry to a hospice. This has the potential to **become standard practice** and is currently the subject of a larger-scale multi-site validation study. The hospice doctor leading the study approached STATDESK whilst studying for an MSc at Kent.

3) Our approach to developing industrial links: SMSAS has always advocated the development of industrial links in order that our research can be translated into real world applications, for instance through **CASE studentships**. A recent studentship, with the Centre for Environment, Fisheries & Aquaculture Science, involved statistical modelling of benthic data. The motivation for this project, and its potential for impact, lies in the importance of estimating coastal benthic populations in deciding applications for licences to dredge for aggregates in UK coastal waters. While contacts with industrial partners were mostly informal in the past, SMSAS has been working with KIE to establish more formal collaborations. For instance, our Calibration case study describes an industrial collaboration with KROHNE Ltd, based in Northamptonshire. This built on initial links established by X Wang with the company. Support for building this into a more formal collaboration, funded through a **Knowledge Transfer Partnership** (KTP), was provided by KIE.

During the REF period we have also been encouraging staff to be involved in **consultancy** work. Our strategy to develop consultancy has been to take advantage of the multi-disciplinary aspect of SMSAS and of our strong link with financial organisations through CASRI. In order to further strengthen these links, and also create new ones, SMSAS is now running cross-group events which provide platforms for Mathematicians and Statisticians to meet non-academic research users. This led, for instance, to a project funded by a **financial organisation**, KPMG, on positive definite matrices that involved staff from Mathematics, Statistics and CASRI. This mathematical project arose thanks to initial links between KPMG and CASRI members. Other examples of consultancy include **classified work** and a project funded by the Department for Environment, Food and Rural Affairs (DEFRA) through David Rogers Associates, Aquatic Biological Consultants, on the control of crayfish plague in England and Wales.

c. Strategy and plans Our aim is to be recognised internationally as a **centre of excellence** in our research fields in Mathematics and Statistics, including areas of research that have direct or indirect impact on industry and society. To support this ambition, we expect all staff to produce

research that is **high quality and influential** within its own field. We regard this as the first condition for our research to have impact, and so our impact strategy is embedded in our research agenda. Next, our strategy to maximise the potential for impact of our research is **twofold**.

1) Building on our successes: We will continue to support long-term research programmes with strong potential impact: Bayesian Statistics, Statistical Ecology, Applicable Mathematics, Algebra. Four examples of current work in these areas where we anticipate future impact are: (i) Predicting the progression of Chronic Kidney Disease in the population is crucial for decision-making by NHS doctors and by patients, but has proved a difficult problem. Collaborating with the Renal Unit at the East Kent Hospitals University **NHS** Foundation Trust, Griffin is developing new Bayesian nonparametric models that have the potential to give realistic measures of uncertainty in the progression. (ii) A current **EPSRC-funded** project led by Rosenkranz is studying symbolic solution methods for linear boundary problems, including potential applications in actuarial science (renewal risk models with tax payments). (iii) Morgan and Ridout have a grant from **Pond Conservation: The Water Habitats Trust** for methodological development for improved surveillance of the great crested newt, a species that the government is required to monitor under EU regulations. (iv) In collaboration with computational chemists at the **pharmaceutical company** GlaxoSmithKline, members of the Statistics group are evolving new methods of quickly and efficiently finding promising lead compounds for treatment of a particular condition, a premium in drug discovery. We will also continue to seek CASE studentships and KTP awards.

2) Developing new opportunities for impact: First, our growing number of undergraduate **industrial placements** will help to foster contact with different companies, and thereby increase our opportunities for forging research links in the future. To support and expand this activity, we have recently recruited a **dedicated placement officer**. We expect this to generate additional consultancy and impact development opportunities in the medium term. Next, building on our successful outreach activities, and the creation of our BSc in *Mathematics and Education*, we have identified enthusiasm amongst secondary Maths teachers in Kent (and beyond) to continue to be exposed to Mathematics and Statistics as part of their professional development. We therefore plan to run, from 2014/2015, **staff development courses for Maths teachers** based on research done at Kent. This will be facilitated by the recent appointment of an **outreach lecturer** who will help set up such courses. We have also recognised that one route for promoting non-academic take-up of our work is by providing **software**, e.g. via staff web pages. For example, the package 'overlap', available through the Comprehensive R Archive Network (CRAN), implements methods for analysing camera trap data based on research by Ridout and an ecologist from Flora & Fauna International, Sumatra; the software was developed with a researcher from **Wildlife Conservation Society, Malaysia,** and has downloads from 40 countries including USA, Japan, Brazil, Korea and Europe. Camera traps have revolutionised the study of cryptic species and some applications of the method are listed in our Ecology case study. Several research programmes at Kent (both in Mathematics and Statistics) aim to produce and implement important algorithms. In order to further strengthen this activity, the University has agreed for SMSAS to **appoint lecturers in numerical analysis** in 2013/2014. Finally, the **newly created team in Finance** within CASRI will greatly expand opportunities for our research in Mathematics and Statistics to have impact in the financial industry, building on existing links, for example through KPMG and JP Morgan. Interactions between the Statistics Group and CASRI will be facilitated by the recently launched MSc in *Statistics with Finance,* the joint Statistics-Finance PhD supervision already in place (a second student is due to start in 2014) and the newly launched Kent Centre for Finance which encompasses members from the Statistics Group, CASRI and the Kent Business School.

d. Relationship to case studies Our case studies arise from 3 long-term research programmes at Kent: Statistical Ecology, Bayesian Statistics and Painlevé equations. Our academic staff have striven to collaborate with users outside academia, especially through the mechanisms explained in Section b. This led to 3 of our case studies: DrugAbuse, Ecology and Painlevé. However, more recently, we have developed a more strategic approach to impact (with the support of KIE) and this has led to new industrial collaborations such as that with KROHNE Ltd (Calibration). Our 4 case studies illustrate the variety of our impacts during the REF period: our research findings have been used all over the world and have benefited manufacturers, governmental agencies, environmental agencies, commercial organizations and engineers to name a few. Our impact strategy, presented in Section c, has been developed by reflecting on the experience gained from the case studies.