Theme F – BioSS Methodological Research
Lay Summaries of Projects

BioSS-1-BET – Biodiversity and ecosystem tools
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This project is directed at the core policy driver “Global climate and nature crises” that focuses on “achieving net zero greenhouse gas emissions and responding to biodiversity loss”. The proposed research extends and develops broad use statistical and mathematical tools for modelling natural populations and community dynamics and biodiversity and environmental systems. The results will be useful for predicting the impacts of climate change and potential management actions on plant and animal populations and communities, and environmental-ecological systems.

This proposal includes six different strands of research (grouped into two modules) spanning natural populations and communities, and environmental-ecological systems. Module 1 focuses on populations and communities: WS1.1) modelling the dynamics of crop:pest:natural enemy systems (e.g., to blueberries); WS1.2) models for spatio-temporal population and community dynamics to assess the effects of environmental changes (e.g., to Scots pine); WS1.3) process-based life cycle models for pests and vectors for disease (e.g., to PCN and tick borne diseases); and WS1.4) a hierarchical spatio-temporal model for aphid phenology and seasonal population dynamics (applied to aphids that are vectors for potato viruses). Module 2 focuses on biodiversity and environmental-ecological systems: WS2.1) complex nonlinear, non-stationary time series with hidden (latent) processes (e.g., to air quality and water chemistry time series); WS2.2) the performance characteristics of joint species distribution models (JSDMs) focusing on the impact and mitigation of contrasting sampling biases when combining data from multiple sources, and on the scalability of JSDMs to large (many species/environmental measures) data sets.

Our overriding objective is to provide statistical and mathematical tools, especially models, that will be used by scientists delivering research involving the dynamics of natural plant and animal populations, the assessment, modelling, and forecasting of biodiversity, and the dynamics of environmental-ecological systems.

BioSS-2-SAT – Sustainable agriculture tools
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Data-driven or digital farming has huge transformative potential to enable a sustainable agriculture. It aims to integrate machine enhanced information streams across a range of spatio-temporal scales, with advances in computational tools and scientific understanding, to optimise real-time management of agro-eco systems. However, much work needs to be done to realise its potential. Here we develop bioinformatics, modelling and statistical methods, tools and approaches to support the transformation of such data streams into information that can drive forward sustainable agriculture.

In livestock farming, including aquaculture, sensor technologies have enormous potential to improve productivity and welfare, via real-time automated monitoring of animal health and behaviour. A similar approach can be pursued for crops, with the intensive monitoring of different quantities potentially leading to significant reductions in disease burden, enhanced growth and yield optimisation. To these ends, the use of molecular sensors (such as those based on modern sequencing techniques) will provide invaluable information. Integrating this monitoring into existing farm management systems will enable problems to be detected and resolved more rapidly than at present, reducing costs and the ecological impacts of production and morbidity, and improving animal welfare.

The increasing use of digital technologies in farming also presents important opportunities for the quantitative research community to develop analytical methodologies that can process and analyse information in real time. This links to broader developments towards methods for "Big Data", and integrated statistical modelling that allows multiple data sources to be used to draw inferences about unobserved processes of interest (such as the current state of health of an animal or plant). BioSS is extremely well placed to make significant contributions to these challenges by applying its quantitative expertise in bioinformatics, modelling and statistics in collaboration with scientists across a broad range of disciplines relevant to agriculture.

We address these challenges by developing novel methods for statistical genetics and bioinformatics to extract greater information from genomic and other molecular data than is currently possible. We also develop modelling and statistical tools that enable use of diverse sources of real-world data that are incomplete, noisy and vary in their characteristics, say, between farms. A common theme is the combination of modern ideas from statistics and mathematics, combined with advances in software and computing to extract the maximum salient information from data streams that are and will be increasingly available to farmers and the agricultural sector.

BioSS-3-LSM – Large-scale and systems modelling
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The most pressing societal challenges of the first half of the 21st century, including climate change, the biodiversity crisis and building a restorative economy, are systems challenges. To solve them requires understanding and quantification of how key systems respond to both global change and local responses that are being, or could be, adopted. To chart a course to a sustainable nature positive Scotland thus requires integration of knowledge about natural systems that support national wealth, health and wellbeing and the dynamics of social systems through which we realise such benefits.

Mathematical modelling of system dynamics provides a powerful set of tools to enhance understanding of complex systems and support decision makers by providing projections and enabling exploration of policy options through scenario analysis. However, the complexity of socio-environmental systems that policy makers must grapple with, and the current state of knowledge about these systems, means that rigorous steps must be taken to ensure that resulting policy recommendations are robust. This requires that systems modelling must be underpinned by efficient computation at scale, suitable estimation of model parameters, the analysis of multiple models to test understanding and the proper quantification of uncertainty. These tools enable modelling to yield qualitative understanding of systems often leading to actionable insights for management. They allow models to provide a framework for synthesising multiple sources of information including understanding how best to collect, analyse and interpret observations and also for determining what further data would most usefully be collected. They allow estimation of current and historic trends in quantities that are difficult, costly or impossible to measure directly. However, there are significant gaps in the current tool set e.g., for inference, uncertainty quantification and analysis of such models, with computational load and data issues being further problems that currently limit use of large-scale and systems modelling to inform policy challenges.

Here we address these issues by developing methods and tools that will be applied, tested and honed through application to large-scale and systems modelling challenges which are the subject of active research in the RESAS Portfolio 2022-27. The research plan is organised into two modules: development of generic tools for large scale modelling; and tools for sectoral modelling and the dynamics of social systems. Critical to using such models to inform policy we will develop approaches for statistical estimation of model parameters as well as tools for comparing and assessing different models using the available data which will, additionally, help to identify knowledge gaps limiting decision making. We will take two complementary approaches to these problems, extending techniques both from Bayesian computational statistics for stochastic process models and methods for uncertainty quantification. We will also develop computational tools for efficient large-scale simulation of biodiversity responses to environmental pressures including landscape management. By integrating soils data for use in large-scale modelling for the Soil Monitoring Framework, we will address the need for statistical techniques to integrate data across scales and to combine systematic surveys and less structured observations. Our work will also address modelling applications focused on specific socio-economic systems with priority in the RESAS Portfolio 2022-27, including the circular economy, farm-to-fork food safety, and responses to biosecurity policy in the cattle trade sector.