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Annual Report 1999

MACAULAY LAND USE RESEARCH INSTITUTE

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INSTITUTE

Macaulay Land Use Research Institute

Craigiebuckler
Aberdeen
UK

Annual Report

1999

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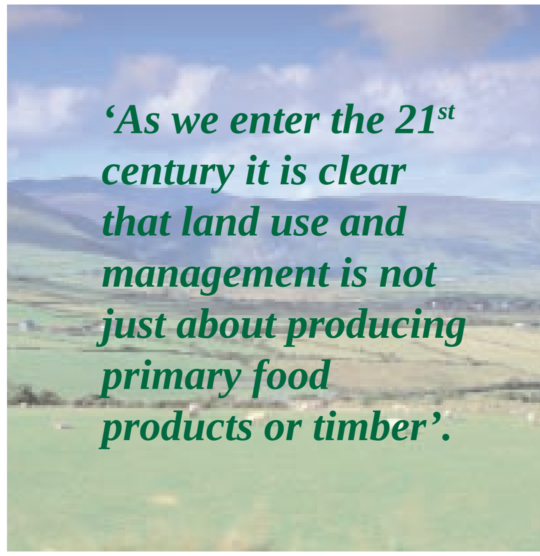
Director's Introduction

The last twelve months have been particularly significant in the life of the Institute for a number of reasons. Not least, has been our response to the Scottish Executive Rural Affairs Department's (SERAD) Strategy for Agricultural, Biological and Related Research (1999-2003). The new Ministers adopted the Strategy when the Scottish Parliament came into being in May 1999. The Rural Affairs Minister, Mr Ross Finnie, launched it in July 1999 in Aberdeen when he also visited the Institute. Since then we have had visits from Mr John Home Robertson, Deputy Rural Affairs Minister with responsibilities for research and several local MSPs as well as those serving on the Rural Affairs Committee. All have taken a keen interest in our research and its relevance to land use policies and legislation, the implementation of CAP reform, Agenda 2000 and the Rural Development Directive.



The Programme of Research

The SERAD Research Strategy provides the Scottish and UK context for the development of our programme of research for the next four years. We have, therefore, oriented our programme to take account of the wider end-uses which the SERAD Strategy targets and the science domains and opportunities (particularly systems research and socio-economics) that it promotes. A description of our programme is given on pages 10-11 and also in our Corporate Plan (2000-2003). More detailed reports on our programmes are given on pages 12-27 of this Annual Report that also highlight some of our recent achievements.

The New Management Structure

In parallel with developing our new programme of research we have also simplified and flattened our management structure. Each of the programmes of research is now a central, functional management unit supported by the service groups. The aim is to enhance the integration of our programme of research and services. This integration provides a greater degree of cohesion in delivering research relevant to our remit as well as providing additional market strength in commercialising our research and consultancy services. Over recent years these have expanded internationally into central and eastern Europe, Africa, China, Pakistan, and Argentina.

The Drivers of Land Use Change

The primary drivers of change in relation to the direction of our research, however, relate to the changes taking place within the rural land using industries and the wider social and environmental perspectives that are now influencing future land use. The primary rural industries, agriculture and forestry, are currently having particularly difficult times. The strength of the pound and lack of demand for primary production from UK agriculture have had a critical financial impact on many farm businesses and the real value of output from both the crop and livestock industries has continued to decline. The fall in log prices of almost 50% since 1996 has also created uncertainties in the forestry industry. The future of both the agriculture and forestry industries is now highly dependent upon the receipt of public funds. Taxpayers have an increasing interest, therefore, in influencing how these public funds are used and the benefits that can be delivered from them. These benefits have much to do with ensuring that we have attractive landscapes, a wide diversity of plants and wild animals, clean water, access for recreation and sport, and an ability to roam and ramble responsibly in the countryside. The Agenda 2000 proposals, through modulation, and the Rural Development Directive will re-deploy some funds currently used for commodity support in agriculture, to deliver such benefits. There is also a call to consider a greater diversity of activity in relation to land use. This includes the possibility of energy cropping and the development of wind farms.

The new Parliament in Scotland is also addressing the wider interests that the public has in the use of the countryside by preparing legislation which aims to facilitate the delivery of countryside benefits, e.g. the Land Reform Bill, that also deals with rights of access, and the National Parks Bill that enhances the importance of conserving and protecting nationally important areas of natural heritage (e.g. Loch Lomond, the Trossachs and the Cairngorms). Scottish Natural Heritage and the Scottish Environment Protection Agency, which are both sponsored by the Scottish Executive, have programmes and statutory responsibilities that also focus on enhancing the quality of our environment.

The Rationale and Goals for our Research

As we enter the 21st century it is clear that land use and management is not just about producing primary food products or timber. It is about producing many other outputs or non-market benefits as well; benefits for which the public is prepared to pay. Whether the public will be prepared to deploy the whole of the £3 billion that annually supports UK agriculture and the rural economy for such purposes is questionable and the consequences of not doing so cannot be readily foreseen. But change in the structure, ownership, and intensity of use of land holdings, as well as the nature and value of the countryside they represent seems inevitable. In addition, the impact of climate change and the possibility of extending the range of crops in agriculture and increasing the yield of forests is also a matter of some uncertainty.

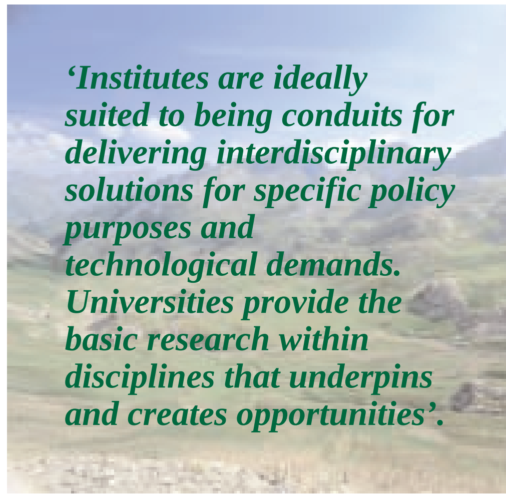
For all these reasons it is vitally important that we continue to research the underlying processes of change at all levels of organisation (the soil; the soil:root interface; the plant, plant community and crop; the behaviour of animals in relation to habitat and vegetation change; the impact of land use on water quality in rivers, estuaries and lochs; and the decision-making behaviour of people in relation to their economic, social and environmental goals) so that we can monitor, model and forecast land use change as well as design decision support systems to manage change. These are the fundamental goals of the Macaulay's programme of research.

The Institute Research Environment

They are also just the kind of mission-oriented, interdisciplinary objectives that are best tackled within an institute research environment. Resources can be specifically deployed and programmes directed and managed to provide the relevant information and knowledge to address the issues that require to be resolved to provide solutions and reduce uncertainty about ultimate outcomes. While programmes of research in institutes do not have the academic freedom of universities and are more strategic and applied than basic, they have to be no less excellent. Nor can they succeed fully without there being collaboration with universities and other institutes. But they do have the advantage of providing for a long-term experimental commitment and a stability that is difficult to achieve in universities that operate within a research funding environment dominated by short-term research grants and contracts.

The unique features of institutes are their distinctive remits and their ability to focus their research on specific topics over a long time-scale, tackle issues in a holistic manner and network effectively. Within the framework of the remit, Directors of Institutes and their scientists have a primary responsibility to develop their research initiatives and operate at the leading edge of their disciplines. Institutes, as centres of excellence, represent research management environments within which innovative interdisciplinary research and technological innovation can flourish. But relevance is a dominant driver in determining what they do. This does not imply that their strategic research should not be speculative. Indeed, if some of it were not to be so it is unlikely that imaginative and visionary solutions would be forthcoming.

The Boards of Governors of institutes and the arrangements with their primary sponsors are also important. Institute Boards include academics and people who are knowledgeable and informed end-users as well as being entrepreneurial business managers. The Board members are in a position to monitor and influence the quality and relevance of institute research programmes and ensure the appropriate allocation of resources on a continuing basis. The sponsors on the other hand, have a direct contractual relationship with institutes and a requirement that the research undertaken meets their needs as well as the needs of others they represent (e.g. in the case of MLURI and SERAD, SNH and SEPA). The sponsor's use of the visiting group peer reviewing procedures every four years ensures the quality and relevance of its commissioned programme.



Institutes are also uniquely placed and constituted (particularly those that are companies limited by guarantee and having charitable status) to develop close working relationships with their end user communities and commercialise their technology transfer through private companies. Successful technology transfer is influenced by the appropriateness of an institute's Board membership, the entrepreneurial skills of the senior management and their scientific colleagues, the specific links developed with industry and/or policy makers, and the balance that is struck between highly innovative strategic research and applied research and development. We are fortunate at the Macaulay in being able to meet these requirements.

Institute / University Relations

The rationale for the institute/university structure in delivering a relevant and focused science strategy for Scotland is strong. Institutes are ideally suited to being conduits for delivering interdisciplinary solutions for specific policy purposes and technological demands. On the other hand, universities provide the basic research within disciplines that underpins and creates opportunities on which innovative strategic research and technology transfer can be developed. To secure economic growth in Scotland and an improved quality of life for its people, it will be important that the distinctive contributions institutes and universities can make, are integrated in such a way as to make the relationship between basic, strategic, applied and developmental research as seamless as possible. Both SHEFC and SERAD research funding strategies currently stress the importance of developing collaborative links with research users. This requires institutes and university departments with common interests to work much more closely together to create high quality multidisciplinary teams of researchers and integrate their research planning accordingly. It also requires them to link more closely with industry and those responsible for policy and, in the case of the Macaulay, to link with those responsible for the management of the environment.

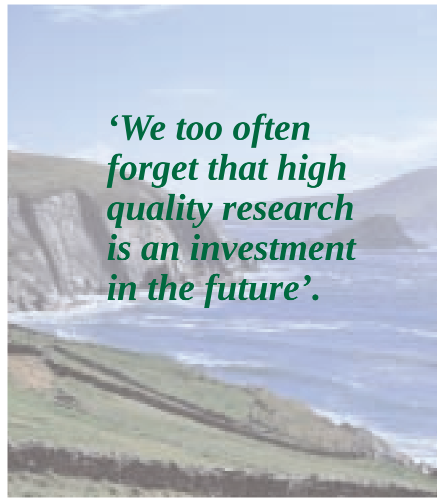
This is why the recent creation of Research Units by the Aberdeen Research Consortium (a consortium of the universities and institutes in Aberdeen) is such an important development. Aberdeen has the opportunity to develop highly competitive research groups in which the Macaulay will play its full part. With the possibility of joint SERAD/SHEFC funding and an ability to attract UK Research Council funding, the potential of the biological and social sciences in Aberdeen is strong.

The Macaulay's joint initiatives with Aberdeen University in Soil Health with the Departments of Plant and Soil Science, and Molecular and Cell Biology and in the Social Sciences with the Arkleton Centre are now both underway, funded respectively by Aberdeen University and the Macaulay Development Trust. It is the Trust's intention to fund these initiatives for a period of three years in anticipation that by then they will become self-sustaining. Other, similar developments are also likely to depend on Trust funding. That is why the Trust is currently realising some of its fixed assets in land. Increasing the investment portfolio of the Trust is crucial to the future development of new research initiatives as well as building facilities that will enhance the ability of the Institute to develop commercially.

Collaboration and Added Value

There are also good reasons to continue to build on existing collaboration across the institutes and research organisations sponsored by SERAD. New initiatives, new scientific opportunities and policy requirements need to take account of the expertise and skill base in which SERAD and the institutes themselves have invested. Research proposals developed through the Committee of Heads of Agricultural and Biological Organisations in Scotland (CHABOS) by the CHABOS Science Committee on topics like biodiversity, provide for possibilities of networking across the institutes and universities in Scotland and the UK, as well as complementing and linking with research themes sponsored by the UK Research Councils (particularly BBSRC, NERC and ESRC). These developments need to continue and be encouraged.

While it is often argued that competition for funding militates against collaboration, the true test is whether potential collaborators and those who fund them are failing to recognise the potential added value that can arise from collaboration. Added value there has to be, and collaboration should only take place when there is a high probability of realising it. The Macaulay has collaborated extensively within Scotland, the UK and Europe in recent years and some of our achievements would not otherwise have been possible. We have been able to access expertise that we do not have and we have gained immeasurably from the exchange and mutual development of ideas. We acknowledge the contribution that our many collaborators have made to the success of our research.



Research as an Investment in the Future

There is no doubt that the major constraint on realising the full potential of Scotland's research base, including the Macaulay, will be funding. The talent exists and as part of the UK funding base our researchers in Scotland remain at the top of the world league in terms of the number of papers published for the amount of money spent on science (Research Fortnight Vol 6, No12). But there has been no significant real terms growth in research and development spending since 1994. Current levels of performance are unlikely to be sustainable unless an increased proportion of our gross domestic product is spent on research and development.

We too often forget that high quality research is an investment in the future. Our ability to remain economically competitive and deliver an enhanced quality of life for the people of Scotland will be determined only in part by the short term issues that dominate the life of a four yearly cycle of Scottish Parliamentary business. Agendas dominated by health services provision and education reflect the matters uppermost in the public's mind. They are the issues upon which politicians will be judged. They are indicative of a culture in society that is obsessed by short-term 'wants' as opposed to long-term aspirations. No one can deny that these 'wants' are important but a balance has to be struck. Research is predominantly about the future and societies, on the whole, focus on the present. So there is a dilemma as to how to influence society to think differently. The adoption of the concept of sustainability and the idea of intergenerational equity provide a clue. If we have a concern about the welfare and quality of life of our children and our children's children we cannot ignore the fact that they will require information and knowledge that we don't have. It is our responsibility to make the necessary investment now to make such information and knowledge available to them in the future. Nor can we ignore the fact that we are abysmally ignorant about many aspects of life that affect us now and will continue to affect us during our lifetime. Issues like BSE and GMOs.

But of course the case for science and research as investments for the future can be undermined if issues like BSE and GMOs fail to be handled objectively. In general the public's view of science is not well served by the way in which the media sensationalise issues and attempt to 'sound bite' them to the point of absurdity. But neither have scientists excelled at explaining complex issues in ways that are meaningful to the public and in ways whereby the individual can come to an informed view. Scientists are also perceived to be too much influenced by vested interests. Their integrity and their objectivity are frequently called into question. There has been a failure to separate the imperatives of populist politics and commercialisation from the objectivity that science and the measurement of uncertainty can provide. If future investment in science and research is to have public support then things will have to be done differently. Creating a more positive relationship between scientists and the societies that they serve will depend on the vigilance of scientists in considering the ethical basis of what they do, and how they behave. It will also depend upon their integrity in being open about their activities and making freely available the information that they produce.

Nevertheless, none of this should detract from the incalculable benefits that have arisen from science and technology in recent decades. The advances, for example, in biotechnology, information technology, agriculture, forestry, health care and environmental management would simply have not been possible without the significant investments made in research since the Second World War. Yet, we are now in a period of unprecedented global technological and societal change. The demand for information grows day by day. It is no less so in the practical business of managing land. Investment in land use research will continue to be needed irrespective of the current economic state of the land using industries. The land will continue to be used and it will continue to be managed. Objectives will change, the environment will change and there will be different people living in and using the countryside with different ideas as to what they expect to gain from the experience. And who can predict with certainty the demands that may be made on our land resources in the future for primary food and timber production? Continuing to fund high quality research enables us to face the certainty of change with a greater certainty of being able to manage change. A focus on contemporary issues to the exclusion of discovering possibilities for the future denies the progressive nature of humankind. We need to redress the balance; we need to increase our investment in research now.

Reflections

As I prepare to retire from the Institute it is interesting to look back and to reflect briefly on the progress that has been made since the Institute was founded in April 1987. I believe that over the last 13 years the Macaulay has built upon the reputation of its predecessor institutes and established itself as a national and international centre for land use research, worthy of its benefactor, T B Macaulay, and the vision of those who had the foresight to recognise a future need. This has not been a trivial task. That it has been possible at all has been due in large measure to the commitment, enthusiasm and professionalism of my colleagues with whom it has been both a privilege and pleasure to work. I have enjoyed their support and I wish them well for the future.

I have been fortunate in not only having colleagues who have accepted the need for, and worked hard to bring about change but also in having a Board of Governors that has guided our affairs so assuredly and given me the personal support that all Directors need. I have also benefited, as has the Institute, from the continued support of SERAD (previously SOAEFD and DAFS). The Macaulay Development Trust has also donated generously to the work of the Institute and to the development of its facilities. It was a particular pleasure to be associated with the development of the Cunningham Building not only as accommodation for visiting workers and students, the Macaulay Research Consultancy Services Ltd and the crèche, but also as a fitting tribute and acknowledgement of the contribution that the first Chairman, Professor Iain Cunningham, made to the establishment of the Institute in its early years. He was followed by Professor Janet Sprent who has continued the tradition of dealing with business expeditiously and with a directness and sense of purpose that is both refreshing and challenging. To both these people I, and the Institute, are greatly indebted.

Peter Newbould, my Assistant Director until 1991, had a major role in the early life of the Institute in managing the planning and building of our new headquarters building at Craigiebuckler. This was opened in 1992. This was a significant event in the development and establishment of the Institute in Aberdeen and is a facility of which we are justly proud. To Peter I owe my gratitude for his perseverance and determination in completing this major project.

I wish also to record my thanks to John Milne, my Deputy since 1992, for his support, wise counsel and guidance; to all those in the senior management team and Director's Unit with whom I have worked closely; to my Secretary, Catherine Smollet, who has worked tirelessly and with the greatest good humour; and to Chris and my family without whose patience, tolerance, and support in all things, little would have been accomplished.

Finally, it gives me great satisfaction that before I retire I will have the opportunity to work with my successor, Professor Margaret Gill. She will take up her appointment in July and from then until my retirement at the beginning of October we will work together to ensure as smooth a change over as possible. I wish her well and all success in leading the Institute and in setting an agenda whereby it continues to prosper and flourish.

Jeff Maxwell, April 2000

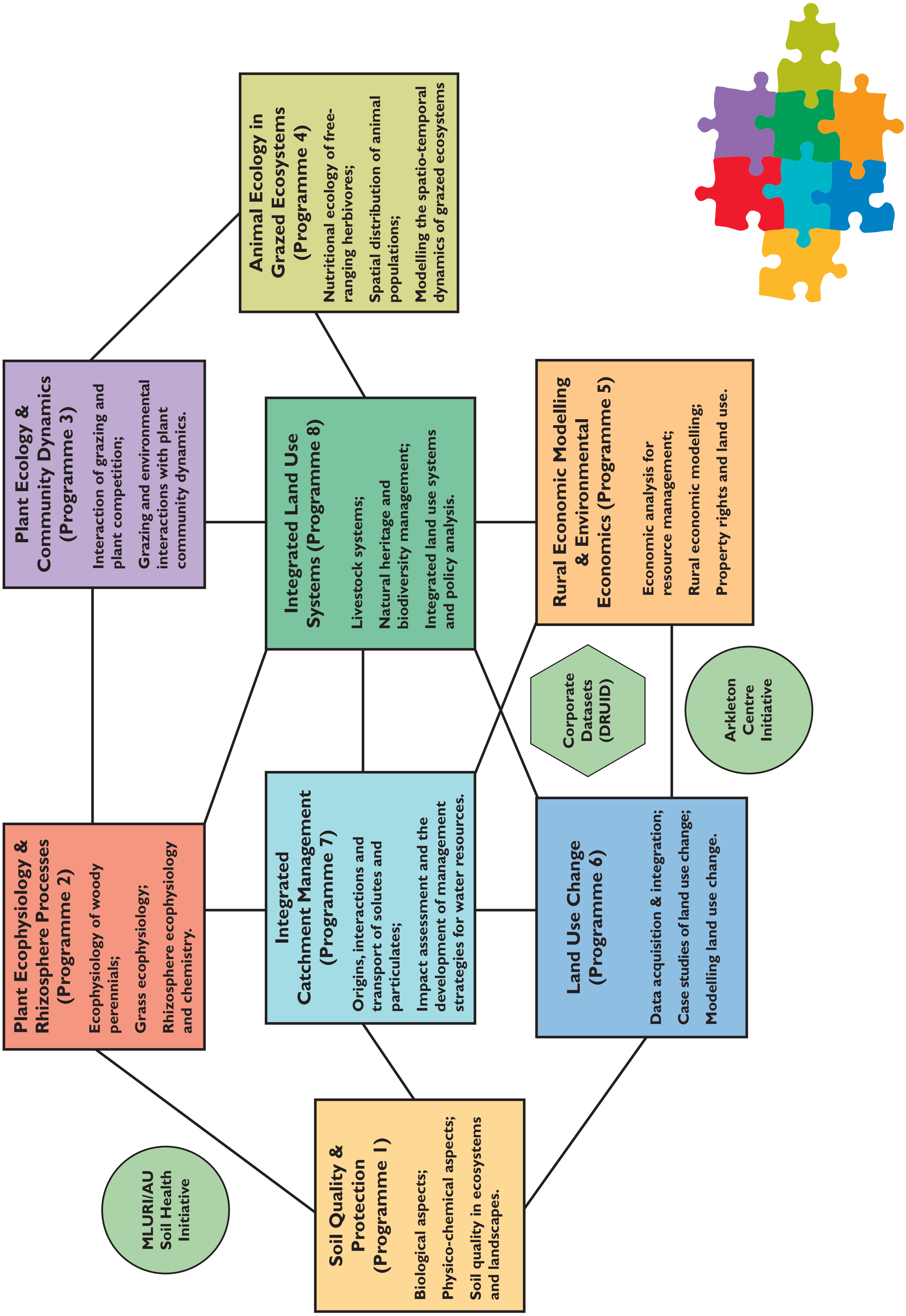


Figure 1. Programme of Research

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The Research Programme and Forward Strategy

T J Maxwell

Our forward strategy for our research will be developed within the context of the UK and international land use research base. In relation to a devolved Scotland it will focus on issues that are uniquely specific to Scotland's land use and environment.

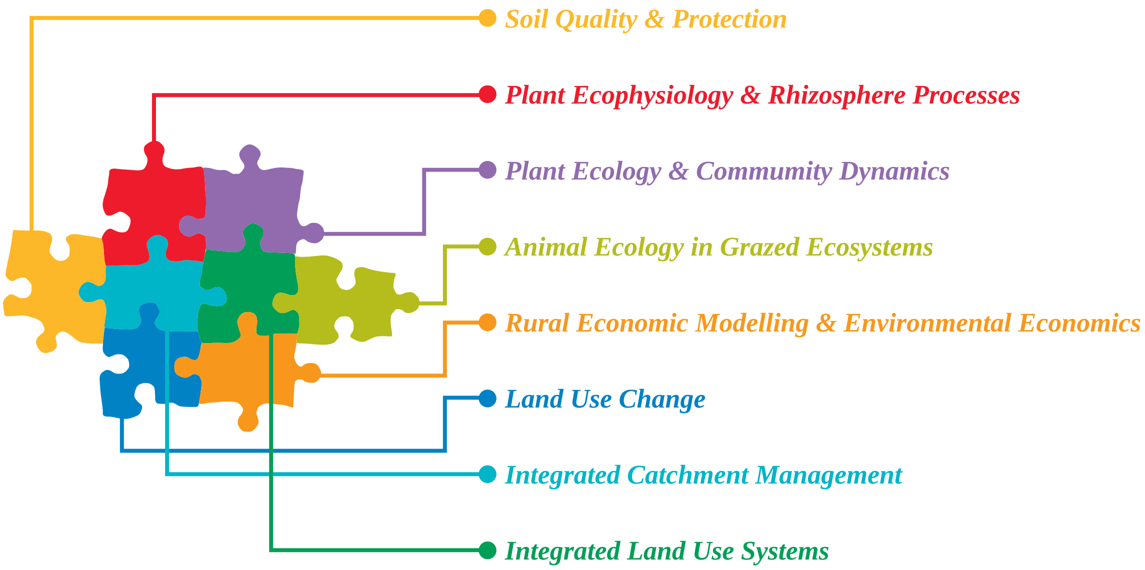
Specifically the Institute aims to:

- Achieve excellence and relevance in the areas of strategic research for which it has an acknowledged international and national reputation;
- Develop its programme in relation to the science and end use domains covered by the SERAD Strategy, and the areas of priority and opportunity it indicates as appropriate;
- Ensure that relevant parts of our programme focus specifically to provide information and understanding to the Scottish Executive for the formulation and implementation of evidence-based policies;
- Collaborate and co-ordinate our research with our sister research institutes, universities and colleges, industry, government departments and their agencies.

The conceptual basis upon which we will continue to develop our programme is that of sustainable development. This requires information that allows a balance to be struck among production and social equity issues whilst maintaining environmental capital and managing the trade off between them to meet specific goals. Our remit and mission implicitly requires us to address this balance in the context of rural land use and to assess the outcome of research in relation to its environmental, economic and social impacts. While it requires us to address issues related to agriculture, it also requires us to address issues related to other land uses; it emphasises the consequences of change, particularly in relation to policy, management and pollution.

From April 2000 our programme will be structured to align it closely to the SERAD Strategy for Agricultural, Biological and Related Research (2000-2003) and to evolve further the integration of our research programmes. In particular, we will more closely link our biophysical research with that on rural socio-economics. We will continue to place an increasing emphasis on developing a multidisciplinary and integrated approach to our research.

The programmes of research are as follows:



The two programmes at the centre of Figure 1 (page 8), Integrated Land Use Systems and Integrated Catchment Management are strategic/applied programmes that integrate and develop the outputs from the other more strategic programmes. They aim to inform decision making in relation to rural land use management and policy. They provide practical information that is relevant to farmers, foresters, estate and natural heritage managers, water resource managers, government and agency policy makers and advisers and to a wide range of other government and non-government bodies. Similarly, the two programmes Rural Economic Modelling and Environmental Economics, and Land Use Change, have direct relevance to land use change, environmental and rural policy development and analyses, to monitoring and forecasting the direction of land use change, evaluating environmental benefits and costs, characterising rural/urban relationships, and measuring regional economic performance.

The strategic programmes of research provide underpinning science that is crucial in maintaining the integrity and the quality of the strategic/applied and applied research and consultancy that we do. Thus, the Soil Quality and Protection programme focuses on the biological and chemical processes in the soil, and how they characterise the resilience of the soil with respect to its different functions (viz. agriculture, forestry, supporting the conservation of the natural and semi-natural habitats, an ameliorator of wastes and pollutants) and the practical implications of developing a soil protection strategy for Scotland. This programme integrates its research directly with the Land Use Change programme with respect to the influence of soil in determining suitability for cropping, landscape ecology and risk assessment. It also integrates its work with the Integrated Catchment Management and Plant Ecophysiology and Rhizosphere Processes programmes, providing information about the movement of nutrients and pollutants in the soil environment, their availability to plants and their leakage to water courses.

The Plant Ecophysiology and Rhizosphere Processes programme describes how nutrient supply affects the uptake, storage and internal cycling of nutrients by plants and very specifically the interacting processes that take place between plants, soil microbes and soil chemistry in the rhizosphere (the soil environment very close to the root surface). This information is crucial to an understanding of how trees and natural and semi-natural vegetation will perform and can be managed, particularly against the background of nil or very low fertiliser inputs. It is also important in understanding the physiological responses of plants to grazing and excretal returns, and the basis of plant competition with respect to the programme dealing with Plant Ecology and Community Dynamics.

The aim of the Plant Ecology and Community Dynamics programme is to predict the changes in vegetation (species, structure and spatial distribution), that occur as a result of changes in grazing management (e.g. intensity of stocking) and/or the impact of climate and pollutants (e.g. atmospheric deposition of nitrogen). Consequently, the context for much of the research in this programme is set by the research that is undertaken in the Animal Ecology in Grazed Ecosystems programme and links to the Integrated Catchment Management programme that also deals with atmospheric pollution.

The Animal Ecology in Grazed Ecosystems programme aims to understand the behaviour of large herbivores such as domestic livestock and wild deer and how they affect ecosystem function and dynamics. Their grazing, trampling and defecation impact on nutrient flows, plant community dynamics and biodiversity. In turn plant community composition, productivity and distribution determine animal nutrition and population performance. The strategic output from this programme underpins the strategic/applied research on natural heritage management and livestock systems in the Integrated Land Use Systems programme.

Each of our programmes of research are integral parts of the whole. Together they represent a significant, unique and important contribution to our understanding of land use in Scotland and the potential ways forward for the future. But they are also providing a platform on which we are building an international portfolio of research and consultancy that we aim to develop further.

Environmental research, integrated with research which aims to improve the efficiency and development opportunities for agriculture and forestry, without compromising environmental quality, will remain central to our programme. This will have both national and international relevance for the next fifteen years at least. In relation to soil quality and the protection of the environment we will build on our initiative with Aberdeen University in molecular microbial ecology. This will provide a greater understanding as to the resilience and functionality of soil, not only as a medium for plant production, but also as a receptor of organic and inorganic wastes, because of its potential to transfer pathogens and toxic chemicals into the food chain.

As resources allow, we will also set our research in a broader rural development context than just agriculture and forestry, and the protection of soil and water resources. We will take greater account of the social dimension within which rural land use will develop over the next 15-20 years. To do this we will up-date the land use database for Scotland and develop methods for detecting and measuring land cover change; we need to continue to up-date and add value to our natural resource data bases and integrate them effectively with others, particularly socio-economic databases. We will integrate further our research on the economic, geographic and human dimension of rural change and develop an integrative framework for the development of multidisciplinary research on socio-ecosystem interactions. This will be undertaken within our collaborative initiative with the Aberdeen University's Arkleton Centre. We believe these initiatives will be important in developing capacity, maintaining relevance and giving depth to our programme.

Soil Quality and Protection

The SERAD Science Strategy has highlighted the importance of research in support of a soil protection strategy for Scotland, echoing similar developments in England and Wales. However, within Scotland significant differences in the soil resource and different patterns of land use and management will require a distinctly Scottish approach. Our aim is to provide the strategic scientific information required to underpin such a strategy. Soil has a wide range of functions in the Scottish environment and the development of a rational basis for soil protection requires a unifying framework, such as that embodied in the term 'soil quality'.

Our research programme is structured around three complementary project areas - the first two deal with basic/ strategic research on the biological and physico-chemical processes that contribute to soil quality and the third with more strategic/applied areas where our process knowledge base may be combined with spatial datasets describing the Scottish environment.

Biological aspects: The aims are to:

- Develop plant and microbial indicators of soil quality for highly organic extensively managed upland soils and more intensively managed lowland soils subject to stresses such as pollution and waste utilisation.
- Contribute to our understanding of the biological factors inherent to the concept of bioavailability for various target organisms, including the transfer of endocrine-disrupting chemicals through the soil-plant-animal system.

Physico-chemical aspects: The aims are to:

- Develop an integrated modelling and experimental approach to understand and represent chemical processes in soil microenvironments.
- Investigate and model the impact of plant exudates on chemical fluxes in soils thus contributing a physico-chemical perspective to the concept of bioavailability.

Soil Quality in Ecosystems and Landscapes: The aims are to:

- Elucidate the role of soil within a range of land uses and ecosystems in Scotland.
- Integrate our knowledge of key processes in soil functionality within a soil quality framework appropriate for the Scottish environment.

Achievements

Biological aspects

One of the few explicit pieces of legislation in the UK affording protection to our soil resource originates from the EC Directive on the Use of Sewage Sludge on Agricultural land. This protection is aimed at controlling the build-up of potentially toxic elements (PTEs) in soil and adversely affecting soil quality in relation to crop production and as a medium supporting microbial activity and diversity. Thus, there are limits on the PTE content of the sludges to be applied to land and of receiving soils. In order to underpin this regulatory framework we are participating in a national trial in collaboration with colleagues at ADAS, Rothamsted, WRc, SAC and UKWIRL.

We are using a range of techniques, including chemical extraction and analysis, microbial biomass and respiration, as well as microbial community analysis to determine the safe limit for PTEs in soils receiving sewage sludge.

- The Biolog Community Level Physiological Profile (CLPP) method showed that just after sludge was applied there was a large and dramatic effect on the microbial population irrespective of what type of sludge was applied.
- One year later, however, the effect of the sludge alone has declined and there appear to be changes in the populations that are associated with the sludge metal content and these could eventually affect the functioning of the soil.
- Biolog CLPPs reflect the activity of the fast growing bacterial population. When the phospho-lipid fatty acid (PLFAs) contents were used to test the soil they also showed that metal induced population shifts had occurred (Figure 1) and, specifically, that some fungal PLFA markers had been reduced.

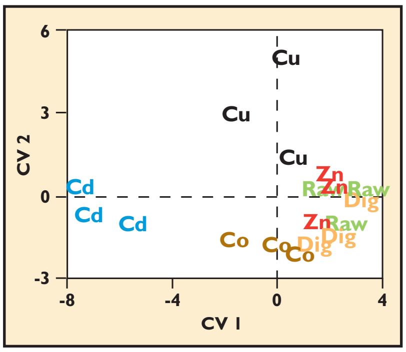


Figure 1. Canonical variates analysis of PLFAs from Hartwood Sewage Sludge site.

Physico-chemical aspects

In a collaborative project with the University of Edinburgh, Scottish Universities Reactor Research Centre, East of Scotland Water Authority and the environmental consultants Dames & Moore we have been working on Cr-contaminated sites in Glasgow (Figure 2). The project is funded by NERC under the URGENT programme and aims to evaluate and predict the efficacy of remediation practices and to produce a decision support tool whereby the likelihood of success for specific remediation techniques can be assessed.

- Chemical analyses carried out by our colleagues at Edinburgh University have shown high levels of Cr contamination on the sites with both trivalent and the carcinogenic hexavalent form present.
- Using techniques such as scanning electron microscopy, electron microprobe analysis and X-ray diffractometry, we have been able to identify the phases present on site.
- Using this chemical and mineralogical information and a knowledge of the chemical processes taking place on site within the ORCHESTRA framework a prototype decision support model has now been constructed.
- Metabolic biosensors and microbial community analysis are being used to assess Cr toxicity at the sites and the potential ecological risk associated with remediation approaches at such sites.

Figure 2. Sampling at one of the Cr-contaminated sites in Glasgow.

Soil quality in ecosystems and landscapes

Weathering is a key process in soils. It can influence the 'inherent quality' of a soil and also the response of soils to pollutants, such as acidic deposition. A recent study, in collaboration with colleagues in the Integrated Catchment Management programme, on podzolic soils developed on granitic parent material in the upland Halladale catchment has shown that the weathering rate in the soil is very slow, making them potentially very susceptible to acid deposition.

- Long-term weathering rates, as expressed by loss of base cations from two soil profiles, are 1.7 and 3.1meq m^{-2} yr^{-1}, the lowest recorded for soils in Scotland.
- Sodium is the cation lost to the greatest extent due to weathering of plagioclase feldspar, mainly in the coarser particle size-fractions.
- Although weathering of plagioclase feldspar is also responsible for providing some of the calcium lost from the profiles, there is also loss of calcium and magnesium from hornblende (present in basic inclusions in the granite) as seen by the presence of dissolution etch pits and denticulate surface features on sand grains examined by scanning electron microscopy.
- Thus, weathering of hornblende is a significant weathering process in these soils and clearly the basic inclusions in the granite, although spatially variable, are an important source of bases for neutralising incoming acidity.
- This variability may provide part of the explanation for the large discrepancy between soil profile weathering rates and catchment weathering rates observed both here and more widely across Scotland. Future work will address this issue.

Highlights

- Developed new infra-red spectroscopic fingerprinting method to quantify peat quality.
- Applied new, sensitive and rapid methods of microbial community analysis to assess impacts of changes in land use on the soil resource.
- Established methods for analysis of alkyl phenols and phthalates in soils, herbage and animal tissues to establish background values of endocrine disrupting chemicals and assess their transfer from sludge to domestic ruminants.
- Applied catabolic and metabolic biosensors and microbial community analysis for monitoring natural attenuation of hydrocarbon contamination.
- Showed how the bioavailability of metals in soils, measured as a proportion of the total concentration, increases significantly following amendment with sewage sludge.
- Completed the first phase of development of the ORCHESTRA modelling tool and prepared a strategy for its distribution to the wider scientific community (see page 40 1998 Annual Report).
- Demonstrated that the overall adsorption capacity of soil for cations has to take into account interactions between the soil phases present.
- Contributed to the development of process-based indicators of soil quality related to soil acidification processes and soil responses to PTE inputs.

Relevance to work of Scottish Executive

Our new programme on Soil Quality and Protection has been developed specifically in response to the Strategy for Agricultural, Biological and Related Research (1999-2003), published by the Scottish Executive Rural Affairs Department. In this we are addressing the 'soil and environmental sciences domain', which is considered to be of significant relevance to sustainable agriculture and of very high relevance to environment and natural heritage. Thus, we have specifically focused our programme to:

- Support the development of a soil protection policy.
- Address issues of scaling knowledge from soil microenvironments to the ecosystem scale.
- Contribute to enhanced understanding of soil processes at the soil-root interface through experiment and modelling.

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Plant Ecophysiology and Rhizosphere Processes

Marginal lands have soils which are often organic and of low fertility and pH, supporting ecosystems dominated by trees or grasslands. Plant growth in these systems is often regulated by the cycling of nutrients, particularly nitrogen and phosphorus, both in the soil by the action of microbes and within the plants themselves. Developing sustainable management strategies for these systems requires an understanding of the processes governing resource (carbon and nutrient) acquisition and use for the growth of herbaceous and woody perennials as mediated by interactions between plants, soil microbes and soil chemistry.

Our strategic research aims to understand the consequences of different management strategies for marginal lands in the context of the processes governing plant growth and competition. The main ecophysiological processes regulating nutrient acquisition and use by plants for growth in extensive systems on marginal lands are considered, along with the complex interactions between vegetation and soil microbes, as mediated by grazing animals.

The programme considers the ecophysiology of woody perennials, grasses, and the rhizosphere in relation to soil chemistry.

Ecophysiology of woody perennials

As trees grow and their capacity for storing nutrients increases, their reliance on soil nutrients declines. Understanding how management affects the storage and remobilisation of nutrients by trees is important for developing sustainable management strategies which in the case of semi-natural woodlands could include avoidance of browsing damage from animals, while in other systems pruning and fertilisation are options. We have:

- Developed techniques to use a range of stable isotopes (^{15}N, ^{41}K, ^{26}Mg) to quantify nutrient cycling in pine trees.
- Collaborated with Lincoln University, New Zealand to show that pruning has little effect upon nitrogen remobilisation elsewhere in the tree canopy.
- Shown that young Scots pine trees rely heavily upon remobilisation of N, K and Mg for their growth in the spring, irrespective of the nutrient supply from the soil (Figure 1).
- Demonstrated that interactions between growth strategies and nitrogen storage and remobilisation explain some of the major differences in the response of birch, rowan and pine saplings to browsing damage.

Grass ecophysiology

Grazing animals have a profound influence on how upland vegetation competes for nutrients from the soil and utilises them for growth. We are studying how defoliation and excretal returns influence grass physiology and growth, both above and below-ground.

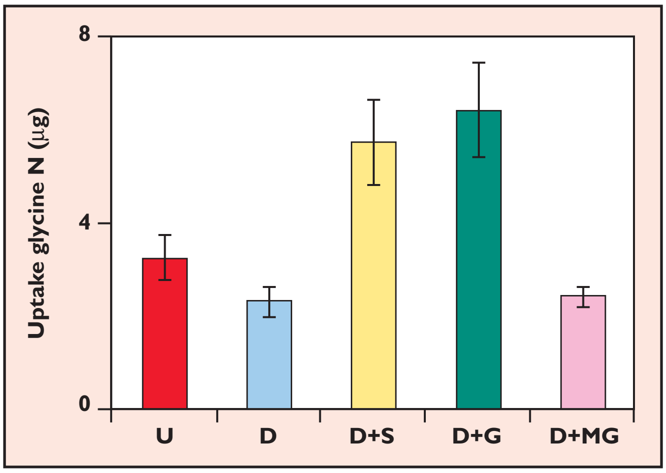

Figure 2. Uptake of N in the form of glycine by plants Lolium perenne *which were either undefoliated U, defoliated plus sucrose added to roots D+S, defoliated plus glucose added to roots D+G, defoliated plus a non-metabolisable analogue of glucose added to roots D+MG.*

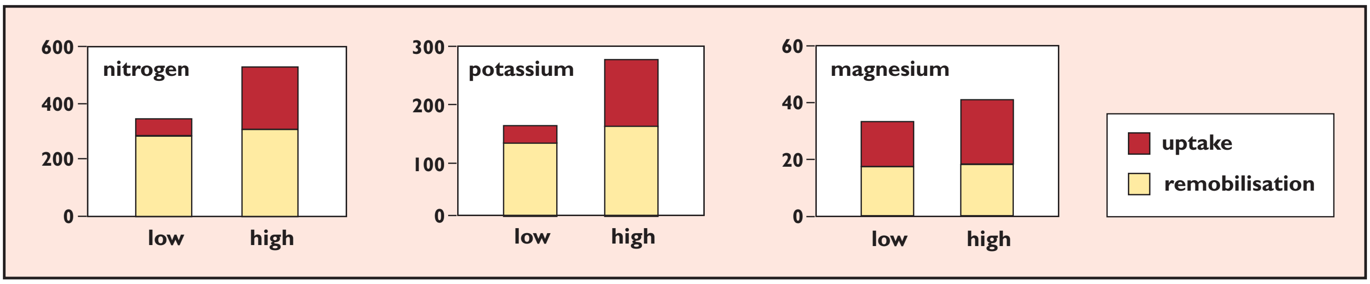

Figure 1. The contribution of nitrogen, potassium and magnesium from both root uptake and remobilisation of stored resources to the spring growth of young Scots pine trees grown with a low and high nutrient supply.

We have:

- determined that *Lolium perenne* can take up glycine through its roots, with defoliation inhibiting uptake, while adding sugars offsets the inhibitory effect of defoliation. Adding an analogue of glucose which cannot be metabolised has no effect on glycine uptake (Figure 2).
- Collaborated with IGER to show that after defoliation of *L. perenne* the flux of nitrate in the xylem is related to nitrate uptake, while the flux of amino acids is not, suggesting translocation of the two forms of nitrogen have different causes.
- Collaborated with INRA (France) to show that at a high N supply *Dactylis glomerata* and *Lolium perenne* are more tolerant to defoliation in terms of maintaining leaf extension rate than *Festuca* spp. (Figure 3).

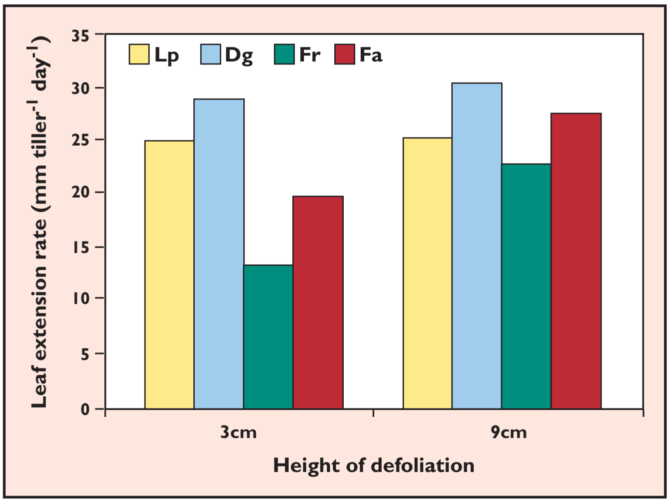

Figure 3. Leaf extension rate (mm tiller[1] day[1]) for L. perenne, D. glomerata, F. rubra *and* F. apendinacea *when clipped to 3cm or 9cm height while growing with a generous N supply.*

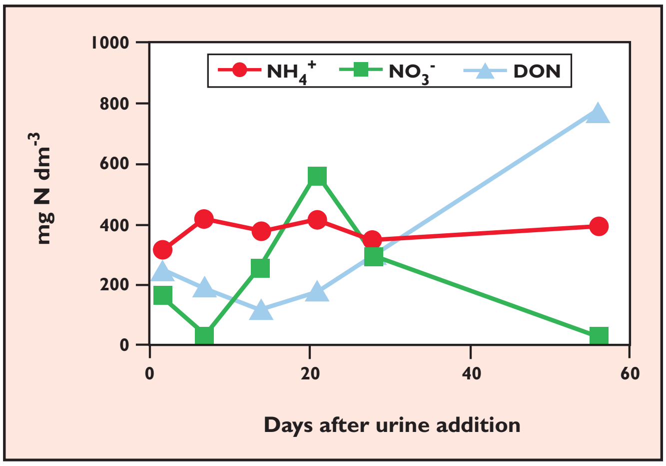

Figure 4. The nitrogen pools in soil solution after urine deposition.

- Shown that some grasses can respond to defoliation by adapting their morphology. *Agrostis capillaris* reduced the height of the leaf growth zone from 11 mm to 9 mm with regular defoliation, whereas *Festuca rubra* was unable to adapt to grazing in this way.

Rhizosphere ecophysiology and chemistry

The growth and activity of soil microbes depend upon the availability of carbon from plant litter, dead roots and rhizodeposition. Grazing animals can influence the interactions between vegetation and soils by defoliation and excretal returns (which affects the availability of both nitrogen and phosphorus in the rhizosphere). We have:

- Shown that defoliation transiently increases rhizodeposition of carbon from roots and that this response is probably due to depletion of the supply of energy to roots inhibiting the readsorbtion of root exudates.
- Collaborated with ITE-Merlewood to use novel ^{13}C pulse-labelling techniques in the field which have shown that increased rhizodeposition with defoliation may result in short-term immobilisation of soil nutrients by microbes.
- Investigated the effects of below-ground herbivory by leatherjacket larvae on grass growth, root morphology and exudate chemistry. Feeding of larvae on *Agrostis capillaris* affected root turnover and architecture as well as the abundance of some soil microbial groups.
- Studied the effects of grazing on soil solution chemistry. Urine deposition increased soil pH and both soil nitrate levels (up to 21 days) and dissolved organic N (Figure 4), and also greatly increased the dissolved organic carbon (DOC). Defoliation reduced the DOC in soil solution, particularly if the grass was cut regularly.

Highlights

We have:

- Increased our knowledge of nutrient cycling in trees by the development of novel techniques to quantify nutrient fluxes in trees, using a range of stable isotopes.
- Determined how grasses respond to defoliation, both in terms of changes in their morphology and ability to take up nutrients.
- Shown that defoliation can cause increased amounts of carbon to be lost from grass roots, in turn leading to short-term immobilisation of nutrients by soil microbes.

Relevance

Marginal lands account for the majority of land use systems in Scotland. Understanding the processes regulating nutrient cycling and plant growth in these systems is a key contribution of this programme to the development of sustainable management strategies for the Scottish landscape and its natural heritage.

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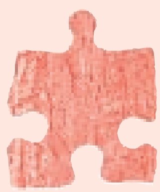

Plant Ecology and Community Dynamics

Large areas of land are managed primarily by the extensive grazing of wild and domestic herbivores. As a consequence, prediction of the effects of land use or environmental change depends on a detailed understanding of the interactions between animal grazing/browsing and the adaptations and ecological trade-offs that different plant species possess. The overall objective of the Plant Ecology and Community Dynamics Programme is to undertake and synthesise research that will provide the means to analyse the effects of different land use scenarios or different environmental change scenarios on the long-term dynamics of plant species and communities.

Aims

The strategic aims of the programme are to provide an understanding of the key processes, and particularly their interactions, which determine the dynamics of grazed ecosystems. Specifically we focus on:

- The role of spatial pattern in plant communities in determining plant competitive relationships, and how this pattern is created by herbivore grazing and soil heterogeneity.
- The interactions of grazing animals and plant competition that determine the dispersal and regeneration of plant species.
- Developing methods for predicting the success of woodland regeneration from an understanding of the ecology of the browsers and the physiological effects of browsing on different tree species.
- Understanding how nitrogen deposition and grazing interact to govern the dynamics of montane plant communities.
- Developing a suite of spatial models that integrate experimental information and have predictive capability.

Achievements

Long-term community change under extensive grazing management

The current objective of European and national agricultural policy is to reverse the drive for production that formed the main aim of the Common Agricultural Policy for many years. The hope is to halt, and possibly reverse, the decline in biodiversity that has been associated with increased intensification of production. To explore how a reduction in stock numbers and fertiliser inputs would affect the composition and productivity of agricultural grasslands, a long-term experiment was started in 1990 with treatments replicated at three sites.

The treatments consisted of a 'normal' agricultural control (fertilised, grazed to 4 cm during the growing season - 4F), and a factorial combination of two sward heights (4 and 8 cm) set during two separate periods (summer and autumn), i.e. 4 cm during both seasons (4), 8 cm both seasons (8), 4 cm in summer and 8 cm in autumn (48) and the reverse (84). All four of the latter treatments were unfertilised and all plots were grazed with Blackface ewes, each with a single lamb. An ungrazed treatment was also included (UN). We have shown that:

- Changes in species composition have been small in all the grazed treatments, with only a few losses or gains of species.
- Rye-grass *Lolium perenne* declined in all treatments, but the decline was smallest where the swards were grazed at 8 cm in the autumn or fertilised (Figure 1a). White Clover *Trifolium repens* benefited in unfertilised swards kept at 4 cm in the summer (Figure 1b).
- The less densely stocked swards showed increases in *Agrostis capillaris* (Common Bent) and *Poa trivialis* (Rough Meadow-grass), as well as moss content.
- Some species present in the seedbank at the start of the experiment later appeared in the vegetation, whereas a small number of species with transient seedbanks must have colonised from outside the sites.

The slow rate of change in vegetation has two implications; predicting future animal output from different management regimes should be relatively simple, but it would be difficult

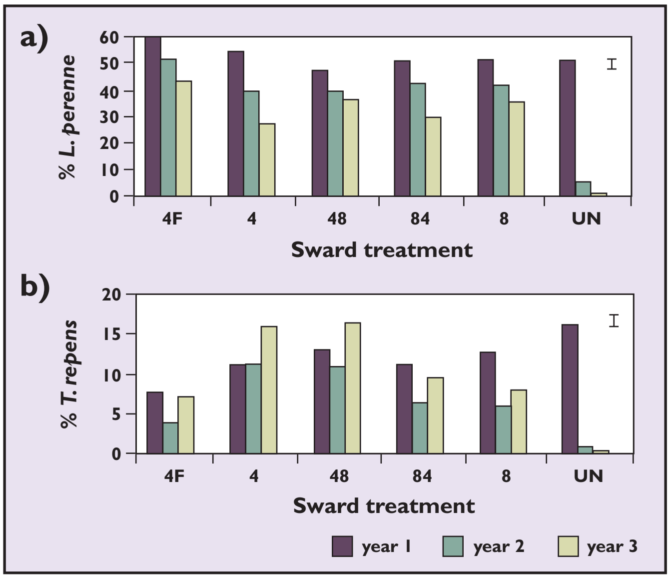

Figure 1. Trends in percentage specific frequency (averaged over three sites) in the different grazing treatments (4F, 4, 48, 84, 8, UN) from year 1 to year 5 after the start of the experiment. (a) Lolium perenne, *(b)* Trifolium repens. *Bars indicate s.e.d.*

to justify grants for reducing animal output on the basis of increases in biodiversity. To achieve a significant/measurable increase in biodiversity may take many years or need more interventionist management.

A new spatial model of vegetation dynamics

The scope of experimental research to investigate processes that occur over large scales or long time periods is limited. Modelling can synthesise the results of experimental work with our understanding of plant biology to predict and analyse vegetation change at large scales or over long periods. To achieve this, an existing model of vegetation dynamics that predicts change through time has been developed further to enable spatial predictions to be made.

The new model, called 'VegeTate' simulates multi-species dynamics within cells in a hexagonal grid, and between cell interactions. The hexagonal structure has many geometrical advantages over the more common square grid, and the co-existence of several species within each cell allows the model to represent many processes that are difficult to characterise in less flexible cellular automata models. For example, animals can trample the neighbours of the plants they graze.

An example of the predictive capability of the model is shown in Figure 2. A heathland, with a small representation of grass and bracken is subjected to heavy grazing. The heather is quickly replaced by grassland (Figure 2a), but the behaviour of bracken shows that the spatial and temporal dynamics of the system have become non-linear. The initial size of a bracken patch determines its rate of spread, because large patches expand whilst small patches remain largely stable in size (Figure 2b).

Since extensively grazed vegetation has spatial structure, it is important to encompass that structure within predictions of vegetation change. Non-linearity in the response of ecosystems means that spatial models may predict change with greater precision than non-spatial models.

Future programme developments

The work of the programme will develop in two main directions; understanding the trade-offs and adaptations displayed by plants in grazed systems, and understanding the effect of space and scale in governing species interactions and community composition. This will involve collaborative work with other groups to:

- Investigate the effects of within species variation in morphology and physiology on the plant's response to defoliation.
- Understand the role of animal-determined heterogeneity in nutrient inputs, offtake, seed dispersal and regeneration from seed, and predict the resultant vegetation change.
- Take new physiological methods to look at the effects of browsing damage on the growth and survival of tree saplings in the field.
- Link our current spatial model of vegetation dynamics with a spatial herbivore foraging model to investigate the interactions of plants and herbivores in a spatial environment.

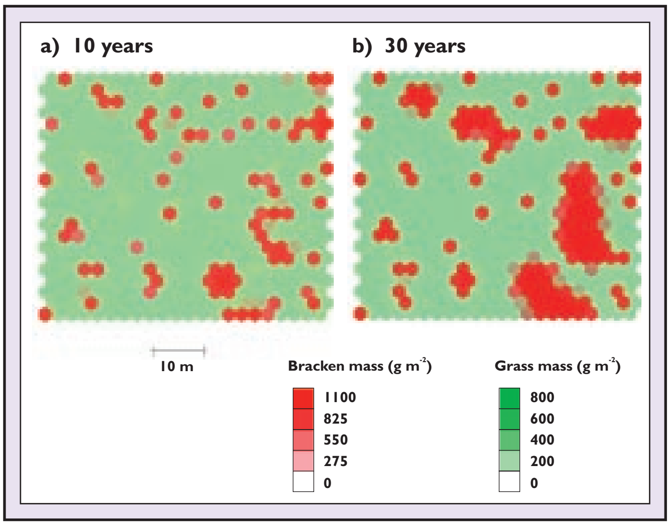

Figure 2. Predicted dynamics of a heather-dominated system subject to heavy grazing in the presence of a small grass and bracken component. Note the increase in size of the larger bracken patches, and the static nature of the smaller ones.

Highlights

- We have been awarded a European Union grant to examine the impacts of sheep on birch ecosystems across climatic and cultural gradients through Scotland, Scandinavia and Iceland.
- We have demonstrated that climate has an effect on controlling seedbank density. A warm, dry climate limits the size of heather's seedbank, which may affect a site's potential for regeneration.
- Initiation of a long-term study into the dynamics of montane heathlands, focused on understanding the interactions between management, grazing and nitrogen deposition.
- Construction and publication of a spatial (coupled-map lattice) model of vegetation dynamics.

Relevance

Understanding the drivers and rates of vegetation change in marginal land is the key contribution of this programme to the research strategy of the Scottish Executive Rural Affairs Department. It is specifically aimed at providing information for the management and sustainable use of Scottish ecosystems and for the maintenance of biodiversity. Our current research will continue to provide an increased understanding of the dynamics of grassland, montane, heathland and woodland systems, and a mechanism for predicting their fates. These ecosystems are an important focus as they are widespread vegetation types and major reservoirs of biodiversity in the Scottish landscape and its natural heritage.

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Animal Ecology in Grazed Ecosystems

Large herbivores, such as domestic livestock and wild deer, are the major determinants of ecosystem function and dynamics in most land-based ecosystems. Through their grazing, trampling and defecation they affect nutrient flows, plant community dynamics and biodiversity. In turn plant community composition, productivity and distribution determine animal nutrition and population performance. Our aim is to quantify the relationships between components of the ecosystem and the foraging behaviour of large herbivores in the natural and semi-natural ecosystems found within Scotland and abroad. Close collaboration with colleagues in the Plant Ecology & Community Dynamics Programme (P3) allows us to measure the impact of grazing on vegetation.

Our strategic research aims are to understand the key processes that determine the inter-relationships between resources in the landscape and the distribution and feeding behaviour of large mammalian herbivores. We aim to increase our understanding of these relationships through the development and testing of foraging theories which involve scaling-up from the level of the individual bite to the landscape. Emphasis is placed on:

- Investigating the role of trade-offs between behavioural goals (e.g. quantity versus quality of forage; feeding versus shelter) in determining the intake and diet selection and the spatial distribution of animal populations.
- Measuring the relationship between resource distribution and the distribution and performance of animal populations.
- Designing predictive models to predict the dispersion of animal populations across landscapes.
- Developing techniques to measure the intake, diet selection and dispersion of free-ranging herbivores.

Particular achievements in the past year have been:

The effect of secondary compounds on diet selection in ruminants

Sitka spruce trees are an important winter food source for red deer and browsing damage represents a significant economic loss in commercial plantations. Sitka saplings contain natural feeding deterrents known as terpenes. Terpene concentrations are under strong genetic control. To examine the role of terpenes in reducing browsing damage to Sitka, a preference experiment was conducted in which browsing damage by tame red deer on high and low terpene clones was compared. The experiment showed that:

- Terpene concentrations are not generally closely related to the morphological traits of Sitka saplings (Figure 1).
- Low terpene Sitka clones received significantly greater browsing damage than high terpene clones (Figure 1).
- Terpene concentrations could be incorporated as a selection trait in Sitka breeding programmes to reduce browsing damage and resultant economic losses.

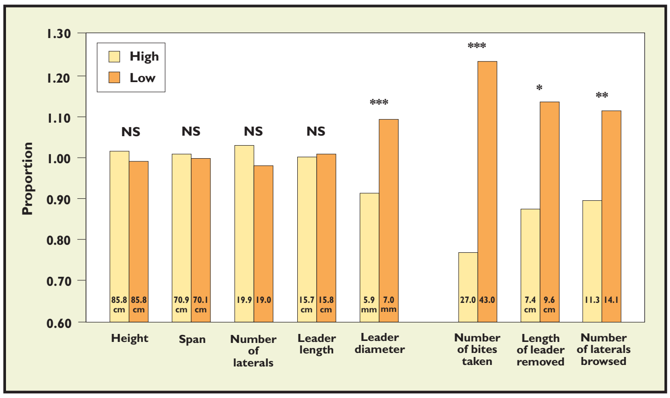

Figure 1. Effect of terpene status (HIGH vs LOW) on tree morphology and degree of browsing by red deer (values represent proportion of mean for each variable).

Grazing intake in different breeds of sheep

Different breeds of sheep show different degrees of seasonality of *ad libitum* food intake. This annual pattern of voluntary intake is thought to be an adaptation to predictable seasonal declines in food availability or quality. But does the phenomenon have any relevance to animals grazing in the field, where other factors such as food availability or quality may be limiting? We tested the seasonal variation in intake and foraging behaviour of three contrasting breeds of sheep grazing at pasture; these were the usually aseasonal Dorset Horn (DH), and the seasonal Scottish Blackface (BF) and Shetland (ST):

- Grazing behaviour and intake of all breeds varied strongly and consistently between seasons. The inherently seasonal ST ewes had the lowest seasonality of intake at pasture, whereas, higher degrees of seasonality of dry matter intake were shown by the BF and DH breeds (Figure 2).

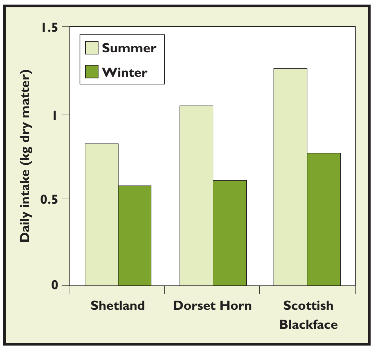

Figure 2. Daily intake for three breeds of sheep grazing similar swards in the summer and winter.

- There was no interaction between food resource availability and seasonality of intake or any other aspect of foraging behaviour of any breed. This suggests that the consistent seasonal changes in foraging behaviour, notably the smaller bites taken in winter, were the result of seasonal changes in food quality (digestibility) rather than biomass availability.
- We cannot readily extrapolate from laboratory feeding studies, where animals' own physiological constraints apply, to foraging ecology in the field, where constraints imposed by the environment, in this case food quality, may be more important.

Spatial impacts of free-ranging herbivores on moorland vegetation at a range of scales

A collaborative research project with the Institute of Terrestrial Ecology (ITE) has provided new information on how vegetation pattern, at a range of scales, influences spatial variation in heather utilisation by free-ranging red deer in the Scottish uplands. The results demonstrate the complexity of factors, particularly the distribution of grass and heather within the moorland landscape, which need to be taken into account in order to make accurate predictions of heather utilisation by red deer and other large herbivores. For example:

- By far the strongest influence on heather utilisation was the distance from the edge of a grass patch. In the most heavily grazed areas within an estate, the difference in utilization between heather within 50cm of a grass patch and heather at more than 5m away could be as high as 20% (Figure 3).
- The location within an individual estate had a substantial effect on heather utilisation at the edge of grass patches, with over 10% difference between locations (Figure 3). Locations with high edge zone utilization also tended to have higher utilisation further away from grass patches. Both are indicators of substantial spatial variation in range use by red deer within each estate.
- There was a consistent pattern of the effect of the dominant grass type on the utilisation of heather near the grass patch, with utilisation around *Agrostis/Festuca* patches the highest, slightly less around *Nardus*-dominated patches, and by far the least around patches of *Molinia*, reflecting the known preferences for these grass species by deer.

Modelling the spatial dispersion of herbivores

A Hierarchical Object-Orientated Foraging Simulator (HOOFS) system has been designed which allows scientists studying herbivory to explore the factors that determine herbivore foraging success and the impacts that foraging has on the environment. Using HOOFS we have examined how:

- Inter-species differences in the functional response, that is the relationship between vegetation biomass and intake rates, and the maintenance cost of the animal may lead to a more or less selective foraging strategy being better in a given circumstance.
- Social interactions between individuals within a herd may constrain foraging efficiency.
- The accuracy and range of herbivore perception and memory affects feeding efficiency. Successful foragers combine accurate perception of their local environment with some knowledge or perception of large scale long-range features of their environment.
- Patterns of vegetation structure can arise from an interaction between foraging strategy of the herbivore and vegetation growth response to grazing.

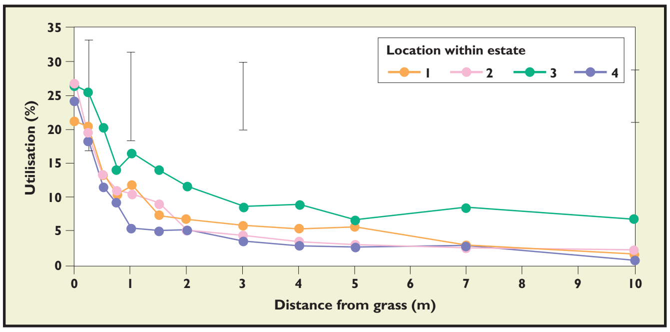

Figure 3. The relationship between heather utilisation and distance from the grass for an estate in the Grampians.

Highlights

- Implementation of extensive research programme on wildlife/livestock interactions in Southern Africa.
- Description of the role of social behaviour of sheep in their foraging behaviour.
- Demonstration of the role of spatial distribution of resources on diet selection in sheep and red deer.
- Creation of spatially explicit foraging models.
- Discovery of plant markers for use in study of uptake and diet selection of free-ranging herbivores.

Relevance

Understanding the intake, diet selection and spatial distribution of herbivore populations on marginal land is the key contribution of this programme to the research strategy of the Scottish Executive Rural Affairs Department. The programme is specifically aimed at providing information for the management and sustainable use of extensive ecosystems both in Scotland and abroad. Our current research will continue to provide an increased understanding of the interactions between herbivores and vegetation at a range of scales from the bite to the landscape. Through links with the Integrated Land Use Systems Programme (P8), technology transfer is achieved through the development of foraging sub-models for incorporation in Decision Support Tools (DSTs) which predict the impacts of grazing by species such as sheep, cattle and red deer on vegetation dynamics, animal production and population dynamics.

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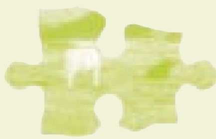

Rural Economic Modelling and Environmental Economics

Rural areas are constantly changing as demands on rural space and resources change over time. Rural development policies, designed to maintain or improve rural incomes and employment, need to be balanced with the protection of environmental resources. This Institute programme contributes to the formulation and evaluation of new policies that impact on rural areas. It concentrates on the economic impacts of policy by modelling effects on people, businesses and the environment.

Aims

This research programme develops new approaches in economic analysis and applies them to policy issues. The principal way this is done is to develop better models that allow us to explore policy issues in innovative ways. We concentrate on two policy areas:

- The economics of the environment and the management of natural resources.
- Rural areas, their structure and role in contemporary society.

In order to inform policy we specifically undertake research to:

- Improve policy instruments that will allow government and its agencies to better intervene in the management of rural resources.
- Develop more sophisticated methods of quantifying the economic impacts of policy, including impacts on the income and employment of people working and living in rural areas.

Achievements

Forestry's contribution to the Scottish economy

Focusing on the economic activities associated with the planting, maintenance and harvesting of woodlands, we have quantified the forestry sector's contribution to the Scottish economy. The analysis takes into account that the sector does not operate in isolation but, through the demand for inputs and supply of timber, has both direct and indirect links with other sectors in the economy.

Figure 1. Commercial harvesting activity.

Based on an extensive survey of woodland owners and managers, a disaggregated version of the Scottish input output tables was derived showing the input requirements and output flows of four different generic woodland types. The results of the study indicated that on a per hectare basis, the output and employment effects associated with farm woodlands and new native woodlands are greater than those from commercial coniferous woodlands. Thus whilst the former have been promoted principally for their environmental and recreational benefits, they do not detract from conventional policy goals of sustaining employment and income in rural areas. Allowing for the dependence of some downstream firms on output from domestic forestry, it was estimated that the total removal of the sector would result in a fall in the total value of Scottish output of £811 million and a loss of 12,130 jobs in the whole economy.

Modelling rural economies

The changes that are occurring across rural areas have been highly diverse, with apparently similar types of rural areas responding very differently to economic, social and environmental pressures. Within this context, there is increasing recognition of the need to develop spatially sensitive rural development strategies. This, in turn, gives rise to a need for information on the structure and nature of sub-national or regional economies.

We have recently completed a study of the structure and performance of the Western Isles economy. Given the nature of contemporary issues affecting the Western Isles, a Social Accounting Matrix (SAM) framework was adopted for the study, which involved collecting detailed information on the full circular flow of income around the region, including details on the roles of different household types in the economy, and the nature and importance of transfer payments to and from the region. Findings indicated that the economy has grown considerably over the last decade but is still lagging behind other areas including the Shetlands Islands, Orkney and the Highlands and Islands as a whole. Moreover it has become more specialised and reliant on the performance of a few key sectors. Both the regional accounts and the model will be used as a tool to help guide local development strategies and to predict the income and employment effects of impacts on the economy.

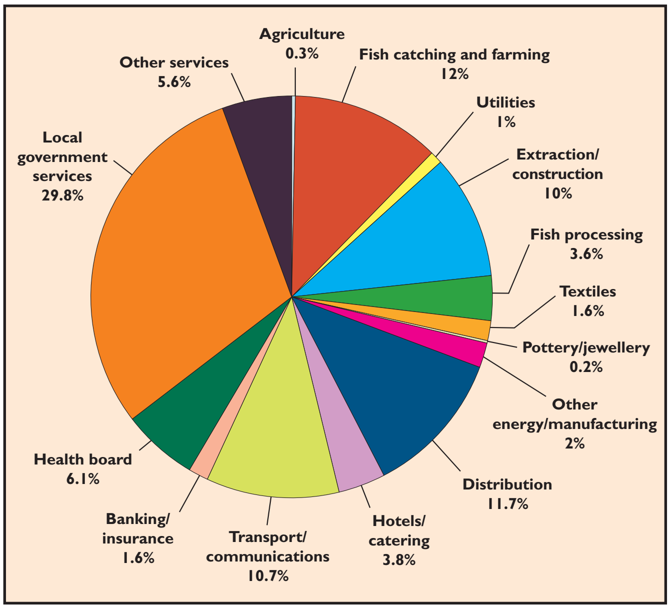

Figure 2. Contributions to total Western Isles GDP by sector.

Environmentally Sensitive Areas (ESA) policy

We have completed a study for the Scottish Executive on the agricultural and economic impacts of the ESA scheme. This provides payments to farmers to protect and enhance the environment in areas of high environmental value.

We found that impacts of the ESA payments on the way farmers farmed were quite limited. Many of the habitats and countryside features protected or enhanced under the scheme are peripheral to the commercial operation of farms, and farmers tend to select options that minimise the adaptation required. Farming intensity was hardly affected by entry into the scheme, but there was a major impact on incomes. Participation in the scheme increased farm incomes by £3,366 on average and there were important benefits for local economies. Payments to farmers of £23m produced additional expenditures resulting in an estimated 514 jobs. Surveys of tourists in ESAs concluded that ESA policy had beneficial effects on tourism.

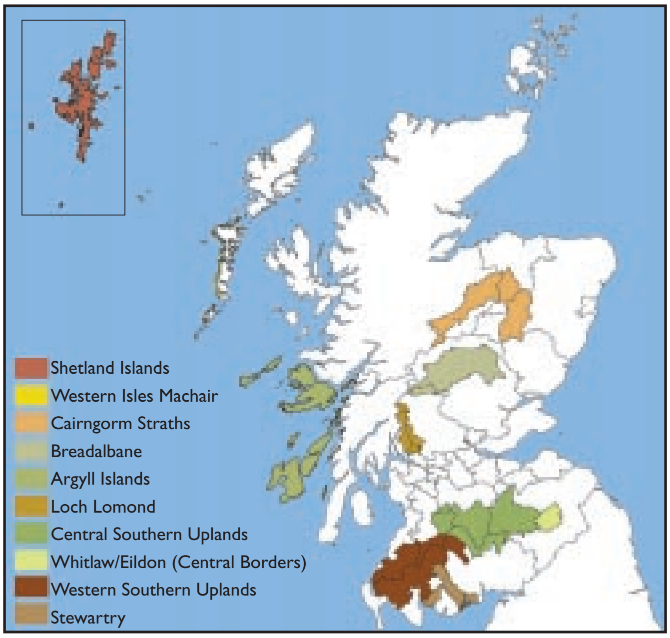

Figure 3. Environmentally Sensitive Areas in Scotland.

Design of policy instruments for countryside access

Policies that pay farmers to allow access on their land have been subject to criticism because recreational benefits have not always ensued. The problem is one of variation between farms and localities in the quality of access, and limited information about preferences for access and the costs of providing it. We have modelled this issue using statistical techniques in order to explore how better information can lead to more effective policy design. The less information that policy makers have, the more important it is that policy instruments are designed to reveal information. Discretionary policies and those involving bidding or auctions have advantages over standardised incentive payments.

Future programme development

The programme will continue to concentrate on developing economic models and approaches that support the analysis of new policy issues. Specifically we will:

- Explore choices and impacts in household location.
- develop improved models for understanding changes at the regional level.
- Develop methods for analysing environmental sustainability and identify efficient policy instruments for delivering sustainability.
- Investigate how rural development can be enhanced or restricted through communal ownership and management of resources.

Highlights

- We have undertaken important contracts for a range of key clients including the Forestry Commission, Scottish Natural Heritage, The Scottish Executive and the Western Isles Council.
- The politically sensitive task of determining the economic impacts of a ban on hunting with dogs is being undertaken by the Economics Group at the Institute.
- The EU has awarded us a major contract for studying impacts of communal ownership on rural development.
- We have a major role in evaluating government and EU policies in the land sector. This has included the ESA evaluation and an investigation into environmental projects funded under Objective 1.

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Land Use Change

The agricultural and forestry land use sectors play a relatively small part in the economy of Scotland(<3%GDP), but remain the predominant influence on the rural environment. Changes in the structure, type or intensity of these land uses will continue to impact on the nature and quality of the rural environment both on-site (e.g. loss of hedges) and off-site (e.g. pollution of watercourses), and the provision of public goods (e.g. biodiversity, amenity). Future change in these sectors may critically affect the environmental sustainability of rural Scotland, and it is essential that management of such change is supported with relevant information.

Aims

In this new programme of research, our aim is to develop innovative methods for documenting actual patterns of agricultural and forestry change, understanding their causes, and develop methods for forecasting future patterns of land use change under different socio-economic and policy scenarios. In this context we focus on:

- ***Data acquisition and integration***. Develop new knowledge and IT-based methods for monitoring (e.g. by remote sensing) and visualising land use/landscape change; organisation and integration of data on rural land use change from other sources (e.g. agricultural and population census).
- ***Case studies of land use change***. Understand drivers of change in different geographical and management contexts around Scotland (e.g. family farm, hobby farm, estate, agribusiness, conservation body etc.), through collaboration with the Arkleton Centre for Rural Development Research.
- ***Modelling land use change***. Develop and critically evaluate alternative approaches to modelling regional land use change (includes empirical, mathematical and simulation modelling).

Achievements

Linking agricultural census data to remotely sensed land cover data

This research aimed to integrate the Land Cover of Scotland 1988 (LCS88) data to the June Agricultural and Horticultural Census (JAHC). The JAHC has the great advantage of being an annual census. However, whilst it is collected on an individual farm basis, it is only reported on at the level of the agricultural parish in Scotland. The challenge of the project was to develop a method for integrating the LCS88, a dataset with high spatial resolution (2-10ha), with the JAHC, a dataset with high temporal resolution but poor spatial resolution (tens of square kilometres).

The method that has been developed makes use of a third dataset, the Land Capability for Agriculture (LCA). This relates to the flexibility of land for agriculture and is a measure of land quality. By segmenting agricultural parishes on the basis of their land quality/LCA class, it is possible to identify in a probabilistic way where elements of the JAHC

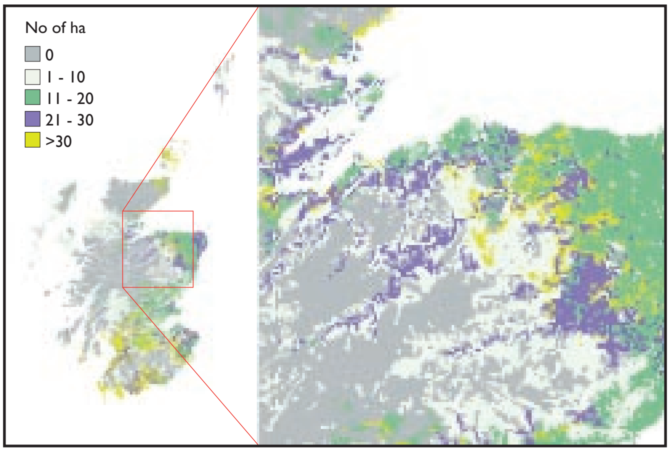


Figure 1. Improved pasture (ha) per square kilometre (km^2).

(e.g. winter wheat, spring barley etc.) might be growing. The precise methodology employs both cluster analysis and quadratic programming stages. The final output is a 1-km resolution modelled surface for the whole of Scotland where each cell contains the estimated proportions of JAHC land use categories (Figure 1). A key feature of the method is that it is "area sensitive", i.e. different sets of interpolation parameters are used in different regions to reflect the variations in bio-climatic conditions around Scotland.

Evaluation of options for new Land Cover of Scotland

We examined the feasibility of creating an operational facility for updating the land cover database for Scotland (LCS) and providing change data. The work included: market research on user needs, a review of the historical coverages of aerial photography (AP) and satellite imagery, and an evaluation of the benefits of a rolling programme versus dedicated image acquisition.

Results of the user needs survey indicated that the interpretation of AP is the best update option. A second conclusion was that AP was much more widely valued as a data resource in public organisations than previously thought, and there is an increasing demand and potential for digital AP imagery (orthophotos) independent of the need for land cover data. The review of the historical pattern of AP and satellite imagery acquisition in Scotland revealed a concentration of photo coverage around the Central Belt and the major agricultural areas such as the Aberdeenshire lowlands (Figure 2) with no centralised co-ordination of flying sorties between the various agencies that commission AP. The value of satellite imagery for land cover mapping in Scotland is currently restricted due to its unreliable availability, regardless of resolution.

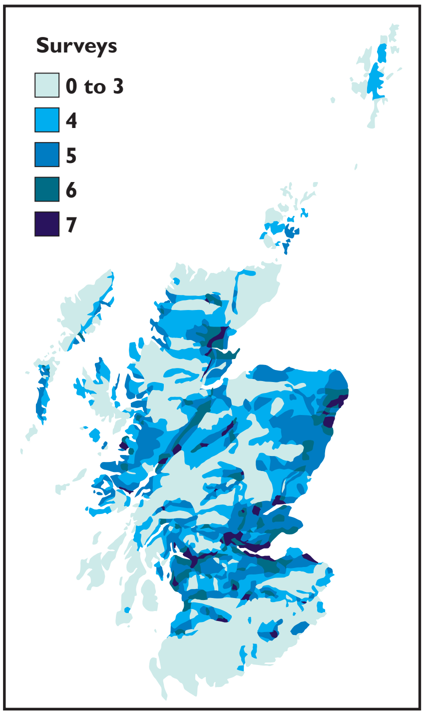


Figure 2. Pattern of National AP Coverages in Scotland.

A proposal to acquire national orthophoto coverage as a national environmental data resource and a precursor to an updated LCS has been developed ("New Image of Scotland" project). The next steps are to turn this potential into a reality that will put Scotland amongst the first nations to possess such a valuable high-resolution data resource.

Development of Prototype Simulation Modelling System

Land use change shows distinct geographic patterns. Some of these may be the intentional outcome of rural policy, others may be both unanticipated and undesirable in terms of their environmental and socio-economic effects. It is therefore important that we develop facilities that enable us to forecast, at least in a general sense, what land use changes are likely under altered economic or policy circumstances, and particularly where they are most likely to occur.

The central problem in forecasting land use change is that such change represents the accumulated effect of individual land managers' behaviour. If enough information were available it might be possible to model all of these individual behaviours. However, this is not a practical option. We are developing a prototype modelling system (FEARLUS) around the simulation platform *Swarm* developed by the Santa Fe Institute. This will allow us to explore the possible application of an alternative approach to predicting land use change based upon new agent-based simulation modelling techniques.

The first version of the FEARLUS model explores the effects of different land managers strategies on land use outcomes. In particular, this model has focused on the influences of neighbours on land manager behaviour – specifically the impacts of imitative *versus* non-imitative strategies. By running the model using a range of such strategies, it has been possible to show that the success of 'imitation' depends on the type of imitation used, the strategies of other agents with which the imitator is interacting, and the heterogeneity (particularly the temporal variability and predictability) of the environment. These results have led to the identification of specific areas for revising the model. (Please also see article on "New Developments in Forecasting Land Use Change".)

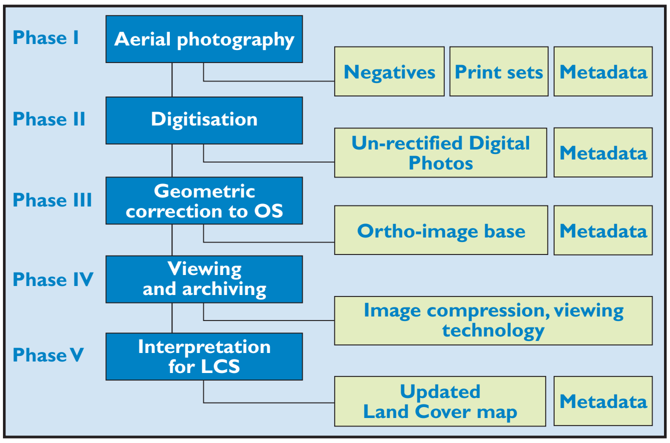


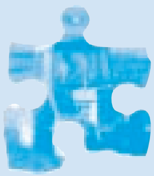
Figure 3. Stages towards an orthophoto image base and an updated Land Cover map for Scotland.

Highlights

- Initiated a major new programme of research on application knowledge-based systems to land cover change detection (SYMOLAC).
- Created new working links with the Arkleton Centre for Rural Development Research at the University of Aberdeen.
- Supported major public inquiry in Wales into landscape impacts of proposed windfarm developments.
- Completed major EU-contract on application of remote sensing to hydrological modelling (HYDALP).
- Created the first version of an agent-based simulation modelling system (FEARLUS) for exploring the dynamics of land use change.

Relevance

Our research contributes to four out of the five key objectives identified in the Scottish Executive's recently launched 5-year strategy for agricultural, biological and related research. Specifically, **maintenance of scientific excellence** in relation to monitoring and forecasting land use change; widening the **range of end-users of research** particularly those in the "environment and natural heritage" area; **enhancing the quality and effectiveness of the research programme** through close collaboration with partners in Scotland, Europe and elsewhere; **fostering knowledge transfer and exploitation**, through involvement of end-users in project steering groups.



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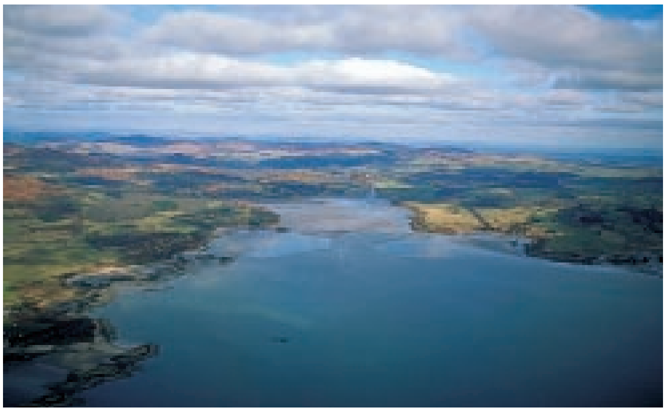
Integrated Catchment Management



Water resources and land use planning can no longer be undertaken in isolation. The watershed or catchment is the appropriate spatial unit for the sustainable management of waters. This has been highlighted in the forthcoming EU Water Framework Directive which aims to enhance the sustainable management of water resources. This requires an understanding of the implications of integrating policies with respect to land use, point source pollution regulation, riverine and fisheries management, and the consequences of trade-offs among production, environmental and social objectives.

Aims

The principal aims of the programme are, therefore, to determine the hydrological factors affecting the quality of water resources, from both point source and diffuse inputs; elucidate the spatial and temporal interactions with the environment that influence water resources; quantify the downstream consequences and interactions of pollutants; and integrate and develop process based decision support systems for scenario analysis, and policy evaluation.

Specifically we aim to:

- Describe, quantify, and model the dominant transport processes involved in the movement of solutes and particulates through catchment systems.
- Interpret the mechanisms controlling the production, consumption and transfer of nutrients and pollutants, and the role of land use and climate in modifying temporal and spatial signals.
- Extrapolate systems understanding at the micro scale to that at meso and macro scales (hillslope - catchment) through the integration of spatial information at appropriate scales.
- Predict the impact of environmental change on biogeochemical cycling at different spatial scales.
- Determine the links between chemical signals and biological impacts in terrestrial environments, and to elucidate the spatial and temporal consequences on ecological status of changes in freshwater environments.
- Develop and evaluate cost benefit approaches to optimising economic and environmental objectives on water resource management.

A groundwater monitoring network for Scotland

The Scottish Environment Protection Agency (SEPA) and Scottish Executive Rural Affairs Department (SERAD) were required to establish a strategic groundwater monitoring network in Scotland in order to assess and monitor the general status of Scottish groundwaters and to satisfy the requirements of EC directives.

A biophysical framework based on the risk of contamination from various land use practices and on the ability of the soil to protect the groundwater was developed and implemented within a geographical information system using existing national scale spatial datasets. A total of 39 biophysical classes were identified which encompassed highly and moderately permeable aquifers as well as the largely superficial aquifers in weakly permeable bedrock. A representative national groundwater monitoring scheme was determined by weighting the spatial distribution of each class by population density, and hence anthropogenic activity, where there is a greater risk of polluting land uses.

Figure 1. Potentially damaging direct discharge into an urban stream.

The development and application of a model to predict the inherent geomorpholocial risk of soil erosion by overland flow

A rule-based model for assessing the inherent erosion risk of Scottish soils was developed and then applied to existing soils and topographic datasets to produce a spatial estimate of the inherent erosion risk throughout Scotland. The attributes used in the model were topsoil texture, slope and runoff potential of the soil. The assessment of erosion risk was made on the assumption that the soils were free of vegetation. Over 25 000 km^2 (32.1%) of Scotland is classified as having a high inherent risk of erosion by overland flow.

The classification gives a baseline estimate of the inherent geomorphological risk of soil erosion by overland flow in Scotland. Future work will incorporate land use and climate data into the rule-base, with particular emphasis on rainfall seasonality, intensity and duration in relation to soil moisture contents and plant growth.

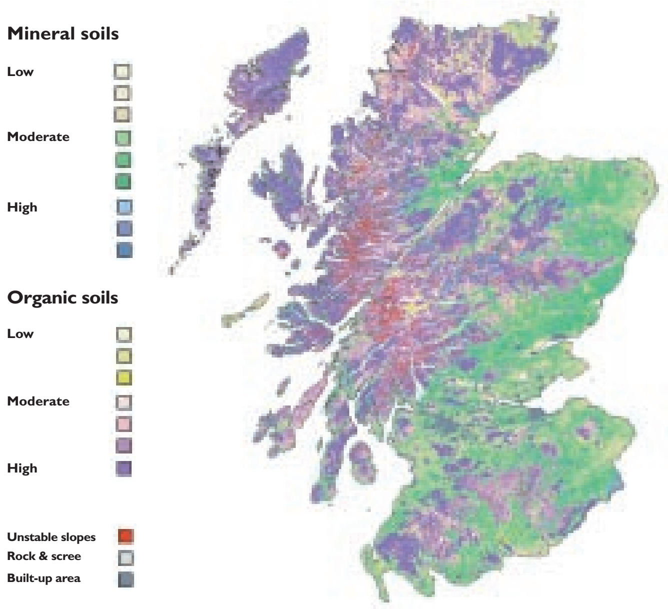


Figure 2. Inherent geomorphological risk of soil erosion by overland flow in Scotland.

Linking terrestrial and aquatic cycles of phosphorus

An important aspect of being able to predict the susceptibility of soils to erode is the potential for the loss of nutrients, such as phosphorus (P) that can be intimately associated with soil particles. Differences in the dominant transport mechanisms that exist between N and P has wide ranging research and policy implications for establishing causal relationships between nutrient loss and ecological effect and the subsequent management of loss. The contrast in transport mechanism, (leaching compared to particulate transport) of N and P suggests that while the former is likely to have originated in drainage waters from the whole of the catchment, the P component in rivers will be much more localised and episodic in nature.

Consideration has been given to the likely value of using soil based indices, such as those recently suggested by MAFF (1998) in reducing the incidences of P driven eutrophication in flowing waters (Code of Good Agricultural Practice for the Protection of Water, 2nd edition. Ministry of Agriculture, Fisheries and Food, Her Majesty's Stationery Office). It has been argued in a recent OECD sponsored workshop that, because no clear link can be made between the soil P content, P loss, P concentration/load in rivers and an environmental impact, soil based indices may not be the most appropriate tool.

A further reason why this approach may not be a helpful way forward is the selectivity of the soil erosion process, both in terms of the size and the nature of the materials eroded. Thus only a limited relationship exists between the properties of the soil *in situ* compared to that of the suspended sediment derived from it. While certain characteristics/attributes of the original parent material can be identified and used to trace the origin of suspended sediment within a catchment. This has required the development and application of new techniques for both phase and compositional fingerprinting of the typically very small samples (mg) of suspended sediment that can be routinely collected in the field. For phase identification a novel method has been developed based on analysis of infrared spectra. The advantage of this method is that quantitative information on mineral, organic and amorphous mineral matter are obtained simultaneously on samples of a few mg mass, i.e. a size which can be obtained routinely from most Scottish waters.

Highlights

- We have been awarded a European Union grant to evaluate the extent of recovery of acidified freshwaters in Europe by 2010. This project focuses specifically on assessing the impact of current and proposed emissions control scenarios of the sustainability of sensitive European freshwater ecosystems.
- Development of a distributed snow-melt model linked to a catchment based flow model which allows for the determination of the impact of climate change on water resources.
- Development of a model to predict the inherent geomorphological risk of soil erosion.
- Production of a special issue of Hydrology and Earth Systems Science focusing on the work of the EU DYNAMO Project - Predicting the impact on environmental change on biogeochemical cycling.
- A recent NERC grant awarded to the Institute has identified that primary production in upland aquatic systems may be limited by the availability of nitrogen in the summer months.
- As part of an EU cost initiative the pan-European consequences of loss of phosphorus from agricultural systems are presently being evaluated.

Relevance

Understanding the nature of the origins, interactions and transport of solutes and particulates within catchment systems is fundamental to the determination of impacts within the environment. This understanding when integrated through decision support tools, allows for the evaluation and development of sustainable management for water resources.

The research effort is directly targeted towards meeting the scientific and technical challenges of the EU Water Framework Directive (WFD). The selection of the catchment as the fundamental spatial management unit, the integration of hydrochemical changes with ecological status, and the incorporation of cost:benefit scenario analysis are strong themes throughout the WFD and are mirrored by the multidisciplinary approach to catchment science being undertaken at the Institute.

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Integrated Land Use Systems

Decisions about the use of land are primarily made by the land owner or land manager. Our research aims to provide information on the options that exist for the use of land, including multiple land use systems, at the level of the individual management unit (e.g. the farm or the estate). The relative importance of the production, environmental and social costs and benefits of different land use options vary with both time and location and influence the choices and decisions made. These decisions will also depend upon prices, costs, market opportunities, technological developments and regional, national and international policies.

In the UK, marginal areas support economic activity through industries such as agriculture (especially livestock agriculture) and forestry and they represent important habitats and landscapes which form part of our natural heritage and support important social structures. The programme is undertaken therefore in three project areas viz. Livestock Systems, Natural Heritage and Biodiversity Management and Integrated Land Use Systems and Policy Analysis. The main emphasis of the programme is:

- Evaluation of options for extensification and diversification of livestock systems, especially development of novel systems of fine fibre production and principles underlying the choice of types of animal in extensive ruminant production systems.
- Measurement and monitoring of habitats and species in relation to land use, including development of new methods of rapid habitat assessment, and development of models and decision support tools to aid natural heritage and biodiversity management.
- Integration of a range of agricultural, farm woodland/ forestry and natural heritage management systems, including development of models and decision support systems.

Some examples of our recent research are given below.

Livestock Systems

UK and EU policies encourage extensification of ruminant production systems, and financial pressures are leading to reduced labour inputs in extensive systems. This is resulting in reduced contact between livestock and humans and we are studying the implications of this for animal health and welfare.

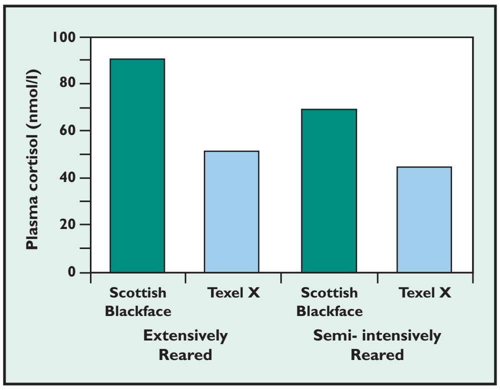

Figure 1. Effects of genotype and rearing system on plasma cortisol concentrations in response to exposure to humans.

We have shown that:

- There are important differences between breeds of sheep in the way they respond to humans, that can be greater than the effect of their rearing system (Figure 1).

Cashmere production of goats is a potentially valuable avenue for diversification of hill and upland livestock producers. However the timing and duration of moulting of the undercoat is variable. Although it has been known for some time that the thyroid hormones (thyroxin and triiodothyronine) are implicated in moulting process, we have:

- Discovered that the deiodinase enzymes which convert thyroxin to triiodothyronine (the active form of the thyroid hormone) are present and active in goat skin.

The potential importance of these deiodinase enzymes in regulating the moulting process is currently being studied.

Natural Heritage and Biodiversity Management

Semi-natural vegetation covers approximately 60% of Scotland. Existing methods of describing the condition of these habitats over extensive areas have been based on systematic surveys and have been very time-consuming and expensive. We have developed new rapid techniques for assessing the state of vegetation over large areas. The technique:

- Is based on a combination of carefully targetted field sampling and rule-based modelling to produce rapid impact assessments with a high level of accuracy.
- Assesses the impact of grazing and trampling on the basis of a number of field indicators – vegetation height, browsing damage, morphology, structure and intensity of trampling and erosion (Figure 2).
- Is being tested in collaboration with Scottish Natural Heritage and the Deer Commission for Scotland.

Integrated Land Use Systems and Policy Analysis

Agroforestry

Our research on agroforestry is designed to provide information on the consequences of introducing silvopastoral systems into upland livestock farms. Recent research has shown that:

- Silvopastoralism, especially with 400 trees per hectare, attracts species of birds normally associated with open

Figure 2. Assessment of grazing and trampling impact on heather moorland.

- fields e.g. wagtails and wheatears, and species usually found in woodland e.g. tits and finches (Figure 3).
- Silvopastoralism can therefore contribute to wildlife diversity on farms.

Livestock support payments

The new EC Rural Development Regulation will change support in Less Favoured Areas from headage payments on cattle and sheep to area payments, but there is a need to take account of land quality.

Based on data on land cover held by the Institute we have developed a system which would:

- Scale payment per hectare to account for quality of rough grazing.
- Avoid bias in relation to farm size.
- Allow flexibility in the system to allow land quality to be defined in other ways in the future e.g. environmental value.

Livestock and rangeland management in Central Asia

The countries of the former Soviet Union are undergoing economic and political reforms at different rates. As part of a multi-disciplinary international team of social and biological scientists, we have been studying the impact of these reforms on livestock and rangeland management in Central Asia. Using a systems analysis approach we have built a model of sheep systems, and identified some of the key biological and institutional constraints on the sheep sector (Figure 4). This has shown that:

- Winter nutrition is one of the key biological limitations to improving flock productivity.

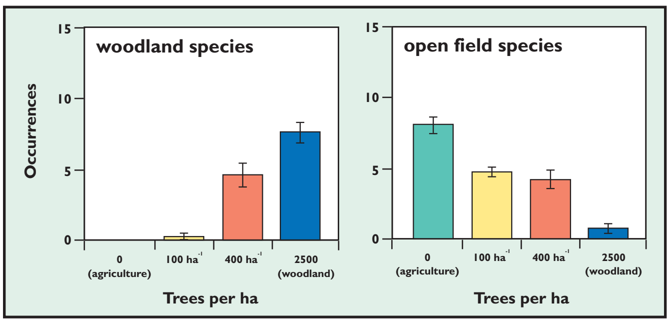

Figure 3. Occurrences of "woodland" and "open field" bird species in upland silvopastoral systems.

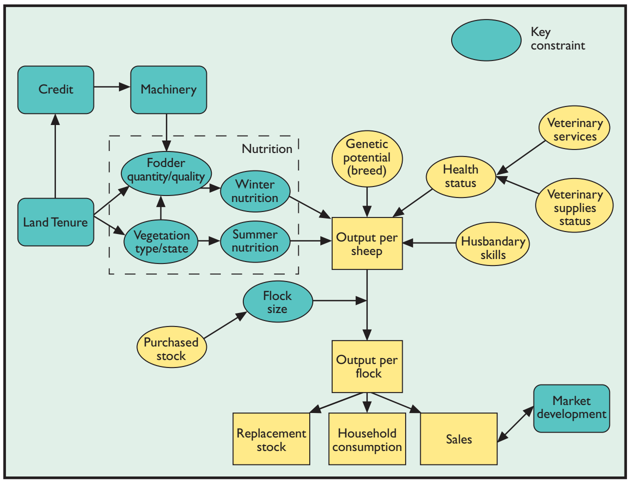

Figure 4. A model of sheep flock productivity in Kazakstan.

- Appropriate land tenure arrangements and rural credit facilities are crucial to the further development of sheep production.

The findings of this research are providing the basis for policy advice to donor agencies and the Government of Kazakstan.

Highlights

- Creation of new multi-disciplinary Integrated Land Use Systems Programme.
- Discovery of breed differences in sheep in response to exposure to humans.
- Discovery of deiodinase enzymes in goat skin with potential to alter the timing of the moulting of cashmere fibre.
- Development of rapid and cheap methods for assessing the state of upland vegetation over large areas.
- Agroforestry systems can enhance biodiversity in upland areas.
- Development of a new model of sheep flock productivity in Kazakstan.

Our research contributes directly to the work of the Scottish Executive by:

- Evaluating options for sustainable land use systems in Scotland
- Assessing the economic, environmental and social consequences of changing land use on farms and estates.
- Suggesting new ways of delivering policies in rural areas.

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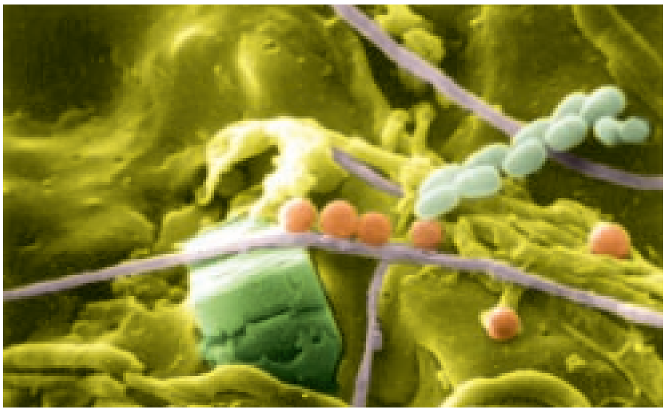
Soil Health and Microbial Diversity

Colin Campbell, Sue Grayston and Steve Chapman



Soils are central to the sustainability of our ecosystems, performing essential functions such as nutrient cycling to support plant growth, the attenuation and transformation of potentially toxic compounds and elements and the maintenance of biodiversity. The ecological functions of soil in turn depend on the maintenance of a healthy and dynamic community of soil biota. Soil and its biotic component has been described as "our most precious non-renewable resource" (Marshall *et al.* 1982) and linking the diversity of the soil biota to ecosystem functioning remains a key ecological question. It is important therefore that we develop the appropriate techniques to investigate links between diversity and function that can be used as indicators of soil quality and health. A number of soil microbiological parameters, notably microbial biomass carbon and basal respiration have been suggested as possible indicators of soil quality and employed in national and international monitoring programs. More recently, microbial diversity (community structure) has also been recommended as a biological indicator of soil quality.

At the Macaulay, new approaches and techniques of using microorganisms are being developed and evaluated for monitoring the health and quality of soil subject to a range of pressures, including land use change, pollution, waste recycling and soil erosion. We research both natural and productive agricultural and forest ecosystems in order to obtain a better understanding of soil microbial diversity and how it influences soil processes.

Soil microbial diversity and functioning

Although soil microorganisms perform many critical processes they vary in their functional capabilities and in many cases we do not know their exact roles. The development and application of new methodologies to characterise, isolate and identify soil biota has indicated that we have only scratched the surface of soil biodiversity. Using molecular techniques it has been estimated that 1.5 million fungal species exist, yet only 5% are described. Similarly, for bacteria there may be 300,000 to 1 million species on earth, yet only 3,000 are described. A typical gram of soil contains 1 billion bacteria, only 10% of which are culturable and there may be 4,000 different microbial genomes present (Torsvik *et al.,* 1990).

How do we measure diversity?

A fundamental problem with many traditional physiological and biochemical methods is that they depend on the cultivation of the microorganisms and/or the analysis of their phenotypic expression (e.g. respiration, enzymes, catabolic potential). Many microorganisms cannot be cultivated under laboratory conditions even when it can be demonstrated that they are metabolically active. In addition, it is not uncommon to get negative results using biochemical test kits due to low gene expression under the test conditions (Torsvik, Sorheim, & Gokosoyr, 1996). At present there are only two approaches that overcome this problem. These are the use of signature lipid biomarkers (SLB) and the nucleic acid technologies (molecular biology). SLBs such as phospholipid fatty acids (PLFA) are specific components of cell membranes that are only found in intact (viable) cells. A range of PLFAs can be extracted from soil that are indicative of major microbial groups e.g. fungi, Gram positive or Gram negative bacteria or actinomycetes. Changes in the PLFA profile therefore represent changes in the total soil microbial community. In most of these methods multivariate data (or fingerprints) are produced that are analysed by principal components (PCA) or canonical variate analysis (CVA) methods.

Over recent years a large amount of effort has been expended in developing nucleic acid methods (molecular biology). Applications of such techniques are relatively few and particularly demanding given the complexity and heterogeneity of soil. The range of methods is diverse but we can determine the degree of complexity of extracted soil DNA by its melting or re-association kinetics, DNA fingerprinting (Figure 1), or insert markers (e.g. *lux* genes for bioluminescence) to follow the population dynamics of

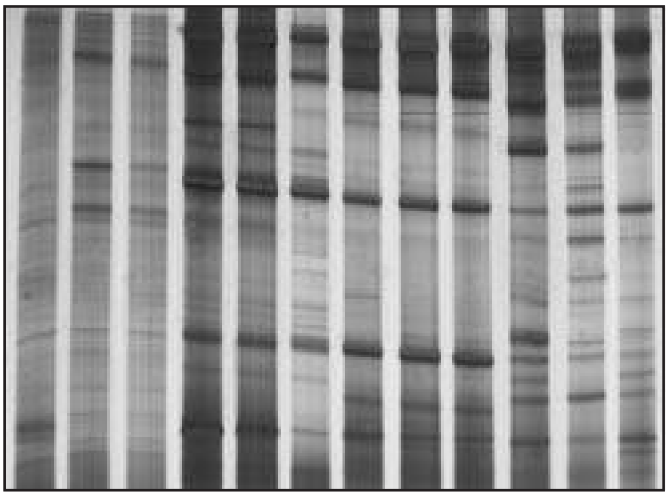


Figure 1. Genetic fingerprint using denaturing gradient gel electrophoresis (DGGE).

individual species. To date however, the molecular methods have provided primarily taxonomic information and have only targeted functional genes in a very few cases.

Other methods are available, however, to assess changes in functional attributes.

Community Level Physiological Profiles (CLPP), assessed using the Biolog system are a means of investigating the physiological diversity present in soils, because they reflect how the microbial communities can potentially utilise a range of carbon substrates. Differences in utilisation patterns are interpreted as differences in the major active members of the microbial community. The assay is based on measuring oxidative catabolism of the substrates to generate patterns of potential sole C source utilisation (Garland & Mills, 1991). This method uses multi-well plates (Biolog) that can test 95 different substrates simultaneously. We have developed the method to test C sources that are ecologically relevant to soil (Campbell, Grayston, & Hirst, 1997) and it has been widely used to examine communities from under different vegetation (Grayston & Campbell, 1996, Grayston *et al.*, 2000) and pollutant stress (Bååth *et al.,* 1998; Johnson *et al.,* 1998). The use of Biolog sole C-source test plates for testing oligotrophic soil communities has several potential limitations not least because the method primarily selects for a small proportion of the total community comprised largely of fast growing bacteria. We have recently developed modified procedures to examine acid soils and also use more recalcitrant C sources that are utilised by slow growing species.

The new methods have been used in conjunction with traditional techniques to examine a range of issues relevant to land use change and management and recent progress in this area is described in the following sections.

Impacts of land cover and land use change

The diversity of soil microorganisms is determined primarily by the vegetative cover but also by the climatic and soil conditions. Changes in land use will affect microbial diversity and so the balance between different microbial processes.

Marginal land use

One of the specific areas of interest to us is the sustainable management of marginal lands. These are characterised by having soils of low nutrient status and include upland pastures supporting natural and semi-natural grasslands, used mainly as grazing resources for herbivores. In these low input systems, soil microbial activity governs nutrient availability and hence plant productivity. Developing management strategies for these systems requires an understanding of the processes regulating soil nutrient cycling and how grazing animals affect these processes.

The growth of microorganisms in soil is generally carbon limited and is stimulated in response to plant inputs, in the form of litter, dead roots and rhizodeposition. Grazing animals can therefore strongly influence the interactions between vegetation and soils as a result of defoliation and excretal returns. Defoliation increases the efflux of C from roots through rhizodeposition and increased root turnover, affecting microbial growth, activity and the structure of rhizosphere communities. Excretal returns alter the availability of both nitrogen and phosphorus directly, and also as a consequence of impacts on soil physico-chemical conditions (e.g. pH).

Figure 2. Upland pastures in the Borders.

Much of the research arising from these issues is undertaken in collaboration with other Institutes and University departments under two national programmes. The first is a programme sponsored by SERAD, coordinated by ourselves, called MicroNet (http://www.scri.sari.ac.uk) featured in last years Annual Report. The second relates to our involvement in the NERC Soil Biodiversity Programme.

MicroNet

This programme, involving MLURI, SCRI, SAC and Aberdeen University aims to quantify the spatial and temporal diversity of soil microbial communities beneath a range of characteristic grassland types with different degrees of management intensity and soil fertility, at ten sites throughout the UK. This is a unique programme, of international significance, because it is developing and applying a wide range of molecular and physiological techniques to the same soil samples. The grasslands range from the extensive, unimproved, *Festuca-Agrostis-Galium* grassland (National Vegetation Classification (NVC – U4a), through the semi-improved, *Festuca-Agrostis-Galium* grassland, *Holcus-Trifolium* sub-community (NVC – U4b) to the improved, intensively–managed *Lolium-Cynosurus* grassland (NVC – MG6). In addition to the increasing fertility gradient from the extensive to the intensive grasslands there is a gradient of grazing pressure, being lowest in the extensive and highest in the intensive grasslands. Soil microbial communities from these grasslands have been characterised using PLFA (Figure 3), DNA reassociation kinetics, NA (nucleic acid) hybridisation, 16S rDNA analysis, DGGE and CLPP. We have shown that soil microbial biomass increased as soil fertility decreased, moving from the improved to the unimproved grasslands. This was accompanied by a shift in microbial community structure with an increase in the proportion of fungi relative to bacteria in the unimproved grassland. The relative abundance of soil bacteria measured as numbers of culturable bacteria and bacterial PLFA were significantly higher in the improved grasslands. In contrast, the numbers of culturable fungi and fungal PLFA were higher in the unimproved grassland and the bacterial:fungal PLFA ratio was significantly lower in the semi-improved and unimproved grasslands (Grayston *et al.*, 2000).

In addition, differences in livestock grazing pressure on the grasslands are also likely to greatly alter substrate supply to soils, with increased soil substrate supply from animal

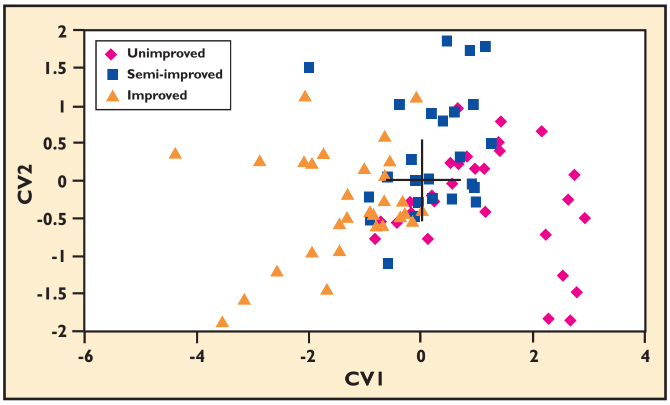


Figure 3. Plot of multivariate analysis of PLFA profiles across grassland types.

excreta and detrital pathways in heavily grazed grasslands. We have shown that regular defoliation of grasses decreases soil microbial biomass due to changes in rhizosphere carbon flow and urine addition changes microbial community structure, favouring bacteria. In a NERC funded initiative with Aberdeen University and the Natural History Museum novel molecular techniques are being used to quantify the activity and distribution of ammonia oxidisers and the ammonia monoxygenase gene in grazed pasture soils. This is providing us with a unique opportunity to relate the activity of different nitrogen transformation processes to microbial community structure. The rRNA probes to ammonia oxidisers and the functional genes involved in nitrification (ammonia monooxygenase) and probes to organic phosphorus mineralisers being developed on the MicroNet Project also with Aberdeen University, are envisaged as being used as molecular indicators of soil health.

NERC Soil Biodiversity Programme

As part of the new NERC Soil Biodiversity Programme (http://www.nmw.ac.uk/soilbio), whose aim is to identify the diversity and functional roles of the soil biota, we are assessing the biodiversity of invertebrate root feeders and their impact on soil microbial community structure and activity (Figure 4).

The aims of this project, which involves MLURI, IGER and Royal Holloway College, University of London, are to characterise the temporal and spatial diversity of insect and nematode root feeders in pastures of varying management

Figure 4. Tipulid (leatherjacket) larvae feeding on clover roots.

intensities. In microcosm studies the impact of root herbivory on rhizosphere carbon flow is being quantified and the effect of this carbon flow on microbial diversity and activity is being assessed using the techniques described above. In addition, the interactions between roots, arbuscular mycorrhizal fungi, root herbivores and microbial communities are being investigated to assess how arbuscular mycorrhizal fungi affect root herbivory. Application of ^{13}C labelling of biomarkers has shown its potential to directly link microbial populations to specific biogeochemical processes. In collaboration with ITE, Merlewood, we have used this technique to study the impact of shoot defoliation (simulated by clipping) on rhizosphere carbon flow and its incorporation into soil microbial communities. This was achieved through application of ^{13}C pulse-labelling to grass swards in the field (Figure 5), which were clipped immediately after labelling, or remained unclipped. This was followed by GC-C-IRMS (gas chromatography-combustion-isotope ratio mass spectometry) of phospholipid fatty acids (PLFA) extracted from the soils, to assess which members of the microbial community were metabolically active, responding to the change in carbon flux.

Figure 5. ^{13}C application in field at Sourhope.

The interactions between root herbivores and the macro- and microflora is a hitherto under-researched, but important aspect of nutrient cycling in soil. This work will substantially extend the knowledge in this area and will provide information which will enable the impact of pesticides and other perturbations to be evaluated, not only on the effects on the invertebrates but on the soil system as a whole. Ultimately, the findings will assist in decision making and formulation of management guidelines for the advisory and farming communities.

Afforestation

Peatland soils that accumulate C and act as a net sink for greenhouse gases such as carbon dioxide may switch to ecosystems that produce a net loss of C if trees are planted or allowed to re-colonise and drain the land. Soil microbial communities in soils undergoing afforestation or expansion of native pine woodland are being assessed in field experiments at Glensaugh, Fetteresso and at Abernethy Forest (co-sponsored by Scottish Natural Heritage). At Abernethy natural pinewood regeneration is encroaching on open moorland (Figure 6). At Abernethy the community level physiological profiles (CLPPs) showed distinctly different microbial communities in the moorland area adjacent to the Scots Pine Forest itself but no change as yet in the intermediate bog area that has been colonised by seedlings. The interpretation, in terms of carbon substrates utilised, was difficult but it was noted that abietic acid, a conifer tree exudate, exhibited a significant increase in utilisation towards the forest end of the transects from moorland to forest. Phospholipid fatty acid profiles (PLFAs) gave a clearer separation of moorland from forest (Figure 7), due partly to a lower bacterial PLFA content in the forest, i.e. the fungal:bacterial ratio increased under the trees and this may be an indicator of switch from C sequestration to increased C release.

Figure 6. Laying out transects at Abernethy forest.

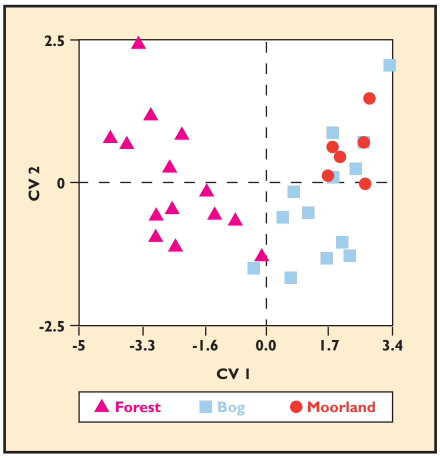


Figure 7. Plot of multivariate analysis of PLFA profiles obtained on transects from tree, bog and moorland at Abernethy.

Land degradation in China

The evolution of microbial diversity in degraded red soils of China that are undergoing improvement for agricultural production are also being studied in collaboration with the University of Zhejiang (Figure 8). Red soils are generally acidic with low organic matter and a high ferric oxide content such that their fertility is often low. These studies have shown the strong link between organic matter inputs and microbial biomass and community structure but we also discovered some unusual physiological profiles in soils under tea bush plantations. Tea bushes are known to produce exudates and litter that are inhibitory to microbes and that also strongly acidify the soil.

Figure 8. Eroded hill slope soils in China.

The microbial diversity of degraded soils of the Southern uplands of the Yangste river are also being investigated in a collaborative project with the Institute of Soil Science, Nanjing, funded by the Royal Society. Inter-cropping of citrus trees and wheat are being used to stabilize the hill slopes and provide a more sustainable system that reduces erosion and the subsequent sedimentation of the river (Figure 9). The diversity of microorganisms associated with these different land uses and their effect on aggregate stability is currently being investigated.

Figure 9. Inspecting experimental plots on hillslopes in Three Gorges area of Yangtze River.

Waste recycled to soil

The application of organic wastes to soil as a recycling option can only be sustained if there are demonstrable 'ecological benefits'. Ecological benefit is usually justified in terms of elevated organic C and its effect on soil conditions and stimulation of microbial activity and nutrient supply but this is only sustainable if threshold levels for pollutants such as potentially toxic elements (PTEs) and persistent organic pollutants (POPs) are not exceeded. Like most organic wastes, sewage sludge is highly variable in content and long term effects are difficult to predict. There are maximum permitted metal concentrations in soils, laid down in UK and EC Directives. More recently the UK Government advised that the total limits for zinc and cadmium should be reduced. These reductions were based on evidence presented on the potentially harmful effects of heavy metals on soil microbial functioning and long-term soil fertility. We are now using microbial community analysis to determine the safe limit for sewage sludge applications to land. In a field experiment at Hartwood different sludges, rich in different heavy metals, have been applied.

The Biolog CLPP method showed that just after sludge was applied there was a large and dramatic effect on the microbial population irrespective of what type of sludge was applied (Figure 10a). One year later, however, the effect of the sludge alone had declined and there appeared to be changes in the populations that were associated with the sludge metal content (Figure 10b). Clearly metal content has selected different microbial populations that could eventually affect the functioning of the soil. When PLFAs were used to test the soil they also showed that metal induced population shifts had occurred and specifically some fungal PLFA markers had been reduced. These effects were apparent even though there has been no reduction in the size of the microbial biomass and suggests that the new methods are more sensitive. The importance of the results are that these changes have occurred at levels of heavy metals close to their respective limits and these changes have been recorded much sooner than expected.

Assessing the health and recovery of polluted soils

It is often assumed that soils with the greatest diversity of microorganisms may be the most resilient to pollutant

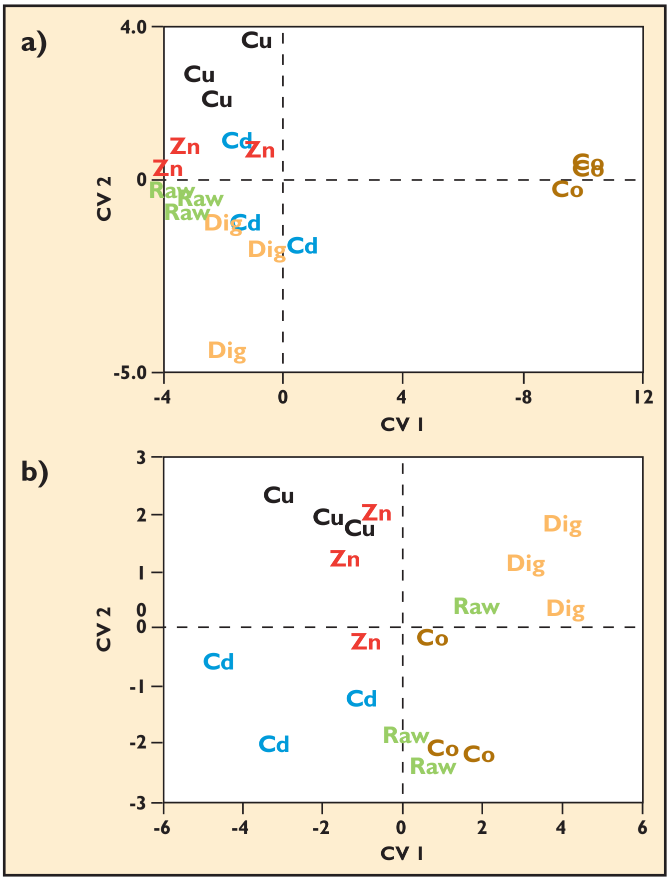


Figure 10. Multivariate plots showing affect of either uncontaminated, digested or raw sludge, and sludge rich in either Cu Cd or Zn a) immediately after application and b) 18 months later.

stress. This is a difficult question to answer because the soil properties that influence diversity as they increase (e.g. organic matter, pH, texture) also influence the bioavailability of many pollutants. It is important therefore when studying the effect of pollutants on diversity to measure their availability at the same time. Bioavailability can be measured using *ex situ* bioassays. This type of bioassay, employing single species, are routinely used to monitor direct toxicity of waters and effluents because they are sensitive, inexpensive, rapid and simple compared with chemical analysis. We have developed similar approaches for soil using organisms exposed to extracted soil pore waters (Campbell *et al.,* 1997; Paton *et al.*, 1997). One method that is very useful is to use bioluminescent organisms. Bioluminescence, the emission of light by living organisms, is a natural phenomenon found in several animals, insects, fungi and bacteria. The bioluminescence is proportional to metabolic activity so that measuring light output can be a simple, fast and sensitive way of detecting potentially toxic conditions in samples. The *lux* genes that code for bacterial luminescence can be inserted into soil bacteria that do not normally exhibit this phenomenon. The construction of a new genetically modified microorganism, by inserting these genes, can be divided into two categories; non-specific metabolic and specific promoter induced biosensors. In the former the light level is proportional to activity and any reduction in light output is indicative of stress on the organism. In the latter the *lux* genes are fused to promoter genes such as catabolic genes such that light output is switched on in the presence of the promoter e.g. a pollutant (Figure 11).

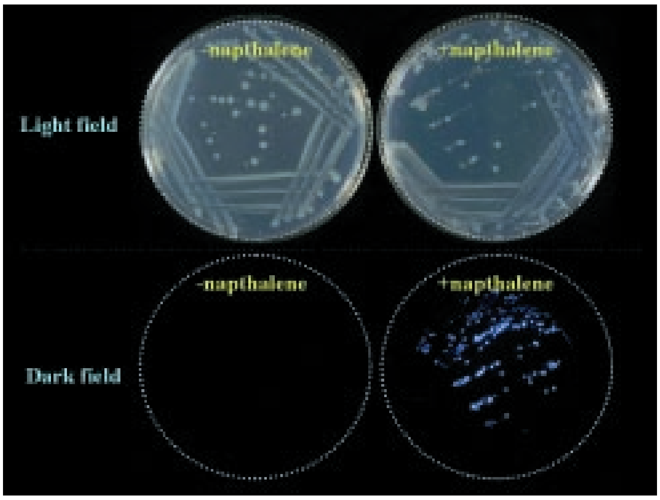


Figure 11. Colonies of the a biosensor bacterium growing on agar viewed in the light and dark. The blue luminescence is switched on only in the presence of pollutant.

Metabolic biosensors are being used to assess Cr toxicity at chromium-waste dump sites in Glasgow (Figure 12) in a collaborative project with the University of Edinburgh, SURRC (Scottish Universities Research Reactor Centre), EOSWA (East of Scotland Water Authority) and the environmental consultants, Dames & Moore. The project is funded by NERC under the URGENT programme and aims to evaluate and predict the efficacy of remediation practices. Community analysis and biosensors are also used to assess the potential ecological risk associated with such sites.

Several different types of promoter induced responsive biosensors are now available including organisms responsive to the types of compounds found when soil is polluted by oil. In conjunction with the University of Aberdeen we have tested both metabolic and catabolic sensors for monitoring oil pollution (Bundy *et al.*, 1999). Catabolic biosensors responsive to salicylate, isopropylbenzene, and octane were tested against three metabolic biosensors for monitoring crude oil pollution. In this study the metabolic biosensors showed toxic responses to the initial pollution by the oil that declined over time while the promoter induced biosensors responded positively to the presence of hydrocarbons throughout the remediation period. This positive response declined, however, over the 120 days of the study as the hydrocarbons were attenuated in the soil

Figure 12. Sampling Cr contaminated site in Glasgow.

showing such processes can be followed successfully using microbial biosensors. In the same study, oil pollution of three different soil types and three different oil types were studied using microbial community analysis. These experiments showed that similar microbial communities developed irrespective of the type of oil contamination but that the communities associated with the different soils were still distinct even after 14 weeks of oil contamination.

Conclusions

The analysis of microbial communities is potentially a sensitive way of detecting changes in soil functioning and could therefore be employed to evaluate the effectiveness of soil protection policies. The techniques may therefore be useful to environmental monitoring agencies as well as provide insight into ecosystem functioning. However, the ability to say that change *per se* is associated with a loss of function or ecosystem harm is not always unequivocal with existing techniques that determine only structure such as PLFAs or DGGE. Other techniques which measure functional attributes e.g. CLPP can show functionality has been affected but the current methods based on sole carbon source utilisation have other methodological limitations which mean they reflect only a portion of the community and only potential functions rather than actual functions. Further methods (e.g. functional genome analysis) that reflect the broad spectrum of functional diversity in soil microbial communities and that also include the contribution of fungi are therefore needed and will be developed within our new programme and in a new joint initiative with the University of Aberdeen.

Soil Health Initiative

Our successful collaboration with the University of Aberdeen in this area, coupled with the need to obtain further information on the other pressures on soil such as pathogens and also to further understand the role of fungi has led to the establishment of a new joint initiative. This £0.85m initiative in Soil Health is between the Macaulay and the Departments of Plant & Soil Science and Molecular & Cell Biology at the University of Aberdeen. The initiative aims to build on existing expertise in Aberdeen to tackle a range of soil health issues and in particular to develop new approaches for studying the role of fungi. Fungi are an integral part of the microbial community and can be particularly important in the highly organic and acid conditions that prevail in Scottish soils as several of our previous studies have shown. The initiative has four main research themes:

- Rhizosphere engineering (manipulation and monitoring of soil microbial and specifically fungal diversity and community structure around plant roots).
- Degradative processes in fungi (the diversity of lignocellulolytic fungi).
- Fungal biosensors (*lux* reporter gene marking of soil fungi to generate biosensors for a range of environmental diagnostics).
- Pathogens in the environment (detection, survival and movement of human pathogens in soil and in organic wastes applied to land).

The soil health initiative directly employs four research fellows but has already been successful in attracting Scottish Office funding for further research into the persistence and transport of *Escherichia coli* 0157 through soils.

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New Developments in Forecasting Land Use Change

Alistair Law, Dick Birnie and Alan Sibbald

The British countryside has been and will continue to be shaped by changes in land use. These changes reflect social, economic and technical pressures but may have significant impacts on the environment (e.g. increased pollution) and the delivery of other public goods (e.g. in terms of amenity or recreation). In the past, the delivery of these public goods was a by-product of land use systems that were predominantly for production of food and fibre. However, because the production of public goods is not currently rewarded through a market system, there is no market mechanism to reward land managers for providing them. The role of much current agri-environment policy is to address this market failure and to ensure a new balance between the production of food and fibre on the one hand and the production of public goods on the other.

There are therefore a number of factors that will drive land use change in the future. At their heart lies this critical balance between private economic good and public environmental good. Striking this balance inevitably depends upon the interaction of market forces, social conditions, and the level of government intervention. The critical question is whether we can ever hope to forecast the likely trends of land use change with sufficient confidence to provide insight as to the consequences of policy implementation? Forecasting land use change is quintessentially a multidisciplinary problem since it involves the co-evolution of socio-economic and biophysical systems. Forecasting land use change requires both new ways of thinking and new approaches to the modelling of such coupled systems.

How to forecast?

Physical and biological science has provided us with both a metaphor for the way the world works and a method for investigating it. The metaphor is broadly a physical-mechanical one and the method is that of testing hypotheses through replicated experiments. But neither this worldview nor the approach is embraced by social scientists. Their approach recognises the critical importance of values and beliefs in moderating human behaviour and is consequently a more descriptive but no less analytical one. There is however a fundamental difference in these epistemologies when it comes to the issue of forecasting. The positivist view, often identified with the physical sciences, is that of an *a priori* given world. On the other hand the transactional or constructivist positions held by many social scientists are based upon the dynamics of interaction between man and the environment.

Land use change happens at the interface between human and biophysical systems. One scientific tradition suggests that it is predictable; another that it is not. There is clearly a cross-disciplinary challenge here. Further we recognise that it is not possible to conduct experiments in the conventional sense (we cannot replicate people!). It is our belief that we can address these problems by drawing on recent developments within research on complex systems, specifically agent-based simulation modelling.

Land use change

Rural land use change

Whilst land use change is a well-recognised phenomenon in both urban and rural settings, we are particularly concerned with rural land use change. This change can manifest itself in several ways:

1) as a physical change associated with a conversion of land from one use to another (e.g. grassland replaced by trees; a change from agriculture to forestry);
2) as a physical change which is associated with a change in the land use management practice itself (e.g. the introduction of new crop rotations);
3) and as a change in the number of purposes to which the current land use pattern is put (for example a sporting or recreational function may be added to an area already used for arable cropping). This, importantly, recognises the significance of multiple land use systems.

Drivers of land use change

We are specifically interested in the factors that influence rural land use change in Scotland. Scotland's national economy can be described as being post-industrial in the sense that both the primary and the heavy industrial sectors are now less important than the manufacturing and service sectors. So whilst agriculture and forestry utilise most of the land area their economic importance is declining.

Economic trends. Agriculture and forestry are the major land uses in rural Scotland and so their managers determine the overall pattern of land use. The terms of trade for the food and fibre they produce are set within the context of EU and global markets both of which involve complex regulatory and support intervention. Both land uses are therefore buffered to an extent from market forces, which would otherwise induce structural adjustment. The principal economic pressure for change, at present, comes from adjustment to the level of public subsidy set by UK and EU governments and, within Europe, the relative values of the pound and the euro. But in a recent analysis of the agricultural industry of the UK, McInerney (1999) concluded that changes in the policy structures that have surrounded agriculture for a long time are not the primary instruments that will determine future change in agriculture. Rather it is low growth in product demand and downward pressures on prices that will determine change. The future of forestry will depend upon timber prices which in turn will depend on global supply and demand trends. It will also depend upon the level of grant support or change in fiscal arrangements made in relation to the perceived recreational and landscape value of forestry or, for example, the role that it may be deemed to have in its contribution to the global sequestration of carbon. Consequently, while they are currently protected from market forces, agriculture and forestry are highly exposed to pressure for change from the political process through which public subsidy is provided.

Economic pressures are, however, modified at the level of the individual management unit (a farm or forest, for example). Decisions to change land use at this level will be influenced by other, unit-specific economic factors such as profitability, scale of enterprise or level of indebtedness. There are also locality-specific factors such as opportunities to diversify (e.g. bed and breakfast) or to find convenient, off-farm employment. Patterns of land use change are therefore dependent upon the interaction of global, local and unit-specific economic factors.

Social Trends. Social trends impact both directly and indirectly on rural Scotland. Surveys of rural life in mainland Scotland have shown that the rural population is growing. This trend reflects choices, made by highly specific groups in terms of their socio-economic class and age, to live in the countryside. But the aspirations they bring with them will create a quite different balance of belief systems in rural communities, with respect, for example, to property rights and pressures on service provision. These trends result in a strong spatial differentiation in social influences between different parts of rural Scotland.

Social trends also impact on rural Scotland indirectly. Much of the Scottish population is urban, with an increasing interest in the use of the countryside for recreational and sporting pursuits as well as having an increasing appreciation for its natural and cultural heritage values. These interests are translated into influence through membership of conservation organizations and are reflected in legislation, e.g. Wildlife and Countryside Act (1981), the setting up of SNH and SEPA, and the current draft Scottish Parliament Bills on Land Reform and National Parks.

Rural land use can no longer be considered in isolation from the widening range of interested parties and in particular the increasing influence of the urban population. These and the agendas of the major charity-based conservation groups such as RSPB and the John Muir Trust are likely to have a significant bearing in setting the legal and policy contexts for future patterns of land use change.

What does this mean for forecasting models?

This brief review of the drivers of land use change has highlighted the following:

1) that change is strongly conditioned by market trends for primary food and fibre products and by government policy which is itself influenced by a wide community of interests;
2) that there is also a strong local dependency, which reflects not only the strength of the individual business but also that of the local economy;
3) that change will not be uniform either regionally or locally;
4) that future changes may be driven progressively less by profit and more by consideration of quality of life, environmental impact or public good;
5) that any change away from profit objectives will be reflected in those who are motivated to buy land thus changing the population of land managers;
6) and that wider social trends will be reflected in changes to the institutional, planning and policy framework.

We recognise that we cannot hope to model all of these individual components in detail. However, since we recognise the importance of this complexity, we should factor it in to our modelling approach rather than assuming it does not exist. In a general sense we are adopting the same approach as JS Lowry did to his painting: that it is by using simplified objects within a landscape that we can focus on the relationships between them. By doing this we reduce the individual detail but retain the essence of a complex web of interactions between agents of different types, with different motivations, and which all influence the overall picture.

Modelling of change process

The aim of this section is to illustrate some examples of our land use change modelling work. These illustrate the importance of human agency in the land use change process and describe how we are building towards a modelling framework that will allow us to explore potential land use changes by adopting an approach that simulates the interactions of these agents directly.

Illustrating the effect of agency in land use change

Generally models of land use change are based upon assumptions concerning biophysical possibility and economic rationality (Golledge and Stimson, 1997). We accept that the behaviour of a population of "agents" which affect land use change may not conform to these assumptions and if other non-specific (and specific) behaviour effects are significant then the value of any rational or normative approach to modelling land use change may be greatly reduced.

In order to test the magnitude of this effect a case study was conducted on the pattern of afforestation in Grampian Region between 1977 and 1988 (Aspinall and Birnie, 1998) using an inductive modelling approach based upon Bayes Theorem (Aspinall, 1992). This examined the relationships between the actual pattern of forestry and bio-physical factors (e.g. soils, elevation, mean annual temperature, mean annual rainfall) in 1977 and re-expressed these in terms of statistical probabilities of afforestation.

Based on an assumption that what happened in the past will happen in the future, it is possible to use the relationships learned from the 1977 distribution to identify/forecast those areas with a high probability of afforestation (Figure 1a). To test the success of this model the actual patterns of afforestation from 1988 were overlaid on the model output (Figure1b).

The results showed that whilst the actual patterns of planting were generally consistent with those areas identified as having a high probability of afforestation there was

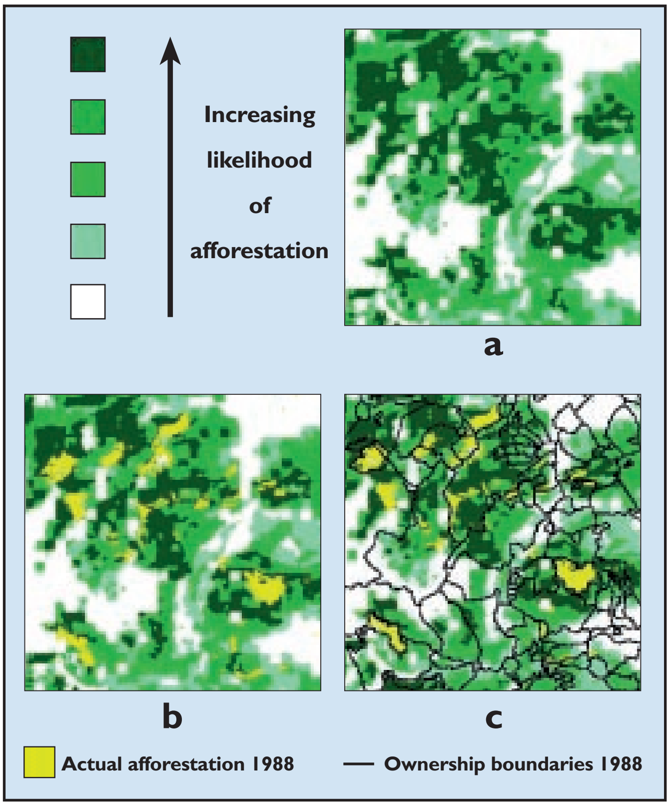

Figure 1. Bayesian model of afforestation.

considerable local variability. Overlaying the land ownership boundaries explained much of this local variability. (Figure 1c). Whilst this study illustrated the power of the Bayesian approach to modelling change, it also highlighted the significant effects of the individual manager in moderating these changes.

The next question, therefore, is whether we can develop a reasonable explanation of an individual's land use choices?

Modelling with individuals

This section describes the potential roles of a farm-level model for assessing the range of feasible land use options available to land managers under a wide range of different scenarios. Its use in the context of forecasting land use change is to identify feasible sets of land use change pathways. These can be explored using different assumptions about the nature of the decision-making strategy employed.

The Land Allocation Decision Support System (LADSS) is a strategic, GIS-based model for whole-farm planning, including grazing systems, arable systems and woodland. It predicts economic, social and environmental outcomes of changes in the allocation of land resources to different uses (Figure 2).

The requirements to make changes in the allocation of land

Figure 2. Example of a land allocation plan and annual labour profiles showing available farm labour. The profile shows when additional labour must be employed and when there are opportunities for farm labour to seek off-farm employment.

at the whole-farm level requires a spatial description of a farm's resources so that appropriate land uses may be allocated to individual fields. It also requires a set of enterprise models which can calculate the suitability and yield of a wide range of land-use enterprises such as livestock, forage, arable and woodland systems. There is also a need to evaluate the labour requirements of any pattern of land use across the farm as well as its impact on landscape ecology and the environment. The potential complexity of such a wide range of land uses and impacts interacting with the range of individual fields on a farm requires that an optimising system capable of finding satisfactory multiple-objective solutions be developed. It is for this purpose that LADSS is being built. It integrates a Geographic Information System (GIS), a simulation system and a multiple-objective optimising system based on the use of genetic algorithms.

Uses of LADSS. In a decision support mode, LADSS could be used by land managers, government department officials and non-government organizations to agree, for example, upon mutually acceptable land-use plans and appropriate levels of subsidy on a farm by farm basis.

In a research mode, LADSS will be used to run experiments over a range of farm types and land manager typologies. Farms types will cover ranges of farm size, production potential (soil and climate), location (remote rural to peri-urban) and structure (range and scale of land-use types currently practised). Farmer typologies will reflect, for example, the range from entrepreneurial to risk-averse behaviours, and their personal circumstances varying from whether, for example, they are pre-retirement tenants with no successors or owner-occupiers with successors already studying at agricultural college. Land managers will then be asked to select the land-use pattern which is most suitable for them and to give reasons for their decision. The outcomes of the experiments will provide understanding that can be incorporated into modelling with many individuals. Examples of useful outcomes of this approach are:

- the potential to simplify the range of farm types that needs to be considered;
- an understanding about the likely range of viable, alternative land-use patterns that may need to be represented for each type of farm;
- the basis for an effective classification of farmer typology;
- provision of understanding of the nature of decisions that may be made (a tendency for one type of farmer to consolidate the current farming system or another to diversify into new systems);
- an indication of the parameters which farmers use to make these decisions, for example;
    - economic decisions may be based on expected level of indebtedness on cash flow or on internal rate of return on capital invested;
    - social decisions may be based on full employment for the farm family or on part-time employment so that other local job opportunities may be exploited;
    - and environmental decisions may be based on the view from the farmhouse or on the protection of a single charismatic species.

Modelling with many individuals

The individual land users we are modelling are part of a larger environment that contains many other actors. Actor is the term used to represent the individual entities, which can include individuals, institutions and organizations, that make up the social environment we are investigating. It is the behaviour of these actors that is modelled by the agents in an agent-based simulation. This is the regional or national land use system and modelling at this level requires consideration of many interactions between the actors present. These actors can represent organizations at many different levels from individual farm households through special interest groups to governments. A modelling approach is needed that can tackle this level of complexity without sacrificing relevant detail.

The relatively new area of science covered by complex system theory addresses exactly this sort of problem. In a complex system the component actors interact to create emergent properties that cannot readily be deduced from the rules of behaviour of individual actors but can often be discovered by simulation. A well-known example of this is the flocking behaviour of birds. The interactions between the actors are very important. It is proposed that the behaviour of the system is an outcome of these interactions and not the detail of the actors themselves.

One approach to address this issue arises from complex systems and uses agent-based simulation. In this approach the interactions between agents at one organizational level are the important factors that create the structure and behaviour of the system at higher levels. A further benefit of agent-based simulation modelling is that space can be represented in the modelling framework and the ways in which physical distance between actors affect emergent behaviour can be investigated. The effects of other relationships between actors can also be investigated such as social distances resulting from the creation of formal and informal networks of actors. An example where both these factors are present is the emergence of machinery rings within Scottish farming communities where both physical distance and social relationships will effect their development and structure. Simulation models track the detailed interacting behaviour of the actors through time and any time-dependencies of emergent behaviour can be seen.

The **FEARLUS** (Framework for the Evaluation and Assessment of Regional Land Use Scenarios) model is one example of an agent based simulation that is being developed to improve understanding of land use change. It uses the SWARM agent based modelling environment developed at the Sante Fe Institute (Langton *et al.*, 1999). This has all the features needed for developing the FEARLUS models giving a fully spatial representation and allowing the creation of models with more than one organizational level.

The current FEARLUS model consists of a set of simple decision-making agents, the land managers, and their environment, which is divided into the regional environment and the external environment. The regional environment is simulated as a rectangular grid of Land Parcels. The model has an internal representation of the biophysical characteristics of the land parcels, which do not change with time, and a representation of the temporally varying

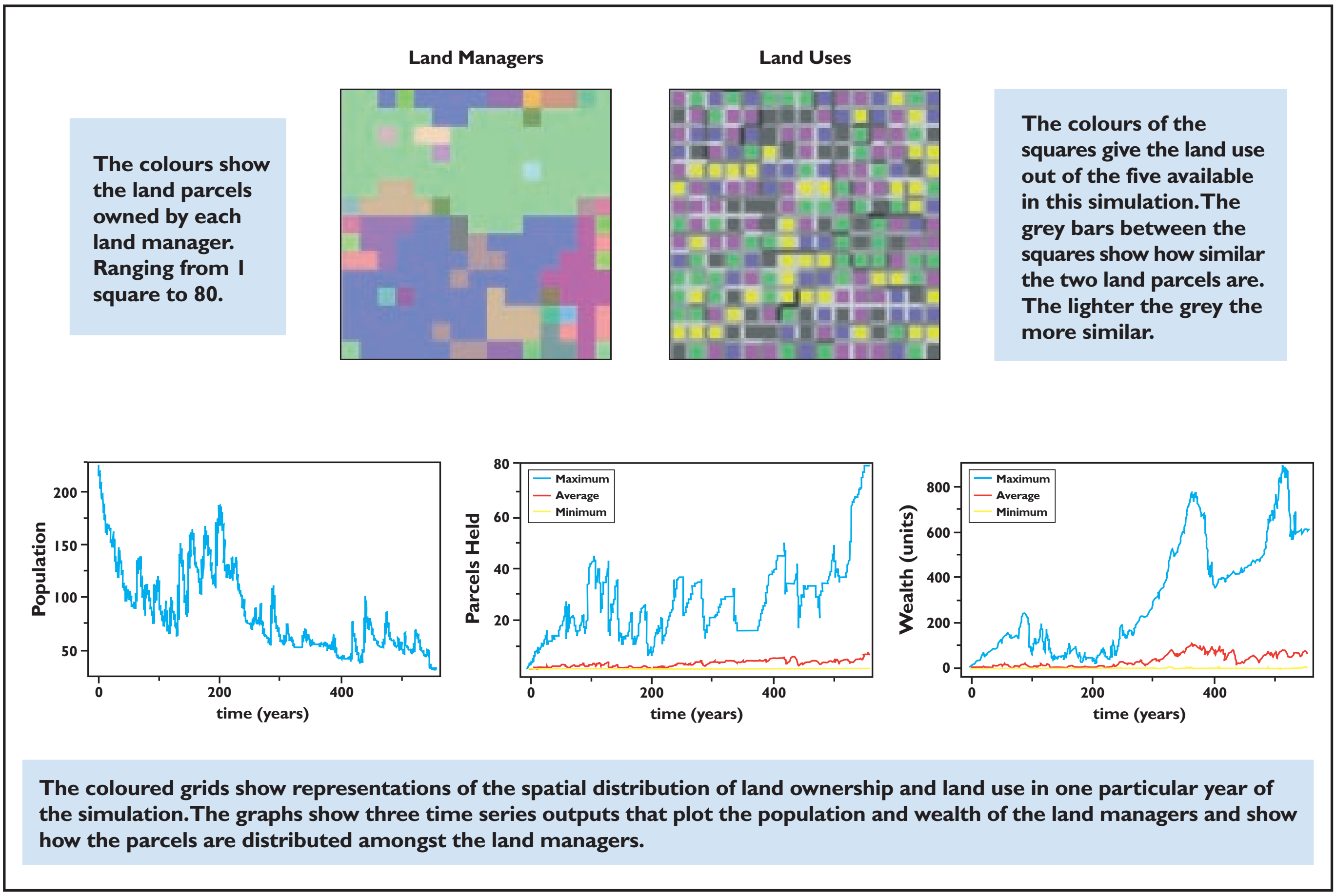

Figure 3. FEARLUS model.

external conditions (which do not vary across land parcels). A set of possible land uses is also represented and the economic return from a given land parcel assigned a given land use is evaluated by matching the representation of the land use with those of the land parcel and external environments (Figure 3).

The focus of our research is on the links between the actors involved. Using agent-based simulation to model these links provides a way of modelling the whole system's response to the drivers of change. This form of modelling provides the opportunity to investigate the non-linear nature of change processes that can be very difficult to tackle by other methods. It is the fact that the interactions between the agents, representing both individuals and organizations, create responses in the system as a whole that are not predictable from the behaviours of the individual agents, that gives power to simulation models of this type. For example, the model of Balinese water temple networks (Lansing and Kremer, 1994) recreated a managed agroecosystem that was almost identical to that the Balinese had developed for themselves. This made efficient use of limited water resources to maximise crop yields. This model system demonstrated an interesting emergent property which was the system's ability to recover from external perturbations such as low rainfall or high levels of crop pests.

The models created in the FEARLUS project will inevitably be simplified representations of the real world and will need to be validated to ensure that forecasts made using such models are a good representation of reality. To that end the modelling effort in FEARLUS will help direct the data collection efforts in other parts of the research programme to create a body of detailed historical knowledge of land use change against which our models can be tested.

FEARLUS models are by their nature designed to help extract trends in land use change and not to give precise prediction of what will happen where. By tackling the problem in this way the FEARLUS approach will aid definition and implementation of policy by illustrating likely paths of future change and by indicating what instruments might be effective in driving this change towards desired outcomes. In regular use, the models would be further constrained by the actual change experienced in the real world giving even better indication of the likely trends. Models of this type have considerable scope for tackling the complex issues raised by the drivers of land use change discussed earlier and some examples of their implementation are summarised in Table 1.

Conclusions

We have described here some of the components of our research aimed at gaining an understanding of land use change. Our longer term aim is to provide tools that will help in forecasting trends in land use change. Alongside the examples discussed in this paper we have a research effort developing mathematical models of land use and will shortly be starting new research developing case studies of land use change to highlight the processes that have driven change in chosen study areas. Many of the processes involved are by

Land reform	Legal frameworks can be implemented as constraints on the behaviour of actors.
Non-productive land use	Actor type can be easily defined to be more or less dependent on the land uses for their economic survival.
Lifestyle	Actor types can be defined to have different behaviours under otherwise identical circumstances. It is also possible for these behaviours to be learnt or to evolve over time.
Trusts	Actors that are organizations are part of the model development and can have their own specific constraints and behaviours.
Environmental change	The environment is explicitly represented in the models as inputs that can vary over both time and space. The level of detail of its representation will depend on the needs of particular models.
Technological change	The modelling system allows for the introduction of arbitrary or systematic changes to model parameters. This would allow technological change to be represented in terms of a change in the input/output relationships of the land uses that use that technology.
Planning policy	This would be implemented as changes in the constraints on the behaviour of the agents in the model at all organizational levels.

Table 1. Examples of the implementation of drivers of change in agent based models.

nature the result of interactions between people. Our colleagues from the Arkleton Centre for Rural Development Research at the University of Aberdeen will bring their understanding of social processes to assist this programme. In all the research areas we will have to investigate the sorts of data we will need to make the models we create useful and be able to validate their outputs. An incremental approach to developing models that allows us to understand the processes and how they are modelled will allow us to demonstrate the potential of the techniques without being constrained by either specific data or a particular theoretical framework.

By linking this range of approaches we will be better able to recognize the strengths and weaknesses of each and be able to choose appropriate techniques to answer the questions we have about land use change. The work covers many disciplines and brings together researchers using very different approaches. This will provide an environment that will allow the development of a strong interdisciplinary base to tackle the difficult questions that do arise in the complex domain of land use and land use change.

Acknowledgements

We would like to acknowledge the contibution of our colleagues in the LADSS and FEARLUS projects: Keith Matthews, Kevin Buchan, Andy Dalziel, Mike Rivington, Joanne Tapping, Nick Gotts and Gary Polhill for their work that is described in this paper.

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How and Why Do Animals Make Foraging Choices

Glenn Iason and Iain Gordon

This is an important question in relation to the use and management of pastoral lands throughout the world.

In order to survive, grow and reproduce, animals are faced with choices on how to acquire and allocate resources, displaying considerable variability in foraging behaviour and digestive processes both within and between species. The food choices made and the amount ingested and digested determine the animal's impact on its environment, whether its prey is plant or animal. In the course of food selection, animals may be faced with food items encountered one at a time, in which case their decision is to either eat or reject each item. An alternative scenario to this essentially binary decision would be when simultaneously faced with a series of food items, from which one or more must be chosen. The duration of daily foraging time, frequency of feeding or the amount eaten per time are of major significance to the animal, but are also determinants of the animal's overall food intake, and hence impact on the environment. But what are the processes by which animals arrive at these decisions?

Evolutionary background

The consumption of food is one of the most fundamental activities of all animals, including livestock and humans. Evolutionary theory tells us that the ultimate goal of animals is to maximise the proliferation of their genes primarily via production of offspring. An important sub-goal must be the optimisation of the lifetime pattern of food intake, so as to meet the nutrient demands of survival, growth and reproduction. The ways that animals have evolved to link their foraging behaviour to its nutritional outcome, form the context for the evolution of the underlying molecular and physiological effector mechanisms. Therefore, to understand not only how, but also why, animals make decisions when choosing their diet, we need to take an evolutionary and goal-oriented approach to the problem. By addressing the challenges that an animal has encountered during its evolutionary history, (e.g. balancing intake of nutrients and energy, avoiding excess, ensuring against future deficiencies, scheduling intake for seasonal and reproductive demands) we can fully understand how it will respond to the vagaries of its present circumstances. This would help us to interpret and predict the responses of animals and humans living in novel environments, including those imposed by changing land use scenarios.

Drivers of foraging behaviour

Some of an animal's foraging decisions and behaviour can be viewed as being 'hard wired', i.e. a genetically determined constituent of the animal's behaviour. Examples of such innate behaviours are suckling behaviours, or the techniques used by squirrels to crack nuts, which are subject to alteration by slow evolutionary selection. Other behaviours reflect decisions that represent an outcome derived by the animal, following assessment of its food environment over various spatial and temporal scales. In order to maximise its foraging efficiency from searching, through ingestion, to digestion of food, an animal must acquire and process information on the amounts, distribution and quality of potential food items. Such assessment would also include sampling the environment for competitors, or risk of predation. These factors, along with the animal's own internal physiological status determined by such things as its age, condition and reproductive status, determine an item's suitability as food. Our recent research has addressed all of these facets of the foraging process, and furthered our understanding of decision-making, particularly by large herbivores (Duncan & Gordon, 2000).

Among the herbivores, fixed or relatively inflexible foraging behaviour would be expected of those species that are highly specialised to particular food types (e.g. pandas, koalas). However, for animals that forage in heterogeneous environments where their diets consist of many different items, such fixed behaviours are unlikely to provide the behavioural latitude necessary to efficiently find and exploit a range of food types. These species, including most domestic ruminants such as sheep, goats and wild red deer, employ more flexible strategies, which include a component of learning in the selection of nutritionally rich food types, or the avoidance of toxic plants. Our research has shown that goats form conditioned aversions whereby they learn to associate a flavour, with a toxic effect of a natural plant

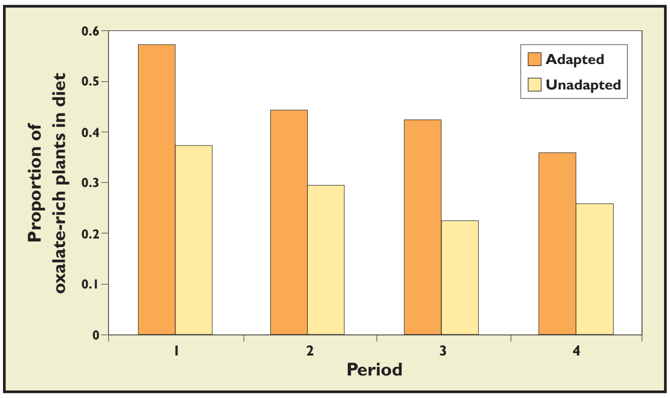

Figure 1. Effect of rumen adaptation to oxalic acid on selection of oxalate-rich plants by goats (Duncan, Frutos and Young, 2000).

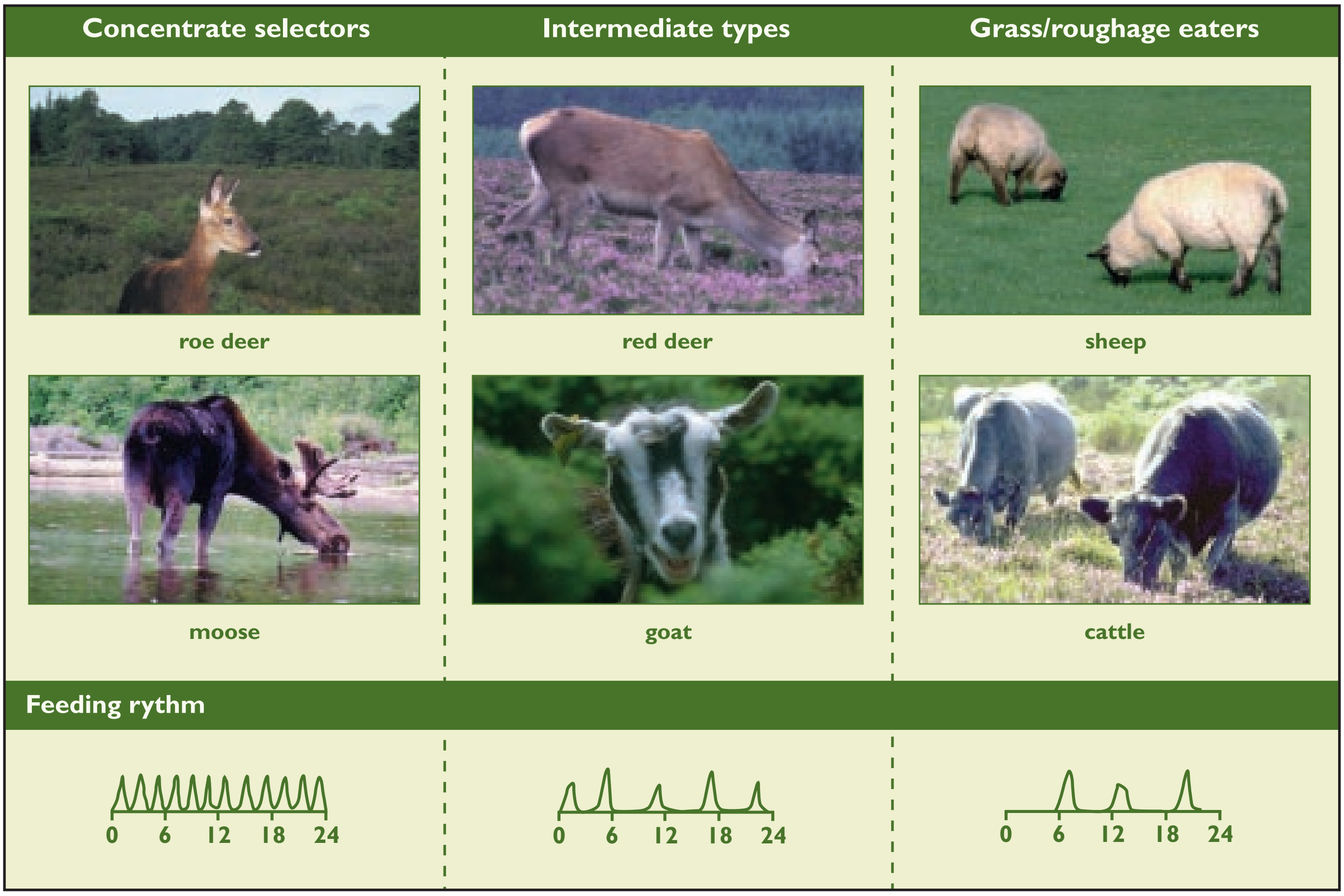

Figure 2. Ruminant feeding types.

secondary compound, such as oxalic acid. These conditioned aversions minimise the consumption of toxins and the strength of the aversive response depends on the magnitude of the toxic dose. However, the aversion attenuates with time, and can be reduced by prior physiological adaptation that diminishes the effects of the toxin (Figure 1). Hence goats are able to retain behavioural flexibility despite this conditioning.

Explaining the variability of foraging behaviour

Our ability to produce general predictions of the responses of herbivores to land-use change and to predict the impact of their foraging, has been dominated by the classification of ruminants into eco-physiological types (Hofmann, 1989). These types are the grazers (bulk roughage feeders, e.g. cattle), concentrate selectors (or the browsers, e.g. roe deer, *Capreolus capreolus*) and intermediate feeders (e.g. red deer and goats) (Figure 2). This simple classification adequately accommodates and describes the feeding habits of the ungulate species. We have focused on the mechanisms of foraging behaviour and digestion underlying this classification, in particular the importance of alternative explanatory hypotheses, such as the effects of body mass and the species' evolutionary history.

Digestion

The ability of an animal to digest its food has long been considered a constraining influence, which directly limits its food choices (Belovsky, 1986). The digestibility of a food substrate is primarily a function of the properties of the food itself. However, comparative studies show that eco-physiological strategies can explain a significant proportion of the variation between species in their ability to digest the fibre component of their feed (Iason & Van Wieren, 1999), fibre being an important determinant of the overall quality of different forages (Figure 3). However, we submitted this to a closer examination, which takes account of the phylogenetic origins and inter-relationships of different species, and found that evolutionary history is a key explanatory factor in their digestive ability (Illius, Gordon & Elston, in preparation). We have also investigated the extent of intra-specific variation in digestibility in order to ascertain the extent to which the (hypothesised) digestive constraint on diet choice is flexible.

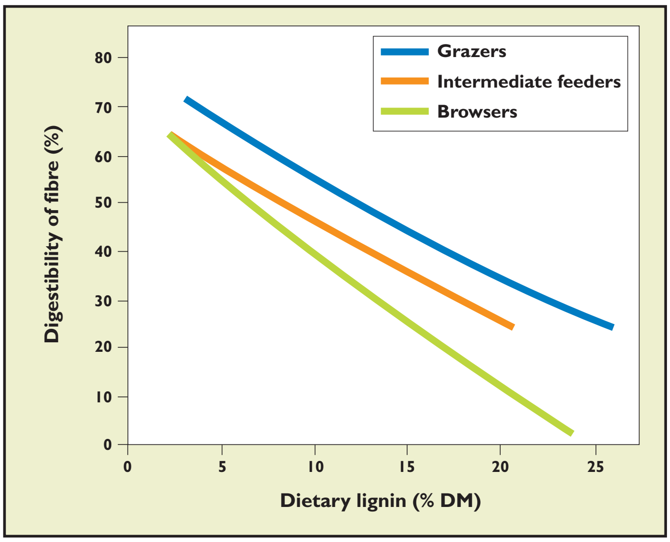

Figure 3. The effect of dietary lignin on fibre digestibility by grazers, browsers and intermediate feeders (Iason and Van Wieren, 1999).

We illustrated, using goats and oxalic acid, how nutritional adaptation interacts with short-term foraging decisions (Figure 1). In seasonal environments, ranging from the Arctic to the tropics, digestive adaptation is required to facilitate the longer-term dietary plasticity of intermediate feeders, to permit utilisation of lower quality forage in winter or dry seasons. We have demonstrated the power of this effect through our studies of mountain hares (*Lepus timidus*), which occupy the most seasonal montane environments in Britain. Although often considered to be a browsing animal, the mountain hare prefers to eat grasses (Hulbert *et al.*, 1996), which dominate its summer diet, in preference to heather (*Calluna vulgaris*) which predominates in the available vegetation, and the diet, in winter (Figure 4). However, the mountain hare's ability to digest the heather increases almost twofold from 31% to 57% digestibility of dry matter, following a period of digestive adaptation (Iason & Van Wieren, 1999). The definition of a digestive constraint is clearly not absolute, and its role in foraging decisions needs to be carefully evaluated.

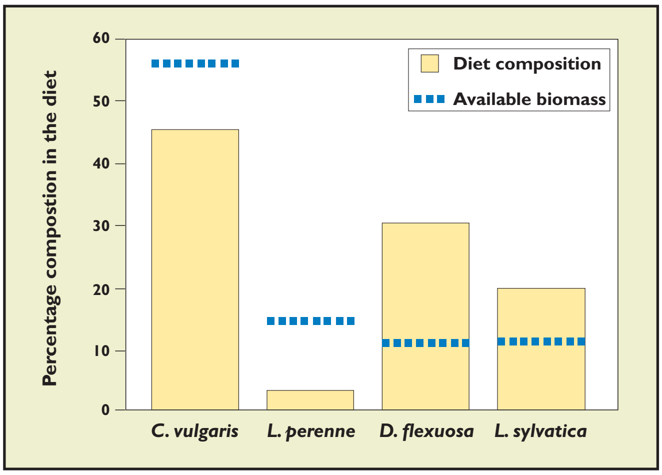

Figure 4. Diet composition of adult female mountain hares in relation to available biomass of the main food plants, in winter (Sept - Jan). (From Hulbert, Mayes and Iason, in preparation).

Grazing time

Because herbivores ingest food which is widely dispersed and of generally low quality, in comparison to that of other trophic types such as carnivores, a further constraint in theoretical models of herbivore diet choice, is the maximum time available for grazing each day. In a similar cross-species comparison, the duration of the daily foraging activity of ruminants (Perez-Barberia and Gordon, 1999), was also found to be related to their phylogeny, with a small amount of residual variation being due to body mass. Just as digestive ability was shown to be very flexible within species, but still phylogenetically constrained in cross-species comparisons, so we have also experimentally demonstrated the existence of extreme flexibility within species, in daily time spent foraging. An experimental study using sheep showed that artificial restriction of the time available for grazing, was behaviourally compensated for such that total daily intake was unaffected by the time restriction. However, compensation in daily intake was only achieved when availability of food resources, defined by the height of a grassy sward, was high (Figure 5; Iason *et al.,* 1999). So our current view is that animals' foraging behaviour and digestive ability are constrained within a genetically determined limit, but within these limits considerable flexibility is retained.

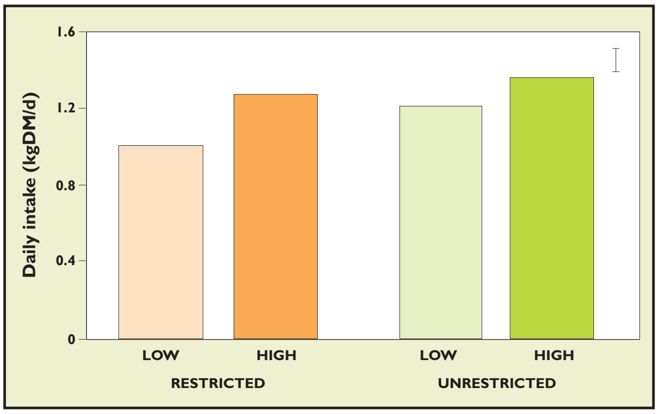

Figure 5. The effect of restriction of available daily grazing time on the daily intake by sheep grazing short and tall grassy swards (Iason et al., *1999).*

Measuring foraging behaviour

If we are to understand the choices which animals make we have to develop methodologies which allow us to measure the behaviours involved. The development of mathematical theory and large-scale observational work allows us to develop hypotheses about how much, what and where animals eat. These hypotheses are then tested under controlled conditions in which animals are offered the opportunity to make choices between foods that differ in things such as structure, distribution and chemical composition. Within our programme at the Macaulay we have a range of techniques we can draw upon to measure behaviour, many of these have been developed in-house. For example, we use swards grown in trays and presented to animals indoors to test hypotheses concerning the interaction between the animal species preferences for plant species and their diet selection in intimate mosaics of plant species. We use the alkane technique to measure the intake and diet selection of free-ranging herbivores. The development of Global Positioning System (GPS) technology which can be carried on the animal is now being used to track red deer stags year-round on a Highland estate (Figure 6). Technique development, particularly to estimate intake, diet selection and the movement patterns of free-ranging animals, both domestic and wild, will continue to be a high priority for our research programme.

Figure 6. A deer stag with a newly fitted radio-collar.

Predicting the impact of foraging behaviour

An understanding of the basis of animal's choices will facilitate targeting of research effort and maximise its utility in solving problems involving the use of animals in land management strategies for animal production or environmental management. Although an evolutionary approach undoubtedly facilitates improved understanding of biological interrelationships, its relevance in solving land use problems may not be immediately obvious. Our current knowledge of the phylogenetic history of a species, is a component of our complete knowledge set which also includes the eco-physiological foraging strategy and body mass. Taken together, these factors can be used to make first order predictions as to how any herbivore will forage, should it be introduced into a novel environment, or should its existing environment be altered as a result of changing climate, land management policies and practices. We then use more detailed studies of particular species on particular plant communities to refine our predictions of the herbivore's food selection and intake, and the responses of the vegetation community, which together determine the impact of herbivores on the environment. For example, following a series of experiments on the intake and diet selection of sheep and cattle grazing *Nardus*-dominated vegetation communities (Hodgson *et al.*, 1991; Grant *et al.*, 1996). Systems experiments were established to investigate the impact of grazing regimes on animal performance and biodiversity in this widespread grassland community. In the systems experiment, the effects of grazing pressure (inter-tussock sward height, 4-5cm or 6-7cm) and mixed (cattle and sheep) or mono-species (sheep) on *Nardus* tussock cover, and structure, vegetation dynamics, animal performance and invertebrate biodiversity were measured over a period of 3 years. The cattle, 12-18 month old steers, were grazed for the period from June until the end of July whilst the sheep were grazed from early June until late September. During the course of the experiment the *Nardus* cover declined most (by 22% units) on the cattle plus sheep treatment grazed at an inter-tussock sward height of 4-5 cm, with little change occurring on the other treatments (Wright and Howard, in preparation). As with the previous experiments, the diets of cattle contained a higher proportion of *Nardus* in their diet than that of sheep at both levels of grazing pressure. There was an enhanced performance of both the ewes and the lambs when grazing with cattle, at both grazing patures (Howard and Wright, 1994). Due to the differences in the structure of the *Nardus* grasslands created by grazing, there were differences in the abundance of different species of arthropod. For example, as cattle grazing produced rounded, relatively short tussock, there was a lower abundance of spiders, which rely on structural vegetation for their webs, in cattle-grazed compared with sheep-only grazed treatments (Figure 7; Dennis *et al.*, 1998 and unpublished). On the other hand, where the cattle grazing at high grazing pressure reduced *Nardus* tussock cover and increased the area of open *Agrostis-Festuca* dominated grassland, there was a greater abundance of cursorial predators such as rove beetles (Dennis *et al.*, 1997).

This example demonstrates the utility of our research approach in integrating the simultaneous role of herbivores in animal production, vegetation management and as providers of nature conservation benefits. The extent to

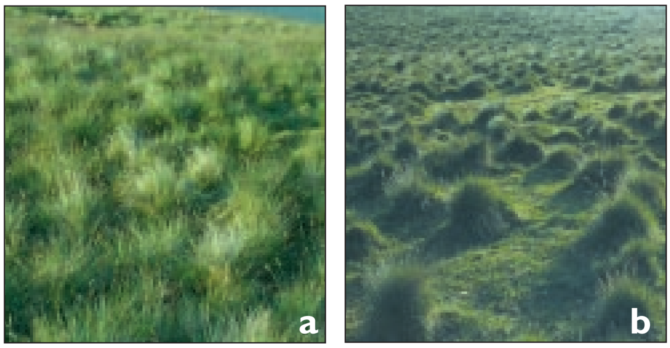

Figure 7. Nardus stricta *- grassland under two grazing regimes, grazed to an inter-tussock sward height of, a) 6-7cm by sheep, and b) 4-5cm by sheep and cattle.*

which the ecological and evolutionary approach provides a platform for investigating these functions, as performed by other animal species occupying more heterogeneous environments, is currently being tested.

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The Future of our Rural Communitites - Challenges and Opportunities Arising from European and UK Policies

Howard Newby
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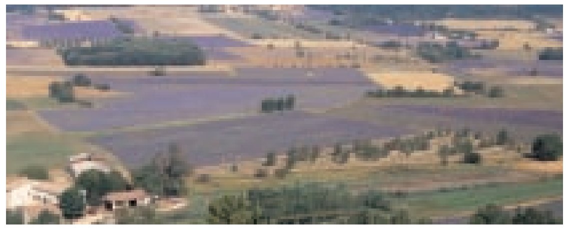
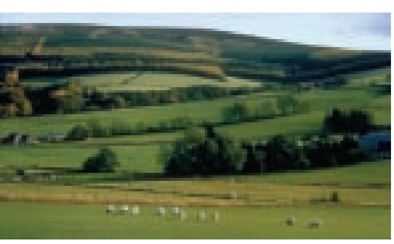
23rd T B Macaulay Lecture, 19 May 1999



Introduction

In the last few months some evidence has emerged that the Government is taking seriously the need to look again at the case for a radical overhaul of public policy on the countryside. A new White Paper is promised (a discussion document on rural England has already been circulated) and the Performance and Innovation Unit in the Cabinet Office is undertaking a project on Government objectives for the English rural economy. Both sets of activities are concerned with government policies in England alone. However, the PIU's research also includes an analysis of the approaches to public policy adopted in Wales, Scotland and Northern Ireland in order to identify and learn from good practice. In this lecture I shall, I confess, be focusing primarily on England, since it is here that many of the most acute public policy dilemmas are apparent - and it is also the context which I know best. It is also the part of the UK which is undergoing institutional change with regard to countryside policy. The Rural Development Commission, of which I was a member for eight years, has been abolished and some of its residual activities absorbed into a new Countryside Agency by linking up with the former Countryside Commission. Much of the old RDC's regeneration work has, however, passed to the new English Regional Development Agencies. In England, at least, therefore we are contemplating a new institutional framework for countryside policy which, in itself, provides an opportunity to rethink countryside policy for the new millennium.

There is an historical irony in the fact that this is being undertaken by a Labour Government, since there are faint historical echoes of the post-war reconstruction of the countryside undertaken after the second World War and enshrined in legislation passed in 1947 (of which more anon). Certainly over the last 50 years or more the countryside has been guided by at least an implicit set of policies, introduced by an old Labour Government, which have, in their way, been remarkably coherent and robust. In this lecture, however, I want to argue that a combination of economic, social and technological change is rapidly bringing to a close whatever post-war continuities of public policy may have shaped our countryside. As a result, certain received assumptions about the nature and character of our rural economy and society need to be re-examined. I shall argue that, just as the experience of the 1930s and 1940s led to a fundamental re-examination of the role of the countryside in our national life and the recognition that the government should take the lead in implementing the nation's vision of its rural future, so today, under a very different set of circumstances, there is the need for a similar public debate and a similar expression of political leadership.



'the future of the countryside hangs in the balance'

I hope I need hardly stress how importantly the countryside is regarded by a large, and arguably increasing, segment of the population. It does, indeed, hold a special place in our affections. But such a perception of the countryside lends itself to the belief that it is constantly under threat. At times a fragile countryside seems uniquely vulnerable to the intentional, or even unintentional, forces of destruction unleashed by modern civilization and technology. I do not wish to add to this perception. Nevertheless, I do believe we are at a cross-roads in the history of our rural society and that urgent consideration is required about the appropriate public policies which will guide the destiny of our countryside into the twenty-first century and beyond. In that respect, the future of the countryside hangs in the balance.

Finally, by way of introduction, I want to stress the extent to which public debate about the future of the countryside is constrained by prevailing cultural perspectives. The first, which is deeply embedded in British, or at least English, culture is anti- urbanism. Our love of the countryside is in part an expression of our failure to come to terms with the realities of urban life. Since the industrial revolution the British have signally failed to develop an urban civilization which is at once sophisticated and humane. We have always rejected it, fleeing instead to seek our solace in the allegedly recuperative powers of the countryside, where it is possible to be at one with nature.

The second cultural perspective is, arguably, a more recent development. It derives in part from an atavistic fear of starvation, given understandable focus by the experience of older generations in two world wars. In modern parlance it is translated into the notion of 'food security'. The countryside is here equated with the production of food, and in the production of food every acre counts. Even the mildest suggestion that the area of land under cultivation might be reduced, or the volume of food production be deliberately diminished, is met with dubious historical analogies dating from the 1930s, vague references to the activities of submarines in the Western Approaches and an airy assertion that an ubiquitous agriculture is undeniably a Good Thing.

1947 and all that

These cultural predispositions are not only of academic interest. They have been embodied in specific pieces of legislation which have provided the framework for our rural economy and society over the last half-century: the Agriculture Act and the Town and Country Planning Act of 1947. Each piece of legislation has, of course, been subsequently amended, revised, reconstituted and consolidated, but in their essentials they remain intact. On the whole, these two pieces of legislation have served the nation well. These are not pieces of legislation which have turned out to be abject failures - on the contrary, one could make out a case that they have been extraordinarily successful. Ironically, it is their very success which is now rendering them obsolete, coupled to the fact that the kind of rural economy upon which they were based has itself been fundamentally transformed with the assistance of these very pieces of legislation. I therefore wish to argue that these pieces of legislation do not provide an appropriate framework for the countryside over the next 40 odd years, whatever their success may have been over the last four decades or more.

'The custody of the countryside could safely be left in the hands of farmers and landowners; all that was required was to contain the spread of urban sprawl'.

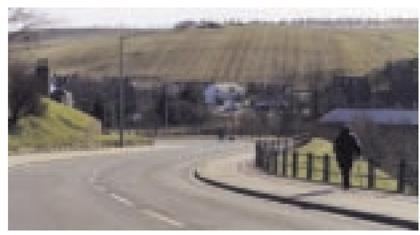
Both pieces of legislation were, of course, very much a product of the post-war reconstruction of the British countryside, a reconstruction which owed a great deal to the cultural perspectives which I have already outlined. The Agriculture Act of 1947, for example, was entirely single-minded in its aims: the production of more and cheaper food; and in this it has, of course, been spectacularly successful. Public policy, therefore, guided agriculture in ways which have profoundly altered both the structure of the agriculture industry and the day-to-day nature of life and work in the countryside. The encouragement of fewer, larger, and more capital-intensive farms resulted eventually in the catalogue of social and economic changes which are frequently associated with the post-war transformation of the countryside: the mechanisation of agriculture, the changing social composition of rural villages and the wide-spread changes in the rural landscape and other environmental aspects of the countryside. These changes have not been haphazard, nor are they the result of some immutable natural law, but the result of policy decisions quite consciously pursued. A large and complex network of institutions has been erected in the public sector in order to effect the transformation that post-war agricultural policy ordained. The consequences have been far-reaching indeed - a move from agriculture to agribusiness, and all that.

It is the very success of the post-war legislation in agriculture which is now creating problems, for the essential goals of the 1947 Act have now been achieved.

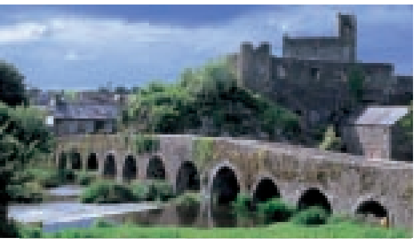
Moreover, UK agricultural policy is now pursued within a European framework. In this context the overall food security objective for Europe, by means of self-sufficiency in cereals, oil seeds, sugar, livestock and livestock products, was fully achieved by 1985. By now one can cite the familiar litany of over-production and high cost, both to the exchequer and the consumer. We have now arrived at a situation in which over 66% of the entire European Community budget is being spent on only 3.4% of the Community GDP and only 8.4% of even the rural labour force. Of course, some of the surreal absurdities of the CAP could be dismissed with a Gallic shrug were the consequences not so tragic - the incalculable 'externalities' of third-world poverty and of environmental destruction in Europe. Fortunately, as the recent GATT and WTO negotiations indicate, the wholesale reform of the CAP can now safely be placed in the 'sooner or later' category: the water is building up behind the dam of agrarian intransigence. Sooner or later it will burst - and so there is all the more reason to have policies in place which will enable us to cope.

Let me now move to the other legislative pillar of the period of post-war reconstruction. The notion that rural society might require some form of rational planning extends from two considerations. The first came from a belief in the need for a modicum of progressive social engineering in order to achieve an improvement in the living and working conditions of those in the countryside - lack of hygiene, over-crowding, poor sanitation, and so on. By the late 1940s this had come to be accepted as a legitimate concern of government, and rural planning as a minimum requirement was concerned with extending and improving the quality of public service infrastructure in the countryside. The second consideration was the desire, increasingly voiced towards the end of the 1930s, to protect the countryside from urban growth. This was based upon a gut feeling that the English countryside needed to be protected, rather than planned in any positive sense. The custody of the countryside could safely be left in the hands of farmers and landowners; all that was required was to contain the spread of urban sprawl.

'an opportunity to rethink countryside policy for the new millennium'



In this respect, the Town and Country Planning Act also turned out to be highly successful: the rate of loss of agricultural land being reduced to half the pre-war level. By controlling these changes in land use, it was believed that the 'traditional rural way of life' could be retained. The countryside was, therefore, for the most part, equated with agriculture, and agriculture, it was assumed, would provide the economic basis for the 'traditional rural way of life'. The latter was, of course, presumed to be beneficial to all rural inhabitants. Yet this occurred at precisely the time when agriculture was being encouraged along the path of technological transformation, thereby displacing hundreds of thousands of farm workers, whose ability to find new jobs was henceforward severely hampered by local planning policies opposed to new industrial and housing development in rural areas. As they left farming they also left the countryside, to be replaced, as we can now see, by urban, overwhelmingly professional and managerial, middle-class newcomers who had been able increasingly to express their preference for, if not a country house, then at least a house in the country. By such means were former agricultural villages turned into commuter settlements, with only a few rural areas, isolated by bad roads and non-existent railways, remaining to be gobbled up by the equally voracious demand for holiday homes and weekend cottages. As I have summarised on a number of occasions before, rural Britain, which was once agricultural Britain, has now become middle-class, urban Britain.



'rural Britain, which was once agricultural Britain, has now become middle-class, urban Britain'.

What now, therefore, is the 'traditional rural way of life' which town and country planning legislation seeks to protect? It is certainly not an agricultural society, nor is it an agricultural economy. Even in the most rural of areas, agriculture and related industries rarely account for more than 15% or so of the employed population, and in most rural areas it is a good deal less than this. Only in terms of land use is rural England still agricultural England. In all other senses - economically, occupationally, socially, culturally - rural England has been comprehensively urbanised.

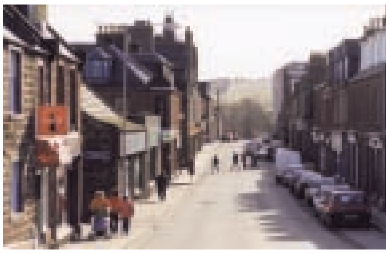
Most of the present rural population, therefore, has little connection with farming, either economically or culturally. This is not to say, however, that they do not care about the countryside. Indeed, from the point of view of many farmers, they care almost too much. It is not a countryside, of course, which many of those who traditionally lived and worked in the countryside would recognise. It probably owes more to the imagery, to which I have already referred, which many of us hold in our minds - an enduring rural heritage, all church bells, thatched cottages, country pubs and Morris Minors. This image of an idyllic British countryside is not only strongly held by those who have moved there (that has indeed been one of their major motivations) but is one which they have sought to implement when faced with the less agreeable reality. It is not surprising, therefore, that many of the newcomers to the countryside have been in the vanguard of the conservation movement. Politically in the ascendancy, they support the 'no growth' or 'low growth' policies for rural areas which have become so typical of rural planning - especially in the south of England. They also contribute to the peculiar myopia of the environmental lobby over social issues and the countryside. The understandable desire to protect the countryside from urban sprawl, enshrined in the 1947 Act, has, in other words, become a charter for NIMBYs.

As a result of all this, the social fabric of the countryside has become transformed, not from the outside but from within. Therefore, both of the 1947 Acts, which have been so influential in defining our public policy for the countryside are no longer appropriate for modern circumstances. They assume that we are dealing with an agrarian society, that rural areas are subject to population decline, that the rural population suffers from a lower standard of living than their urban counterparts, that there is a shortage of land, and that agriculture is a protector of the natural environment. In today's circumstances, however, reality is rather different. The rural economy is predominantly a service economy, most rural areas are subject to the pressures of population growth, rather than decline (indeed the early results of the 1991 Census show that the fastest growing districts include the 'remoter, mainly rural' areas), overall the rural population is more, rather than less, affluent than their urban counterparts, there is now a 'surplus' of land for agricultural purposes, given current technologies and policy considerations, and agriculture is seen, by many at least, as offering a threat to the environment through the destructive consequences of many modern farming practices. An in all of this the legitimate needs of those who live and work in the countryside have been overlooked. The 'local' rural population that see themselves all too often as strangers in their own village.

Where do we go from here?

I want to begin by placing people back at the heart of our countryside policy. I do so because it is the activities of people which creates the countryside that we cherish. As we are constantly reminded, the British countryside, whether viewed aesthetically or ecologically, is a managed countryside and its quality therefore depends upon the underlying characteristics of the rural economy and society. The unfortunate tendency in recent years to regard the countryside as though it were nothing more than a series of landscapes and wildlife habitats has obscured this fact. Historically, as I have emphasised, the use of land and fabric of rural society were largely based on primary production, most importantly the production of food. In post-war Europe, as we have seen, the strategic and economic importance of this function led to the development of mechanisms of public policy whose aim was to secure food supplies. Now, however, priorities are changing. Technological improvements, rising economic prosperity and the internationalisation of markets have increased productivity, diversified demand and sources of supply, and undermined the strategic and political imperative of maximising traditional productive capacity.

'I want to begin by placing people back at the heart of our countryside policy'.



Meanwhile, the emphasis of other economic activities is shifting. In most rural areas there has been a general decline in the economic prominence of primary production compared with those high in added value. At the same time, rural economic activity has been increasingly integrated into the national, and then international, economy. As a result, those born and brought up in rural areas have tended to lose control over their own future. Many who live and work in rural areas believe themselves to be pursuing other peoples' goals - working for firms often owned by 'outsiders'; using technologies (most recently information and communication technologies) developed for differently structured industrial and urban economies; and enacting the role of 'scene shifters' for an urban population whose primary concern for the countryside is almost entirely visual. Whether these changes are good or bad is not the issue. What is an issue is to determine how the rural population can participate in the overall prosperity of Britain (and, indeed, Europe) through a commensurate contribution to that prosperity. Preservation of a 'traditional rural way of life' is simply inconsistent with this.
From this it is possible to derive a list of policy objectives. They would include:

Self-sufficiency: ensuring that rural communities develop in such a way as to encourage enterprise, responsibility, and ownership.

Opportunity: ensuring that economies in rural areas provide a suitable range of job opportunities - suitable both in kind and in scale - for rural communities.

Vitality: ensuring that rural communities are places where people both live and work, and that they can provide for a wide variety of residents.

Equity: ensuring that rural communities have reasonable and affordable access to services, and are not disadvantaged by their rurality.

Amenity: ensuring that development occurs in ways which preserve and enhance the rural environment.

'The aim should be to extend opportunity, to enfranchise the rural population with the right to choose, but not to determine what that choice will be'.

In a perfect world, of course, rural development would occur through the mechanism of the market and intervention through public policy would be unnecessary. However, we know that healthy rural economies were not evolved strictly through market forces because market inefficiency is inherent in the very nature of rurality. In simplest terms, the distance from key markets keeps rural communities from attaining, or in some cases maintaining, critical economic mass. But it is equally clear that public intervention can only enable, rather than enact, economic development. Rural communities have to be helped to help themselves, but the aim is to remove, rather than strengthen, rural dependency, and to develop an economic and social structure which is both diverse and robust. We are not, therefore, talking about Gosplan, nor making the patronising assumption that the rural population must, by definition, be cooped up in rural areas to provide some 'local colour' for urban visitors. The aim should be to extend opportunity, to enfranchise the rural population with the right to choose, but not to determine what that choice will be.

That is the goal. But there are serious issues which will shape any strategy designed to help rural communities attain this goal. Among them:

- how can we help rural areas adjust to, and profit from, change without forfeiting the values they hold dear?
- how can rural development programmes accommodate the diversity of rural characteristics, assets and needs?
- how can we reverse the historic dependency on rural areas - on agriculture, on some other industry, on transfer payments and on state-subsidised development?
- how can the array of public policies and programmes designed to help rural areas be integrated into a more coherent and effective strategy?

In the past, questions like these were addressed via a rather stale debate on the advantages and disadvantages of 'top-down', as opposed to 'bottom-up', planning. We now recognise, however, that economic and social vitality cannot be delivered by an agency whose sole purpose is to disgorge goodies into a disadvantaged area. National agencies have the responsibility of developing the framework within which priorities are set and instruments developed but their role is essentially an enabling one. It is for the rural communities themselves to create their own development strategies and it is at this level that the integration of development policies, the protection of cherished values and ways of life and the maintenance of diversity are best guaranteed.

Conclusion

These comments are, I recognise, likely to be regarded with some disdain in certain quarters. But the lack of a clear set of objectives for countryside policy can no longer be fudged. Rural areas and economies are expected to face substantial further changes in the future, as world trade organisation and European-wide pressures for reform of the Common Agricultural Policy continue, as processes of economic restructuring of technological change alter the spatial configuration of economic activity and as the processes of population and household change continue to unfold. In addition to these social and economic issues public debate and concern over our environmental matters has grown markedly over the last 25 years. Together, these economic, social and environmental factors, have created a dynamic process of rapid change in rural areas, a process which is still imperfectly understood and certainly not uniform in its consequences across the UK.

The present government's reappraisal of countryside policy is, I believe, a step in the right direction. The government seems ready to recognise that just as it would be insane to destroy the rural environment through destructive agricultural and industrial development, so it would be equally misguided to believe that we can place the countryside in aspic. If rural communities do not change, they die; and the ultimate guarantor of a prosperous and environmentally attractive countryside is the well-being of its population. For the last decade the concern for conservation has so dominated our thinking about the countryside that these more fundamental issues have rarely been addressed in public debate. But, now that productive agriculture no longer needs so much land, the opportunity is there to develop an innovative approach to rural development. This may well involve a progressive shift away from supporting food production and towards promoting appropriate development, housing, public services and a better social balance within the rural community. This will be a relatively small price to pay, not only for the retention of a beautiful countryside, but for the revitalisation of rural society. Only government can take a lead on this, but, having taken a lead, the government must then step back, for, once the framework is in place, it will be for the rural population itself to guide its own destiny into the next century and beyond.

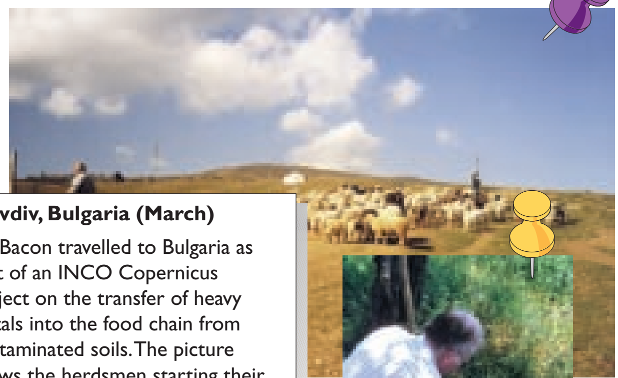
'it will be for the rural population itself to guide its own destiny into the next century and beyond'.

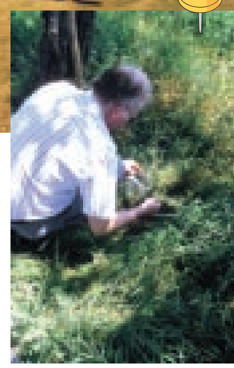
A Year in The Life of The Macaulay Institute

A selection from our photo album of some of our events and visits abroad during 1999

Edinburgh Science Festival (March)

David Miller presented a very successful exhibit on 'Modelling Future Countrysides' in the exhibition hall of the Royal Botanic Gardens as part of the Edinburgh Science Festival. Visitors were able to model the visual impact of building windfarms and fly through various landscapes.



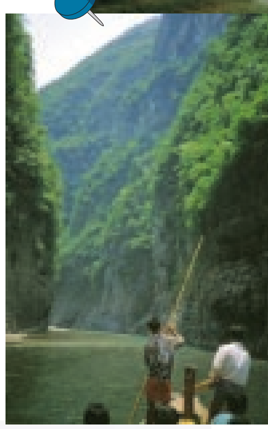


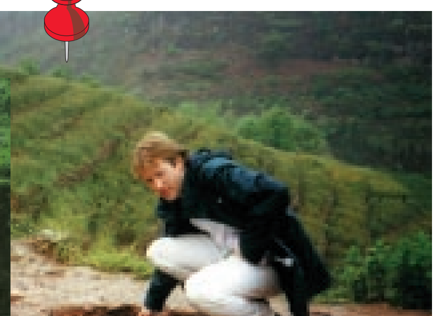
Plovdiv, Bulgaria (March)

Jeff Bacon travelled to Bulgaria as part of an INCO Copernicus project on the transfer of heavy metals into the food chain from contaminated soils. The picture shows the herdsmen starting their daily trek to take the village livestock from the coral to the higher grounds for grazing. Jeff also visited Poland and Romania as part of the project. He is pictured taking soil samples in July in Romania (right).

Macaulay Lecture and Exhibition (May)

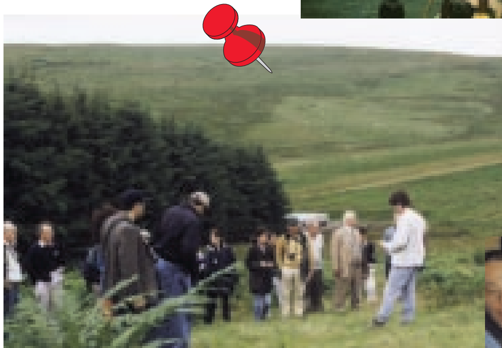
We were delighted to welcome Professor Howard Newby to the Institute to give the 23rd Macaulay Lecture. Professor Newby's lecture 'The future of our rural communities - challenges and opportunities arising from UK and European policies' is featured on pages 44-47 of this publication. In addition, on the morning of the lecture, we mounted an exhibition of the Institute's work and we were delighted to welcome a great many guests to view the displays. The picture shows Professor Newby in conversation with Professor Janet Sprent, Chairman of the Institute's Board of Governors, outside the Institute.





Yangtze River, China (April)

Colin Campbell travelled to China as part of our involvement in the Three Gorges Project. The microbial diversity of the degraded soils of the Southern uplands of the Yangtze River are being investigated in a collaborative project with the Institute of Soil Science in Nanjing, which is funded by the Royal Society. Ways of increasing the stability of hill slopes to reduce soil erosion and sedimentation of the river are being investigated.



Bracken Conference field trip (July)

Several members of staff attended 'Bracken 1999' in Manchester. The post-conference field trip included a visit to our Sourhope Research Station in the borders. Delegates are pictured out in the field with Robin Pakeman talking about his work on bracken control. The delegates also had the opportunity to taste some cooked bracken! (right).

Northern Pakistan (May and November)

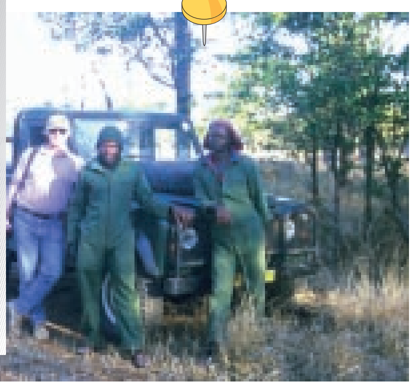
Several members of staff are involved in an EU project which is looking at rangeland management and livestock feeding strategies in Pakistan's Karakorum region (see 1998 Annual Report, page 70). Alan Duncan, Alison Hester, Iain Wright and Iain Gordon visited Pakistan in May for a project meeting and also to supervise the field work of two of the PhD students who are part of the project. Alan returned in November to continue the supervision. The pictures show Alan Duncan (right) and Alison Hester (far right) in discussions with members of the villages.

Kazakstan (May)

Iain Wright has been visiting Kazakstan as part of a project funded by the Department for International Development to explore policy options for improving the management of livestock and rangelands in Kazakstan (see 1998 Annual Report page 62). Iain is pictured in May with a family who were interviewed as part of the project (right) and in January, interviewing a Kazak shepherd on horseback (left).

Zimbabwe (June)

Iain Gordon has several projects underway in Zimbabwe. In June he went over to attend a workshop as part of the EU project on 'natural resources management' in the mid-Zambezi valley (see 1998 Annual Report page 68). Iain then went on to visit some of his PhD students who are working over there, including a visit to Savé Conservancy to see Alistair Pole who is working on a PhD on the interactions between wild dogs and hyenas. The picture shows Iain with two of the members of this project, who have been involved in tracking the wild dog packs.



Training course (August)

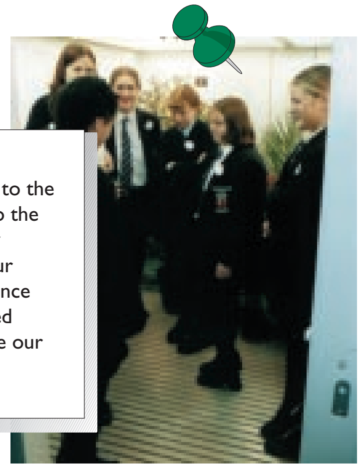
Eight grassland specialists from Qinghai Province, Central China, visited the Institute in August as part of an EU-funded international training course on rangeland science. The participants spent one week at the Institute HQ and then embarked on a field trip visiting relevant sites across Scotland. Some of the delegates are pictured with Andrew Nolan from the Institute discussing heather moorland management in Ralia Estate, Speyside.

The Lord Provost

We were pleased to welcome a great many visitors to the Institute during the year (see Director's introduction page 3). Among our many visitors from all walks of life we were delighted to welcome The Lord Provost of Aberdeen, Miss Margaret Smith. The Lord Provost is pictured with Alistair Smith in the Analytical Laboratories on her tour of the facilities.

Aberdeen's Techfest - September

We hosted visits of several school groups to the Institute and we also opened our doors to the public on the family day. Among our many exhibits our visitors were able to enjoy our successful exhibit from the Edinburgh Science Festival (see above left), visit our controlled environment rooms (right) and experience our model of the Dee catchment (left).



Commercial Services

The Institute's corporate commercial strategy provides comprehensive research and consultancy in

- **Natural Resource Management,** including
- **Water Quality and Catchment Management,** and
- **Soil Quality and Protection**

to national and international markets. These business sectors integrate research, consultancy, training and resource management skills and expertise in soil and plant science, plant and animal ecology, animal nutrition, hydrochemistry and hydrology, geography, agriculture and forestry. They also integrate, and have ready access to all our other specialised business sector services.

These specialised services are also stand alone business sectors comprising

- **Soil and Land Evaluation**
- **Geographic Information Services**
- **Landscape Change Analysis**
- **Economic Policy and Survey Analysis**
- **UKAS accredited Analytical Services** (soils, water and a wide range of specialised chemical analyses relevant to land remediation management and the oil industry).

We operate a 'one-stop-shop' to access our highly qualified and experienced staff and the full range of our integrated and specialised services. Our portfolio of international contract experience extends throughout Europe to southern Africa, the Indian sub-continent, China, Central Asia and South East Asia.

The contacts for our integrated and specialised services are provided below.

Biomathematics and Statistics Scotland

Biomathematics and Statistics Scotland (BioSS) contributes research, consultancy and training in statistics and mathematics to agricultural and biological organisations in Scotland. The long-term collaborative relationships between BioSS and the Macaulay Institute have led to experimental designs and data analyses that are both efficient and innovative, often stimulating methodological research that has wider impact.

The primary activities of the BioSS Environmental Modelling Unit at the Institute are:

- statistical consultancy for the Institute's scientists;
- collaborative research with scientists from the Macaulay and elsewhere;
- applied statistical research on environmental issues;
- related contract work for government agencies and private sector.

The majority of the Macaulay's research projects are dealt with at a consultancy level. For these projects, the professional statistical input may only require a small amount of time, but this input often has a disproportionate effect on the course, and ultimately the successful outcome, of the project.

Scientific problems that require the use of advanced statistical methods develop over time into collaborative projects, or sometimes become the topics of statistical research. Whilst the statistical input to these projects can be very great, correct handling of the statistical issues is the key to success.

Two examples of the interactions between the Institute and BioSS are described briefly below:

Impact of large herbivores on upland vegetation communities

The extent, and cause, of impacts of herbivores on upland vegetation communities has been debated for many years. In response, Macaulay scientists have been developing a method for rapid habitat assessment over large upland areas which involves ascribing the impact on each visited area to one of 5 impact classes. Complementary developments in BioSS now allow the analysis of the recorded impacts, taking account of differential habitat and spatial effects.

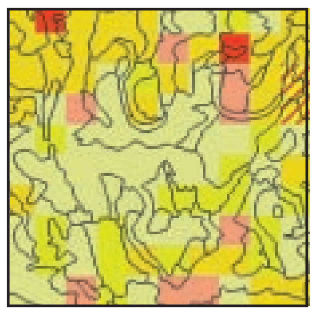


Figure 1

Figure1. Grazing impacts ranging from low (pale yellow) to high (red) recorded using rapid habitat assessment methodology, with vegetation boundaries in black.

Incentive design under limited information

In recent years European governments have increasingly intervened in agriculture to procure environmental services from farmers. Collaborative research between the Institute's economists and BioSS involves the use of statistical modelling to explore the benefits derived from policies designed under different levels of information. The specific case of incentive-based schemes to enhance the supply of public access to farmland has been considered, using a range of distributions of the public's willingness-to-pay (WTP) for the enhanced access. Farmers will only apply to join the scheme if the payment level exceeds their opportunity cost. By purchasing additional information about WTP for individual farms, the overall net benefit from the scheme can be increased by raising the payment level to farms that enter the scheme but refusing entry to farms where WTP is below a certain threshold.

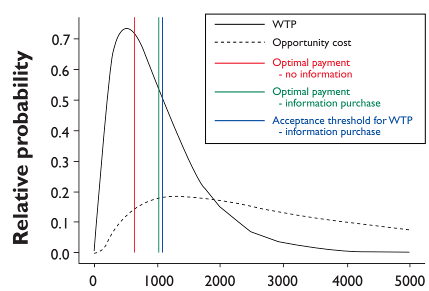


Figure 2

Figure 2. Assumed WTP and opportunity cost distributions, together with optimal payment levels under the no information and information purchase models and the acceptance threshold for WTP in the information purchase model.

Contact: David Elston

Staffing as at 1/1/00 Miss E.I.Duff Mr D.A.Elston (Head of Unit) Dr M.E.A.Hodgson Dr J.M.Potts

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1 April 2000

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Research Officers
Hamish A Anderson BSc PhD CChem FRSC
Tony C Edwards BSc PhD
John D Miller HNC CChem MRSC
Simon J Langan BSc PhD
Nelleke Domburg MSc PhD
Sarah M Dunn BSc MSc PhD
Stephen J Hillier BSc PhD
Allan Lilly BSc MSc PhD

Research Staff
Moira McMaster HNC
Yvonne E M Cook HNC
Rachel C Helliwell BSc MSc
Annette Kelly HNC BA
Caroline M Thomson HNC
Sheila Gibbs
Frank W Milne
Helen Watson BSc MSc
Lynne Johnston BSc

Staff undertaking Doctorates
Rachel C Helliwell BSc MSc

Staff who have left Integrated Catchment Management since the last Annual Report
Pippa J Chapman BSc PhD
Donald M L Duthie BSc

INTEGRATED LAND USE SYSTEMS (P8)

Programme Manager
Iain A Wright BSc PhD

Programme Secretary
Margaret W Forsyth

Research Officers
Peter J Goddard BVet Med PhD MRCVS
Roy Behnke AB MA PhD (MRCS)
Stewart M Rhind BSc PhD
Alan R Sibbald HNC
David J Henderson BSc
Keith B Matthews MA MSc
Gary G Wright BSc FRSSoc MICDDipl
Peter Dennis BSc PhD
Margaret Merchant BSc PhD
Andrew J Nolan BSc
Michael T Rae BSc PhD

Research Staff
A Robson Fawcett AIMLS (G)
Jim E McLeod BSc
C Glyn Stanworth BSc PGDip
Kevin Buchan BSc
Patricia M Colgrove HND (H)
T Gordon Common HNC (S)
Andrew J I Dalziel BSc
Jess H Griffiths BSc MPhil (H)
Jerry P Laker BSc MSc
Hilary Redden BSc
Grant C Davidson BSc
David D Hamilton BSc
Carol E Kyle HNC
David J Riach HNC
Michael Rivington BSc
Anneke M Stolte BSc MSc
Joanne C Tapping BSc
E Clare Waterhouse BSc (MRCS)
Brenda Copland
Audrey R Stephen

Staff undertaking MPhil and Doctorate respectively
Hilary Redden BSc
Keith Matthews MA MSc

Staff who have left Integrated Land Use Systems since the last Annual Report
Alistair J Macdonald SDA NDA
Claire R C Morgan-Davies BSc MSC
Susan M Williams BA

ANALYTICAL SERVICES

Service Manager
Alistair Smith BSc PhD CChem FRSC

Secretary
Lynda M Keddie

Electron Microscopy
Martin Roe BSc
Evelyn McMurray BSc

Isotope Ratio Mass Spectrometry
Andrew J Midwood BSc PhD
Jennifer J Harthill HNC
T Dawn Morley HNC
Diane Smith BSc

Organic Mass Spectrometry
Alan Hepburn CChem MRSC HNC
Maureen M Proceé HNC

Inorganic Element and Colourimetric Analysis
Gareth E Newman BSc
Susan M McIntyre HNC
Lesley J Sinclair BSc
Anna L Hendry HNC
Laura J Elrick BSc
Ann A Bruce
Marjory A Wood

Institute Staff

Soil Analysis
I Jason Owen BSc MSc PhD
Donna Macdonald HNC

Gas Chromatography
Arlene M Murray HNC
Gillian L Sim BSc
Gillian Martin BSc
John Price BSc BAgr PhD (MRCS)

Biological Analysis
Pat E Moberly BSc

Radiochemistry
Terry Atkinson LRSC (Consultant)

Staff who have left the Analytical Group since the last Annual Report
Scott Caird BSc
Kathleen H Davidson
Catherine Dickey

COMPUTING & INFORMATION SERVICES

Service Manager
Christopher H Osman BSc MSc PhD CPhys MinstP

Secretary
Lynda M Keddie

Computing Support
David T Bryant BA
Geoffrey A Reaves BSc MBCS I.Eng
Iain McDonald BA
Helen Lockhart
Philip Simpson MA PhD

Library
Lorraine E Robertson BA ALA DipEd
Jean A McGuiness Blib ALA Cert TESOL

Staff who have left Computing and Information Services since the last Annual Report
Lynne R McKellar MA
Lindsay Robertson BSc

SOIL SURVEY AND LAND EVALUATION

Service Manager
James H Gauld BSc PhD MISS

Secretary
Karen Ross (MRCS)

Staff
John S Bell BSc
Richard L Hewison BA MSc (MRCS)

GIS AND DATA SERVICES UNIT

Ann Malcolm BSc DMS (MRCS)
Margaret M McKeen BSc MSc (MRCS)

Staff who have left GIS and Data Services Unit since the last Annual Report
Neil Brooker BA MSc
David A Tulett BSc MSc Dipl Surv

RESEARCH STATIONS

Head of Services
John A Milne BA BSc PhD FRSA

GLENSAUGH (G)
Farm Resources
Officer-in-Charge
David L Nelson BSc JP

Staff
Norman G McEwan (Head Shepherd)
John W Black Jnr (Grieve)
James Scott (Shepherd)
Brian Sinclair
June Scott (Cleaner)

Experimental Animal Facilities
Officer-in-Charge
A Robson Fawcett AIMLS

Animal House
A Craig MacEachern
Una MacQueen HND

HARTWOOD (H)
Officer-in-Charge
George K D Corsar BSc MS

Staff
Ian Boustead (Grieve)
Robert Graham (Head Stockman-Cattle)
Jim C MacDonald BSc (Stockworker-Sheep Records)
Robert Armstrong (Stockworker)
Betty Farley (Cleaner)

SOURHOPE (S)
Officer-in-Charge
Harry M Sangster BSc DipFBom

Staff
Geoffrey D Gittus (Deputy Officer-in-Charge)
John L Wallace (Head Shepherd)
Patricia Gentry (Recording Officer)
T Gavin Rogerson DipFBom (Goats)
Pamela Tapson (Shepherd)
Matthew J Wilson (Shepherd)
Dorothy H Wallace (Cleaner)

Staff who have left the Research Stations since the last Annual Report
John W Black Snr (G)
Jane Bowker MA (G)
Andrew G Brown (G)
Sheila M Humphries HNC (G)

Institute Staff

James C Pringle (S)
Catherine Walsh HND (H)

FINANCE AND ADMINISTRATION

Institute Secretary
David W Murdoch BSc CA MBA

Institute Deputy Secretary/Financial Controller
David T Wilkinson MA

Secretary's Typist
Nikki Macpherson BA

Personnel Administration
Eileen J Cockburn
General Office
Julie McKenzie
Fiona J Wilson

Financial Administration
William G Morrison SHND
Paul Davidson
James E Price BSc (MRCS)
Catherine B Adams
Janice M Laing
Jacqueline S Wales

Secretaries/Typists
Margaret W Forsyth (Programmes 6 and 8)
Lucy M Burnett (Programme 4)
Iona M Shand (Programmes 2 and 3)
Aileen Stewart (Programmes 1 and 7)
Carol A Smith (Programme 5)

Telephonist
Coral A R Bannister
Kay Stewart

Stores
Lynne Thomson

Technical Services
Bert W Stuart HNC
James S Anderson
Gordon J Ewen HNC
Graham J Gaskin HNC
Allan I A Wilson HNC
David W Clark HNC
David J Sim
Gordon W Stott

Cleaners
Margaret Kindness
Ruth P Penny
Nessie M Rennie
Meg A Walker
Marjorie C Watt

Outdoor Staff
Brian N Kemp

Security Staff
Ernest C Milne
Robert Craigen
Alan E J Rhynas
William Smith

Cunningham Building Caretaker
Catherine Milne

Staff who have left the Finance and Administration Group since the last Annual Report
David H Burgess
Christina M R Burness
Murray G C Mainland
Wilfred Wallace

BIOSS STAFF BASED AT MLURI

Head of Group
David A Elston BA MS Cstat

Other Staff
Elizabeth I Duff BSc
Matthew E A Hodson BA PhD
Jacqueline M Potts PhD BSc MSc

HONORARY FELLOWS

G Anderson BSc PhD
E J Dey MBE
Professor J M M Cunningham CBE BSc PhD FIBiol FRAg Soc FRSE Hon Assoc RCVS
P Newbould BSc BAgr DPhil
E A Piggott OBE
Professor T S West CBE FRS BSc DSc CChem FRSC FRSE
E G Williams BSc PhD
M J Wilson BSc PhD DSc FRSE

HONORARY ASSOCIATES

J F Darbyshire BSc MSc PhD
P C DeKock MSc DPhil
V C Farmer BSc PhD CChem FRSC FRSE
R Glentworth BSA (Manitoba) PhD
R Grant MA BSc
R H E Inkson BSc FSS FIS
R C Mackenzie DSc PhD FGS FRSE
J W S Reith BSc CChem FRSC
R A Roberston OBE BSc
A M Ure BSc PhD CChem FRSC

HONORARY RESEARCH ASSOCIATE

Professor H G Miller OBE BScFor PhD DSc FIBiol FICFor FRSA FRSE

Visiting Workers & Students

During 1999

Visiting Workers

Brigitta Aman, Reindeer Husbandry Unit, Swedish Agricultural University, Uppsala Sweden.

Ian Bishop, University of Melbourne, Australia.

Hugh Dove, CSIRO Plant Industry, Australia.

Maria Dubikova, University of Comenius, Slovak Republic.

Luthando Dziba, University of Fort Hare, South Africa.

Chantal Gascued, INRA, France.

Francois Gastal, INRA, France.

Jon Petter Gustafsson, Royal Institute of Technology, Stockholm, Sweden.

Gudberg Jonsson, University of Iceland, Iceland.

Sung-Ki Kang, Kon Kuk University, Korea.

Sigrio Lammer, University of Bonn, Germany.

Per-Arne Melkerud, Swedish University of Agricultural Sciences, Sweden.

Jerome Molenat, INRA, France.

Ashok Pharande, Agricultural University of Mahatma Phule, India.

Jozua Roux, Eastern Cape Province University, South Africa.

Peter Ryan, Middlebury College, Vermont, USA.

Riccardo Scalenghé, Universita di Torino, Italy.

Filip Tack, University of Gent, Belgium.

Amrish Tyagi, National Dairy Research Institute, India.

Judith Van Cleeff, University of Western Australia, Australia.

Andrew Wall, Middlebury College, USA.

David Whitehead, Landcare Research, New Zealand.

Xiaoe Yang, University of Zhejiang, P R China.

Ying Ye, University of Zhejiang, P R China.

Zhong Yue Shen, University of Zhejiang, P R China.

Yong Zhou, Agricultural University of Huazhong, P R China.

Visiting Students

Amine Arigue, Ecole Nationale des Ingénieurs des Travaux Agricoles, France.

Peter Beattie, University of Stirling, Scotland.

Carmen Bernzen, Ruhr-Universität Bochum, Germany.

Soran Besarani, University of Aberdeen, Scotland.

Hilda Blanchet, Pradeau la Sede Institute, France.

Karine Bourda, Pradeau la Sede Institute, France.

Daragh Brady, Scottish Agricultural College, United Kingdom.

Pia Bustos, University of Aberdeen, Scotland.

Laëtitia Chegard, Ecole Nationale Supérieure d'Agronomie de Rennes, France.

Christian Deitrich, Europa Fachhochschule Fresenius, Germany.

Goedele Digneffe, Katholieke Hogeschool, Kempen, Belgium.

Christophe Egret, University of Lille, France.

Einar Gretarsson, University of Aberdeen, Scotland.

Keith Gunn, University of Aberdeen, Scotland.

Louise Hayward, University of Edinburgh, Scotland.

Elizabeth Hunter, Middlebury College, Vermont, USA.

Jae-Beom Jang, University of Jeonjh, South Korea.

Vivian Kwok, Chinese University of Hong Kong, Hong Kong.

Marilyne Laurans, Ecole Nationale Superieure d'Agronomie de Montpellier, France.

Christopher Liddle, University of Aberdeen, Scotland.

Catriona MacDonald, University of Aberdeen, Scotland.

Rebecca Mackenzie, University of Aberdeen, Scotland.

Keith MacMillan, University of Aberdeen, Scotland.

Séverine Montez, Pradeau La Sede Institute, France.

Claire Murray, The Robert Gordon University, Scotland.

Jae-jak Nam, National Institute for Agricultural Science and Technology, South Korea.

Jean Pierre Paul, Mauritius Sugar Industry Research Institute, Mauritius.

Elizabeth Rees, University of Aberdeen, Scotland.

Charles Robelin, Ecole Polytechnique Palaiseau, France.

Alan Shand, University of Aberdeen, Scotland.

Louise Simms, University of Aberdeen, Scotland.

Pascal Sixt, Rural Resources Management College, France.

Douglas Smith, University of Edinburgh, Scotland.

Bryan Spears, The Robert Gordon University, Scotland.

Nicholas Vuichard, ISIMA, Clermont-Ferrand, France.

Andrew Wall, Middlebury College, Vermont, USA.

Geert Willems, Agricultural University of Wageningen, The Netherlands.

Tingmei Yan, Chinese Academy of Sciences, P R China.

Yuangen Yang, Chinese Academy of Sciences, P R China.

Marie Young, The Robert Gordon University, Scotland.

Postgraduate Research Students

Current PhD students with University and funding sources as at 1 January 2000

Asher Aftab, University of Edinburgh, Macaulay Development Trust

Trina Ames, University of Sheffield, NERC

Zoë Archer, University of Aberdeen, BORC

Ahmed Ayoub, Robert Gordon University, Self funding

Jon Ball, Robert Gordon University, RGU

Ursula Bausenwein*, University of Dundee, SOAEFD

Sally Burgess, University of Aberdeen, Scottish Agricultural College

Cameron Campbell, Robert Gordon University, RGU

Weiso Chen, Robert Gordon University, RGU

Alexis Comber, University of Aberdeen, MLURI/University of Aberdeen

John Cooper, University of Strathclyde, Highland Malt Distilling Ltd

Patricia da Silva, University of Aberdeen, Aberdeen Research Consortium

Julian Derry, University of Edinburgh, DfID

Jerone Dijkstra, Agricultural University of Wageningen, ECN Netherlands

Conor Doherty, University of Bradford, NERC/DETR

David Doxford, University of Sunderland, University of Sunderland

Jeroen Filius, Agricultural University of Wageningen, ECN Netherlands

Elzbieta Frak-Petit, INRA, INRA/Auvergne Region

Alex Freeman, University of Edinburgh, EPSRC CASE

Alistair Geddes*, University of Lancaster, MLURI

Jenny Gimpel, University of Lancaster, NERC

Martina Girvan, University of Aberdeen, NERC

Gwen-Aelle Grelet, University of Aberdeen, Aberdeen Research Consortium

Alisdair Hardy, University of Edinburgh, West of Scotland Water

Rachel Helliwell*, University of Aberdeen, EU

Lindsey Hewitson, University of Edinburgh, Macaulay Development Trust

Gary Hill*, University of Aberdeen, MLURI

Gordon Hudson*, University of Aberdeen, MLURI

Anne Humble, University of Aberdeen, ERSRC

Sarah James, University of Edinburgh, BBSRC

Brenda Keir, University of Aberdeen, BORC

Clemencia Licona-Manzur, University of Edinburgh, Consejo Nacional de Ciencio y Technologia, Mexico

Daisy Macdonald, University of Edinburgh, SOAEFD

Lynne Macdonald, University of Aberdeen, Macaulay Development Trust

Zivayi Magidzire, University of Edinburgh, DfID

Donatella Malaguti, University of Bologna, MURST/CPRV

Helena Martins, Technical University of Lisbon, Junta Nacional de Investigacoa Cientifico, Portugal

Keith Matthews*, Robert Gordon University, MLURI

Safia Mediene, Aix-Marseille, INRA/Provence Alpes Cote d'Azur Region

Charles Moyo, University of Pietermaritzburg, Zimbabwe, European Union

Raja Muhammad Omer, University of Aberdeen, European Union

Sander Oom, University of Edinburgh, Macaulay Development Trust

Alistair Pole, University of Aberdeen, University of Aberdeen/MLURI

Netty Purchase, University of Aberdeen, Bight Trust

Abdur Rahman, University of Aberdeen, European Union

Shaila Rao, University of Aberdeen, NERC

Catherine Reid, University of Plymouth, University of Plymouth/MLURI

Gabrielle Rouzard, Robert Gordon University, EU 'FAIR'/ BORC

Jia-en Sheu, University of Aberdeen, Self funding

Beth Spiers, Strathclyde University, Self funding

Marc Stutter, University of Aberdeen, DETR

David Stephens, Canterbury University, New Zealand Higher Education Link Scheme

Bruce Thomson, Robert Gordon University, Self funding

Wendy van Beinum, Agricultural University of Wageningen, Macaulay Development Trust

Mary Walsh, University of Dundee, NERC

Elaine Wilson, Robert Gordon University, RGU, Aberdeenshire Council, Macaulay Trust

Paul Withers, Open University, Self funding

Gerard Wynn*, University of Aberdeen, MLURI

Jo Anna Mairi Wynn, University of Manchester, NERC CASE

(* indicate staff undertaking Doctorates)

Programme of Research

Current projects as of 1 January 2000

(unless stated research programmes are funded by SERAD)

PROGRAMME 1: SOIL QUALITY & PROTECTION

Programme Manager: E Paterson

Biological Aspects

011328 Effects of sewage sludge applications to agricultural soils on soil microbial activity and the implications for agricultural productivity and long term soil fertility (Jeff Bacon)

011554 Concentrations of environmental oestrogens (xenoestrogens) in tissues of domestic animals grazing pasture treated with sewage sludge (Stewart Rhind)

011612 Microbial processes and diversity as quality indicators of soils subject to land use change (Steve Chapman)

011677 Fungi and the rhizosphere: Manipulation and monitoring of soil fungal diversity and community structure in the rhizosphere (Soil Health Initiative) (Colin Campbell) [Macaulay Development Trust]

011678 Fungi and lignocellulose degradation: Molecular analysis of fungal catabolic diversity (Soil Health Initiative) (Colin Campbell) [Macaulay Development Trust]

011642 Effects of long-term nitogen deposition on VA mycorrhizal functioning in grasslands (Colin Campbell) [Non-commissioned joint with Natural Enviroment Research Council]

Physico-chemical Aspects

012697 Chemical fluxes in soils-processes and properties (Jeff Bacon)

012698 The influence of plant exudates on ion fluxes in the soil-plant system (Jeff Bacon)

012649 Health risks of heavy metals in the food chain of industrial areas of Central and Eastern Europe (Jeff Bacon) [European Commission]

012627 Multicomponent transport of reactive chemicals in physically and chemically heterogeneous systems (Hans Meeussen) [Macaulay Development Trust]

012626 Integrated assessment and modelling of soil contaminant behaviour, transport and impact at remediable urban sites (Ed Paterson) [Natural Enviroment Research Council]

012647 Urban regeneration of coalfields: generic studies of contaminated land and groundwater issues exemplified in Wolverhampton (Alistair Smith) [Natural Enviroment Research Council]

012593 Modelling metal interactions with humic substances (David Lumsdon) [Non-commissioned]

Soil Quality in Ecosystems & Landscapes

013670 Geochemical controls on the spatial and temporal solute chemistry of surface waters (Derek Bain)

013699 Process based indicators of soil quality and their application in support of a Scottish soil protection strategy (Ed Paterson)

013571 Effects of afforestation of agricultural land on heavy metal mobility in soil (Derek Bain) [European Commission]

013629 Improving the productivity and sustainability of crop systems on fragile slopes in the highlands of South China and Thailand (Jeff Wilson) [European Commission]

013632 Sorption-microflotation method for the purification of water from soluble components of fuels and oils (Ed Paterson) [European Commission]

013685 Survival and dispersal of *E.coli* O157 in Scottish agricultural soils, and potential for contamination of private water supplies (Ed Paterson) [University of Aberdeen]

013695 Studies on the Environmental Persistence of TSE infectivity (Ed Paterson) [MAFF]

PROGRAMME 2: PLANT ECOPHYSIOLOGY & RHIZOSPHERE PROCESSES

Programme Manager: P Millard

Ecophysiology of Woody Perennials

021700 Nutrient uptake and remobilisation in relation to survival, growth and development of young trees in regenerating semi-natural woodlands (Pete Millard)

Grass Ecophysiology

022613 Acquisition and utilisation of nitrogen by plants of upland ecosystems (Barry Thornton)

022701 Adaption of upland grasses to herbivory and excretal returns, and consequences for plant competition (Barry Thornton)

022438 Phenotypic and genotypic basis of population dynamics in heterogeneous species - rich grassland (Pete Millard) [Flexible Funding]

022591 Physiological and molecular responses of grasses to defoliation and their consequences for the vegetation dynamics of grazed swards (Barry Thornton) [Non-commissioned joint with BBSRC]

Rhizosphere Ecophysiology & Chemistry

023622 Rhizodeposition from grasses in relation to whole plant C-partitioning, as affected by defoliation and nutrient supply in extensively managed grasslands, and associated impacts in soil microbial communities (Eric Paterson)

023702 Rhizosphere processes of grazed ecosystems: carbon fluxes and microbial community structure and function (Sue Grayston)

023703 Organic matter inputs to soil and their effects on the soil solution chemistry of nitrogen, phosphorus and carbon (Charlie Shand)

023398 Development and application of molecular biological techniques in studies of the interactions between microbes, nutrient cycling and vegetation among a range of agriculturally important pastures, to enable scaling from microcosm to field (Sue Grayston) [Flexible Funding]

023640 Importance of root production and rhizodeposition in relation to interactions with microbial biomass and plant nutrient uptake in extensively managed systems (Eric Paterson) [Macaulay Development Trust]

023650 Effects of leaf nitrate on mineralisation and uptake of N from organic patches (Eric Paterson) [BBSRC]

023651 Assessment of the influence of natural and applied selection pressures on the interactions between diversity of ammonia oxidising bacteria, functional gene diversity and ammonia oxidising activity (EDGE) (Sue Grayston) [Natural Enviroment Research Council]

023659 Biodiversity of invertebrate root feeders and their impact on soil microbial communities (Sue Grayston) [Natural Enviroment Research Council]

023661 Management of field experiments at Sourhope (Pete Millard) [Natural Enviroment Research Council]

023589 Colloid chemistry in soil solution and its impact on P transfers from grasslands (Charlie Shand) [Non-commissioned joint with BBSRC]

023590 Plant stress effects on C:N efflux into the rhizosphere (Sue Grayston) [Non-commissioned joint with BBSRC]

PROGRAMME 3: PLANT ECOLOGY & COMMUNITY DYNAMICS

Programme Manager: R J Pakeman

Interaction of Grazing & Plant Competition

031488 Influences on plant species balance in extensively managed grassland grazed by sheep and cattle (Titus Barthram)

031548 Extent and development of spatial aggregation of species in extensive grassland communities (Carol Marriott)

031614 Maintenance and function of biodiversity in grazed systems: understanding the role of the regeneration niche (Robin Pakeman)

Grazing & Environment Interactions with Plant Community Dynamics

032487 Responses by tree saplings to browsing damage by cattle and red deer (Alison Hester)

032549 Spatially explicit models of vegetation dynamics (Colin Birch)

032675 Spatio-temporal dynamics of montane dwarf shrub-dominated vegetation: control by climatic, nutrient and management factors (Andrea Britton)

032694 Human interactions with the mountain birch forest ecosystem: implications for sustainable development (HIBECO) (Alison Hester) [European Commission]

032641 Spatial pattern and process in the fragmentation of heather moorland (Alison Hester) [Macaulay Development Trust]

032692 Integrated bracken control and vegetation restoration: long term vegetation change (Robin Pakeman) [University of Liverpool]

032585 Transitional Machair Systems of the Outer Hebrides (Robin Pakeman) [Non-commissioned]

032637 Control of reproduction of bracken (Robin Pakeman) [Non-commissioned joint with Natural Enviroment Research Council]

PROGRAMME 4: ANIMAL ECOLOGY IN GRAZED ECOSYSTEMS

Programme Manager: I J Gordon

Nutritional Ecology of Free-ranging Herbivores

041550 Conditioned food aversions and their influence on the foraging behaviour of free-ranging ruminants (Alan Duncan)

041704 Inter-relationships between nutrition, behaviour and diet diversity (Glenn Iason)

041578 Effects of food-borne glucosinolates on human health (Alan Duncan) [European Commission]

041646 Theory and optimisation modelling in whole-animal goal-oriented food intake studies (Iain Gordon) [University of Edinburgh]

041573 Mechanisms of food selection by mountain hares and their importance to native woodland dynamics (Glenn

Iason) [Non-commissioned joint with Natural Enviroment Research Council]

041684 Food intake and performance in Soay sheep (Iain Gordon) [Non-commissioned joint with Natural Enviroment Research Council]

Spatial Distribution of Animal Populations

042485 Measurement of the ranging behaviour of red deer using a Global Positioning Satellite system to aid development of computer-based models (Angela Sibbald)

042552 Effects of spatial aggregation of grass species on frequency dependent selection in grazing herbivores (Iain Gordon)

042553 Spatial and temporal variation in population performance of red deer in relation to density, climate and land cover (Iain Gordon)

042705 Investigate the role of behavioural processes in determining the relationship between the spatial distribution of animal populations and their resources (Angela Sibbald)

042592 Natural resources management within multispecies systems in the mid-Zambezi Valley: Implications for sustainable development in dry lands area of Southern Africa (Iain Gordon) [European Commission]

042644 Opportunities for increased food production from livestock through improved rangeland management and animal feeding strategies in transhumance pastoral systems of the Hindu Kush- Karakoram-Himalayan region (Alan Duncan) [European Commission]

042639 Tracking of environmental uncertainty in foraging herbivores (Iain Gordon) [Macaulay Development Trust]

042681 Participatory development of community based management plans for livestock feed resources in the semi-arid areas of Zimbabwe (Iain Gordon) [Natural Resources Institute]

042682 Research training fellowship in wildlife conservation: A study of the effects of natural factors and livestock competition on the population viability of the huemul (Hippocamelus bisculus) in the temperate rainforest of Chilean Patagonia (Iain Gordon) [The Wellcome Trust]

042506 Quantify the role of species interactions during foraging on the functioning of mammalian communities (Iain Gordon) [Non-commissioned]

042663 Competition and co-existence in the African carnivore guild (Glenn Iason) [Non-commissioned]

Modelling the Spatio-temporal Dynamics of Grazed Ecosystems

043706 Investigate the spatio-temporal interactions between herbivore populations, plant communities and soil resources (Iain Gordon)

043594 Environmental variability and productivity of semi-arid grazing systems (Iain Gordon) [Natural Resources Institute]

PROGRAMME 5: RURAL ECONOMIC MODELLING & ENVIRONMENTAL ECONOMICS

Programme Manager: J R Crabtree

Economic Analysis for Resource Management

051529 Design of strategies for environmental and compliance monitoring (Bob Crabtree)

051707 Methodological development to support economic analysis of natural resource management (Bob Crabtree)

051683 Evaluating the economic impact of irrigation controls (Bob Crabtree) [Flexible Funding]

051689 The local economic impact of fox hunting in Scotland (Bob Crabtree) [Flexible Funding]

051657 Integrated water basin management: estimation of environmental and full recovery costs under the EU Water Policy Directive (Bob Crabtree) [Macaulay Development Trust]

051574 Improving Agri-environmental policies: A simulation approach to the role of the cognative properties of farmers and institutions (Bob Crabtree) [Royal Agricultural College Cirencester]

051721 Economic Evaluation of the Community Woodland Supplement (Bob Crabtree) [Forestry Commission]

Rural Economic Modelling

052609 The development of alternative methodolgies for the analysis of rural sustainability (Deb Roberts)

052669 Assessing sustainability: quantitative approaches to examining environmental policy impacts on rural sustainable development (Gary Hill)

052679 Household Location and Rural Development: Arkleton Centre/MLURI Joint Initiative (Deb Roberts) [Macaulay Development Trust]

052696 Forests Role in Tourism (Deb Roberts) [Forestry Commission]

052726 Research Support advice to the Scottish Parliament Rural Affairs Committee (Deb Roberts) [Aberdeen Research Consortium]

Property Rights & Land Use

053667 Changing property institutions in land: Impacts on rural development and local economic and social benefits (Bob Crabtree)

053654 Communal ownership: Implications for rural development in peripheral areas (Bob Crabtree) [European Commission]

PROGRAMME 6: LAND USE CHANGE

Programme Manager: R V Birnie

Data Acquisition & Integration

061666 Methodologies for evaluating the spatial characteristics of landscape and landscape change (David Miller)

061708 Change detection from multi-resolution time series image data for monitoring land cover change in Scotland (Dick Birnie)

061691 Methods of peatland rehabilitation in Northern Europe (David Miller) [European Commission]

061598 Integrated System for Analysing and Reporting on the Social, Economic and Environmental Dimensions of Rural Land Use Change (Dick Birnie) [Flexible Funding]

061634 Automated land cover change detection (Alistair Law) [Flexible Funding]

061652 Streetscapes: their contribution to wealth creation and quality of life (David Miller) [Scottish Enterprise]

061719 The use of spatial analysis tools to explain patterns in forest landscapes due to management and ownership in Britain and Portugal (David Miller) [British Council]

061561 The structuring of remote sensing and land cover knowledge for automated land cover change detection (Alistair Law) [Non-commissioned]

Case Studies of Land Use Change

062709 Case studies of land use change in Scotland: Arkleton Centre/MLURI Joint Initiative (Dick Birnie)

Modelling Land Use Change

063608 Framework for evaluation and assessment of regional land use scenarios (FEARLUS) (Alistair Law)

063710 Empirical modelling of land use change: A Bayesian statistical approach (Dick Birnie)

063633 Automatic analysis of the results of complex land use simulations (Alistair Law) [Non-commissioned joint with University of Aberdeen]

063662 Theoretical Land Use Science (Keith Farnsworth) [Non-commissioned]

PROGRAMME 7: INTEGRATED CATCHMENT MANAGEMENT

Programme Manager: R C Ferrier

Origins, Interactions & Transport of Solutes & Particulates

071493 Use of long-term monitoring sites and historical re-sampling strategies in the detection of environmental changes (ECN) (John Miller)

071607 The application of soil hydrological and land cover data to the regional modelling of gaseous nitrogen emissions (Allan Lilly)

071611 Characterisation and origins of dissolved organic nitrogen (DON) and dissolved organic carbon (DOC) in upland soils (Berwyn Williams)

071711 Spatial and temporal aspects of nutrient source and sink relationships: Implications for formation, transport and environmental impact (Tony Edwards)

071712 Spatial modelling of catchment scale hydrological and hydrochemical processes (Sarah Dunn)

071579 Significance of physical heterogeneity for scaling of solute chemistry in soils from fine scale to subcatchment (Tony Edwards) [Flexible Funding]

071665 Chemical speciation of trace metals in freshwater and seawater (Tony Edwards) [Non-commissioned joint with Natural Enviroment Research Council]

Impact Assessment & the Development of Management Strategies for Water Resources

072713 Assessing the impact of change on the biogeochemistry of terrestrial and acquatic ecosystems (Bob Ferrier)

072714 Economic analysis of environmental control policies (Thanasis Kampas)

072727 RECOVER 2010: Predicting recovery in acidified freshwaters by the year 2010, and beyond (Bob Ferrier) [European Commission]

072720 EMERGE - European Mountain Lake Ecosystems: Regionalisation diagnostics and socio-economic evaluation (Bob Ferrier) [NIVA]

PROGRAMME 8: INTEGRATED LAND USE SYSTEMS

Programme Manager: I A Wright

Livestock Systems

081556 Development of efficient, biologically sustainable and economically viable upland sheep systems (Alan Sibbald)

081715 Production of high quality fibre from sheep and goats (Margaret Merchant)

081716 Matching animal genotype to extensive production systems: Implications for nutrition, welfare and product quality (Pete Goddard)

081630 Effect of undernutrition *in utero* on the development of the reproductive system in sheep (Stewart Rhind) [Flexible Funding]

081499 Selection of goats for resistence to gastro-intestinal nematodes (Margaret Merchant) [joint with Moredun Research Institute]

081604 Selecting for reduced aggression in pigs (Hans Erhard) [MAFF]

081581 Neuroendocrine control of appetite and reproduction in sheep (Stewart Rhind) [Non-commissioned]

Natural Heritage & Biodiversity Management

082528 Development of methodology for large-scale habitat assessment (Andrew Nolan)

082623 Environmental Change Network: Measure long-term changes in climate, soils, vegetation and wildlife populations at two upland agricultural sites in Scotland (David Henderson)

082624 Integrating remotely sensed vegetation indices with biophysical data to provide measures of the structure and biomass of upland vegetation types (Gary Wright)

082668 The cost effectiveness of biodiversity provision (Gerard Wynn)

082717 Feasibility of developing a decision support tool (Wood Deer) to aid the management of deer in woodlands in the uplands of Scotland (Iain Wright)

082687 Deer Management (John Milne) [European Commission]

082587 Effect of change in grazing pressure of sheep on erosion and vegetation cover on Trotternish, Skye (David Henderson) [Flexible Funding]

082601 Modelling plant and animal biodiversity in a Scottish catchment devoted to agriculture (Peter Dennis) [Flexible Funding]

Integrated Land Use Systems & Policy Analysis

083436 Suitability of whole tree harvesting of Sitka spruce as a sustainable land use on different site types within the UK (Mike Proe)

083557 The role of spatially distributed interactions in integrated land-use systems (Alan Sibbald)

083718 Development of decision support tools for strategic farm-scale multiple-objective land use planning (Keith Matthews)

083693 European Livestock Policy Evaulation Network: Development of a livestock policy decision support system (ELPEN) (Iain Wright) [European Commission]

083577 Developing agroforestry systems for the Southern Hill Region of the Yangtze River (Alan Sibbald) [Royal Society]

083722 Use of Isotopically Labelled Plant Material to Simulate Nutrient Dynamics in Decomposing Harvest Residues (Mike Proe) [Forestry Commission]

CORPORATE PROJECTS

090676 An integrated data management, analysis and retrieval system for land use information about Scotland (DRUID) (Alistair Law)

090415 Monitoring of Environmentally Sensitive Areas in Scotland (Jim Gauld)

Staff Publications

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BACON, J.R., CRAIN, J.S., VAN VAECK, L. AND WILLIAMS, J.G. Atomic spectrometry update. Atomic mass spectrometry. *Journal Analytical Atomic Spectrometry*, 14, 1633-1659.

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QUARTIERI, M., TAGLIAVINI, M., MARANGONI, B. AND MILLARD, P. Il ciclo interno dell'azoto negli alberi di pesco. *Frutticoltura*, No.2. 61-66.

WILLIAMS, B.L. Disturbance of the nitrogen cycle - review. *Journal of Applied Ecology*, 36, 620-621.

Conferences & Visits Abroad

Conferences In The UK Attended by Staff During 1999

ARCHER, Z.A. Society for the Study of Fertility Annual Conference. University of Wales, Aberystwyth, 4-8 July.

BACON, J.R. Annual General Meeting of the Editorial Board of ASU. Teddington, 16-18 March.

BACON, J.R. Executive Committee Meeting of Atomic Spectroscopy Updates. Cambridge, 20 September.

BACON, J.R. Sewage Disposal: The Biological Impact. Burlington House, London, 11-12 November.

BACON, J.R. Society for Environmental Geochemistry and Health, 17th European Conference. Glasgow, 28-31 March.

BAIN, D.C. Earth Science and the Natural Heritage. Edinburgh, 4-5 November.

BAIN, D.C. From Magmas to Mud (and Back). University of Reading, 13-15 December.

BAIN, D.C. Mineralogy and the Environment. University of Aberdeen, 7-8 January.

BEECHAM, J.A. ASAB 1999 Winter Meeting, Evolution of Mind. London Zoo, 2-3 December.

BEECHAM, J.A. BES Winter Meeting. Leicester, 5-7 January.

BEECHAM, J.A. IALE 8th Annual Conference - Heterogeneity in Landscape Ecology: Pattern and Scale. Bristol, 6-8 September.

BEECHAM, J.A. BES Winter Meeting. University of Leeds, 20-22 December.

BIRCH, C.P.D. BES Annual Symposium - Ecological Consequences of Environmental Heterogeneity. University of Sussex, 23-26 March.

BIRCH, C.P.D. Bracken '99. University of Manchester, 20-23 July.

BIRCH, C.P.D. BES Winter Meeting. Leicester, 5-7 January.

BIRCH, C.P.D. BES Winter Meeting. University of Leeds, 20-22 December.

BIRNIE, R.V. Enabling Access to Geographic Information in a Devolved Scotland. Edinburgh, 26 November.

BIRNIE, R.V. Native Woodlands Policy Forum Seminar. MLURI, 14 June.

BIRNIE, R.V. Bracken '99. University of Manchester, 20-27 July.

BIRNIE, R.V. The Scottish Parliament and Rural Policy: What Room for Manoeuvre? University of Aberdeen, 3 November.

BIRNIE, R.V. The Scottish Parliament: Supporting Policy with Geographic Information. University of Edinburgh, 3 February.

BIRNIE, R.V. The Scottish Parliament: The Consequences. University of Dundee, 24 September.

BRITTON, A.J. BES Winter Meeting. Leicester, 5-7 January.

BRITTON, A.J. British Ecological Society Winter Meeting. University of Leeds, 20-22 December.

BROOKER, N. ESRI UK User Conference. University of Keele, 27-29 April.

BROOKER, N. The Scottish Parliament: Supporting Policy with Geographic Information. University of Edinburgh, 3 February.

BROWN, K. 1999 Land Reform Convention Conference. University of Stirling, 20 November.

BROWN, K. The Scottish Parliament and Rural Policy: What Room for Manoeuvre? University of Aberdeen, 3 November.

BUNDY, J. Exposure Assessment: Its Role in Ecotoxicology. Cardiff, 7-9 September.

CAMPBELL, C.D. Using the Past in the Future of Scotland's New Native Woodlands. Perth, 23 November.

CAMPBELL, C.D. BSSS 1999 Autumn Conference, Sustainable Management of Soil Organic Matter. Edinburgh, 15-17 September.

CAMPBELL, C.D. Manipulation of the Root Environment. University of Manchester, 29-31 March.

CHAPMAN, P. Sustainable Management of Soil Organic Matter. Edinburgh, 15-17 September.

CHAPMAN, P. IAHS Symposium on Impact of Land Use Change on Nutrient Loads from Diffuse Sources. Birmingham, 19-20 July.

CHAPMAN, S.J. BSSS 1999 Autumn Conference, Sustainable Management of Soil Organic Matter. Edinburgh, 15-17 September.

CHAPMAN, S.J. Society for General Microbiology 143rd Meeting Symposium: Detection of Microbes in the Natural Environment. University of Edinburgh, 14-15 April.

CHAPMAN, S.J. TERICA: Trace Gas Fluxes and Ecosystem Functioning. ITE, Edinburgh, 13-14 January.

COMBER, L.J. AGI Scottish Group Workshop. Edinburgh, 2-3 February.

COMBER, L.J. GIS Research UK, University of Southampton, 14-16 April.

COMBER, L.J. IALE 8th Annual Conference, Heterogeneity in Landscape Ecology: Pattern and Scale. IACR, Long Ashton, 7-8 September.

COMBER, L.J. Remote Sensing Society Conference 1999. University of Wales, Cardiff, 9-10 September.

COMBER, L.J. Scottish Land Reform Convention. University of Stirling, 20 November.

COMBER, L.J. The Scottish Parliament: Supporting Policy with Geographic Information. University of Edinburgh, 3 February.

COULL, M.C. Agriculture and Waste: Management for a Sustainable Future. Edinburgh, 31 March - 2 April.

CRABTREE, J.R. ADAS Agriculture and the Environment Conference. Warwick University, 14-16 April.

CRABTREE, J.R. Agricultural Economic Conference - Strategy for Agriculture. London, 25 November.

CRABTREE, J.R. Decision Trees. Edinburgh, 8 October.

CRABTREE, J.R. The Agricultural Economics Society. Queen's University, Belfast, 20-29 March.

CRABTREE, J.R. Valuation of the Environment Beyond 2000. London, 23 November.

CRABTREE, J.R. The Scottish Parliament and Rural Policy: What Room for Manoeuvre? University of Aberdeen, 3 November.

DA SILVA, P. Society for the Study of Fertility Annual Conference. University of Wales, Aberystwyth, 4-8 July.

DALZIEL, A.J.I. UK Agroforestry Forum Annual Meeting - Farming with Trees. Greenmount College, County Antrim, 28-30 June.

DAWSON, L.A. Scottish Roots Group Annual Meeting. SAC Edinburgh, 3 November.

DENNIS, P. 10th Biennial Culterty Workshop. Culterty, 2-3 October.

DENNIS, P. Agriculture and Biodiversity: Focus on pastoral systems: grazing management and policy. DETR London, 7 July.

DENNIS, P. IALE 8th Annual Conference - Heterogeneity in Landscape Ecology: Pattern and Scale. Bristol, 6-8 September.

DENNIS, P. Landscape Sensitivity International Conference. University of Stirling, 2-3 September.

DENNIS, P. BES Winter Meeting. University of Leeds, 20-22 December.

DUNCAN, A.J. BSAS Winter Meeting. Scarborough, 22-24 March.

DUNCAN, A.J. Food and Cancer Prevention III. Norwich, 5-8 September.

DUNN, S.M. Agriculture and Catchment Water Quality. London, 19 January.

DUNN, S.M. IAHS Symposium on Impact of Land Use Change on Nutrient Loads from Diffuse Sources. Birmingham, 19-20 July.

DUNN, S.M. Scottish Snow Group Meeting. Bridge of Allan, Stirling, 19 May.

EDWARDS, A.C. BSSS 1999 Autumn Conference - Sustainable Management of Soil Organic Matter. Edinburgh, 13-17 September.

EISER, D.A. IUFRO. University of Aberdeen, 23-27 August.

FRASER, A.R. Near and Mid-Infrared Spectroscopy in Quality Control and Quality Assurance. Stirling, 15 April.

GAULD, J.H. Landscape Engineering: the Importance of Soil and IPSS Annual General Meeting. Silsoe, Bedfordshire, 29 September.

GAULD, J.H. BSSS 1999 Autumn Conference, Sustainable Management of Soil Organic Matter. Edinburgh, 15-17 September.

GEDDES, A. Enabling Access to Geographic Information in a Devolved Scotland. Edinburgh, 26 November.

GEDDES, A. GIS 99. London, 30 September.

GEDDES, A. The Scottish Parliament: Supporting Policy with Geographic Information. University of Edinburgh, 3 February.

GEELHOED, J.S. European Perspectives on Contaminated Land. SCI, London, 22 April.

GEELHOED, J.S. Society of Environmental Geochemistry and Health, 17th European Conference. Glasgow, 29-31 March.

GIMONA, A. Ecological, Land Use and Political Issues in the UK, Italy and Netherlands. Chester, 16-18 November.

GIMONA, A. GIS Research UK. University of Southampton, 14-16 April.

GODDARD, P.J. British Deer Farmers' Association Annual Conference. Edinburgh, 13 November.

GODDARD, P.J. National Seminar on Capercaillie. Perth, 14 February.

GORDON, I.J. British Association Annual Festival of Science. Sheffield, 17 September.

GORDON, I.J. Windsor Meeting Reunion. London, 29-30 March.

GORDON, I.J. BES Winter Meeting. University of Leeds, 20-22 December.

GORDON, I.J. UK Forum on Agricultural Research in Development. University of Nottingham, 24 February.

GRAYSTON, S.J. Annual Meeting of the Stable Isotope Mass Spectometry Users Group. Devon, 19-21 January.

GRAYSTON, S.J. BSSS 1999 Autumn Conference - Sustainable Management of Soil Organic Matter. Edinburgh, 15-17 September.

GRAYSTON, S.J. Scottish Roots Group Annual Meeting. SAC, Edinburgh, 3 November.

GRAYSTON, S.J. NERC Soil Biodiversity Programme Annual

Meeting. Grange-over-Sands, 10-11 November.

HELLIWELL, R.C. Scottish Snow Group Meeting. Bridge of Allan, Stirling, 19 May.

HENDERSON, D.J. 1999 Hill Land Use and Ecology Discussion Group Meeting. Skye, 11-13 May.

HESTER, A.J. Native Woodland Discussion Group: Annual Field Meeting. Strathpeffer, 3-6 June.

HESTER, A.J. Native Woodland Policy Forum Seminar. MLURI, 14 June.

HESTER, A.J. Seminar and Demonstration on Hill Cattle and Native Woodland Management. Crianlarich, 26 May.

HESTER, A.J. BES Winter Meeting. University of Leeds, 20-22 December.

HESTER, A.J. Using the Past in the Future of Scotland's New Native Woodlands. Perth, 23 November.

HEWISON, R.L. Introduction to National Vegetation Classification. Kindrogan Field Centre, 27-31 July.

HEWISON, R.L. Vegetation Dynamics and Land Use in Scotland. Edinburgh, 9-10 November.

HEWISON, R.L. Using the Past in the Future of Scotland's New Native Woodlands. Perth, 23 November.

HILL, G.W. The Agricultural Economics Society. Queens University, Belfast, 26-29 March.

HILL, G.W. The Scottish Parliament and Rural Policy: What Room for Manoeuvre? University of Aberdeen, 3 November.

HILLIER, S.J. From Magmas to Mud (and Back). University of Reading, 13-15 December.

HILLIER, S.J. Mineralogy and the Environment. University of Aberdeen, 7-8 January.

IASON, G.R. BES Winter Meeting. University of Leeds, 20-22 December.

KAMPAS, A. Annual Conference of Operational Research Society. Edinburgh, 16 September.

KAMPAS, A. The Design and Implementation of Voluntary Approaches - Free Rider, Competitiveness and Transactions Costs Issues. Dublin, 9-10 September.

KEDDIE, L.M. SABRI Safety Co-ordinators & Site Engineers Meeting. Moredun Institute, 13 May.

KEIR, B. BSAS Winter Meeting. Scarborough, 21-24 March.

LANGAN, S.J. Mineralogy and the Environment. University of Aberdeen, 7-8 January.

LANGAN, S.J. BSSS 1999 Autumn Conference - Sustainable Management of Soil Organic Matter. Edinburgh, 15-17 September.

LANGAN, S.J. Earth Science and the Natural Heritage. Edinburgh, 4-5 November.

LAW, A.N.R. The Scottish Parliament: Supporting Policy with Geographical Information. University of Edinburgh, 3 February.

LEADBEATER, S. Land Reform in Scotland: The Great Debate. University of Aberdeen, 27 April.

LEADBEATER, S. The Scottish Parliament: Supporting Policy with Geographical Information. University of Edinburgh, 3 February.

LEADBEATER, S. 1999 Hill Land Use and Ecology Discussion Group Meeting. Skye, 11-13 May.

LEADBEATER, S. Digital Cameras for Aerial Survey. Kodak House, Hemel Hempstead, 24 November.

LEADBEATER, S. Remote Sensing Society Conference 1999. University of Wales, Cardiff, 8-10 September.

LILLY, A. Transport in Structured Soils. SCRI, Dundee, 6 January.

LUMSDON, D.G. Society of Environmental Geochemistry and Health, 17 European Conference. Glasgow, 29 March.

LUMSDON, D.G. BSSS 1999 Autumn Conference – Sustainable Management of Soil Organic Matter. Edinburgh, 15-17 September.

LUND, J. Fundamentals of PR. Aberdeen, 11 March.

LUND, J. Manipulation of the Root Environment. University of Manchester, 29-31 March.

LUND, J. Practical Public Relations. Aberdeen, 8 October.

LUND, J. Taking Radio Seriously. MLURI, 10 November.

MACDONALD, L. BSSS Autumn Meeting - Sustainable Management of Soil Organic Matter. Heriot Watt University, Edinburgh, 15-17 September.

MACDONALD, L. Scottish Roots Group Annual Meeting. SAC Edinburgh, 3 November.

MALCOLM, A. The Scottish Parliament: Supporting Policy with Geographic Information. University of Edinburgh, 3 February.

MALCOLM, A. Using the Past in the Future of Scotland's New Native Woodlands. Perth, 23 November.

MALLAND, D. Mineralogical Society, Minerals and the Environment. University of Aberdeen, 7-8 January.

MATTHEWS, K.B. 18th Workshop of UK Planning and Scheduling. University of Salford, 15-16 December.

MAXWELL, T.J. Stirling Royal Society Landscape Conference. Stirling, 2-4 September.

MAXWELL, T.J. Heather Trust Range Management for Wildlife Conference. Perth, 24 September.

MAYES, R.W. MAFF Contractor's Meeting - Chemical Contaminants from Food Production. Brighton, 13-14 December.

MAYES, R.W. MAFF Radiation Research Project Seminar. London, 3-4 March.

McGUINNESS, J.A. Biosis/Edina Training. University of Edinburgh, 11 February.

McGUINNESS, J.A. BIDS Autumn Workshop. University of Strathclyde, 6 September.

McMURRAY, E.M. 27th Scottish Microscopy Symposium. Glasgow, 10 November.

MEEUSSEN, H.C.L. Transport in Structured Soils. SCRI, Dundee, 6 January.

MEEUSSEN, H.C.L. Manipulation of the Root Environment. University of Manchester, 29-31 March.

MIDWOOD, A.J. Estimating Uncertainties in Analytical Analyses. London, 27-28 January.

MILLARD, P. Manipulation of the Root Environment. University of Manchester, 29-31 March.

MILLER, D.R. 36th Annual Symposium of British Cartographic Society. University of Glasgow, 11-12 September.

MILLER, D.R. Bracken '99. University of Manchester, 20-26 July.

MILLER, D.R. British Wind Energy Association. University of Cambridge, 1-2 September.

MILLER, D.R. Enabling Access to Geographic Information in a Devolved Scotland. Edinburgh, 26 November.

MILLER, D.R. Fire Research - 'Masterclass'. Glen Tanar, 8 June.

MILLER, D.R. From Quill Pens to Terabytes: Authenticity and Admissibility of Digital Data. Lloyds of London, 25 October.

MILLER, D.R. Native Woodlands Policy Forum Seminar. MLURI, 14 June.

MILLER, D.R. Virtual Reality in Geography. University of Leicester, 4 January.

MILLER, D.R. The Scottish Parliament: Supporting Policy with Geographic Information. University of Edinburgh, 3 February.

MILLER, J.D. Networking of Long-term Integrated Monitoring in Terrestrial Systems - No Limits. Oxford, 24-26 March.

MILNE, J.A. Heather Trust Range Management for Wildlife Conference. Perth, 24 September.

MILNE, J.A. BSAS Winter Meeting. Scarborough, 21-24 March.

NOLAN, A.J. Environmental Management in Practice. Perth, 6 November.

OOM, S. BES Annual Symposium – Ecological Consequences of Environmental Heterogeneity. University of Sussex, 23-25 March.

PAKEMAN, R.J. Bracken '99. University of Manchester, 20-26 July.

PAKEMAN, R.J. BES Winter Meeting. Leicester, 5-7 January.

PAKEMAN, R.J. BES Winter Meeting. University of Leeds, 20-22 December.

PATERSON, E. BES Annual Symposium - Ecological Consequences of Environmental Heterogeneity. University of Sussex, 22-25 March.

PATERSON, E. Earth Science and the Natural Heritage. Edinburgh, 4-5 November.

PATERSON, E. Mineralogy and the Environment. University of Aberdeen, 7-8 January.

PATERSON, E. Scottish Roots Group First Meeting. University of Dundee, 3 February.

PATERSON, E. BSSS 1999 Autumn Conference, Sustainable Management of Soil Organic Matter. Edinburgh, 15-17 September.

PATERSON, E. Manipulation of the Root Environment. University of Manchester, 29-31 March.

POLHILL, G.G. Java and Corba Seminar. Linlithgow, 12 January.

RAE, M.T. Society for the Study of Fertility Annual Conference. University of Wales, Aberystwyth, 4-8 July.

RAHMAN, A. BSAS Winter Meeting. Scarborough, 21-24 March.

RHIND, S.M. Society for the Study of Fertility Annual Conference. University of Wales, Aberystwyth, 4-8 July.

RIVINGTON, M. Home-grown Cereals Authority Agronomy Roadshow. Inverurie, 30 November.

ROBERTS, D.J. ESRC Urban and Regional Studies Economics Group. Carlisle, 6-8 January.

ROBERTS, D.J. IUFRO New Opportunities for Forest-Related Rural Development. Aberdeen, 23-28 August.

ROBERTSON, L.E. Agents Presentations re Journal Subscriptions. Cambridge, 18 February.

ROBERTSON, L.E. Effective Knowledge Management by Grampian Information. Aberdeen, 2 September.

ROBERTSON, L.E. ISI Web of Science Service. Glasgow Caledonia University, 29 July.

ROBERTSON, L.E. SALG Meeting. SASA, Edinburgh, 19 November.

ROBERTSON, L.E. Sydney Plus User Group Annual General Meeting. Newcastle, 12 November.

ROBERTSON, L.E. Biosis/Edina Training. University of Edinburgh, 11 February.

ROE, M.J. 27th Scottish Microscopy Symposium. Glasgow, 10 November.

ROE, M.J. Mineralogy and the Environment. University of Aberdeen, 7-8 January.

ROUZAUD, G. Food and Cancer Prevention III. Norwich, 5-8 September.

SHAND, C.A. Agriculture and Environment Group SCI. London, 23 November.

SHAND, C.A. BSSS 1999 Autumn Conference- Sustainable Management of Soil Organic Matter. Edinburgh, 15-17 September.

SHAND, C.A. Mineralogical Society, Mineralogy and the Environment. University of Aberdeen, 7-8 January.

SIBBALD, A.R. Farm Woodlands for the Future. University of Cranfield, 8-10 September.

SIBBALD, A.R. MAFF Workshop - The Future of Farm Woodland Research. University of Cranfield, 28 October.

SIBBALD, A.R. UK Agroforestry Forum Annual Meeting - Farming with Trees. Greenmount College, County Antrim, 28-30 June.

SMITH, A. Endocrine Disruptors in the Environment: The Analytical Challenge. Warrington, 11-12 October.

SMITH, A. Steering Group Meeting of NERC URGENT Contaminated Land Project. BGS, Nottingham, 13 April.

STOLTE, A. National Seminar on Capercaillie. Perth, 14 February.

STUART, A.W. SABRI Safety Co-ordinators & Site Engineers Meeting. Moredun Institute, 13 May.

THORBURN, A.P. Enabling Access to Geographic Information in a Devolved Scotland. Edinburgh, 26 November.

THORBURN, A.P. Using the Past in the Future of Scotland's New Native Woodlands. Perth, 23 November.

TOWERS, W. Agriculture and Waste: Management for a Sustainable Future. University of Edinburgh, 31 March – 1 April.

TOWERS, W. Regional Forest Strategies in Different Forest Cultures of Europe Summer School. Inverness, 21 August.

TOWERS, W. Native Woodlands Policy Forum Seminar. MLURI, 14 June.

TOWERS, W. New Opportunities for Forest-Related Rural Development. University of Aberdeen, 23-28 August.

TOWERS, W. Using the Past in the Future of Scotland's New Native Woodlands. Perth, 23 November.

TREONIS, A.M. Masterclass on the Application of Isotopic Techniques. ITE, Merlewood, 30 June - 2 July.

TREONIS, A.M. BSSS 1999 Autumn Conference - Sustainable Management of Soil Organic Matter. Edinburgh, 15-17 September.

VAN BEINUM, W. Society for Environmental Geochemistry and Health, 17 European Conference. University of Glasgow, 29-31 March.

VAN BEINUM, W. Transport in Structured Soils. SCRI, Dundee, 6 January.

VAN DER HORST, D. GIS Research UK. University of Southampton, 14-16 April.

VAN DER HORST, D. IALE 8th Annual Conference, Heterogeneity in Landscape Ecology: Pattern and Scale. Bristol, 7-8 September.

VAN DER HORST, D. Integrating Approaches in Ecology Workshop. Culterty, 24-25 September.

VAN DER HORST, D. The Scottish Parliament: Supporting Policy with Geographic Information. University of Edinburgh, 3 February.

VAN DER HORST, D.The Scottish Parliament and Rural Policy: What Room for Manoeuvre? University of Aberdeen, 3 November.

WATERHOUSE, C.C. BES Winter Meeting. Leicester, 5-7 January.

WATERHOUSE, C.C. Fire Research - 'Masterclass'. Glen Tanar, 8 June.

WILLIAMS, B.L. BSSS 1999 Autumn Conference - Sustainable Management of Soil Organic Matter. Edinburgh, 15-17 September.

WOOD, K.A. Near and Mid-Infrared Spectroscopy in Quality Control and Quality Assurance. Stirling, 15 April.

WRIGHT, I.A. Using the Past in the Future of Scotland's New Native Woodlands. Perth, 23 November.

WYNN, G.F. Land Reform in Scotland: The Great Debate. University of Aberdeen, 27 April.

WYNN, G.F. The Agricultural Economics Society. Queens University, Belfast, 26-29 March.

Conferences & Visits Abroad

Conferences Abroad Attended by Staff During 1999

AFTAB, A. 9th Annual Conference of the European Association of Environmental and Resource Economists. Norway, 25-27 June.

BACON, J.R. Certification Meeting for Analysis of Cabbage Sample. Brussels, 14-16 September.

BAIN, D.C. Euroclay 1999. Krakov, Poland, 5-9 September.

BAIN, D.C. Clay Minerals Group Spring Meeting. Dublin, 25-26 March.

BAIN, D.C. Clays in the Environment. Banska Stiavnica, Slovakia, 10-11 September.

BEHNKE, R.H. 10th Arctic Ungulate Conference. Tromso, Norway, 9-12 August.

BEHNKE, R.H. 5th International Rangeland Congress. Townsville, Australia, 19-23 July.

BISHOP, I. Our Visual Landscape. Switzerland, 23-27 August.

BRITTON A. International Association of Vegetation Science Symposium. Bilbao, Spain, 26-30 July.

BROWN, K. Co-operative Strategies to Cope with Agro-Environmental Problems. Berlin, Germany, 27-29 October.

BUGALHO, M. V International Herbivore Nutrition Symposium. San Antonio, Texas, 10-16 April.

BUNDY, J. *In Situ* and On Site Bioremediation Battelle 5th International Symposium. San Diego, 19-22 April.

CHAPMAN, P. American Society of Limnology and Oceanography Aquatic Sciences Meeting. USA, 1-5 February.

CHAPMAN, S.J. International Peat Symposium 1999 – Chemical, physical and biological processes in peat soil. Finland, 23-27 August.

COMBER, L.J. Irish Organisation for Geographic Information. Dublin, 19 October.

CRABTREE, J.R. 9th Annual Conference of Agricultural Economists. Warsaw, Poland, 24-28 August.

CRABTREE, J.R. 9th Annual Conference on the European Association of Environmental and Resource Economists. Norway, 25-27 June.

DENNIS, P. 5th IALE World Congress - International Association for Landscape Ecology. Colorado, 29 July - 3 August.

DUNCAN, A.J. IX Indian Animal Nutrition Society Meeting. India, 2-4 December.

DUNCAN, A.J. V International Herbivore Nutrition Symposium. San Antonio, Texas, 10-16 April.

DUNN S.M. Soil Hydrological Workshop. Sweden, 25-27 August.

EDWARDS, A.C. EU COST Phosphorus Workshop. University of Cordoba, 11-14 May.

EDWARDS, A.C. Phosphorus Workshop SERA 17 Group. Agriculture Canada, Quebec City, 7-11 July.

ERHARD, H.W. 33rd International Congress of the International Society for Applied Ethology. Norway, 17-21 August.

FARNSWORTH, K.D. Ecosud '99. Greece, 31 May - 2 June.

FARNSWORTH, K.D. 4th ESMBT Meeting: Theory and Mathematics in Biology and Medicine. Amsterdam, 29 June - 3 July.

FARNSWORTH, K.D. INDEX '99: Indices and Indicators of Sustainable Development – Systems Analysis Approach. St Petersburg, 11-16 July.

FERRIER, R.C. Critical Loads Workshop. Copenhagen, 20-26 November.

FERRIER, R.C. ESF Standing Committee for Life and Environmental Sciences Workshop. Spain, 10-13 May.

GEDDES, A. Regional Studies Association – Regional potentials in an Integrating Europe. Bilbao, 18-21 September.

GEELHOED, J.S. Bodem Breed 1999 - 11th National Symposium of Soil Research. The Netherlands, 29-30 November.

GIMONA, A. 5th IALE World Conference. Colorado, 28 July - 3 August.

GORDON, I.J. Mid Zambezi Valley Project Workshop. Zimbabwe, 8-10 June.

GORDON, I.J. Grassland Ecophysiology and Grazing Ecology. Brazil, 24-26 August.

GORDON, I.J. Resources, Individual Strategies and Population Processes: Ecological Research for the Conservation and Management of Wildlife. France, 7-9 July.

GOTTS, N.M. Agent-Based Social Simulation SIG Meeting. Barcelona, 20-21 September.

GRAYSTON, S.J. EU Cost Action E6 Eurosilva Forest Tree Physiology Research Workshop. Slovenia, 8-14 September.

HELLIWELL, R.C. Terrestrial Ecosystem Research in Europe: Successes, Challenges and Policy. The Netherlands, 19-23 June.

Conferences & Visits Abroad

HILLIER, S.J. Clay Minerals Group Spring Meeting. Dublin, 24-26 March.

IASON, G.R. Resources, Individual Strategies and Population Processes: Ecological Research for the Conservation and Management of Wildlife. France, 7-9 July.

IASON, G.R. V International Herbivore Nutrition Symposium. San Antonio, Texas, 10-16 April.

LAKER, J.P. ESPACE Symposium: Preserving Biodiversity by Extensive Grazing. Paris, France, 22-23 June.

LANGAN, S.J. Critical Loads Workshop. Copenhagen, 20-26 November.

LILLY, A. Modelling Root Water Uptake in Climate and Hydrological Models. Paris, 30 September - 2 October.

MACDONALD, D. 9th Annual Conference on the European Association of Environmental and Resource Economists. Norway, 25-27 June.

MAXWELL, T.J. Royal Danish Academy of Sciences & Letters and Royal Society of Edinburgh Joint Symposium. Copenhagen, 16-18 September.

MAYES, R W. V International Herbivore Nutrition Symposium. San Antonio, Texas, 10-16 April.

MERCHANT, M. 50th Annual EAAP Meeting. Switzerland, 23-26 August.

MILLARD, P. Grassland Ecophysiology and Grazing Ecology. Brazil, 24-26 August.

MILLER, D.R. Our Visual Landscape. Switzerland, 23-27 August.

MILNE, J.A. 5th International Rangeland Congress. Townsville, Australia, 19-23 July.

PAKEMAN, R.J. 8th European Ecological Congress. Halkidiki, Greece, 18-23 September.

PAKEMAN, R.J. Information Day for DGXII Biodiversity. Brussels, 19 April.

PROE, M.F. First Euroforest Congress. Madrid, 27-30 October.

RHIND, S.M. 3rd Conference of the European Society of Domestic Animal Edocrinology. France, 26-28 November.

RHIND, S.M. Concerted Action Meeting. France, 25 November.

SIBBALD, A.R. European Grassland Federation Symposium 'Grasslands and Woody Plants in Europe'. Greece, 27-30 May.

SIBBALD, A.R. Livestock Farming Systems Conference, Switzerland, 19-21 August.

SMITH, A. Spring Meeting of the Korean Chemical Society. Seoul, 20-30 April.

WHERRETT, J.R. Linking Forest Sustainability to Aesthetics: Do People Prefer Sustainable Landscapes? University of British Columbia, 24-27 February.

WHERRETT, J.R. Our Visual Landscape 99. Switzerland, 23-27 August.

WILLIAMS, B.L. International Peat Symposium 1999 – Chemical, physical and biological processes in peat soil. Finland, 23-27 August.

WILSON, J.J. Annual Meeting of the Italian Soil Science Society. Gressoney Saint Jean, 22-25 June.

WRIGHT, I.A. 5th International Rangeland Congress. Townsville, Australia, 19-23 July.

WRIGHT, I.A. Livestock Farming Systems Conference, Switzerland, 19-21 August.

Financial Statement

For Year Ending 31 March 1999

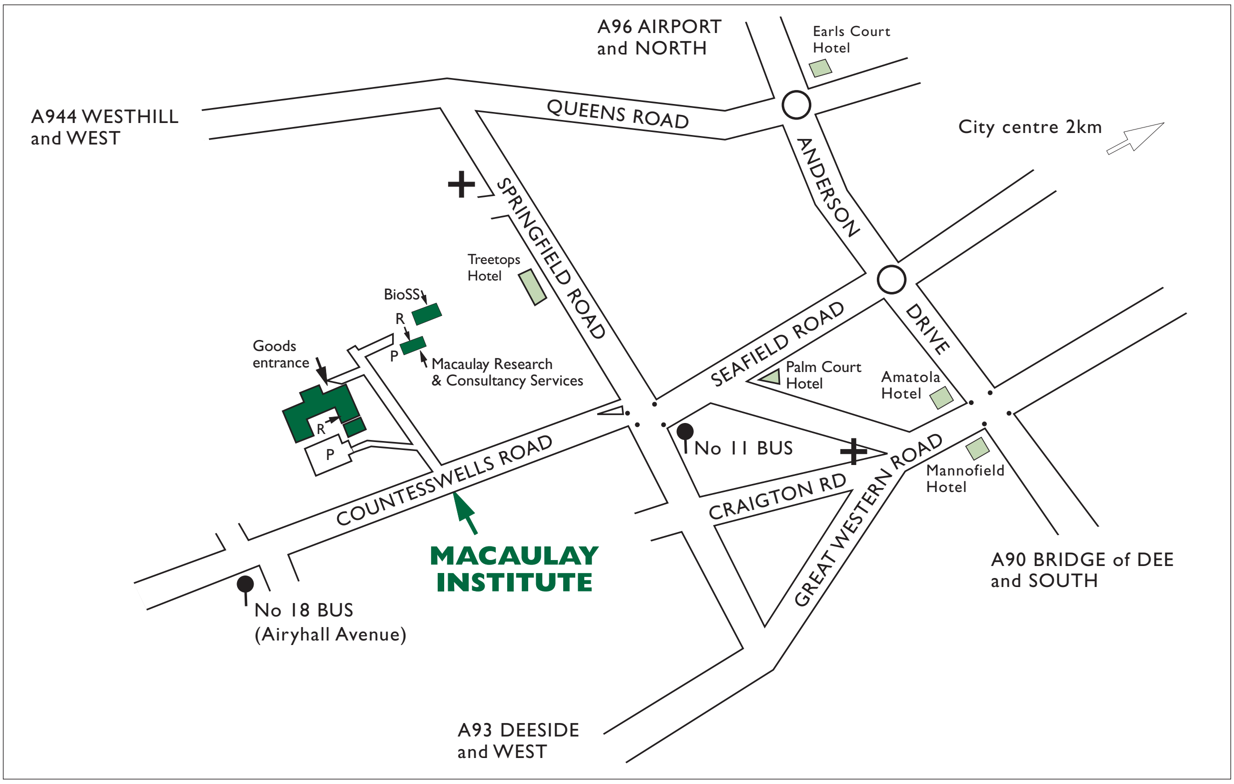
Income	£k
Scottish Office Agriculture, Environment and Fisheries Department	5,816
SOAEFD Flexible Research Funding and other SOAEFD contracts	708
European Union research contracts	460
Contract Research	809
Other income	243
Total Income	**8,036**

Expenditure	£k
Staff costs	5,260
Research expenditure including Research Station costs	1,553
Other operating costs	1,160
	7,973
Surplus	63

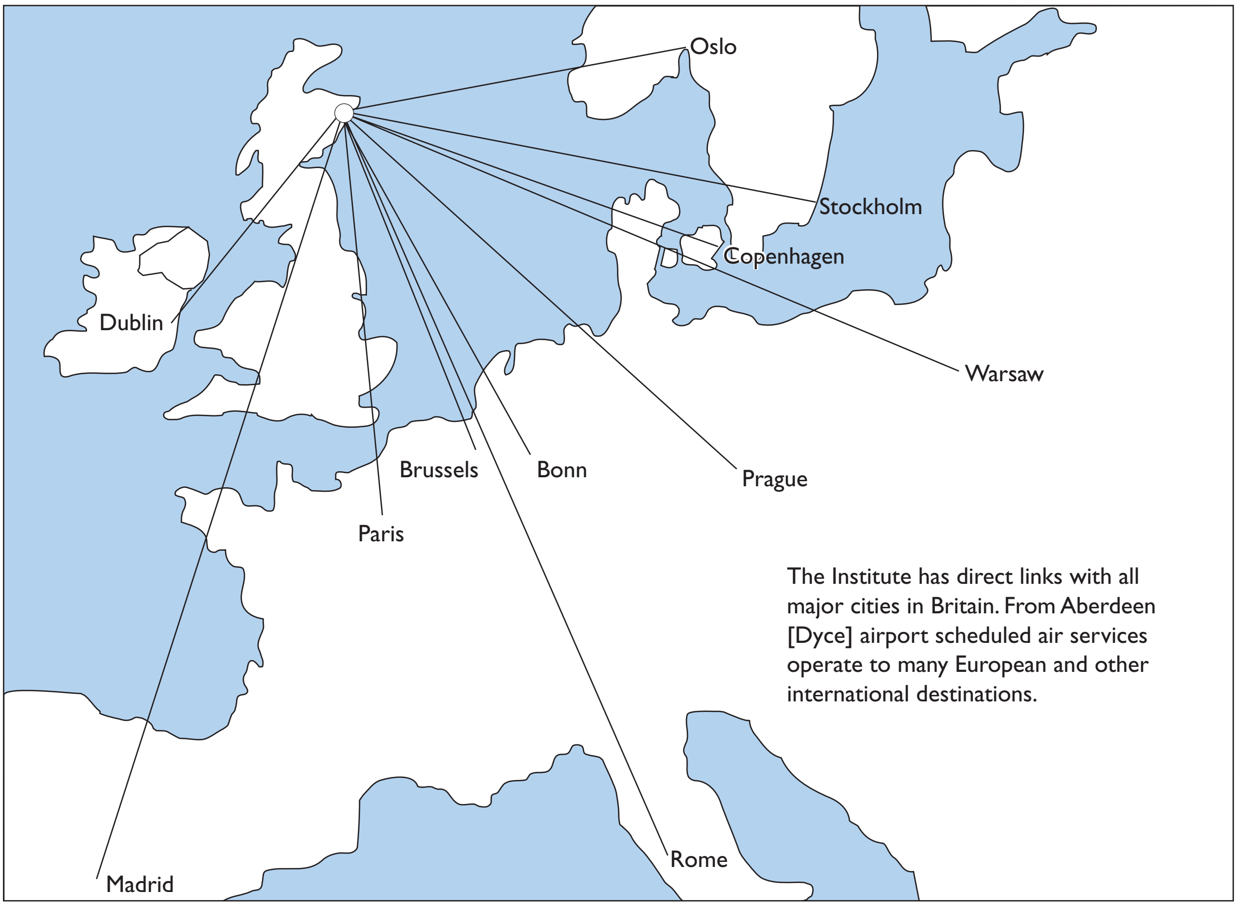
The capital funds received from SOAEFD totalled £275,648

During the year the turnover of Macaulay Research and Consultancy Services was £867,781

Macaulay Connections



The Institute is on the east coast of Scotland on the western outskirts of Aberdeen. It is well served by direct British Rail Intercity and Scotrail links. By road from the south the A90 runs directly from the motorway network at Perth. From the north follow the A96 from Inverness.



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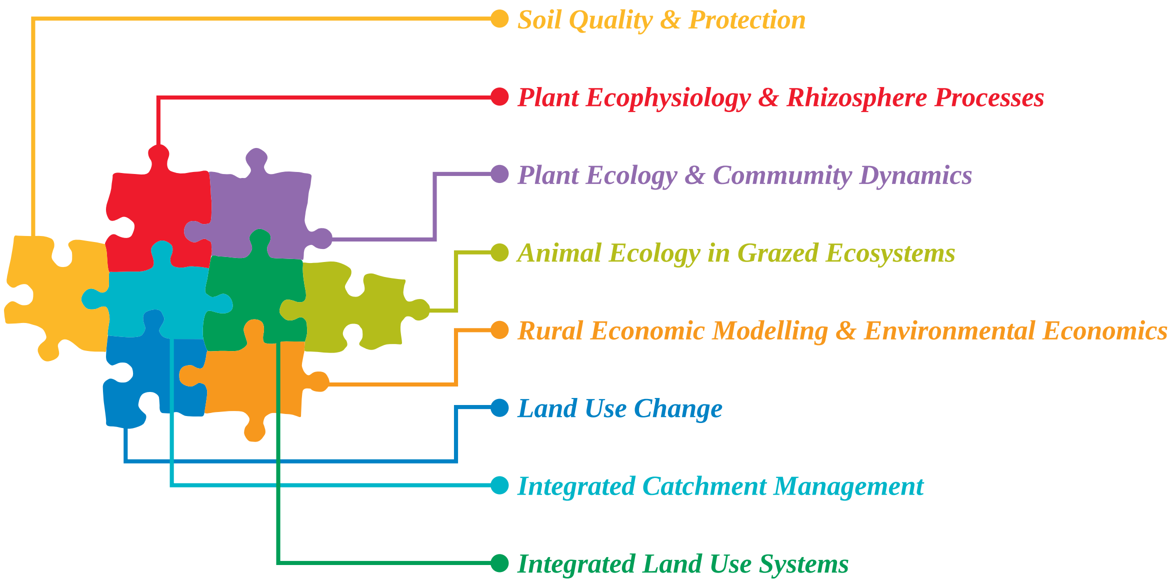

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