Institution: University of Kent

Unit of Assessment: 10 (Mathematical Sciences)

Title of case study: New statistical tools for ecologists

1. Summary of the impact

The impact of statistical ecology research at Kent is on both the **survey design** of data collection on wild animals, and the **analysis** of the resulting data. As a result of our research, better quality data are being collected more efficiently, and a wide range of new methods of data analysis are being used. This is essential for the conservation and management of wild animal populations and the preservation of biodiversity. New methods developed at Kent are now standard tools used in ecology. Examples of impact are improved understanding of the decline of British farmland birds, underpinning conservation action plans; and analysis of data from tiger surveys, supporting the Indonesian Government's National Tiger Recovery Plan.

2. Underpinning research

Research in statistical ecology undertaken at Kent over more than 25 years has involved many PhD students and RAs, as well as permanent members of staff. The specific underpinning statistical ecology research cited here was conducted at Kent by **Besbeas** (RA 1999-2002, lecturer 2003-2006, RA 2013-present), **Freeman** (RA 1994-1997), **Guillera-Arroita** (PhD student, 2009-2012), **Morgan** (1972-present), **Ridout** (2000-present).

In 2005, the **National Centre for Statistical Ecology** (NCSE, www.ncse.org.uk) was established as a joint research centre between the Universities of Kent, Cambridge and St Andrews, supported by an EPSRC Mathematics **Multidisciplinary Critical Mass Award**. In 2010, NCSE expanded to include the Universities of Bath, Bristol, Exeter, Glasgow and Sheffield, together with the Centre for Ecology and Hydrology (CEH), while the University of Cambridge dropped out, following departure of staff. This expansion was achieved with the aid of a joint EPSRC/NERC grant, and total funding to date exceeds £2,000,000.

To ensure that our research is relevant and responds to the changing demands of the real world, as technology advances, since 2010 NCSE has included four non-academic **Project Partners**: Biomathematics and Statistics Scotland; the Centre for Environment, Fisheries and Aquaculture Science (Cefas); the Game and Wildlife Conservation Trust; and Marine Scotland.

Estimating the survival of wild animals and integrated population modelling. The **use of covariates** in describing mortality of wild animals originated at Kent. The ecological insights that can result from this approach are illustrated by **[3.1]**, which models the mortality of Soay sheep (*Ovis aries*), showing how population regulation depends in a complex manner on measures of climate, population density and individual characteristics, differentially for animals of different ages. This led on to a highly-cited *Science* paper **[3.2]**.

Research at Kent has also pioneered methods of **integrated population modelling (IPM) [3.3, 3.4]**, which are now in widespread use by wildlife conservation authorities, including the innovative use of **state-space models**. This approach integrates different types of information into a single analysis, which can greatly reduce the uncertainty of estimates or indeed make possible the estimation of features that cannot be estimated from a single data source. The method can also deliver increased power for detecting the possibly subtle effects of covariates, such as climatic factors. This is important for understanding the effects of climate change. Kent statisticians have applied the methodology to several bird species, including northern lapwings (*Vanellus vanellus*), grey herons (*Ardea cinerea*), snow geese (*Chen caerulescens*) and great cormorants (*Phalacrocorax carbo*), and have continued to develop the methodology; for example, by extending it to multi-site models, where animals can move between sites.

Occupancy modelling and camera trap data. Occupancy surveys, which aim to estimate the proportion of study sites at which a species is present, are widely used by practicing ecologists and wildlife managers. Direct estimates of the proportion of sites occupied are misleading, because species are often not detected when present, and the statistical analysis must account for this. The work of **Guillera-Arroita [3.5]** covers both design and analysis of occupancy studies, including the development of **hidden Markov models** for occupancy data collected along a transect. The methods were developed for studying tigers in Sumatra, but are applicable much more widely. One

method of assessing species presence at a site is the use of camera traps – cameras linked to detectors that trigger a photograph when an animal passes; these have revolutionised the study of cryptic animal species. The time of the photograph is recorded and **[3.6]** provides a method of using these data to estimate temporal overlap of competing species or predator and prey species.

3. References to the research

All references except **[3.5]** are papers in international journals. The research reported in **[3.5]** is the subject of six refereed papers in international journals.

[3.1]* Catchpole, E.A., **Morgan, B.J.T.**, Coulson, T.N., **Freeman, S.N.** and Albon, S.D. (2000) Factors influencing Soay sheep survival. *Journal of the Royal Statistical Society Series C-Applied Statistics*, **49**, 453-472. doi: 10.1111/1467-9876.00205

[3.2] Coulson, T., Catchpole, E.A., Albon, S.D., **Morgan, B.J.T.**, Pemberton, J.M., Clutton-Brock, T.H., Crawley, M.J. and Grenfell, B.T. (2001) Age, sex, density, winter weather, and population crashes in Soay sheep. *Science*, **292,** 1528-1531. doi: 10.1126/science.292.5521.1528

[3.3] Catchpole, E.A., **Freeman, S.N.**, **Morgan, B.J.T.** and Harris, M.P. (1998) Integrated recovery/recapture data analysis. *Biometrics*, **54**, 33-46. doi: 10.2307/2533993

[3.4]* Besbeas, P., **Freeman, S.N.**, **Morgan, B.J.T.** and Catchpole, E.A. (2002) Integrating mark-recapture-recovery and census data to estimate animal abundance and demographic parameters. *Biometrics*, **58**, 540-547. doi: 10.1111/j.0006-341X.2002.00540.x

[3.5] Guillera-Arroita, G. (2012) Occupancy modelling: study design and models for data collected along transects. *PhD thesis, University of Kent*. (Supervisors **B.J.T. Morgan** and **M.S. Ridout**).

[3.6]* Ridout, M.S. and Linkie, M. (2009) Estimating overlap of daily activity patterns from camera trap data. *Journal of Agricultural, Biological and Environmental Statistics*, **14**, 322-337. doi: 10.1198/jabes.2009.08038

(References marked with a star best indicate the quality of the underpinning research.)

4. Details of the impact

The impact of Statistical Ecology research at Kent has been to improve substantially the effectiveness of wildlife conservation policy and practice by providing better methods of data collection and analysis. The beneficiaries of the research are individuals, charities and environmental agencies that collect and analyse ecological data and the organisations that plan and implement management and conservation strategies that utilise these data.

A variety of approaches are used to encourage the incorporation of our new methodologies into ecological practice. These include workshops and multidisciplinary conferences, studentships with collaborating bodies, joint research with external agencies and provision of computer software. Before detailing impact in (a) and (b) below, we expand on the context.

Multidisciplinary conferences: EURING meetings have been held regularly since 1986 to promote collaboration between ornithologists, statisticians and population biologists. Kent statisticians have contributed to all of them, editing or co-editing proceedings of 6 of the 9 meetings. NCSE initiated the highly successful and influential series of International Statistical Ecology Conferences (St Andrews 2008, Kent 2010, Oslo 2012, Montpellier 2014, British Columbia 2016). Both conference series incorporate training workshops and attract strong participation from outside of academia; for example, approximately 1/3 of the 146 participants at the 2010 ISEC at Kent were from outside academia (e.g. Alaska Dept of Fish & Game; British Trust for Ornithology; Microsoft; Proteus Consulting, New Zealand; Snow Leopard Trust, India; US Geological Survey; Wildlife Conservation Society, Malaysia).

Studentships with collaborating bodies, some funded by CASE awards, have addressed the spread of an invasive species (CEH), the effect of dredging on benthic organisms (Cefas) and the phenology of overwintering wild birds (the Wildfowl and Wetlands Trust). These close collaborations ensure that research is directly relevant to ecologists. Two research students have produced introductory videos, targeted at an ecological audience, to facilitate uptake of new methods published in *Methods in Ecology and Evolution*, a journal of the British Ecological Society **[5.1]**, and two students won a poster prize at the *International Congress in Conservation Biology,*

Auckland, New Zealand, 2011.

Current projects with external agencies/users include developing models for the spread of ring-necked parakeets (*Psittacula krameri*) with the British Trust for Ornithology (BTO); devising new models and methods for evaluating the effect of global warming on the phenology, abundance and distribution of British butterfly species, with Butterfly Conservation; and investigating the causes of the decline of sea birds in the North Sea, with CEH. These close links promote the wider use of our methodology within these non-academic institutions.

a) Estimating the survival of wild animals and integrated population modelling [3.1-3.4]

Discussion of the sheep model **[3.1, 3.2]** now appears in several textbooks on ecological modelling **[5.2]**. The estimate of the annual survival of shags developed in **[3.3]** was incorporated in the update of *The Birds of the Western Palearctic* **[5.3]**. Our models demonstrated the probable reason for the decline of the Northern Lapwing, a species that is now on the UK red list of globally threatened species **[5.4]**. Organisations such as the BTO use information about population decline "to inform the public, opinion-formers and decision-makers... and to make a significant contribution to environmental policy." **[5.5]**

Our methodology for **integrated population modelling (IPM) [3.4]**, which allows the combined analysis of data from different sources, is now widely used by ecologists. For example, the methodology has been used extensively by the BTO to "understand the demographic mechanisms that drive population changes and hence to better identify the ecological causes of change and the management actions needed to alter population trajectories." **[5.5]**. This testimonial also highlights the important contribution of other areas of statistical ecology research at Kent, including "analyses of survival involving individual covariates" **[3.1, 3.2]** and "occupancy modelling" **[3.5]** and concludes that our work "makes a particularly important contribution to ecological science within the UK and to the policy-relevant work that flows from this". Another testimonial indicating the impact of IPM on ecological practice, from the Head of the Ecology Department at the Swiss Ornithological Institute **[5.6]**, states that the paper **[3.4]** "changed the view of population ecologists about the quantitative treatment of their data" and leads to "more efficient conservation actions, because management decisions can be reached earlier or with more certainty".

b) Design and analysis of occupancy studies [3.5-3.6]

In 2009, **Guillera-Arroita** visited Sumatra and provided training on occupancy modelling to 30 people from the Indonesian Ministry of Forestry and 8 NGOs **[5.7]**. A training manual was developed and translated into Indonesian **[5.7]**. Many of the participants were co-authors of a landmark 42-author article reporting the first island-wide assessment of tigers in Sumatran rainforests, based on occupancy surveys conducted in priority tiger landscapes across Sumatra. **Guillera-Arroita** led the analysis, with advice from **Morgan** and **Ridout**. There is great public interest in this flagship conservation species and this open-access article, which is readily accessible to the public via the Wikipedia page on Sumatran Tiger, plays an important role in informing the public, as well as those more actively involved in its conservation, of the current status of the species. From November 2011 to July 2013, this article has been viewed 3583 times.

The survey informed the **Indonesian Ministry of Forestry's National Tiger Recovery Programme** which is using "science-based adaptive management" by providing the baseline against which future progress in conservation will be gauged. The survey is highlighted in the Global Tiger Recovery Program Implementation Report (Box 6, p.18) **[5.8]**. Priorities identified in the report (p.19) include development of a $10million Global Environment Facility grant for transforming the effectiveness of biodiversity conservation in priority Sumatran tiger landscapes, and "the occupancy approach of **Guillera-Arroita** will be the main monitoring technique" **[5.7]**.

New methodology for camera trap data **[3.6]** was also motivated by Sumatran tiger data, but has since been applied in many other conservation and wildlife management projects, including human-tiger conflict in Nepal; carnivores in South Africa and Madagascar; sympatric cat species in Thailand; feral cats and dingoes in Australia; and various cat species in Thailand, Borneo and Brazil. Rapid uptake of the methodology was facilitated by (i) publication of a follow-up paper in *J. Zoology*, targeted at ecologists, with an accompanying podcast discussing the work in non-technical terms and (ii) provision of an R package (overlap) developed with a scientist at Wildlife Conservation Society, Malaysia, and available through the Central R Archive Network (CRAN).

Occupancy surveys are widely used for amphibians and reptiles, for example by fieldworkers involved with National Amphibian and Reptile Recording Scheme (http://www.narrs.org.uk/) and it

is widely recognised that there is scope to improve survey technique. For example, the government is required by EU regulations to undertake surveillance to assess the status of the great crested newt (*Triturus cristatus*), and a recent report commissioned by Natural England (NECR080, 2011) noted that "attempts at assessing population status have been hampered by problems with survey data". To address this need, **Guillera-Arroita**, **Morgan**, **Ridout** and NERC fellow **McCrea** have collaborated with scientists from Kent's Durrell Institute of Conservation Ecology (DICE) to improve the design and analysis of amphibian and reptile surveys, for example to detect trends in occupancy over time. **Morgan** was part of a NERC Knowledge Transfer grant ("Development of standardised protocols for assessing reptile and amphibian populations") led by Griffiths (DICE), aimed at improving current practice.

As a final example of impact, our work on occupancy, and the accompanying software SODA from **[3.5]**, has been used by staff of the Albany Pine Bush Preserve Commission and the Wildlife Diversity Unit of New York State Department of Environmental Conservation to design occupancy surveys to support a state recovery plan and monitoring program for the Frosted Elfin butterfly (*Callophrys irus*), a species that is threatened under New York conservation law **[5.9]**.

Summary: The beneficiaries of the research are individuals, charities and environmental agencies that collect and analyse ecological data and the organisations that plan and implement management and conservation strategies that utilise these data. The cited examples illustrate how novel statistical methodology developed at Kent has changed the practice of wildlife managers and conservation ecologists in collecting and analysing their data. As we have described, considerable effort is expended to encourage uptake. The impact has worldwide **reach** because the methods are generic and used by ecologists working on many different species, even when the initial methodological development was motivated by a particular application. Impact is also **significant**, because the species involved are often critically endangered and efficient data collection and analysis is essential to provide reliable inputs to management and conservation programmes.

5. Sources to corroborate the impact

[5.1] Videos of PhD student research, including some of the research from **[3.5]**, help practicing ecologists to rapidly familiarise themselves with novel methodology and see how it should be applied: http://www.methodsinecologyandevolution.org/view/0/VideoPodcastArchive.html.

[5.2] An example of textbook discussion of the Soay sheep models **[3.1, 3.2]** is Chapter 1 of J. Clark's *Models for Ecological Data*, Princeton University Press (2007). ISBN: 9780691122625.

[5.3] The estimate of the survival of shags from **[3.3]** for *Birds of the Western Palearctic* is in Wanless, S. & Harris, M.P.1997. *Phalacrocorax aristotelis* Shag. *BWP Update* 1: 3-13.

[5.4] Probable causes of the decline in lapwings are discussed at http://www.bto.org/birdtrends2010/wcrlapwi.shtml

[5.5] Letter from the Director of Science at the British Trust for Ornithology confirming that BTO is routinely using IPM and highlighting the impact of Kent's work on "ecological science within the UK and the policy-relevant work that flows from this." (See Contact 1.)

[5.6] Email from the Head of the Ecology Department at the Swiss Ornithological Institute explaining how research at Kent on IPM has changed the practice of population ecologists. (See Contact 3.)

[5.7] Email from the Technical Manager, Fauna & Flora International, Program Aceh, Indonesia, highlighting the importance of **[3.5]** to conservation work on the Sumatran tiger and confirming the impact of the training course run in Indonesia. (See Contact 2.)

[5.8] The Global Tiger Recovery Program Implementation Report, highlighting the impact of occupancy modelling is at: http://www.globaltigerinitiative2013.org/site/wp-content/uploads/2012/07/GTRP_Implementation_Report_2012.pdf

[5.9] Use of SODA software from **[3.5]** to plan occupancy surveys for the Frosted Elfin butterfly is reported in Bried *et al* (2012) *Northeastern Naturalist*, **19**, 673–684.

If any of the links above is no longer working, pdf copies are available on request.