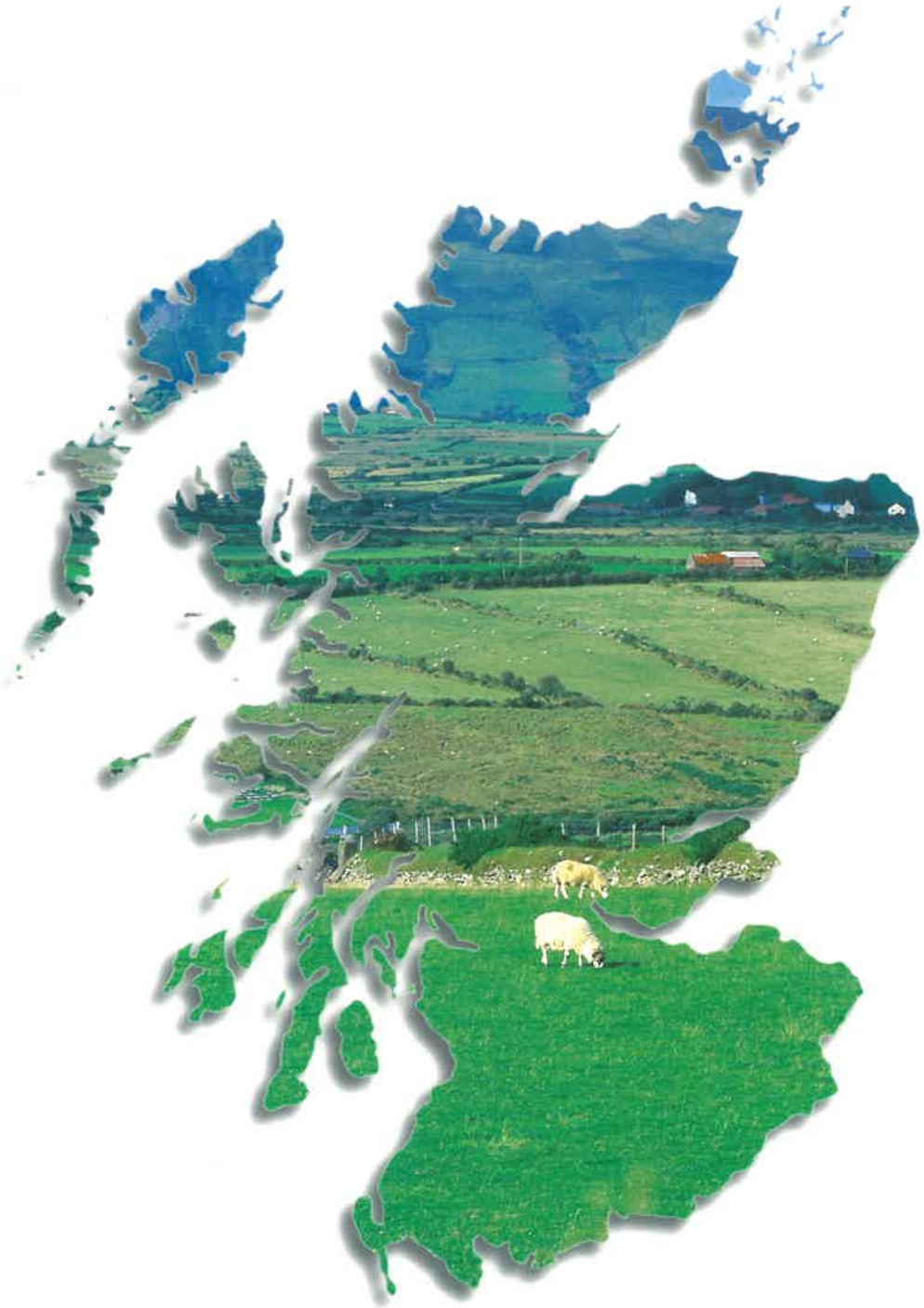
MACAULAY LAND USE RESEARCH INSTITUTE

1998

ANNUAL REPORT



Creating sustainable solutions for our land and people

THE MACAULAY LAND USE RESEARCH INSTITUTE

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Macaulay Land Use Research Institute

Craigiebuckler
Aberdeen

Annual Report 1998

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Director's Introduction

By the time this Annual Report is published, Scotland will have a new Parliament and its Members will have responsibility for the funding of the research that is undertaken in the Scottish Agricultural and Biological Research Institutes of which the Macaulay Land Use Research Institute is one. In this Annual Report, therefore, we have outlined our research programmes in the context of the rural development strategies and policies that have been introduced during the last eighteen months and which are of particular importance to the future of rural land use in Scotland. We have described the programmes in a way that demonstrates their relevance to creating sustainable solutions for the land and people of Scotland.

Since the founding of the Institute in 1987 we have striven to ensure that our research has practical relevance to the management and use of land as well as undertaking research that is relevant to policy. We are committed to continue to undertake research that remains central to the future wellbeing of the Scottish countryside and the farms and estates that are its core. At a time when agriculture is at something of a crossroads, it is appropriate to review the possible changes in rural land use that are likely to take place during the next 10-15 years. Such change will present real challenges to Scotland's new Parliament, to its rural communities, to its researchers and all who have a responsibility for the management of land. The introductory section to the reports of each of our programmes provides an analysis of the issues that are likely to confront agriculture and rural land use as we enter the millennium. The programme reports also highlight some of our recent achievements and explain how they have the potential to contribute to sustainable rural development.

In a series of short articles we also present examples of our technology transfer. These articles explain how the data we hold on soils, land cover and climate are used in a range of applications. In addition, a series of projects are presented that are of practical relevance to the management of land, the natural heritage and river catchments.

The research that we do also has relevance to the United Kingdom as a whole and internationally. We report on a selection of collaborative research and consultancy projects. These range from work done with our collaborators in Europe funded by the European Commission to work involving bilateral co-operation and collaboration in Europe, Central Asia, Australia, New Zealand, Canada, Japan, Africa and Pakistan. The Institute's international reputation is well established and places land use research in Scotland at the forefront in the rest of the world.

I believe that the work that is presented in this report does great credit to the staff of the Institute. It represents good value for money and serves the interests of Scotland well. During the last four years over 160 papers per annum have been published in peer reviewed international journals in addition to over 200 per annum other non-refereed papers, articles and contract reports. The annual income derived from tendered contracts and consultancies and other sources exceeded £2.8m per annum in 1998/99 representing over 30% of our income and enabled the resource base of the Institute to remain secure.

We look forward to the further development of the Institute to ensure that the continued funding of the Institute by the Scottish Parliament, the investments made by the Macaulay Development Trustees, and the commitment and achievements of the staff over the last 12 years, can be fully exploited. Our reputation is built on relevance and excellence and our aim is to continue to serve the land and people of Scotland well into the next century.

T J Maxwell
March 1999

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Summary

Agriculture is faced currently with many uncertainties and difficulties and it seems inevitable that in the longer term, irrespective of the policy changes that may arise from CAP reform and Agenda 2000, agriculture will be characterised by a low but highly selective growth in demand for its primary produce, downward pressure on prices, and higher resource productivity. There will be less of a requirement for resources to provide food supplies, fewer and bigger farms, and more part-time farming businesses. The consequences for land use change seem inevitable. There will be less land in conventional primary food production and there will be a change in the relative intensity that land is farmed, depending on farm size, farm type and land quality. It is difficult to come to any other conclusion than that agriculture (as a primary food-producing activity) will become of diminishing importance in terms of rural land use in the longer term. In Scotland alternative land uses such as forestry, biomass crop production, nature conservation management and facilities for sport and recreation and tourism will become of increasing importance. New demands from society will require that future rural land use delivers multiple benefits in greater measure than they have done previously. The demands for these benefits will not be delivered by chance nor by default but rather by proactive decisions and management, and they will be paid for. Current Scottish Office proposals towards integrating agriculture within the broader context of rural development and Agenda 2000 plans to increase the proportion of structural funds, at the expense of commodity support, will provide opportunities for the development of a range of farm and land-based activities.

The benefits from this wider view of rural development can be classified as being economic, (e.g. incomes and contribution to GDP arising from agriculture, forestry and other non-food goods and services), social (e.g. diversity of employment and provision of community services), and environmental (e.g. maintaining soil and water quality, biodiversity, landscape and providing other non-market goods and services). Government policies also require that they should be lasting, that is they must be sustainable and they must be integrated into strategies for the sustainable development of rural resources. A key objective of the research at the Macaulay Institute, therefore, is to evaluate the trade-off between these benefits for a range of land uses at the farm, estate, river catchment and regional scales. Our role is to develop the knowledge and understanding whereby a wide range of interest groups can decide what they regard as sustainable and what is not. Our role is to receive and provide information and through an acquired understanding and knowledge of biophysical, economic and social processes, assist in the objective interpretation of this information in creating sustainable solutions for our land and people.

Introduction

Research on any topic, if it is to be relevant to societies' needs, has to be set in the context of an objective analysis of the issues, developed within an appropriate conceptual framework and undertaken by the application of a rigorous methodological approach. As a topic for research, rural land use is no different in these respects to any other, but it does have some characteristics that are different and which makes the activity particularly challenging. These differences arise from the fact that the research involves many disciplines, across a wide range of biophysical and spatial scales and focuses on the understanding and prediction of change.

Analysis

As a starting point, and to provide perspective, it is important to recognise that for the last century at least, rural land use in the United Kingdom and in much of Europe has been dominated by agriculture. Since the Second World War, and particularly since the introduction of the Common Agricultural Policy (CAP), the agricultural industry has received significant financial incentives to continue with this activity. The fact that this has now led to an oversupply of many primary food products has brought current agricultural land use under close scrutiny. Because it is such a dominant land use, any change in agriculture is likely to have a significant impact on other land uses and the economic, social and environmental fabric of rural areas. It is important, therefore, in setting the context for rural land use research, to have a view of the way in which agriculture is likely to change over the next 10-15 years.

Agriculture in the United Kingdom is faced currently with many uncertainties and difficulties: a strong pound, Agenda 2000 and CAP reform proposals, the next round of WTO negotiations, low world prices for many commodities, falling farm incomes, competition from world markets, the continued controversy over BSE and GMOs, food safety, animal welfare, access to the countryside and environmental damage. While all these issues are likely to influence the way the agricultural industry will change in the future, it is nevertheless, likely to be the underlying economic performance of primary food production that will determine the ultimate outcome. McInerney (1998), in a recent analysis of the agricultural industry of the UK, 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, upward pressure on costs and the downward pressures on prices that will determine change. Such economic forces are 'inexorable and invariant; policy interventions may hasten or delay them along their path, disguise or divert them for a number of years, but in the end they will break out and catch up with where they were always going.'

As he points out, the crucially important fact for conventional agricultural production, is that the income elasticity of demand for food in the UK is now only about 0.2 (i.e. if consumers' incomes rise by 1% the amount they spend on food rises by only 0.2%). Thus, even if consumer's incomes in real terms rise by 1.5% per annum over the next 10 years, as they have in the 1990's, consumer spending will increase by 15% but expenditure on food will increase by only 3% which converts to a demand for primary products from agriculture of 2.5%. The message for the agricultural sector is that, if it does not adapt, its incomes will rise by 2-3% while those of everyone else will go up by 15%. In order to retain the existing parity between the incomes of full-time farmers and those in the rest of the economy over the next 10 years, there would need to be an 11% reduction in the number of farmers which, as it turns out, is the same rate of reduction that has been taking place over the last 25 years. There has also been a relentless increase in efficiency within the industry over the same period of between 1 – 2% per annum. From 1970 this has led to a reduction of 100,000 in the agricultural employed workforce to less than 300,000 in 1997 of which 150,000 were part-time employees. The number of farmers has remained about the same over the same period at 300,000 but only 60% are in full-time employment in agriculture.

Another factor that has also become clear is that farmers, as primary food producers, are now dealing with an increasingly discriminating consuming public. Its demand for a safe and wide range of food products, free of additives and agrochemical residues, has become overwhelmingly apparent. Food that has a declared nutrient content and has been produced within the highest animal welfare standards, and has associated with it the perception of being traditional, natural, home-grown and wholesome, are all characteristics that many present day consumers expect. Part of the future success of agriculture, therefore, will depend also on how well it meets the discriminating demands of its consumers of food and how effectively it operates in an increasingly competitive market.

Thus, the conclusion for the longer term, although redirected by the policy changes that arise from Agenda 2000 and CAP reform, is that agriculture will be characterised by a low but highly selective growth in demand for its primary produce, escalating costs and downward pressure on prices, and higher resource

productivity. There will be, therefore, less of a requirement for resources (land and labour) to sustain food supplies, fewer and bigger farms, and more part-time farming businesses. The consequences for land use change seem inevitable. There will be less land in conventional primary food production and there will be a change in the relative intensity that land is farmed, depending on farm size, farm type and land quality.

While there is less demand for primary food production on the one hand, there is, however, a greater demand for environmental goods and services on the other. These demands are no longer just associated with conservation and protection and a reaction to the extreme exploitation of land for production purposes. Countryside agencies and non-government voluntary bodies focus increasingly on environmental enhancement and proactive environmental management. There is also a demand for access and governments are under pressure to legislate for that right. Consequently, it is almost certain that the reform of the CAP will lead to payments to land managers in some areas for the delivery of environmental goods where now they receive support for food production. These payments will be linked to more positive land management for wildlife and habitats, the planting of trees and hedgerows, and the creation of landscape features and visual amenity. Countryside agencies will enter into partnership and provide financial support to facilitate access. Negative environmental impacts from anthropogenic activity, including agriculture and forestry, will be increasingly controlled. The requirement by the EU that all member states produce catchment plans will also require that environmental objectives to maintain high levels of water quality are integrated fully into land management objectives.

However, it is the social dimension of rural land use, although not often explicitly stated, that lies at the heart of the political debate surrounding CAP reform. It is the social dimension that will undoubtedly dictate the rate of change that takes place. Much of the financial support that has been deployed into agriculture has been as much to do with retaining a rural population and community infrastructure as it has had to do with primary food production. Yet as we have seen, while such financial support has perhaps slowed down the reduction of employed workers in agriculture in the UK, it has not stopped it. Nor has it stemmed the reduction in aggregate farm incomes (the return to farmers and their spouses for their labour, management skills and own capital invested in agricultural production after providing for depreciation). Accepting that there have been significant year-to-year fluctuations, aggregate farm incomes have declined in real terms over the last 25 years by almost two-thirds. So what does this mean for Scotland's farm and estate businesses?

In Scotland, large units with land of good quality are increasingly likely to become intensive agri-businesses with the aim of achieving greater efficiency in production through optimising inputs and maximising the usable product to meet precise requirements. Medium-sized businesses are likely to become increasingly diversified while smaller businesses will operate on a part-time basis. There will also be the amalgamation of business units leading to further structural change. A new attitude of entrepreneurship will develop, seeking both to add value to primary produce and to exploit environmental goods on the farm. That land will convert to other forms of use is certain if farm and estate businesses are to remain viable. Current proposals towards integrating agriculture within the broader context of rural development and increasing the proportion of structural funds, at the expense of commodity support, will provide opportunities for the development of a range of farm - and land - based activities. These may include, forestry, industrial biomass crops for local heat and electricity production, nature conservation management, sport and recreation, tourism and accommodation provision. The proposition is that, together with changes resulting from land reform, the increased availability of structural funds will encourage and facilitate down-stream processing, a greater diversity of employment by attracting new business into rural areas, and a greater degree of social and community infrastructural stability.

In summary, it is difficult to come to any other conclusion than that agriculture (defined as a primary food producing land use activity) will become of diminishing importance. New demands from society will require that future rural land use delivers multiple benefits in greater measure than they have done previously. The demands of these benefits will not be delivered by chance nor by default but rather by proactive decisions and management. The benefits can be classified as being economic, (e.g. incomes and contribution to GDP arising from agriculture, forestry and other non-food goods and services), social, (e.g. diversity of employment and, provision of community services), and environmental (e.g. maintaining soil and water quality, biodiversity, landscape and other non-market goods and services). They must also be lasting, that is they must be sustainable. The benefits that we identify are very different, however, in their characteristics and it is not clear that in achieving one benefit we can necessarily achieve another. But this is what sustainable development is all about and represents the conceptual framework within which we have developed a significant component of our research.

Creating Sustainable Solutions for Our Land and People

There are, however, no absolutes in determining sustainability. Depending on their economic, social and environmental status, and the stage that they have reached in their development, what is regarded as being sustainable in one community may be regarded as unacceptable in another. For example, if a community is poor it will tend to concentrate on finding solutions that maximise economic growth and increase personal incomes. It will exploit natural and other resources and there will often be a trade-off between achieving economic benefits and creating a negative impact on the environment. On the other hand, rich communities that have disposable income will tend towards maintaining and enhancing the environment and conserving natural resources. In this case the ethical

Figure 1.

emphasis is less concerned with the interests of the contemporary human being and more to do with the wellbeing of future generations. Because there are significant regional variations in economic, social and environmental status, UK and European rural development policies recognise that the nature of the trade-offs between the components of sustainable development will be different, depending on the region under consideration.

For example, the Government's 'Framework – Towards a Development Strategy for Rural Scotland' (1998), states 'that to enable rural development strategies to be effective, national policies must be flexible, must reflect the three components of sustainable development and must be integrated'. There is a clear recognition that 'there is no one rural Scotland for which a single, separate development strategy is appropriate; development strategies need to reflect the diversity of rural Scotland.' Because of this variation and because sustainable development is about the way people perceive their status, their lifestyles, their environment and express their aspirations for the future, its implementation is crucially dependent upon their involvement. It is not surprising, therefore, that the Government's 'Framework' recognises explicitly 'that the planning and delivery of rural development strategies requires community involvement and a strengthened structure of partnership'. National and local government, their agencies, voluntary bodies, land owners and local communities will all have to find new ways of interacting and finding a common purpose. This is no mean challenge and one that, in Scotland, is likely to continue for some time to exercise the minds of those who have been recently elected to the new parliament. That there is evidence already that partnerships of a variety of kinds have been successfully put in place, augurs well for the future. However, their success will not only depend on individuals finding a common purpose. It will also depend on the extent and quality of the information and the knowledge that they have about the resources about which they are concerned. That depends, at least in part, on the output from research undertaken at the Macaulay Institute.

Our Method of Approach and Programme of Research

For researchers, 'creating sustainable solutions for our land and people' is not a trivial task. It demands that the research that we do is relevant within the overall concept of sustainable development and addresses issues that relate in one way or another to our ability to evaluate the trade-off between economic, social and environmental benefits, (Figure 1). The role of the researcher is to develop the knowledge and understanding whereby communities can decide as to what they regard as sustainable and what is not (Maxwell, 1997). In this respect there is participation with the community and the researcher's role is to receive and provide information and through an acquired understanding and knowledge of biophysical, economic and social processes, assist in the objective interpretation of this information. The type and range of information and knowledge required will, of course, depend on the biophysical and geographic scale with which one is dealing.

For these reasons, and within the context of its particular skills and range of expertise, we undertake research at the Macaulay Institute, at scales that are related to relevant operational and functional management units such as the farm, estate, river catchment and region. We focus, therefore, upon:

- assessing the opportunities for the integration of livestock production systems, farm and estate forestry, native woodland regeneration and natural heritage management (deer and other wild herbivore, biodiversity and landscape) of marginal land, land that in Scotland comprises 85% of the total;
- developing an understanding of the impact of land uses, land management and anthropogenic pollution on the soils and waters of river catchments towards the design of integrated catchment management plans;
- having a strategic understanding of those soil processes and characteristics that most usefully describe their ability to support sustainable plant production; indicate their capacity to absorb and utilise agricultural and other industrial wastes; and their ability to recover from toxic contamination;
- appraising and evaluating land use options and policy at a range of scales, but particularly at the farm and regional scales, in relation to their economic, social and environmental impacts, and to measure and monitor change; and
- developing effective ways of transferring the findings and benefits of our research to end-users by utilising modern methods of group facilitation and information technology.

The overall objective of our research is to describe, in so far as it is possible to do so, the trade-off or impact relationships for a range of different land use activities in the context of a defined area of land.

The approach we use involves the following types of activity (see Figure 2). The first involves the acquisition of resource information and through a process of reductive and inductive research leads to descriptions of the quantitative relationships between the components of rural ecosystems

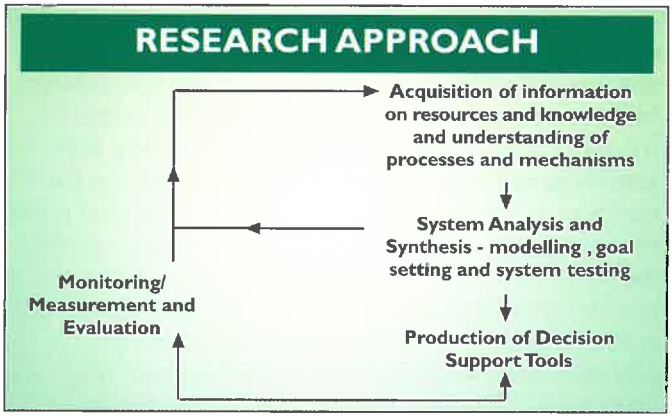


Figure 2.

at a variety of biological, chemical, physical and social scales. We also incorporate qualitative and conceptual knowledge and understanding derived from the experience of end-users. The second involves the analysis and synthesis of information and knowledge, which depends upon conceptual and mathematical modelling at varying temporal and spatial scales (Figure 3). These models are then linked to form the basis of decision support tools which we believe is a practical way of delivering output from our research in an objective and explicit way (Maxwell, 1996). We also develop indicators of change and measure and monitor change; this involves activities such as the development of sustainable accounting procedures, the collection and collation of natural resource and biophysical data to develop standards and to facilitate full life-cycle evaluation of land use and management options. The specific issues that are of major concern to us in our programme of research are structured currently around four main themes:

- The first is the **Sustainable Management of Marginal Lands**. This theme contains four programmes viz. **Land Use Options for Plants, Natural Heritage Management – Vegetation Dynamics, Natural Heritage Management – Herbivore Foraging, and Land Use Options for Animals**. Collectively these programmes address the impact of wild and domestic grazing animals on habitats, vegetation change, biodiversity and

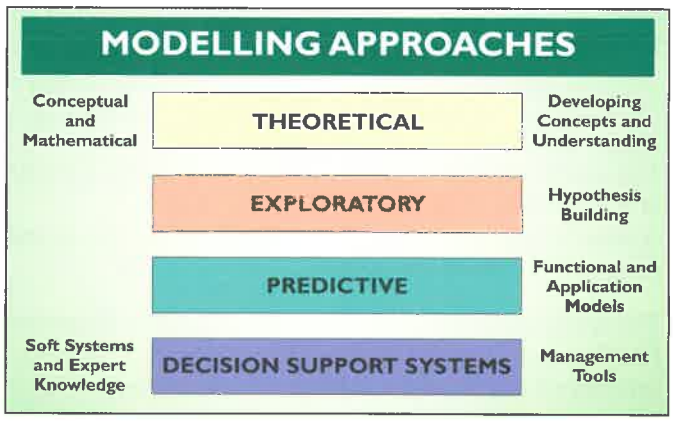


Figure 3.

landscape. They investigates alternative options of land use including forestry and farm woodlands, natural woodland regeneration, deer and cashmere goat farming, fine wool production, animal welfare and the evolution of livestock farming systems within new policy contexts. The output from this research provides information on the operational management needs and the economic opportunities and benefits of marginal land use, the impacts on, and benefits to the environment and the consequences for employment in the remoter areas of Scotland.

- The second theme, **Integrated Catchment Management**, contains a programme of research on **Atmospheric Deposition, Land Use and Water Quality**. It focuses on the impact of land use and land use change, and the benefits of integrated management control of diffuse and point source pollution on river and stream water quality. It also evaluates the impact of anthropogenic atmospheric acid deposition on land resources at local, regional and national scales.

- The third theme, **Sustainable Management of Soils** contains a programme of research on **Soil Quality, Contaminated Land and Waste Utilisation** and is concerned with the development of process-based soil quality indicators that define the resilience of soils. It also defines the benefits and risks of organic waste utilisation on land as well as characterising the remediation potential of contaminated sites. Soil fertility and functionality are fundamental characteristics of land and determine both its economic potential and its inherent worth. To that extent it is a crucial determinant of both economic and environmental sustainability.

- The fourth theme, **Sustainable Integrated Land Use Options** contains two programmes, **Geographical and Resource Analysis, and Socio-economic and Policy Analysis**. These programmes undertake geographic, natural resource, socio-economic and policy analysis of environmental and rural development issues. This involves assessing land use potential by combining environmental datasets to produce land suitability and risk analysis maps, and assessing the economic, environmental and social benefits and impacts of land use options at farm, estate and regional scales.

- There are three additional programmes **Soil-Plant-Animal Interactions, Long-term Measurement and Monitoring of Change**, and **Decision Support System Development** that cut across the thematic structure. They focus on specific issues that are designed respectively, to achieve a strategic understanding of the interactions between the biophysical components of soils, plants and animals; to measure and monitor long-term changes in land cover, and a range of environmental and biophysical

variables; and to develop decision support systems as output from each of the mission-oriented programmes and as a practical means of effecting technology transfer.

The recent highlights and achievements from each of these programmes and their relevance to sustainable development are presented on pages 12 – 33 of this Annual Report.

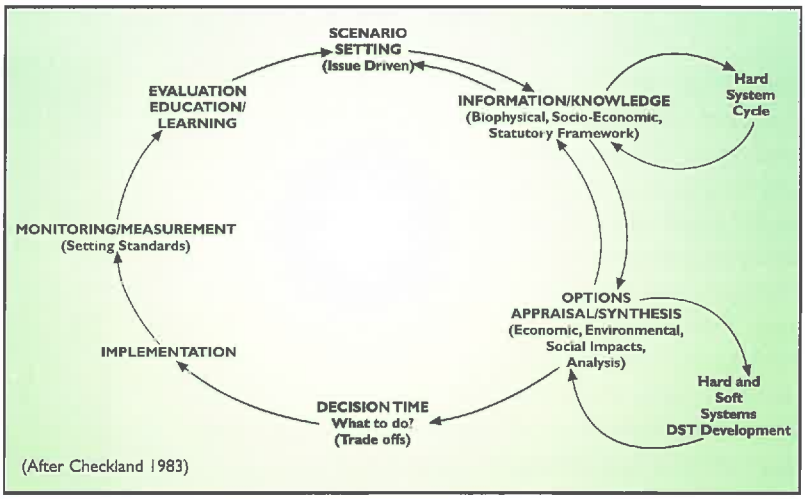


Figure 4.

There are many ways in which the output of our programmes are transferred to end users but the way in which communities as a whole can benefit from our research is described after Checkland (1983) in Figure 4. The decision-making process is undoubtedly complex but this particular format describes how the process of analysis, synthesis, and options appraisal is undertaken in an ordered and structured way. Using the appropriate analytical tools it enables the trade-offs between competing objectives and potential benefits to be logically tested and decisions explicitly taken. The full involvement of all the stakeholders is crucial in the decision-making process. The role of the researcher is to build the stakeholders' capacity to assess and analyse existing knowledge and information, but it is the stakeholders who set the agenda. Researchers are able to act independently and explore a range of scenarios that may not occur to the stakeholders themselves. In this way they can contribute uniquely and objectively to the debate and contribute new perspectives and knowledge to the learning process. Through a process of continued evaluation and education and the setting of appropriate standards, policies and management plans will be revised and the ultimate goal, the creation of sustainable solutions for the land and people of the community, will be achieved.

Future Developments

Since 1994 environmental research integrated with research that aims to improve the efficiency and development opportunities of agriculture and farm and estate forestry in marginal areas, without compromising environmental quality has been central to our programme. While this will continue it is now necessary to set our research in a broader rural development context. In relation to sustainable development it requires us to take greater account of the social dimension that rural land use will develop over the next 15-20 years. To do this we must continue to up-date our natural resource databases and integrate them with others, particularly socio-economic databases.

We believe that it is also important to develop a general theory of socio-ecosystem interactions. This arises from a significant gap in rural development theory and in understanding the co-evolution of social, economic and environmental systems. Since sustainable development is about achieving a balance between economic and social equity whilst maintaining environmental capital, and managing trade-offs between them, it is important for us to consider a theoretical basis on which to pursue our research within this context. We intend also to build on our established links with Aberdeen University's Arkleton Centre to develop integrated research on the economic, geographic and human dimensions of rural change.

There are two other important developments. Recognising the importance of land cover change as an indicator of the stock of natural capital, and its consequent importance in the land use policy cycle and measurement of environmental change, we will develop and apply novel cost effective methods for detecting and measuring land cover change. This research will be used as a platform for developing links to the International Geosphere, Biosphere and International Human Dimensions Programmes (IGBP/IHDP) joint project on Land Use and Cover Change (LUCC). Finally, in developing our strategic understanding of soil processes we will collaborate with Aberdeen University's Plant and Soil Science, and Molecular and Cell Biology Departments on an internationally significant research initiative in molecular microbial ecology.

References

Checkland P (1983) 'Systems Thinking, Systems Practice'. Wiley, Chichester.

The Scottish Office (1998) 'Towards a Development Strategy for Rural Scotland – A Framework'.

Maxwell T J (1996) 'Meeting Land Use Research Needs and Delivering Output to End-Users'. MLURI Annual Report, 1995.

Maxwell T J (1997) 'Developing Sustainable Land Use for the 21st Century'. MLURI 10th Anniversary Lectures. MLURI.

McInerney J (1998) 'Agriculture at the Crossroads'. The Massey-Ferguson National Agricultural Lecture, 1998. Sponsored by AGCO Ltd at the Royal Society of Arts, London.

Geographical and Resource Analysis

Our challenge is to identify the potential for multiple benefit land use systems. What do they look like? How can their benefits be assessed and measured? Can the trade-offs between social, economic, environmental, local and national interests be exposed? Will land use change move towards delivery of such systems or away from it? Our view is that sustainable "solutions" will vary from place to place and through time. They may also comprise elements of land use that have no contemporary analogues (e.g. novel crops; intimate mixtures of conservation and production activities).

Our approach is therefore fundamentally geographical and largely dependent upon the use of novel computer modelling technologies which allow us to explore and visualise possible "future countrysides".

The research programme currently has 3 foci:

1) Land resource analysis:

acquiring and organising data about the countryside. This covers basic resource assessment (e.g. by remote sensing), spatial modelling of resource data, and the integration of physical, biological, social and economic data (e.g. through use of spatial modelling techniques and GIS).

2) Land use options analysis:

identifying the potentials of land resources to support different land uses (e.g. biomass crops or sewage sludge re-cycling), exploring new spatial configurations or intensities of land use (e.g. silvopastoral or low input systems) and the creation of land use decision support tools that allow alternative land use options to be explored in terms of the social, economic and environmental impacts (e.g. management unit Land Allocation Decision Support System LADSS).

3) Land use change analysis:

understanding how land use systems change and how they might change in the future (e.g. simulation modelling project to develop Framework for Evaluation of Regional Land Use Scenarios FEARLUS).

Rapid Site Characterisation by Remote Sensing

The opportunities to explore alternative land use options are often limited by the lack of appropriate data on the land resources. The general move towards precision agriculture and our specific interests in developing management unit decision support tools like LADSS have highlighted this deficiency and there is a universal need for low cost data acquisition systems.

Previous research has shown the potential use of aerial photography, aerial videography, and multi-spectral scanners for defining fine scale variation in soil properties. We have been able to show that there is a strong negative correlation between wide band green and red reflectance (550-750 mm) of soils and their surface organic matter content. This relationship can be used to classify multi-spectral scanner data (Figure 1). However, such data are only obtained from satellite platforms and may not be available for specific sites of interest.

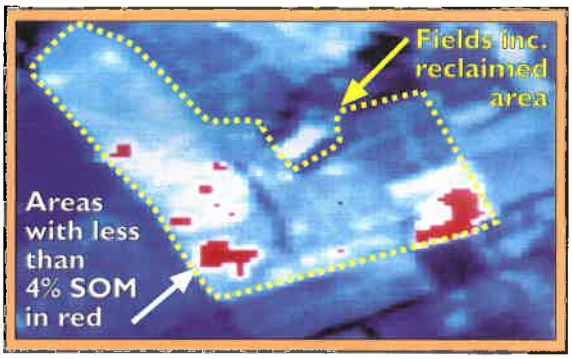


Figure 1. Single band satellite image with % surface organic matter classification.

Highlights

- **Awarded major SOAEFD grant with BioSS and Aberdeen University to develop automated system for detecting land cover change.**
- **Created method for scaling plot experiment results to regional estimates of nitrous oxide emissions from agricultural soils.**
- **Initiated new project with BioSS, ITE and the Arkleton Centre on developing integrated system for analysis and reporting on the social, economic and environmental dimensions of rural land use change.**
- **Completed first interactive modelling project (STORMS) which used www technology for both research collaboration and public access to results.**
- **Initial testing of multiple objective land use planning tools using genetic algorithms as a basis for optimization process (LADSS).**
- **Invited to present results at Sante Fe Institute workshop on Constructive Cellular Automata Theory.**

We are collaborating with the University of Dundee to develop a low cost hyper-spectral instrument based upon modified video technology. This will be mounted in a light aircraft and can provide a complete visible/near infrared spectrum within a range of spatial resolution from 0.5 to 2 m on the ground. This instrument will be used in combination with a medium format metric camera, which provides photographs of photogrametric quality.

Complex biological systems: silvopastoral agroforestry

Silvopastoral systems comprise intimate mixtures of trees and pastures. They represent a novel land use system for the UK. One of the expected benefits of silvopastoral systems is that they provide an opportunity for farmers to gain income from timber without the income stream effects associated with conventional farm forestry. However, such systems may also have other benefits, for example, in terms of more efficient resource use.

At the Institute's experimental farm, Glensaugh, soil moisture deficits often limit pasture growth during the summer. However, results from our silvopastoral experiment on the farm, show that trees may moderate this effect. The results show that for the first 6 years after planting there was no significant difference between the agricultural carrying capacity below hybrid larch (planted at 400 stems/ha) and that of the agricultural control. For the next two years, both characterised by dry summers, the carrying capacity below the hybrid larch which had reached an average height of 4 to 5m

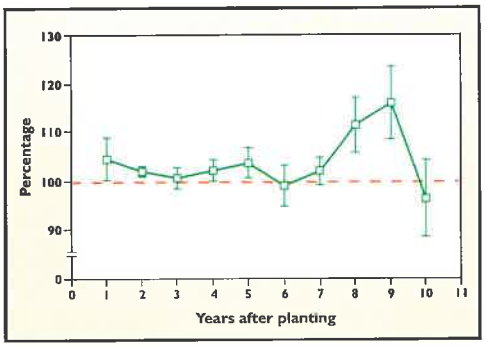


Figure 2. Annual agricultural productivity for hybrid larch 400 trees ha^{-1} as a percentage of agricultural control.

increased to around 116% of the control. This effect was lost in year 10 as a result of the wet summer (Figure 2).

The results highlight some of the potential synergistic effects that intimate mixtures of trees and pastures may produce.

Novel Land Uses: Visual Impacts of Windfarms

The UK Government has set a target of 20% of all electrical energy to be derived from renewables by 2025. In Scotland, recent assessments have shown wind energy to offer the greatest potential for development.

A principal concern of local residents, planning authorities and countryside groups is the visual impact of windfarms. By their very nature, windfarms need to be sited on exposed locations. However, our research has shown that exposure does not necessarily equate directly with visibility. We have developed a visibility analysis tool that calculates the intervisibility of possible windfarm sites and all locations around about it (zone of visual influence). This is achieved using a digital terrain model, land cover data and spatial analysis functions within a GIS.

The research has been directly applied to windfarm planning in Scotland, for example, Figure 3, illustrates a visibility analysis for 5 proposed windfarms on the Mull of Kintyre. Similar visual impact analyis has been used as evidence to a planning enquiry for a windfarm development in Wales.

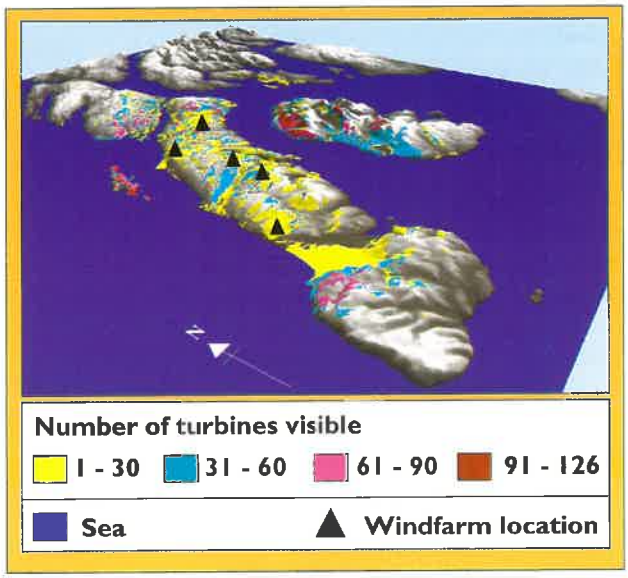


Figure 3. Modelled turbine visibility for Kintyre Peninsula.

Sustainability

Sustainable development is a keystone concept in the evolution of future policies concerning the countryside. In the UK this is to be achieved by a more "joined-up" approach to rural development policy, integrating housing, transport, agriculture, energy and the environment into a more coherent framework.

At the present time, however, many of our countryside policies are still highly sectoral, and an application of our research is to identify where these policies might be in conflict and to reveal opportunities for better integration. For example, by delivering both agricultural outputs and environmental benefits for the same support cost. By exploring land use options at farm, regional or national levels we are contributing to the evolution of integrated sustainable development.

Contact: Dick Birnie

Socio-Economic and Policy Analysis

Recent economic, political and social changes have brought about fundamental changes in the nature of rural areas across Europe. The impact of the pressures has been highly diverse across rural space with apparently similar types of rural areas responding very differently. However all have had profound political, social, economic and environmental effects and this has led to concern about the economic viability and sustainability of rural areas.

We undertake research to assist policy formulation on rural issues. We are working on methods for identifying the economic impacts of policy measures to help underpin policy design for land use, environmental protection and other rural issues. The economics of the environment and the opportunities a quality environment provides for rural areas are also central to our research.

Changing rural-urban interdependencies

A continuing decline in the importance of agriculture and the growth of the service sector have both contributed to a change in the economic structure of rural areas. Using the example of Grampian, North East Scotland, we have analysed the strength, nature and distribution of contemporary rural-urban interdependencies using Social Accounting Matrix methods.

Results from the analyses (see Figure 1) have shown that:

- the magnitude of dependencies between rural and urban Grampian are not significant: despite the region's peripherality, both areas have stronger links with the rest of the world than each other.
- there are potentially stronger spillover effects from urban to rural Grampian than vice versa.
- the results indicate that studies of contemporary rural-urban relationships need to look beyond commodity flows to a broader range of relationships that now exist between rural and urban areas.

Right-to-roam: access to the countryside

Together with ENTEC U.K. Ltd we acted as consultants to the Department of the Environment, Transport and Regions (DETR) in determining the cost of alternative access proposals to open land in England and Wales. A statutory right will cost the taxpayer £3m a year compared with £16m a year for voluntary agreements. The Minister for the Environment announced on March 8th 1999 that statutory powers would underpin the development of new access by local negotiations.

Rural development and transport policies

Changes in transport costs play a key role in determining patterns of rural development and part of our research is aimed at examining both the short run and long run effects of changes in transport policies. Specific areas of interest relate to:

- the impact on rural households of increased fuel duties
- the determinants of rural-urban commuting patterns

In an attempt to reduce the environmental costs of car use, the current government has a commitment to increase fuel duties. Analysis has considered how the impact of fuel duties differs between households. The results suggest that:

- fuel duties bear unduly on rural households who are less directly responsible for the social costs of car use, and have more limited options for altering their driving habits.
- whilst *on average* the impact of fuel duties on the cost of living of rural households will be small, there is a huge diversity in the

Highlights

- **Increased understanding of inter-linkages between rural and urban areas.**
- **Analysis of the impact of increased fuel duties on rural households.**
- **Contributed to the cost-benefit analysis comparing statutory and voluntary access policies for DETR.**
- **Assessed the economic benefits from Natura 2000 sites.**
- **Identified costs of abating nitrogen loss from farms in the Ythan catchment.**

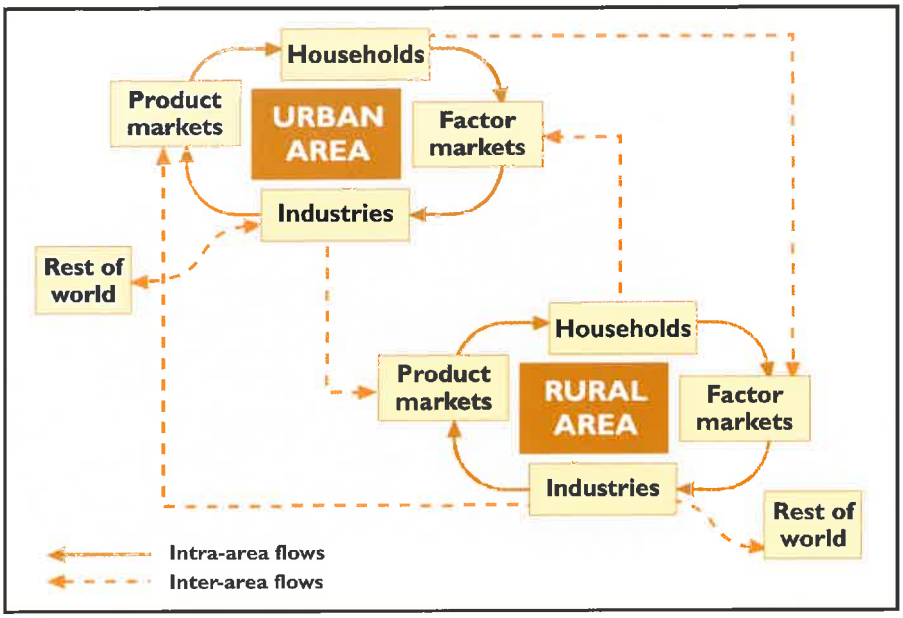


Figure 1. Changing rural-urban interdependencies.

extent to which such households are affected.

- most rural households will not adjust their travel patterns in response to an increase in fuel duties but will adjust in other ways to absorb the additional cost. Thus the tax is not only inequitable but also inefficient.

Costs of reducing nitrate losses from farming

Because of nitrate leaching in the river and possible eutrophication, the Ythan catchment in NE Scotland is under review for designation under the EU Nitrates Directive. The catchment has around 600 farm businesses and is extremely diverse in land use, including pig, dairy, cropping and livestock farms. We have developed programming models of typical farms to examine the effect on farm incomes of regulation to reducing nitrate losses. These models are indicative only but show that:

- some reductions in loss could be made at low cost through improved slurry storage and spreading.
- if more substantial reductions are needed then the marginal abatement costs increase substantially (see Figure 2).

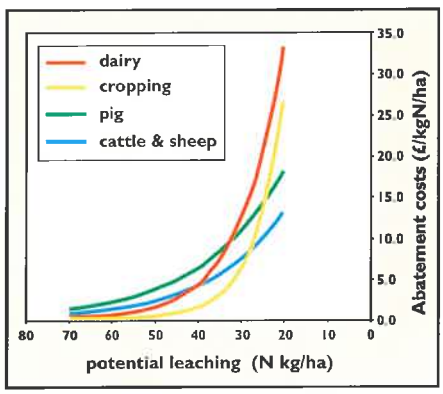


Figure 2. Costs of reducing nitrate losses from farming.

Economic benefits from Natura 2000 designations

We examined how the local economic benefits of Natura 2000 sites can be maximised.

The potential benefits identified were grouped under three general headings:

- benefits related to the management of conservation sites.
- economic activities, including agriculture, forestry and tourism, taking place on the site or wider area.
- changes in the image of the area affecting the ability to market local goods and services.

The study concluded that:

- the designation of sites will not automatically generate these socio-economic benefits for these sites.
- action needs to be taken to raise the profile of the Natura 2000 designation to give it the same level of public recognition that other site designations such as National Parks enjoy.
- the high variability in site characteristics such as topography, size, accessibility and location suggests that potential for generating socio-economic benefits is also very variable.

Sustainability

Economic and policy analysis is vital for assessing the impacts of alternative courses of action on the well-being of communities and our environmental assets. We approach sustainability by developing models to better understand the impacts of policy measures. Specific research on transport policy, environmental protection and generating benefits from natural assets (public access to the countryside, environmental valuation, economic spin-off from designated sites) has demonstrated how policies can be best designed for sustainable development.

Contact: Bob Crabtree

Integrated Catchment Management

The past decade has seen the emergence of the concept of sustainable development as a major international policy initiative. Thus, issues relating to water supply and quality have been placed firmly on the political agenda at international, European, national and regional levels. Alongside this increased concern for the integrity of water resources, there has been an increasing realisation that water resource and land use planning can no longer be undertaken in isolation and that the watershed or catchment is the appropriate spatial unit for the management and planning of freshwater resources. In addition, the catchment is also a key management unit in the protection of the marine environment, where rivers can represent a major transport mechanism for pollutants and nutrients from land to sea.

Snowmelt Modelling

Snow forms an important component of the hydrological cycle in many Scottish rivers that have their headwaters in mountainous regions. Future changes in climate are likely to affect the snow resources in Scotland. We have:

- developed a spatially distributed model of snow processes to link with a hydrological model (DIY).
- applied the model to the headwaters of the River Dee.
- found that wind redistribution of snow is important - variability in the depth of snowpack affects the rate at which meltwater is released.
- found that the gradual release of meltwater in spring can be important in sustaining baseflows in the river well into the summer months (Figure 1).
- demonstrated how changes in the snow regime resulting from climate change will affect hydrological flow paths and streamflow characteristics.

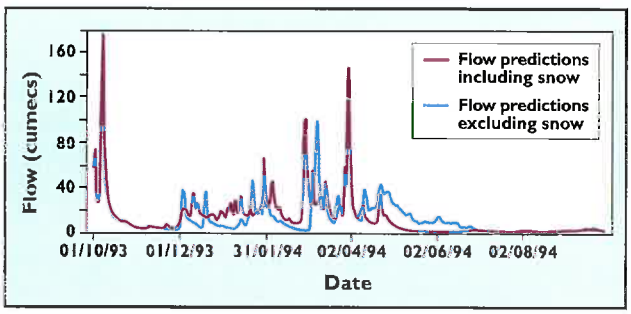


Figure 1. Effect of snow on stream flow in the headwaters of the Dee.

Hydrochemical Processes

At landscape scale, a suite of hydrochemical models have been used to investigate the relative effects of atmospheric deposition and land use on river water concentrations and fluxes of key water quality determinands. Research suggested that the most appropriate way in which existing model structures can be applied to large landscape based units is through the identification of 'functional units'. These are parcels of land in which soils, topography and land use can be considered to be dominated by similar key processes in determining water quality. By simplifying the landscape into a number of discrete functional types modelling approaches can be combined which provide predictions of changes in water quality under different regional scenarios. An example of such an approach is illustrated in Figure 2 in which water quality changes over a yearly time period have been predicted using the INCA (**I**ntegrated **N**itrogen model for **CA**tchments) model.

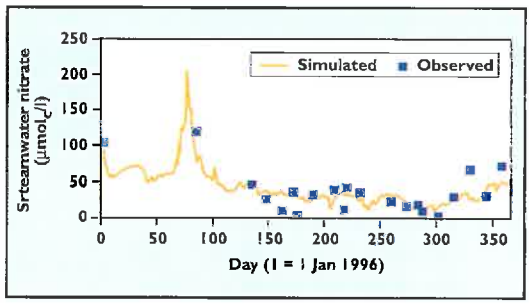


Figure 2. Simulated and observed streamwater nitrate.

Highlights

- **Development of a new dynamic modelling framework to assess the potential interaction of nitrogen deposition and climate change on ecosystem biogeochemistry at a range of spatial scales.**
- **The use of novel statistical approaches to determine the complex signals contained in hydrochemical records.**
- **A strategic evaluation of the mineralogical characteristics of suspended sediment.**
- **The development of a geochemically based critical load assessment of the soils of Korea, and the production of a national risk map.**
- **The development of a procedure for the extraction of DON and DOC pools in soils that also determines inorganic nitrogen and microbial N pools.**

Improved statistical techniques have also been used to aid the interpretation of catchment hydrochemistries. The variations in stream chemistries can be ascribed primarily to three components: long-term trend, seasonality and changes in flow. The technique fits terms to long-term trend, variable amplitude seasonality and a variable slope flow relationship that allows these components to be plotted separately. Figure 3 illustrates the application to stream chemistries from two catchments at Balquhidder in central Scotland which provides evidence for the decline on sulphate-S concentrations over time as a response to international pollution abatement policies.

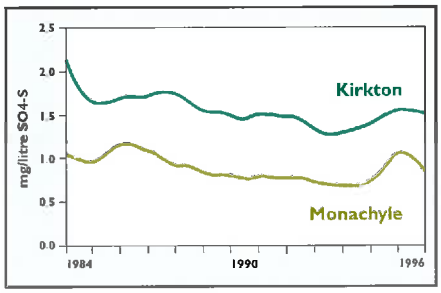


Figure 3. Longterm trend in stream sulphate-S concentrations at Balquhidder, C.Scotland.

Stream Sediment

Suspended and stream bed sediment both represent a mechanism whereby strongly adsorbing solutes can be transported downstream. As a consequence of the selective nature of erosional processes, suspended sediment is composed of material from a diverse range of sources, which include soil erosion, direct inputs of domestic/industrial wastes, or that formed in-stream through biological activity. Figure 4 shows a strong relationship between the urban land area within a catchment and the suspended sediment load.

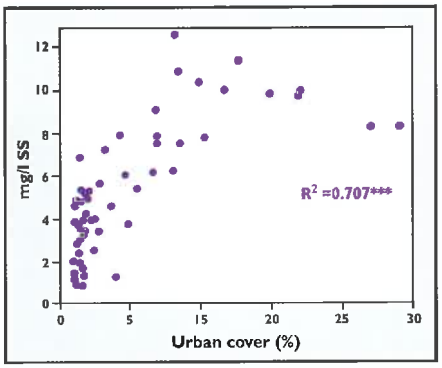


Figure 4. Relationship between degree of urbanisation of catchment areas and mean SS concentrations (1990-1994)for 58 rivers in Scotland.

Characterisation of sediments in terms of their mineralogical and organic composition is necessary to understand the potential functioning of sediment.

State-of-the-art, fully quantitative methods of analysis based on techniques such as X-ray diffraction, and infrared spectroscopy have been developed specifically for the analysis of sediment samples and used as diagnostic tools to answer such questions as the origin of a river's suspended sediment, and the extent of lead pollution and mobility in a former mining area. These techniques have general and wide applicability to problems relating to the characterisation of sediment (Figure 5).

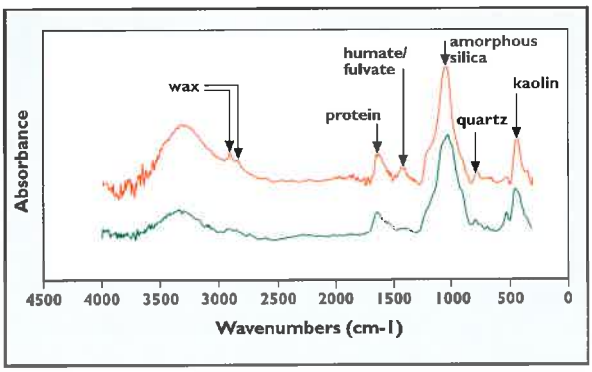


Figure 5. Vertically attenuated total reflectance inrared spectra of river sediment collected on silver membrane filter. Typical filter loading 0.1mg sediment.

Suspended sediment can influence nutrient cycling in two ways. Firstly because it represents a direct loss of elements and secondly because of its influence on the composition of the solution phase. For reactive species such as phosphorus, sediment may act as a potential source or sink for dissolved P (Figure 6).

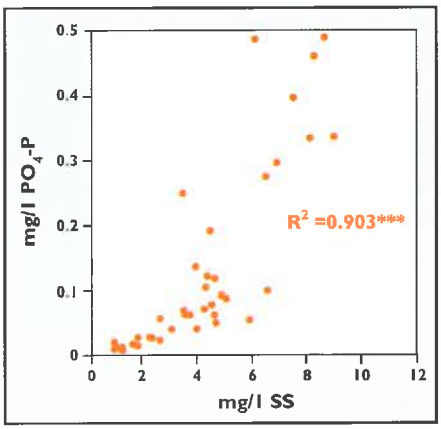


Figure 6. Relationship between SS and phosphate concentrations for 58 rivers in Scotland (mean data 1990-1994).

Sustainability

An integrated approach to catchment management reflects the linking of more than one sectorial interest at both the strategic and operational level. Centralised approaches as put forward within the proposed EU Water Framework Directive (COM(97)49) would enhance the development of a coherent strategy, associated with a high degree of co-ordination throughout the whole of Europe. At the other end of the spectrum, local initiatives generally involve liaison between agencies, non-governmental, and voluntary bodies. A suggested optimal approach for the development of a more integrated approach to catchment management and the sustainable use of water resources, is to provide a mechanism by which EU/National strategies for management are targeted upon specific issues such as eutrophication, acidification, and water resource management. Such a strategy reflects our approach within the Programme, where the objective is the integration of process understanding within a framework capable of providing tools for scenario assessment and pro-active management towards sustainable catchment management.

Contact: Bob Ferrier

Soil Quality, Contaminated Land and Waste Utilisation

This programme addresses the requirements implicit in the commitment of the UK Government to Sustainable Development (DOE, 1994) where soil quality has been selected as a key indicator (DOE, 1996). It also addresses the range of stresses on the UK soil resource as identified by the Royal Commission on Environmental Pollution in their report on the 'Sustainable Use of Soils' (RCEP, 1997). The output of our research will lead to the development of soil quality indicators which will be based on key processes and, hence, should be applicable at a range of spatial scales, including the management unit, and will address the pressures on the soil resource from waste utilisation on land and the presence of contaminants from current and historic anthropogenic activity.

Process-based indicators of soil quality

Significant progress has been made in the development of a conceptual framework for the assessment of soil quality, taking into account the multifunctionality of soils in land use systems.

The role of soil in minimising pollutant impacts has been analysed in terms of the key processes involved and the associated soil properties thus helping us to identify indicators that reflect the capacity of the soil to deal with pollutants, such as potentially toxic elements (PTEs).

In earlier work a simple additive approach was used in terms of the soil components that comprise the active surfaces in soils but recent work by Lumsdon (see page 61) has shown that the components can, in fact, interact with one another. This will require to be incorporated in future models.

The transport reactions involved in the mobility of pollutants have now been modelled within the context of convective-diffusive processes using the new ORCHESTRA framework, described by Meeussen (see page 40).

In terms of pollutant response, our microbial work is largely concerned with the impacts of pollutants on the activity and diversity of micro-organisms but in the overall assessment of soil quality microbiological studies play an important role in processes involving soil organic matter turnover.

The approach has also allowed for an objective assessment of our research requirements within the context of a mission-oriented programme dealing with soil quality (Figure 1).

Site Typology for Analysis Measurement and Modelling in Ecosystem Research (STAMMER)

This approach uses existing information held in the Scottish Soils Database to examine the relationships between soil type, plant community and climate.

Soil, plant and climate data for the 3090 sites in the National Soils Inventory have been combined to give a summary of soil function in relation to plant growth in Scotland. Thus, it represents the first objective assessment of the range of site conditions in Scotland.

Three out of the four most common site types have brown forest soil as the soil component, improved grass or arable as the vegetation and fall within two climate classes. However, in terms of the soil component alone almost 25% of the sites have peat soils.

Sites with semi-natural vegetation greatly exceed those under introduced crops highlighting the importance of natural heritage management. Some vegetation categories, such as arable and blanket bog, show strong preferences for a narrow range of soil types whereas others, such as coarse

Highlights

- **A new conceptual framework has been developed for the assessment of soil quality that takes the multifunctionality of soil into account.**
- **The function of soil in minimising pollutant responses has been used to identify the key processes and properties involved and used to develop our research strategy.**
- **New data has shown that the active surfaces in adsorption processes interact with one another and that soil cannot therefore, simply be viewed as the sum of its components.**
- **A new modelling framework, ORCHESTRA, has been developed that enables conceptual models to be implemented in computer code.**
- **Microbial approaches developed during earlier studies of pollutant impacts have been applied to the effects of afforestation of moorland.**

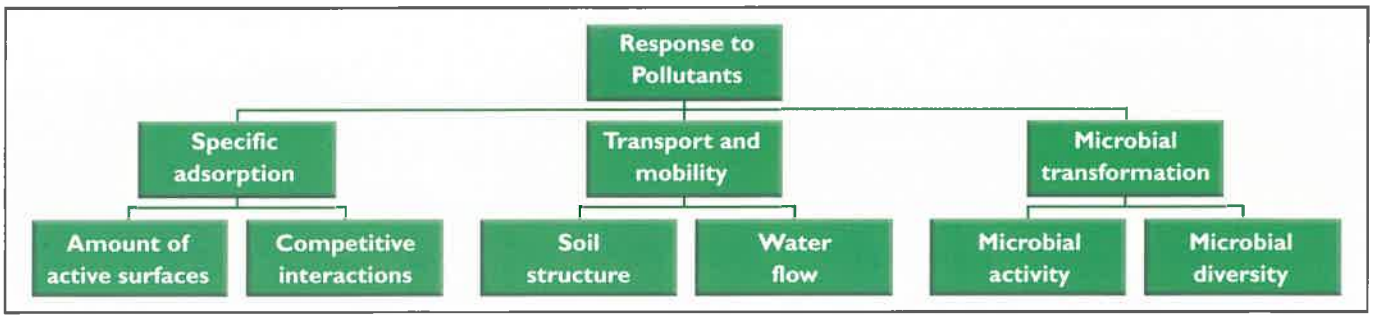


Figure 1. Conceptual diagram for quality indicators in pollutant responses.

grassland and coniferous forestry, occur on a much wider range of soils.

The analysis has also highlighted some specific examples of soil/land cover combinations, which although not extensive, may present particular risks. For example, the majority of mineral alluvial soils are under arable cropping or improved grassland systems which often require large inputs of fertilizers, pesticides and herbicides. The transport mechanisms of these need to be monitored to safeguard surface and ground water resources.

The work has also given insight into the applicability of soil quality indicators, as proposed by DETR, to the Scottish soil resource. Two of the main indicators are pH and soil organic matter content and whilst both of these may be readily applied to the largely mineral soils used for arable and intensive grassland they are unsuitable for most of the Scottish soil resource. For these soils natural heritage objectives will be far more important and there is a need to derive meaningful indicators of soil quality for this function.

Biological indicators of soil quality

Changes in soil quality following native pine forest regeneration on open moorland have been studied, in collaboration with Scottish Natural Heritage, at Abernethy Forest which is part of the native woodland expansion in the NE Highlands of Scotland.

A range of physical, chemical and microbiological parameters have been measured across transects from forest to moorland to assess their sensitivity to soil changes.

A major decrease in the size of the microbial biomass was seen moving from forest to moorland though soil basal respiration varied little along the transects. This is reflected in the metabolic quotient (Figure 2) which is a measure of how rapidly the microbial population is turning over carbon. Some consider this to indicate 'stress' in the population though it may merely reflect changes in the microbial population.

Preliminary analysis of PLFA (phospholipid fatty acid) data indicates a shift towards a fungally dominated population at the forest end.

Analysis of CLPPs (community level physiological profiles) using the Biolog™ approach has not shown great differences but this may reflect the fact that the method is biased towards extractable bacterial populations. Therefore, an approach is now being developed that will evaluate the response of the whole soil to the addition of selected substrates.

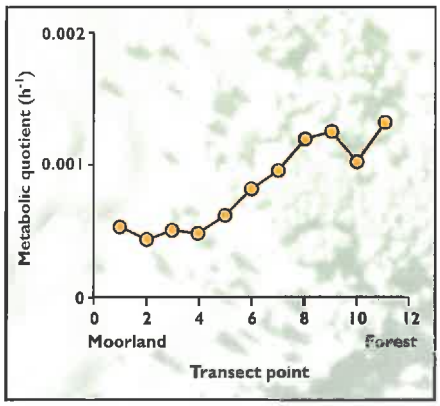


Figure 2. SNH/MLURI transects at Abernethy.

Sustainability

Soil quality is a valuable integrative concept which can assist in the development of sustainable land use strategies. Using suitable indicators, anthropogenically induced stresses on soils may be maintained in a range within which key processes may be maintained and from which natural recovery is possible. Our programme is aimed at developing such indicators taking into account the range of functions which soils undertake in the environment. These include provision of a suitable medium for plant growth, immobilisation of contaminants derived from anthropogenic activities, exchange of gases with the global atmosphere and the creation of a suitable environment for the maintenance of biodiversity. Each of these functions depends on key soil processes and by identifying these processes we can identify process-based quality indicators.

Contact: Ed Paterson

Land Use Options for Plants

Marginal lands in temperate climates have soils which are often organic, and of low fertility and pH. These soils support two main kinds of ecosystems, shrub, woodland and forestry systems which are dominated by trees, and marginal grasslands. Developing management strategies for these systems, which balance production with achieving environmental objectives, requires an understanding of the processes governing resource (carbon and nutrient) acquisition and the growth of herbaceous and woody perennials. This, in turn, requires an understanding of the interaction between the soils and plants of these systems, and the impacts of grazing animals.

The strategic aim of our research in both tree-based systems and grasslands is to understand:

- the consequences of different management strategies for low input systems in the context of the processes governing plant growth and competition; and
- the main ecophysiological processes regulating nutrient acquisition and use by plants for growth in extensive, sustainable systems on marginal land.

The programme considers both the ecophysiology of trees and of marginal grasslands.

Ecophysiology of trees

Processes of internal cycling of nutrients

We have continued to study the processes of storage and remobilisation of nutrients for the seasonal growth of trees. We have:

- collaborated with Land Care Research (New Zealand) to determine the effects of elevated CO_2 on storage and remobilisation of nitrogen by southern red beech, *Nothofagus fusca* (Figure 1).
- initiated collaboration with INRA (France) to couple measurements of xylem sap velocity with amino acid translocation to quantify nitrogen remobilisation in field-grown trees.

Figure 1. Open top chamber site at Christchurch, New Zealand, where we are studying the responses of Nothofagus *to elevated CO_2 in collaboration with Land Care Research and Canterbury University.*

Impact of management on nutrient cycling and tree growth

With our understanding of the processes of internal nutrient cycling we are collaborating extensively to develop strategies for the sustainable management of trees in a wide range of land use systems. We have:

- quantified the response of three tree species to defoliation mimicking browsing damage by deer to determine the consequences for woodland regeneration.
- collaborated with Lincoln University (New Zealand) to determine the effect of pruning on nitrogen allocation within radiata pine.
- run collaborative field experiments with Agriculture and Agri-Food Canada to determine the impact of the timing of fertiliser applications and irrigation on tree

Highlights

Ecophysiology of trees

We have collaborated internationally to:

- **study the processes of N storage and remobilisation**
- **use our knowledge of these processes to refine orchard management strategies**
- **determine the effect of pruning on N allocation in trees**

Ecophysiology of marginal grasslands

We have developed an understanding of how grasses respond to defoliation by:

- **nutrient cycling for leaf growth**
- **morphological adaptations above and below ground**
- **competing for nutrient uptake**

development in fruit orchards.

- collaborated with the University of Bologna to refine the management of pear and peach orchards.

Site suitability for whole tree harvesting

Collaborative experiments with Forest Research (an Agency of the Forestry Commission) are being used to determine the effects of whole-tree harvesting on sustainable forest management. By comparing whole-tree removal to conventional (stem-only) harvesting we have shown that:

- whole-tree harvesting can reduce growth of Sitka spruce in the following rotation.
- removal of conventional harvest residues can affect the species composition of ground vegetation following replanting.
- whole-tree harvesting affects microclimate, particularly by increasing mean wind speed near to ground level (Figure 2).
- the presence of conventional harvest residues can influence the nutrition of trees following replanting.

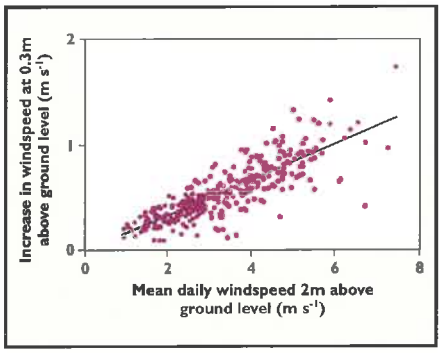


Figure 2. Increase in mean daily windspeed at 0.3m above ground level due to whole-tree harvesting in relation to the mean daily windspeed measured 2m above ground level in Teinland Forest, Moray.

Ecophysiology of marginal grasslands

Remobilisaton of nitrogen following defoliation

Several techniques for quantifying the response of upland grasses to defoliation at the field scale in terms of their ability to remobilise nitrogen for leaf regrowth are being developed. We have:

- analysed xylem saps of *Lolium perenne* after defoliation and shown rapid decreases in nitrate and amino acid concentrations and changes in the ratio of asparagine to glutamine (Figure 3).

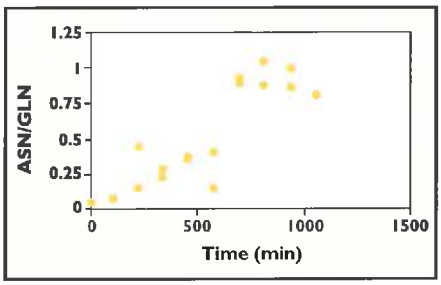


Figure 3. The impact of defoliation on the asparagine/glutamine ratio recovered in xylem saps of Lolium perenne.

- determined the seasonal cycle of protease activity in the roots and basal internodes of *Molinia caerulea* consequent of nitrogen remobilisation.

Consequence of defoliation on root growth and morphology

The impacts of defoliation of grasses on their ability to take up nutrients have been studied. We have:

- collaborated with INRA (France) to characterise the morphological adaptation to repeated defoliation in a range of grass species.
- determined the impact of defoliation on the inhibition of nitrogen uptake from a patch by roots of *Lolium perenne*.
- developed a method using n-alkane values to identify roots from different grass species (Figure 4), allowing field measurements to be made.

Modelling carbon and nitrogen allocation

In collaboration with INRA (France) we have developed a conceptual model of resource acquisition and allocation within a generalised plant, in order to interpret responses of whole plants to their neighbour in terms of both the direct and indirect effects of competition.

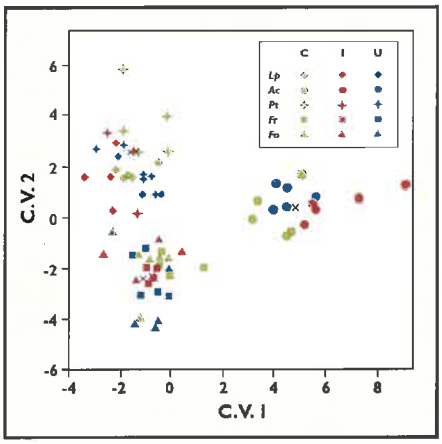


Figure 4. Identification of grass roots using a novel n-alkane signature to separate roots from different species.

Sustainability

Ecophysiology of trees

Changing patterns of land use result in trees being grown in a wide range of management systems. Because fertilisers are seldom applied the majority of nutrients used for growth come from the soil or through internal cycling. As trees grow and their storage capacity increases their reliance on soil nutrients declines. By understanding the physiology of nutrient storage and remobilisation we aim to develop more sustainable management strategies for a wide variety of tree-based systems.

Ecophysiology of marginal grasslands

In order to develop strategies for the sustainable management of hill and upland pastures it is important to understand how grasses respond to defoliation, in terms of their ability for regrowth and competition with neighbouring plants, particularly for nutrients. We aim to contribute to developing sustainable management strategies by understanding key physiological processes regulating plant competition in marginal grasslands.

Contact: Pete Millard

Natural Heritage Management - Vegetation Dynamics

Grazing by wild and domestic herbivores modifies and controls the dynamics of sown and semi-natural communities. However, the effects of grazing also operate in conjunction with those caused by soil, climate and other management practices. Our aim is to be able to predict how grazing and other factors affect vegetation, which in turn will modify the grazing behaviour of herbivores. Close collaboration with colleagues in the Natural Heritage Management – Herbivore Foraging research programme provides the means to simultaneously study the grazing animal and the grazed vegetation. Our focus is developing strategies for sustainable extensive management of large areas of grassland, heathland and woodland that are characteristic of Scotland, but which can be adapted to pastoral systems in other parts of the world.

Our strategic research aims to understand the key processes that govern species abundance in plant communities such as competition, recovery after defoliation, dispersal and regeneration, and how these are controlled by grazing and the environment. Emphasis is placed on:

- understanding the ecology of dwarf-shrub and tree species in order to produce sustainable management strategies for a wide range of communities, from montane heaths to native woodland.
- predicting the succession of species within grasslands under different management regimes, in order to predict the consequences of changing agricultural policy.
- understanding the processes of dispersal and seedling regeneration in order to predict the invasion or spread of species within systems.
- developing spatial models to predict changing species dominance and the spread of species into neighbouring communities.

Particular achievements in the past year have been from the following areas:

Heathland dynamics

Strategies are being developed at the Institute to favour the regeneration of heather on wet heathland whilst preventing the spread of competing species, in particular *Molinia caerulea* (purple moor-grass). Experiments have shown that in the critical period following burning:

Highlights

Where grasslands are managed extensively, grazing animals have the opportunity to be selective in their choice of food plants – more preferred species are grazed down in preference and thus have less leaf material to photosynthesise.

To predict the effects of pasture management we set up an experiment where five grass species were grown in adjacent patches:

- **Half of the patches of each species were cut uniformly and regularly to 3 cm or 6 cm respectively, and patches were arranged so that each species at each height treatment was adjacent to every other combination of species and height (Figure 1). Patches competed under two conditions of equal 'grazing selectivity' and two conditions of unequal selectivity.**
- **Results show that rates of spread were lowest when the management simulated hard grazing (3 cm) as reserves were necessarily used to produce new leaf material.**
- ***Agrostis capillaris* (common bent) was the most aggressive of the species. It resisted invasion by other species, and spread rapidly when cut at 6 cm whilst its neighbours were cut at 3 cm.**
- ***Agrostis* is usually low in preference to grazing animals, so this species could come to dominate extensively managed pastures.**

Figure 1. Part of the experiment investigating competition between grass species. The patches of the different species have been subjected to the two simulated grazing treatments (3 cm and 6 cm). Species were Agrostis capillaris, Holcus lanatus, Lolium perenne, Poa trivialis *and* Festuca rubra.

- heather (*Calluna vulgaris*) regeneration is more rapid when protected from grazing, but competition with *Molinia* is more severe.
- low (grass height 12 cm) and high (6cm) grazing pressures during the summer prevented an increase in *Molinia* cover, whilst heather increased on both, though more so under low grazing pressure (Figure 2).

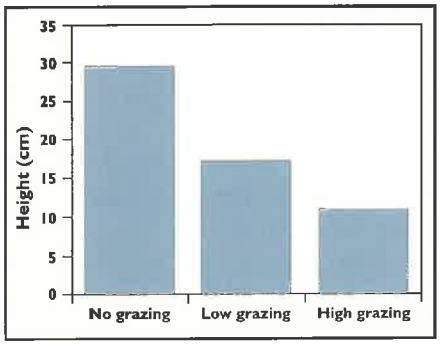


Figure 2. Calluna vulgaris *height gain two years after burning.*

- summer only grazing meant that *Molinia* was preferred to heather, such that utilization rates were considerably higher on both grazed treatments – *Molinia* 18.4 % against 4.6 % for heather on the low grazing treatment, 37.6 and 13.5 % on the high grazing treatment.
- where stock control is possible, wet heath can be managed to maintain heather cover by burning where potential competitors are present.

Grass:heather competition

Grazing herbivores do not behave randomly, but select forage according to preferences related to food quality and also to proximity to other food sources. We are developing models to predict how the spatial arrangement of grass and heather patches affect herbivore distribution, their offtake and subsequent vegetation change:

- the distribution and offtake of deer and sheep are strongly affected by the nature of heterogeneity in the vegetation. Consequently, grazing and trampling of heather is concentrated in the immediate vicinity of grass patches.
- a large quantity of experimental data on animal distribution, behaviour and plant species growth is now being combined with detailed vegetation maps to generate models to predict heather fragmentation under different scenarios.
- the model will produce explicitly spatial information that can be validated against future data sets and vegetation maps.

Sustainable management of grasslands

Previous research at the Macaulay has demonstrated that long-term management of grasslands dominated by *Nardus stricta* (mat grass) and *Molinia* can be manipulated to achieve desired goals. A long-term research project has similarly focussed on understanding the role of grazing on the dynamics of grasslands dominated by fine-leaved grasses *Agrostis capillaris* and *Festuca* spp.

- on the more fertile of the two experiments, maintaining the sward around 4.5 cm resulted in the smallest change in community composition (Figure 3) and a continuing dominance of *Agrostis capillaris* and the *Festuca* species. Lower stocking levels resulted in the expansion of less preferred species such as *Deschampsia flexuosa*, higher stocking levels increased the moss present in the sward.
- the less fertile site had both *Nardus* and *Molinia* present. The grazing management regimes allowed for the expansion of *Nardus* in the 3 cm and 4.5 cm treatments, but maintaining the sward at 6 cm prevented the expansion of *Molinia* and very little change in community composition (Figure 3).
- no blanket prescription for sustainable grazing is possible; site specific factors such as soil fertility and the presence of unpalatable, competitive species must be taken into account.
- however, changes in sward composition are slow, such that management to reverse undesirable changes can be easily carried out.

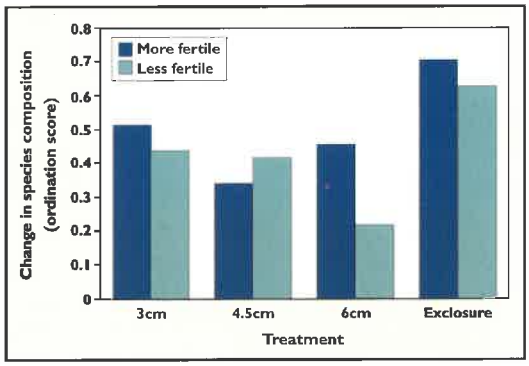


Figure 3. Overall effects of sward grazing treatments on species composition as measured by change in ordination scores (DCA) over six years at the two grassland sites. One unit on the y-axis represents approximately 50 % change in sample composition.

Sustainability

Understanding the key processes that control species composition in semi-natural communities and extensively managed pastures allows for the development of sustainable and predictable management. However, this understanding of processes such as competition and regeneration also gives us the capability to extrapolate and hence predict the effects of changing climate and other anthropogenic changes. Further new developments will focus on the interactions of grazing and the environment in a range of systems. One new project focuses on the ecology of montane heaths and will specifically investigate the interaction of grazing, climate and nitrogen deposition to test this approach for finding sustainable approaches to managing land under changing conditions.

Contact: Robin Pakeman

Natural Heritage Management - Herbivore Foraging

We are studying the relationships between aspects of the landscape and the foraging behaviour of domestic and wild herbivores in heterogeneous ecosystems, such as the semi-natural vegetation and permanent pastures of upland UK and natural ecosystems in Europe, Africa and Asia. Technology transfer is being achieved through the development of foraging sub-models for incorporation in Decision Support Tools, which predict the impacts of grazing by species such as sheep, cattle and red deer on vegetation dynamics, animal production and population dynamics.

Our aim is to increase understanding of herbivore/habitat relationships through:

- the development of theory on herbivore foraging and distribution.
- testing hypotheses concerning the relationship between animal foraging behaviour and distribution and the distribution of food, shelter and conspecifics.
- development of techniques for measuring herbivore distribution, activity, intake and diet composition.

The Small-Scale Spatial Distribution of Large Herbivores

Large herbivores move through the environment whilst foraging and this results in a dynamic spatial distribution of the population. We are developing theories which are leading to a new understanding of these processes, regarding them as the result of many individual decisions made at random, but chosen from a biased probability distribution. Individual animals make a sequence of decisions each of which can be likened to spinning a roulette wheel marked into sectors with all the possible outcomes. The probability of any given outcome is proportional to the weighting the animal places on that particular behaviour and so can be biased by changing the relative weighting of these. Inherent animal characteristics are augmented by learning which biases the decision probabilities in favour of outcomes more likely to benefit the animal. When this process is repeated thousands of times, among many animals it produces biased diffusion. Since the vegetation responds to feeding by herbivores, a feedback affects the diffusion process, producing a reaction-diffusion system. Multiple objectives (for example food quality and predator avoidance) in the animal's decision making are combined in the biased random choice model by multiple labelling of sectors on the imaginary roulette wheel. Optimisation using, for example genetic algorithms, shows how animal distributions can match habitat variation in arbitrarily complex systems. This theory is being used in the development of models of the response of heather-grass mosaics to grazing.

Deer browsing in native woodlands

Our current work aims to understand the determinants of deer browsing in native woodlands as a basis for sustainable management of deer and of woodlands for timber production and conservation value. In conjunction with the RSPB, monitoring of woodland regeneration at their Abernethy reserve in 1997 showed:

- deer density and seedling density explained 68% of variation in proportion of seedlings browsed, which declined as local seedling density increased above about 500 ha^{-1} (Figure 1).

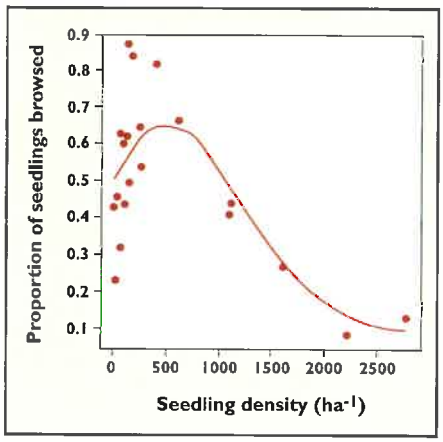


Figure 1. Relationship between seedling density and proportion of seedlings browsed in 1997 at Abernethy (adjusted for deer density).

Highlights

- **Refined the understanding of herbivore distribution using a biased random choice theory**
- **Tested the effect of food dispersion, shelter and social behaviour in herbivore foraging behaviour**
- **Developed techniques for measuring short term changes in herbivore intake and diet composition**
- **Released the HillDeer Decision Support Tool (see p46)**
- **Established collaborative research projects on herbivore/habitat interactions in the UK, Europe, Asia and Africa.**

- even after statistically controlling for red and roe deer density (counted in each km^2 twice yearly from 1992-97), our ability to explain the extent of browsing at lower tree densities remains very poor.

These results have been instructive in focussing our on-going work with captive red deer, under controlled conditions in large enclosures. This research examines the effects of local tree spacing, and the visibility of seedlings relative to the surrounding heather canopy, on red deer foraging behaviour, and seedling damage.

Sheltering behaviour of sheep

We are investigating the effect of sward conditions and micro-climate on the choices sheep make about where to graze. An experiment was set up in which sheep were offered a trade-off between food availability and degree of climatic exposure (sheltered, short sward patches vs. exposed, long sward patches). Patch choice was measured by spraying indigestible markers onto patches and measuring their concentration in faeces. The severity of climatic conditions was quantified by calculating the lower critical temperature (LCT) for sheep on exposed and sheltered patches from meteorological data and fleece characteristics. LCT represents the temperature threshold below which sheep must expend energy to maintain core body temperature. We found that sheep showed an over-riding preference for long swards even when climatic conditions were relatively severe. Providing shelter on short swards had no impact on patch choice even when animals grazed in conditions close or even below their LCT (Figure 2). This work leads us to conclude that, at the patch scale, food availability has a dominant influence on the choices sheep make about where to forage. In forthcoming work we will investigate similar questions at the landscape scale.

Measuring short-term intake in free-ranging herbivores

Conventional intake measurement techniques using dietary and dosed alkanes provide estimates averaged over 5 to 7 days. We have modified the method to allow intakes to be determined over a much shorter period. If animals are dosed with an even-chain length alkane and allowed to feed on vegetation sprayed with a second even-chain alkane, intake can be estimated from the faecal excretion patterns of these alkanes (Figure 3). Spraying different vegetation types with different even-chain alkanes allows short-term diet composition to be determined. In indoor validation studies with sheep we have shown that:

- calculations based on areas under faecal excretion curves of the relevant alkanes give better estimates of diet composition and intake than relative faecal concentrations at one or more time points. This is due to differences in the time course of excretion of dosed and herbage alkanes.
- longer chain alkanes (e.g. dosed C34 with herbage C32 and C36) give better estimates of diet composition and intake than shorter chain alkanes (dosed C26 with herbage C24 and C28).

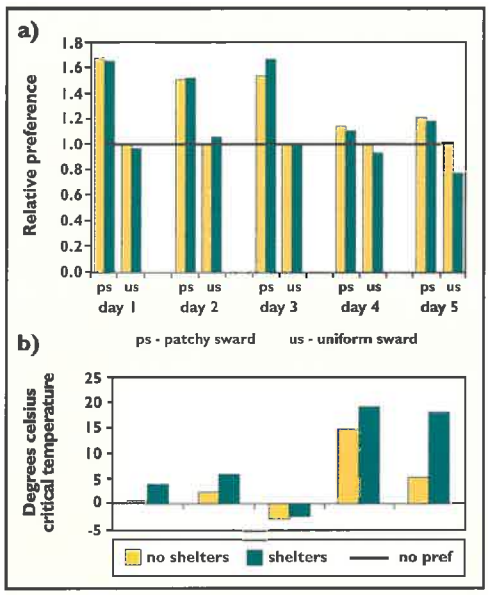


Figure 2. a) Effect of sheltering short swards on relative preference for long sward patches (or their equivalents on uniform plots) b) Discrepancy between ambient micro-climate on short swards and lower critical temperature of sheep (low values signify severe micro-climate).

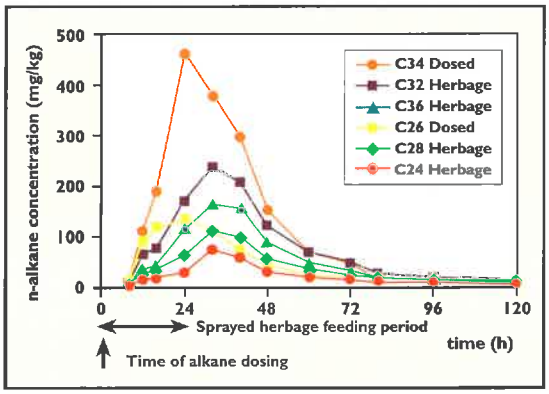


Figure 3. Faecal excretion curves, in sheep, of dosed C26 and C34 alkanes, and C24, C28, C32 and C36 alkanes sprayed onto timothy (Phleum pratense).

Sustainability

Through their grazing, trampling, defecation and urination large herbivores affect nutrient flows, vegetation community dynamics and the responses of associated fauna within terrestrial ecosystems. In turn, system characteristics such as resource composition, productivity and distribution determine individual nutrition and population performance of herbivores and consequently the economic output of a management system.

Our research aims to develop a knowledge of the behaviour of herbivores foraging in extensive systems in order to provide objective guidance for the sustainable management of natural resources.

Contact: Iain Gordon

Land Use Options for Animals

Many of the marginal lands of the world are grazed by ruminant livestock. Within the European Union and the UK, livestock products form the basis of output from much of the marginal, hill and upland areas. Also within the European Union there are surpluses of some traditional livestock products and there is concern about the sustainability of agricultural management practices with respect to their impact on the environment and on animal welfare. In general, current EU and UK Government policies encourage the extensification of production systems and diversification of the rural economy.

The aim of our research is to:

- identify options for land use systems by ruminants on marginal land, taking account of the biophysical, economic and social environment.
- investigate the biological properties of those systems.

Our research takes account of agricultural output and efficiency, environmental impacts and the welfare of the animals. Within this context we are concentrating on developing principles concerning the sustainable utilisation of semi-natural vegetation and permanent pasture resources by populations of traditional and alternative ruminant species. The research focuses on grazing systems, animal fibre biology, animal behaviour and welfare, and the impact of policy on livestock systems.

Grazing systems

As grazing systems become more extensive, it is less feasible to modify the animal's nutritional environment. Thus the appropriate choice of breed or genotype in relation to the nutritional environment becomes more important. In an experiment at Bronydd Mawr Research Station, in collaboration with the Institute of Grassland and Environmental Research we have shown that:

- there are important interactions between genotype of cattle and the type of pasture they graze.
- there is little difference in performance of Welsh Black and Charolais-cross steers when grazing permanent pasture, but Charolais-cross cattle perform less well when grazing *Molinia*-dominated rough grazing (Table 1).

	Permanent pasture	*Molinia*-dominated pasture
Welsh Black	1.02	0.73
Charolais-cross	0.91	0.43

Table 1. Live-weight gain (kg/day) of Welsh Black and Charolais-cross cattle when grazing two types of pasture.

Animal fibre biology

Following the development of a new type of cashmere goat, suitable for European conditions (the Scottish Cashmere Goat), in collaboration with the Roslin Institute, we set up a number of genetic selection lines. These were a) a line selected for maximum value of cashmere produced (value line), b) a line selected for reduced fibre diameter (fine line) and c) a randomly-bred control line. The results of genetic selection show that:

- selection for value of cashmere produced has increased cashmere production per goat by 16g/year without any significant increase in diameter (Figure 1).
- selection for finer fibre has reduced diameter by 0.19µm/year, but also reduced fibre weight by 9%/year (Figure 1).

Highlights

- **Cashmere production increased by 16g/year by genetic selection.**
- **New automatic blood sampling equipment used to study animal welfare.**
- **New research on uptake of xenoestrogens by sheep grazing pasture treated by sewage sludge.**
- **Development of framework for evaluation of EU livestock policy.**
- **Identified role of winter feeding in new emerging systems of livestock production in Central Asia.**

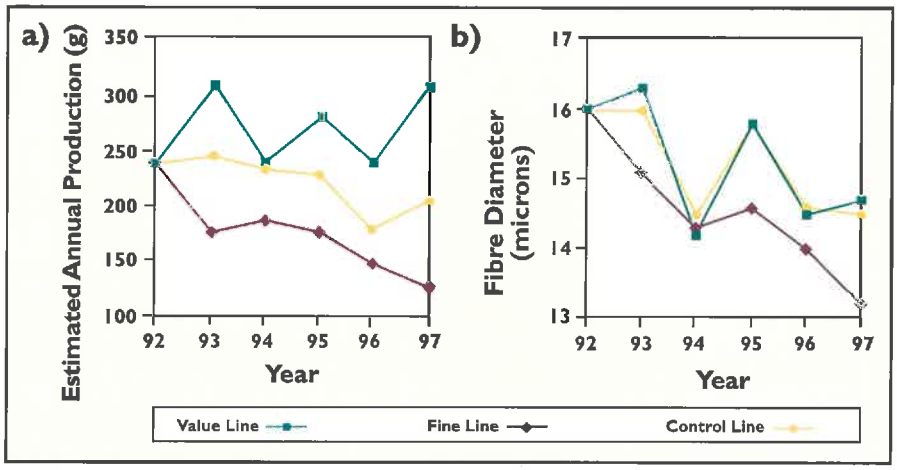


Figure 1. Selection responses in a) estimated annual production and b) fibre diameter of cashmere.

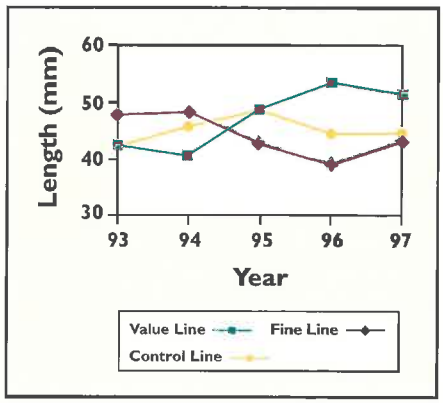


Figure 2. Selection response in cashmere staple length.

- part of the increase in weight of cashmere produced was a consequence of an increase in fibre length (Figure 2).

Animal behaviour and welfare

In studying aspects of animal welfare we attempt to integrate measurement of aspects of behaviour and physiology. We have recently developed new automatic blood sampling equipment which allows us for the first time to collect blood samples remotely when we see animals performing particular types of behaviour. We have used this unique equipment to measure the concentration of cortisol in the blood of farmed red deer performing a range of behaviours. This has shown that:

- we can separate the physical and psychological elements of stress.
- the stereotypic activity of fence pacing is associated with elevated levels of cortisol, indicating that the deer are stressed when fence pacing (Figure 3).

Policy and livestock systems

The European Commission Urban Waste Water Treatment Directive prohibits disposal of sewage sludge at sea, with the result that more sewage sludge is likely to be deposited on land. Sewage sludge contains relatively high concentrations of substances with oestrogenic activity (xenoestrogens), but little is known about the potential impact of ingestion of these compounds by livestock grazing land treated with sewage sludge. Accordingly we are:

- undertaking research to examine the uptake of xenoestrogens from sewage sludge by grazing sheep.
- collaborating with nine other European institutions to study the physiological impacts of xenoestrogens on reproductive function in sheep.

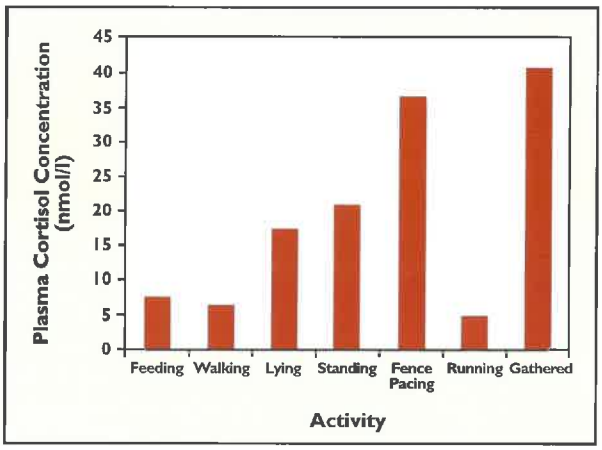


Figure 3. Plasma cortisol concentration when deer are performing a range of activities.

Other policy related research which is relevant to the European Union and Central Asia is described on pages 57 and 62.

Sustainability

The options that exist for land use by animals are determined by whether the systems are economically, environmentally or socially sustainable. Our research is aimed at providing information which can help identify the appropriate balance between economic, environmental and social objectives. Diversification of livestock systems can help maintain income and employment in fragile rural areas. Grazing systems need to be developed which ensure adequate levels of animal performance, acceptable standards of animal welfare and which do not lead to degradation of the environment. An understanding of these trade-offs is essential for the formulation of policy.

Contact: Iain Wright

Soil-Plant-Animal Interactions

Developing management strategies for marginal grasslands, which balance productivity with achieving environmental objectives, requires an understanding of the processes regulating soil nutrient cycling and how grazing animals affect these processes. To achieve this we need to understand the interactions between plants and microbes mediated through the carbon lost from plant roots as rhizodeposition. In addition we need to determine the links between soil microbial diversity of nutrient cycling and the impacts of grazing animals (via defoliation and excreta returns) on soil nutrient dynamics. Understanding the interactions between soils, plants and animals in terms of nutrient cycling is important for achieving a variety of conservation, production and environmental objectives.

The strategic aims of our research are to:

- determine if the impact of pasture management (e.g. defoliation or fertilisation) alters rhizodeposition of carbon, both qualitatively and quantitatively.
- develop and utilise a range of molecular and physiological techniques to quantify soil microbial diversity and its activity in upland soils.
- use these techniques to determine the degree of coupling between soil microbial and plant communities and study the impact of grazing animals (via defoliation and urine returns) on soil plant interactions in terms of soil nitrogen and phosphorus cycling.

Rhizodeposition of carbon

We are studying the coupling of plant growth to nutrient cycling in the soil through the influence of the rhizodeposition of carbon compounds on the soil microbes. This involves quantifying the changes in rhizodeposition by grass species in response to defoliation and under conditions of varying nitrogen supply. By growing *Lolium perenne* (a fast growing species) and *Festuca rubra* (a slow growing species) under axenic conditions we have shown that:

- defoliation of both species increased the release of organic compounds from the roots.
- both species actively re-assimilated released compounds and the subsequent partitioning in plants was strongly dependent on N-supply.
- low N-supply to *L. perenne* increased dry matter partitioning to the root system and increased the proportion of fine roots and rhizodeposition of C.

Soil microbial diversity and activity

Micronet Programme

We are studying the links between plant and soil microbial communities as part of the co-ordinated programme Micronet, involving MLURI, SCRI, SAC and Aberdeen University. The programme aims to quantify the spatial and temporal diversity of soil microbial communities across a range of characteristic grassland types subject to different management intensities (Figure 1). By the determining community level physiological profiles of grassland soils and more general indicators of microbial biomass we have shown that:

- microbial biomass increases and the predominance of bacteria compared with fungi increases with grassland improvement
- microbial communities in improved grassland are characterised by greater utilisation of sugars and citric acid, in contrast to unimproved sites, which were characterised, by greater utilisation of carboxylic acids, phenolic acids and neutral amino acids (Figure 2).
- Differences in soil microbial biomass, activity and community

Highlights

Through multidisciplinary experiments we have determined how:

- **defoliation alters rhizodeposition of carbon from grass roots.**
- **pasture management alters soil microbial diversity of activity.**
- **urine additions to soil alter the cycling of both N and P.**

Figure 1. Establishing field plots at Sourhope Research Station.

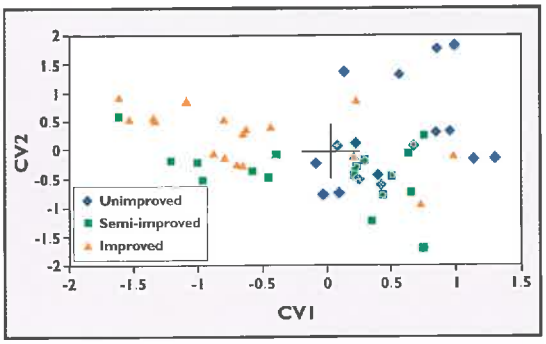


Figure 2. Discrimination of soil bacterial communities by their utilisation of carbon substances, as shown by multi-variate analysis.

structure between the grassland types were consistent over time, but the broad scale measures, soil microbial biomass carbon and respiration, showed little temporal variation, unlike bacterial numbers which varied significantly with time.

Impact of grazing and defoliation

By carrying out experiments in sward boxes and applying synthetic mixtures corresponding to sheep's urine and simulating grazing through defoliation we have shown that:

- synthetic urine addition increased numbers of soil bacteria.
- grasses subjected to regular defoliation and treated with urine had significantly more bacteria associated with the rhizosphere than undefoliated grasses or fallow soil.
- urine additions greatly increased the utilisation of oligosaccharides, carboxylic acids, basic amino acids, heterocyclic N substrates and amides, perhaps reflecting the release of dissolved organic nitrogen (DON) compounds from the soil, or as components of urine (e.g. glycine).

Impact of defoliation and urine returns on soil nutrient cycling

The quantity of N returned in urine represents an intense perturbation especially on extensively grazed areas where the only other N additions are from atmospheric deposition. The fate of the urine N depends on the rates of N transformations in the soil and uptake by the plant. By comparing the effects of synthetic sheep's urine *in situ* at two sites, one improved and the other unimproved, we have shown that:

- uptake of urine N by grass was greater on the improved than unimproved site, because grass at the unimproved site was scorched and died.
- soil at the unimproved site had a greater soil microbial biomass and content of DON, but the addition of urine decreased DON amounts.
- community level profiles of the soil microbes indicated a lower utilisation of basic amino acids in the unimproved soil which is consistent with the greater DON content.

The addition of urine has a marked effect on the chemistry of the soil, mainly by increasing pH. Such changes can have important consequences for the availability of phosphorus, which can be limiting in soils with high organic matter contents. We have shown that:

- synthetic urine addition increased P uptake in the improved soil.
- where uptake did not occur, because of scorching, there was an increase in the quantity of phosphorus in the soil solution.
- dissolved organic (DOP), molybdate reactive (MRP) and dissolved condensed forms of phosphorus (DCP) were all increased by the treatment with urine (Table 1).
- more than 5 months after the urine treatment, dissolved condensed phosphorus was the main component of phosphorus in the soil solution in both soils (> 60 %) indicating that this form was the least available for uptake by plants.

	Fasset		Strathfinella	
	Control	Urine	Control	Urine
TDP	10.4 ± 5.2	59.3 ± 9.0	10.3 ± 1.5	9.5 ± 1.9
MRP	1.6 ± 0.7	8.5 ± 1.9	2.8 ± 0.8	1.9 ± 0.3
DOP	2.2 ± 0.7	18.3 ± 3.5	3.3 ± 0.5	1.6 ± 0.4
DCP	6.6 ± 3.9	32.5 ± 4.5	4.2 ± 0.6	6.1 ± 1.3

Table 1. Mean contents, mg P m^{-2}, of TDP (Total dissolved phosphorus), MRP, DCP and DOP in soil solution extracted from Fasset and Strathfinella soils, averaged over 6 sample dates, 1, 2, 4, 5, 12 and 23 weeks after treatment with synthetic sheep's urine. Errors are the standard errors of the means (n = 18).

Sustainability

Our aim is to understand the complex interactions between vegetation and soil microbes and determine how grazing animals alter these interactions. Such an understanding will enable the consequences of different management strategies for upland pastures to be determined in terms of the sustainable cycling of soil nitrogen and phosphorus. This is important in relation to both managing future changes in land use in the uplands (e.g. pasture extensification) and for considering the environmental consequences of management (e.g. nutrient losses from soil) or the impacts of environmental change (e.g. atmospheric N deposition or climate change).

Contact: Pete Millard

Long-term Measurement and Monitoring of Change

Measurement of changes in environmental capital is central to our ability to assess sustainability. Changes in environmental capital in the context of land use relate to the activities of agriculture, forestry, water and mineral extraction, abandonment and reduced use of land or use of land for natural heritage management. External influences, such as atmospheric pollution, and pollution of water courses, soil or the food chain can also cause changes in environmental capital as they relate to the impact on land resources. The aim of our research is to improve the quality of measurement and monitoring of change in environmental capital.

The key issue is to determine what variables should be measured, how they should be measured and at what scale measurements should be made, and whether added value can be obtained by combining sets of measures. The cost-benefit of long-term monitoring and measurement is also assessed. These present researchers with a number of important challenges.

The importance of measurement of change in environmental capital was recognised by governments, including the UK, that were signatories of the Convention on Biodiversity and Sustainable Development. The European Union through legislation in its Directives has played a central role in measuring environmental impact by encouraging monitoring. Monitoring has been a key component of assessing environmental change after the introduction of Agri-Environment measures, such as the Environmental Sensitive Areas Scheme. It is well recognised by government that there is a need to have in place monitoring strategies that are scientifically robust, efficient and cost-effective.

Scientific approach

A land use system can be considered as a socio-ecosystem, i.e. a system containing human, physio-chemical and biological elements. At any point in time it is possible to measure the status of a socio-economic system by measuring the inputs to the system, such as pollutants, nutrients, or the supply of labour and capital (see Figure 1;1). It is also possible to measure the outputs of the system in terms of the production of food and water of a particular quality or other market or non-market goods (see Figure 1;3). A third source of measurement of the status of a socio-economic system is by measurement of the components within the system, such as the chemical composition of the soil, the liveweight of an animal or the amount of labour being used in a process (see Figure 1;2). Measurement of change in land use often involves making measurements of inputs, outputs or status within such a socio-ecosystem over a sequence of time-intervals, and this is termed monitoring. Examples of such an approach in our current research programme are measurements made as part of the Institute's membership of the UK Environmental Change Network, where measurements are made of atmospheric deposition (input), species composition of vegetation (state) and water quality (output), and Land Cover Change where research is focussed on changes in land cover (state).

The development of a greater understanding of socio-ecosystems, often involving the modelling of key processes, has suggested that a more effective way of monitoring change is to measure changes in processes rather than states. This is likely to give a more sensitive indicator of the status of a socio-ecosystem. For example, rather than measure change in the frequency of a vegetation species, it is possible to

Highlights

- **Improved methods of trend analysis have been applied to hydrochemical data from the UK Environmental Change network sites at Glensaugh, Moor House and Sourhope.**
- **Variations in stream chemistries can be ascribed primarily to three components: long-term trend, seasonality and changes in flow. We have used a smoothing technique to fit terms to long-term trend, variable amplitude seasonality and a variable slope flow relationship. The technique allows these components to be plotted separately and the variance due to each to be tabulated.**
- **In an example for NO_3-N, there has been a long-term increase in its concentration at all sites. The influence of the weather has been identified, particularly at Moor House, with increases due to enhanced N mineralisation. There are also indications of a change in seasonal amplitude that may be indicative of N retention in the soil.**

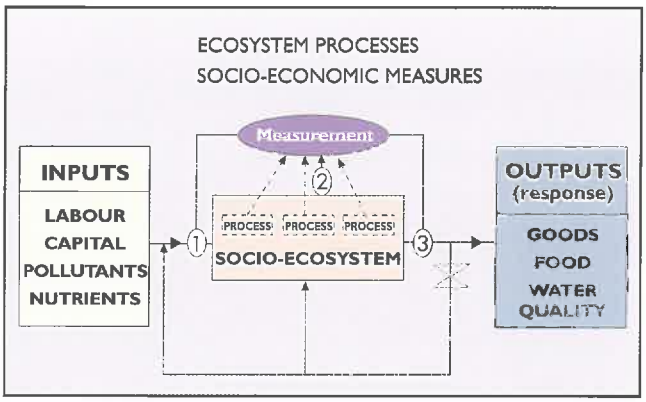


Figure 1. Model of role of measurements in monitoring a land use system.

measure its utilisation rate by grazers, which will influence the extent to which that species will survive in a grazed environment and give an early warning of what its frequency will be in the future. This approach to measuring processes is being developed within the programme in measuring soil and vegetation change at a Natura 2000 site and at a larger scale in measuring habitat change in deer forests. Moreover the combined use of measurements of processes and states, linked to modelling, has a considerable potential to enhance the information that can be gained from what used to be regarded as routine monitoring.

Another means of enhancement is by combining measurements made at one temporal and geographical scale to provide more information at another scale. Figure 2 gives a descriptive title for each of the different projects within the current programme. Within the programme measurements are being made at different frequencies from every 10 years in the case of Land Cover Change to hourly in the case of some of the Environmental Change Network measurements. Within and between projects measurements are also being made at different geographical scales from that of the experimental plot to the region. By combining measurements made, for example, on land cover change with those of measures of biodiversity of vegetation and animals, albeit at different temporal and geographical scales, it allows us to add value to these measurements in a number of the projects within the programme (Soil and Vegetation Change at a Natura 2000 Site, Deer Habitat Change and Biodiversity and Land Use Change projects). A key objective is to combine remotely sensed measurements with those made *in situ*. These examples above relate to combining only biophysical measurements and there remains the challenge to be met of combining socio-economic and biophysical variables to provide a wider view of changes in environmental capital.

Achievements

Measurement of change in chemistry of soils

- at an upland site in Scotland with podzolic soils a significant decline has taken place in percentage base saturation in the top soil horizons in the past 40 years due to a decline in exchangeable base cations.
- the probability of identifying true differences in variables of soil chemistry using the Environmental Change Network protocols was assessed and showed that the current measurement frequency was appropriate for most variables.

Measuring land cover change

- historical air photographs have been interpreted both in conjunction with and independently of the information provided by a recent set of photographs. An informed approach, where interpreters have access to previous photographs and interpretations, produces more conservative estimates of land cover change and more consistent results.

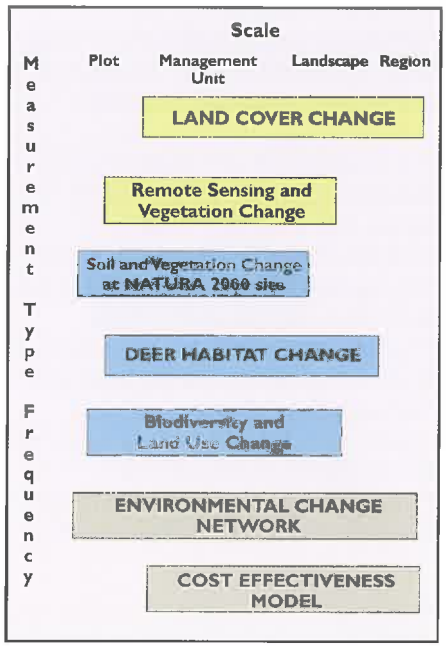


Figure 2. Current projects showing the range of scales studied and frequency of measurements.

Sustainability

Measuring change in biophysical and socio-economic variables in land use systems is a key feature in establishing sustainable land use solutions. Monitoring can be extremely demanding on resources and this poses a set of economic issues relating to the cost/benefit of alternative monitoring specifications. In general the issues are those of evaluating alternatives in terms of cost, precision, value of benefits, and risk of policy failure in the absence of adequate monitoring. A current project is developing an appropriate appraisal methodology and applying cost-effectiveness modelling to three contrasting environmental monitoring situations to help provide cost-effective sustainable solutions.

Contact: John Milne

Decision Support Systems Development

The UK has invested strongly in Information Technology (IT) and has one of the highest IT growth rates in Europe. Around 75% of its large manufacturing companies have resource planning systems and the extension of these into land management has considerable potential.

The management of land use requires the integration of often complex ideas, large quantities of data and deals with interactions over long periods of time. The building of computer-based Decision Support Tools (DSTs) offers a powerful approach in dealing with such integration. Advances in computer languages to aid programme design, in computing power and in the ability to display information are some of the technical reasons why the time is ripe for developments in this area. Moreover IT is becoming more pervasive and potential users are now receptive to the use of DSTs.

The multiple objective nature of land use decision-making in the UK has meant that a range of government departments, government and non-government agencies and land managers have an increased requirement for more sophisticated tools for policy formulation and implementation. These tools can also be of value in education and teaching about land use issues.

The development of computer-based decision-support systems identifies closely with a number of topics identified by the Technology Foresight Steering Committee, viz. Environmentally Sustainable Technology, Modelling, Simulation and prediction of Complex Systems and Information management. The application of such systems to environmental management is supported by the Scottish Environmental Protection Agency and Scottish Natural Heritage. The Scottish Office has also recently produced a Consultation Paper (Review of Conservation Advice to Farmers and Crofters, 1999) with one of its terms of reference "to review the current mechanisms for the delivery of conservation advice to farmers, and how they might be improved". This programme has, as one of its aims, improvement of technology transfer in this area.

Strategic Objectives

Although there are a range of applications for DST in land use management, there are a number of common features, such as the development of user interfaces, databases, derived data products and the integration of sub-models, which require to be developed to effectively realise the potential of DST. The strategic objective of the programme of research is to provide a set of resources and tools which are generic to the development of DSTs in the area of land use management. These resources and tools would, in particular, be available to facilitate transfer of the results of the Institute's programmes of research to the user community described above through the development of DSTs. The main focus of current work is:

- designing and developing a Database Resource and User Interface (DRUID) which is appropriate for scientists using land resource and use information.
- designing and developing a framework to allow the integration of models of the biophysical processes involved in land management, and
- designing user interfaces which meet the specific needs and abilities of the range of potential users involved.

Highlights

The Institute has developed a database, called DRUID (Data Resource and User Interface Development), which is designed to be easy-to-use by researchers in the development of DSTs and which is sufficiently flexible to include new or derived datasets.

DRUID:

- **includes data sets on soils at a number of scales, the Land Cover of Scotland 1988 data set, information on administrative boundaries, agricultural census statistics, climate and topography**
- **provides meta-data information, including data standards**
- **has a user interface which is easy to use**
- **allows the addition of new data sets as they become available**
- **uses state-of-the-art software for holding and manipulating spatial data**
- **was developed with the help of a users' group of researchers**

A key feature is the development of both data and model standards so that the quality of data and the outputs from models can be guaranteed. In an analogous manner to the DRUID project, which facilitates the integrated use of different data sets, a project has been initiated to develop an infrastructure for integrating models, predominantly developed within the Institute, which describe the biophysical processes involved in land management. A key feature of the infrastructure will be the ability to achieve this integration across a range of geographical scales. The research will involve the designing of a standard for the development and description of land use-based models. It will also include the creation of a formal language to describe models that will be sufficiently rich to allow the development of a prototype interface to enable the models to be used together in DSTs (see Figure 1).

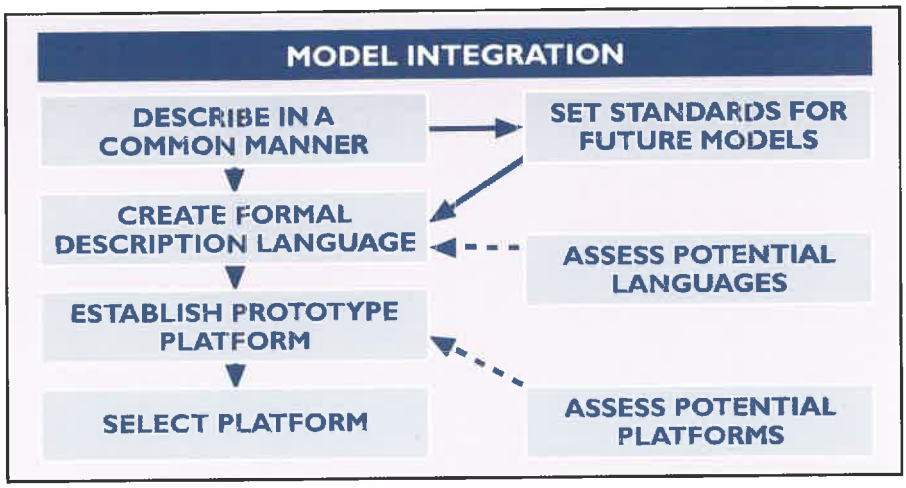


Figure 1. Diagram of the development for an infrastructure for integrating models.

Applications

- HillDeer and HillPlan are two DSTs which predict the impact of large herbivores on the productivity and dynamics of upland vegetation and, in the case of HillDeer, population dynamics. They both arose out of a successful DST, the Hill Grazing Management Model, which was launched in 1993 and which predicts the effect of sheep grazing on the utilisation rate of upland plant species. Both HillDeer and HillPlan have common features. They have the same overall structure, are non-spatial, are individual animal-based and contain similar foraging and vegetation dynamics sub-models and are written in the programming language, C++.
- A prototype integrated terrestrial and aquatic Spatial Decision Support System (SDSS) has been developed which holds past and current spatial and attribute information on the physical and chemical characteristics of water bodies and their catchments, and interprets how nutrient status (in particular phosphorus status) has and will change over time. The prototype version was built using Excel and Arc View 3. It will have value to agencies such as the Scottish Environmental Protection Agency (SEPA).
- A prototype DST has been developed and built as a tool to assist in the management of upland landscapes in relation to biodiversity. It predicts species assemblages of some insect taxa in relation to geographical location, land cover characteristics and grazing management.
- A DST (Native Woodland Restoration Model) has been developed which predicts appropriate native woodland communities for areas of land through combining spatially based information on soils, land cover, topography and exposure. The output is in a map-form with associated woodland community descriptions. It aids the spatial design of new woodlands and is of potential value in developing indicative native woodland planting strategies.

Sustainability

The decision support tools being developed and the infrastructure being put in place in the programme are an important means whereby the findings of research can be transferred to the user community which makes strategic and also management decisions on land use matters. One of the challenges for the future is to ensure that the concepts of sustainable development pervade policy development and implementation in the use of land resources. The DSTs, being developed in the Institute, have an important role to play in informing and training policy-makers and in increasing the awareness of land managers and practitioners of such issues. HillDeer is a good example in its application by the Deer Commission for Scotland and by individual Deer Management Groups to the sustainable management of Scotland's upland resources.

Contact: John Milne

Technology Transfer – Selected Applications of Land Use Research

Our Corporate Plan has as one of its objectives the technology transfer of the Institute's findings. Indeed, our very existence and continued relevance to those who manage and own land, to those who create policies with respect to its use and to those who advise others, is dependent upon communicating effectively the results of our research. This is done through the publication of papers in peer reviewed journals, presenting papers at conferences and meetings, interacting directly with our end-user community and creating decision support tools. The following short articles provide examples of the different approaches we take. Some of the current technology transfer issues that are important and, in particular, the way we use our natural resource databases combined with our knowledge of biological and socio-economic processes, to create sustainable solutions are highlighted.

LCS88 Update

The Land Cover of Scotland (1988) (LCS88) was the first ever full census of the vegetation resources of Scotland. The project was undertaken by the Institute on behalf of the Scottish Office, and was based on the interpretation of specially flown aerial photography, most of which was acquired in 1988. The survey was stimulated by a number of environmental issues at that time (e.g. Flow Country afforestation). Its purpose was to provide an authoritative audit and a baseline for measuring change in the Scottish countryside.

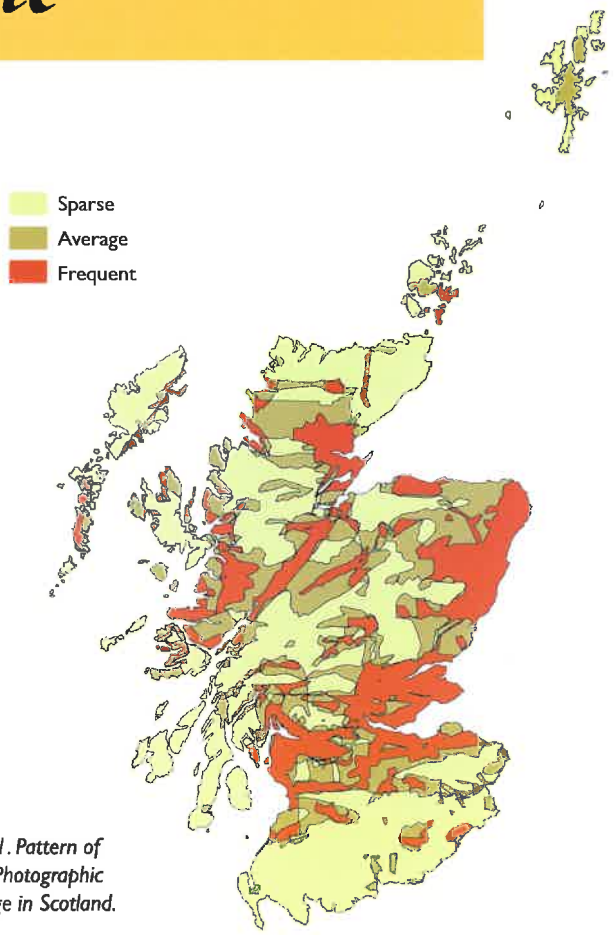


Figure 1. Pattern of Aerial Photographic coverage in Scotland.

The Macaulay team interpreted all the aerial photography according to a standard classification system and created, in effect, a land cover map for the whole country at 1:25,000 scale. This map was conceived as a digital map from the outset and it has become one of the core datasets in the Institute's environmental database (see DRUID page 37). LCS88 has been extensively used by and for other organisations such as the Scottish Office, Scottish Natural Heritage, Royal Commission on the Ancient and Historical Monuments of Scotland, Forestry Commission and the Scottish Environmental Protection Agency. The range of applications of LCS88 within the Macaulay includes projects on: moorland mapping, sewage sludge recycling, native woodland regeneration, biomass energy assessment, and soil erosion risk assessment.

The full value of the LCS88 will not be realised, however, until it can be compared with a contemporary land cover database and information on land cover change produced.

A number of options exist for providing land cover change information. Valuable experience has been gained from the ITE Countryside Surveys and SNH's National Land Cover Monitoring Scheme. However, these surveys are based on sampling approaches. There are no precedents for the creation of a high-resolution, land cover change database. The creation of such a database for Scotland represents a considerable challenge.

A team from the Institute and BioSS has received special funding from the Scottish Office to develop appropriate methodologies for measuring land cover change. A technical workshop, held jointly with the ITE in 1996, identified the range of possible options. These included a simple repeat exercise using aerial photography, and a series of hybrid solutions, which included both ground survey and satellite image elements. A follow-up meeting for potential users of the data was held in 1998. This concluded that a method based upon repeat aerial photography coverage was the most desirable option and this is currently being pursued with a consortium of private, public and private interests aimed at raising the necessary finance.

Alongside this funding initiative the research work has focused on the specific issues associated with deriving reliable estimates of change from a time series of aerial photographs. One of the proposed options is to develop a rolling programme of change detection based upon the use of opportunistic aerial photo coverage (e.g. from Ordnance Survey mapping programme). However, a review of the existing aerial photo archive held by the Royal Commission on the Ancient and Historical Monuments of Scotland in Edinburgh has shown how biased the existing coverages are to the more built up areas (Figure 1). It would not, therefore, be possible to derive reliable change estimates for the whole country from these, and so a dedicated aerial photographic approach is meantime preferred. In the future, either harmonisation of aerial photography to a 10-year cycle (e.g. to coincide with the population census) or the use of new generation high-resolution satellite images remain options.

Contact: Dick Birnie

The development of a hydrological classification of UK soils (HOST)

Hydrologists are often required to predict river flows when designing flood protection or river management schemes. Where historical records exist, flow indices can be calculated statistically but where there are none, or few records, other methods need to be used. A knowledge of the spatial distribution of soils within a catchment and an understanding of the pathways of water movement through the soil allowed the development of the Hydrology of Soil Types (HOST) classification which allows hydrologists to predict river flows for ungauged catchments.

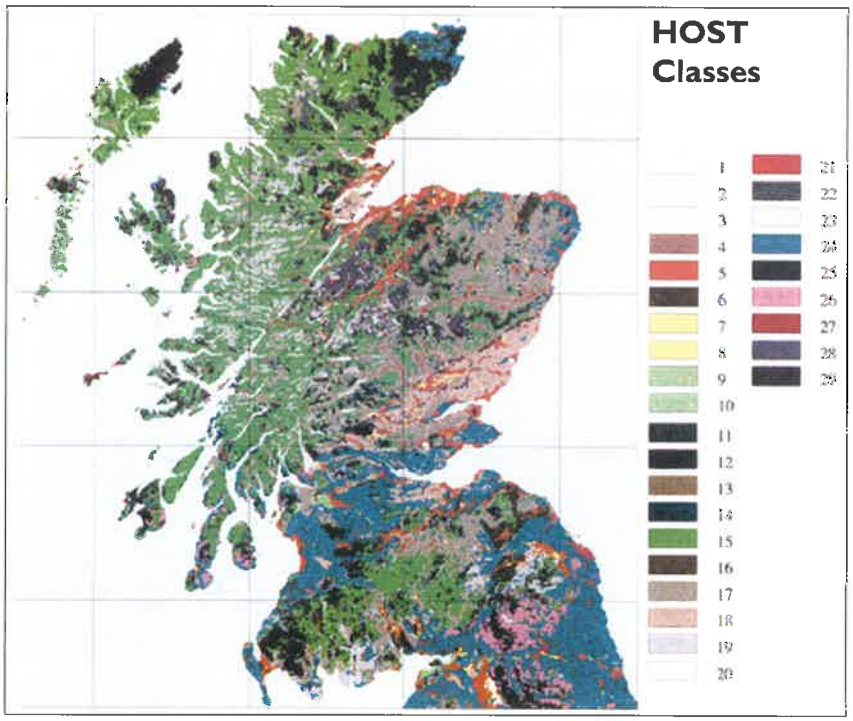


Figure 1. Distribution of HOST classes.

Many existing catchment scale hydrological models require large amounts of soil data such as soil moisture retention characteristics and hydraulic conductivities to function. Unfortunately, these soil properties are inherently spatially and temporally variable, and are only rarely available. However, in the UK, there are large amounts of both spatial (soil maps) and point soils information (in excess of 24,000 soil profiles) which were used to develop an entirely new and novel classification of the hydrological response of UK soils (HOST).

A series of pedotransfer rules, functions and expert knowledge were applied to these profile data to derive a set of semi-quantitative attributes that could be used in multiple regression analyses against two hydrological indices in order to develop the classification. Although the information on the spatial distribution of soils within catchments was obtained from existing 1:250 000 scale soil maps (the only scale of maps that gives national cover), the classification itself is not scale specific. The hydrological indices of *Base Flow Index* and *Standard Percentage Runoff* were derived from the National Water Archive located at the Institute of Hydrology. The results from these multiple regression analyses were used to firstly derive a series of conceptual models of flow through UK soils (Figure 2) and then to subdivide these model according to the perceived rate of flow, leading to the development of a 29 class system.

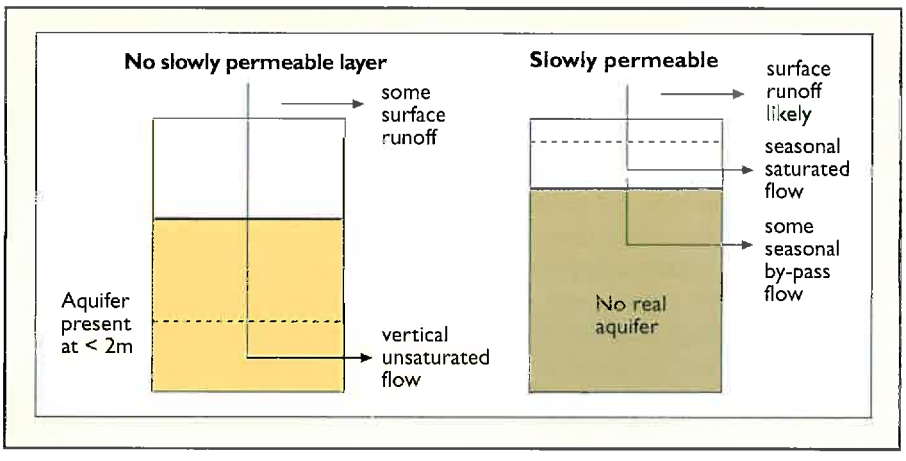


Figure 2. Examples of the conceptual models.

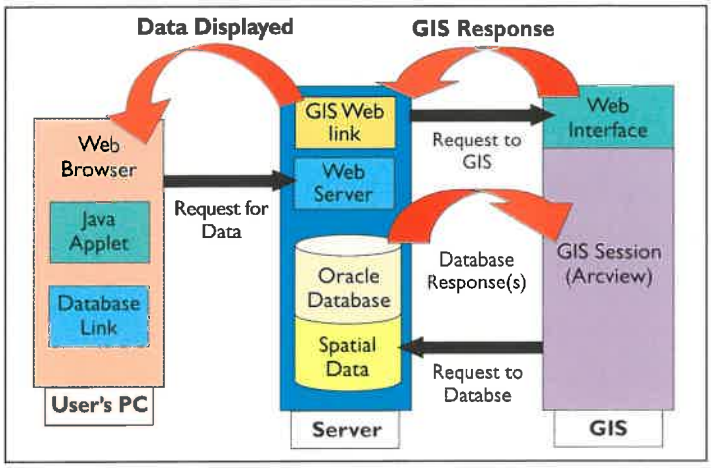
Although the main purpose of developing HOST was to improve the prediction of river flows in ungauged catchments, it was quickly realised that the classification was sufficiently flexible to be used in a number of applications where the characterisation of the flow pathways through the soil is of importance. In particular, HOST has been used for various environmental assessments such as the assessment of the vulnerability of groundwaters to pollution, the risk of contamination to private water supplies by micro-organisms and in developing risk assessments for waste recycling. The classification has also been used as a template for deriving parameters for a distributed catchment scale hydrological model.

Currently HOST deals primarily with water movement and the physical condition of the soil, however, as the basic building block used in the development of the classification was the soil profile there is considerable scope for integrating soil chemical data within the HOST framework to provide a powerful tool for parameterising hydro-geochemical models.

Contact: Allan Lilly

Data Resource and User Interface Development Project

The data the Institute holds is a major asset for research and the DRUID project is developing an integrated system for accessing this resource. The development of platform independent World Wide Web browsers gives the functionality needed to provide a flexible, easy to use interface to this data that is available to all staff without them needing to use specialist software packages.



Internal components of DRUID system.

There are four distinct components to the work:

- The development of the interface to the data.
- The creation of a database of the Institute's spatial data.
- The creation of a metadata database describing the Institute's data holdings.
- The integration of the metadata, spatial and a spatial data into a single data resource.

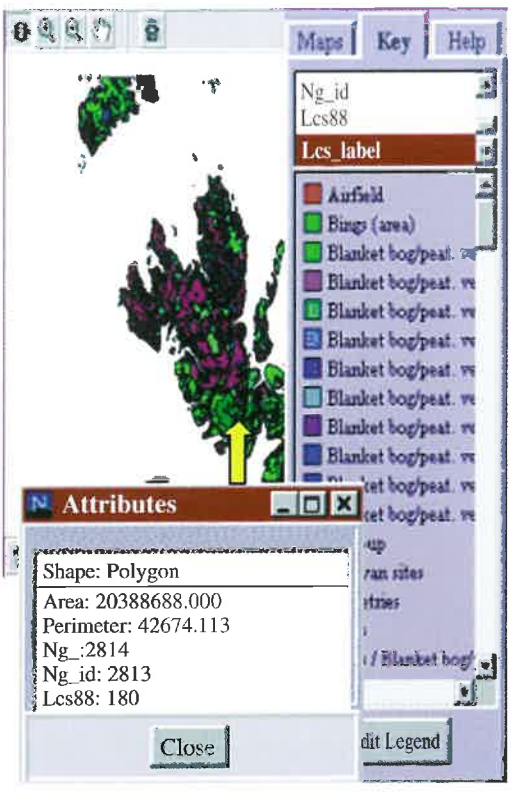


Figure 1. Interface components.

The interface (Figure 1) gives the user a single point of access to spatial and aspatial data and to the metadata. The interface has been developed using new software tools supplied by ESRI a major vendor of Geographic Information Systems (GIS). The Internet Map Server allows the interface to access the functionality of the Arcview GIS across the Institute's Intranet and this obtains any spatial data requested using ESRI's Spatial Database Engine (SDE). SDE allows the data to be stored within an ORACLE database giving efficient access to all users from a secure and easily maintained centralized resource.

The first phase of the development of the DRUID project has incorporated five major data set groups.

These are:

- Soils
- Land Cover
- Climate
- Administrative Boundaries
- Topography

The main aspatial data set is the soil inventory and other soil profile data. The other data sets from the soils group are digital versions of the 1:250,000 and 1:25,000 soils maps.

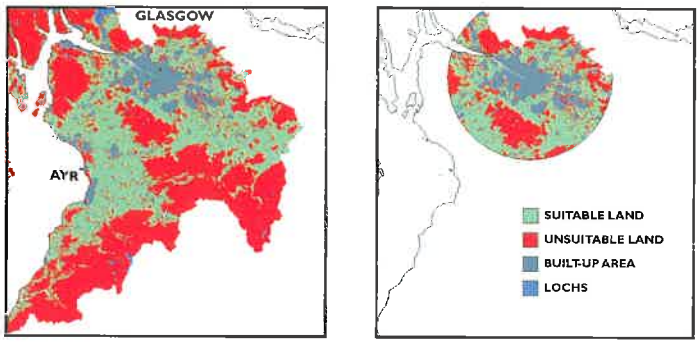
This resource has major benefits for all the research staff in the Institute who need to use these data sets. The data is in a single managed database that ensures a consistent route for access and guarantees that the quality of the data is known and defined. The metadata resource ensures that the researchers have access to all significant information that will help them use the data effectively.

The future development of the DRUID project will increase the number of data sets accessible through the interface including many derived data sets resulting from research at the Institute. The functionality of the interface will be increased to allow more GIS analysis to be performed without having to transfer the data to a local computer. However, that will be expected for more complex processing and future developments will add tools to the interface that allow data to be transferred to all the major GIS, statistics and modelling packages used in the Institute. The metadata will be expanded considerably in the future to add information on all data held by the Institute. This will include our holdings of paper maps and aerial photographs. This will be made available in a national standard format, 'The Discovery metadata' format developed by the National Geographic Data Forum, to all interested parties as part of the Institute's World Wide Web site.

Contact: Alistair Law

Risk assessment/land suitability of organic waste recycling to land

A key requirement of the EU Urban Waste Water Treatment Directive is the ban on the disposal of sewage sludge at sea from the end of 1998. The Institute made a significant contribution to the policy change in Scotland, where sea disposal was the outlet for 75% of the sludge produced, and informed end-users of the varying potential for the alternative of recycling to land in different regions of the country.



a) Based on biophysical and land use parameters.

b) Within 30 kilometres of Glasgow.

Figure 1. Land suitability for sewage sludge utilisation in the West of Scotland Water Authority Area (part).

We have developed a method for classifying land according to its suitability for sewage sludge utilization. The classification incorporates a range of soil and site attributes, for example, soil pH, slope and land use, which are known to influence the suitability of land for sludge recycling, and is informed by the findings from fundamental research within the Institute.

Outputs

Both national and regional suitability maps (Figure 1a) have been produced by applying the classification to a range of datasets within the Macaulay environmental database. These include the National Soils Inventory held within a relational database and the 1:250 000 soils map, the 1:25 000 scale land cover map and the SOAEFD June census data manipulated within a Geographic Information System (GIS). Additional analysis have included:

- an assessment of the constraints imposed arising from different farming systems.
- an assessment of the impact of potential public perception scenarios by applying buffers (exclusion zones) around settlements.
- an assessment of travel distance from sludge outlets related to regional land availability (Figure 1b).

Uses and benefits

The work provided a valuable overview of the impact of a European Union Directive in a Scottish context.

- A critical review of the short-term security and long-term sustainability of regional sludge recycling policy within a Scottish context could be made by analysing the relationship between the quantity and quality of the waste streams and the land area suitable for recycling. This indicated a twenty fold difference in the annual land requirement between predominantly rural and predominantly urban areas. This analysis was partly responsible for a realignment of the sludge policy in the West of Scotland away from one based largely on recycling. Here the annual land requirement (between 10 and 15% of suitable land depending on application rate), particularly with a transport distance imposed (Figure 1b), greatly exceeds that of any existing recycling strategy within the UK;
- The review indicated that in most agricultural soils, heavy metals from sludge would largely be strongly or very strongly bound to soil components that could only be sustained if soil pH levels were maintained at existing levels. This is particularly the case with the potentially more mobile metals such as cadmium and zinc.
- The review also indicated the impact of potential changes in regulatory levels for heavy metals in sludge-amended soils. Such changes have considerable implications for the long - term attractiveness of a waste to land strategy.

The work has been used extensively in policy formulation and assessment by the public sector (West of Scotland Water Authority (WOSWA), Central Regional Council, Grampian and Highland Regional Councils, Strathclyde Greenbelt Company) and the private sector (Hyder Industrial, Halcrow Crouch) as they prepared their Private Finance Initiative bids to build, own and operate sludge treatment works for the public water authorities.

Future developments

The work is being further developed in a number of ways. Firstly, in collaboration with SAC, in a co-ordinated programme 'Waste to Land' (see opposite page); secondly, the approach is being applied at the farm scale and will ultimately interface with our farm based Land Allocation Decision Support System (LADSS); thirdly, we wish to determine the impact of waste recycling over time and whether the activity itself alters the suitability and processes of different soils and lastly we intend to validate the chemically based metal sensitivity model using a biological target.

Contact: Willie Towers

Waste to land- regional and catchment scale assessments

Changes in international, European and UK legislation are likely to result in an increase in the amount and range of waste products which will be applied to agricultural land. These will include wastes arising from agriculture itself as well as those produced by other industries. Of the wastes currently applied to land in Scotland the vast majority are derived from the agricultural industry with over 15m tonnes per year. The remaining 4% consists of exempt wastes, such as blood and guts, food and paper waste which account for 367,000 tonnes per year and sewage sludge which only accounts for 200,000 tonnes per year.

Significant benefits may be derived from many of these wastes, particularly where their use is combined with reduced usage of inorganic fertilisers but there are also risks that must be considered.

Benefits

- Source of plant nutrients (N,P) with potential to reduce inorganic fertilizer input.
- Organic matter to improve soil physical properties.
- Manipulation of soil nutrient cycles.

Risks

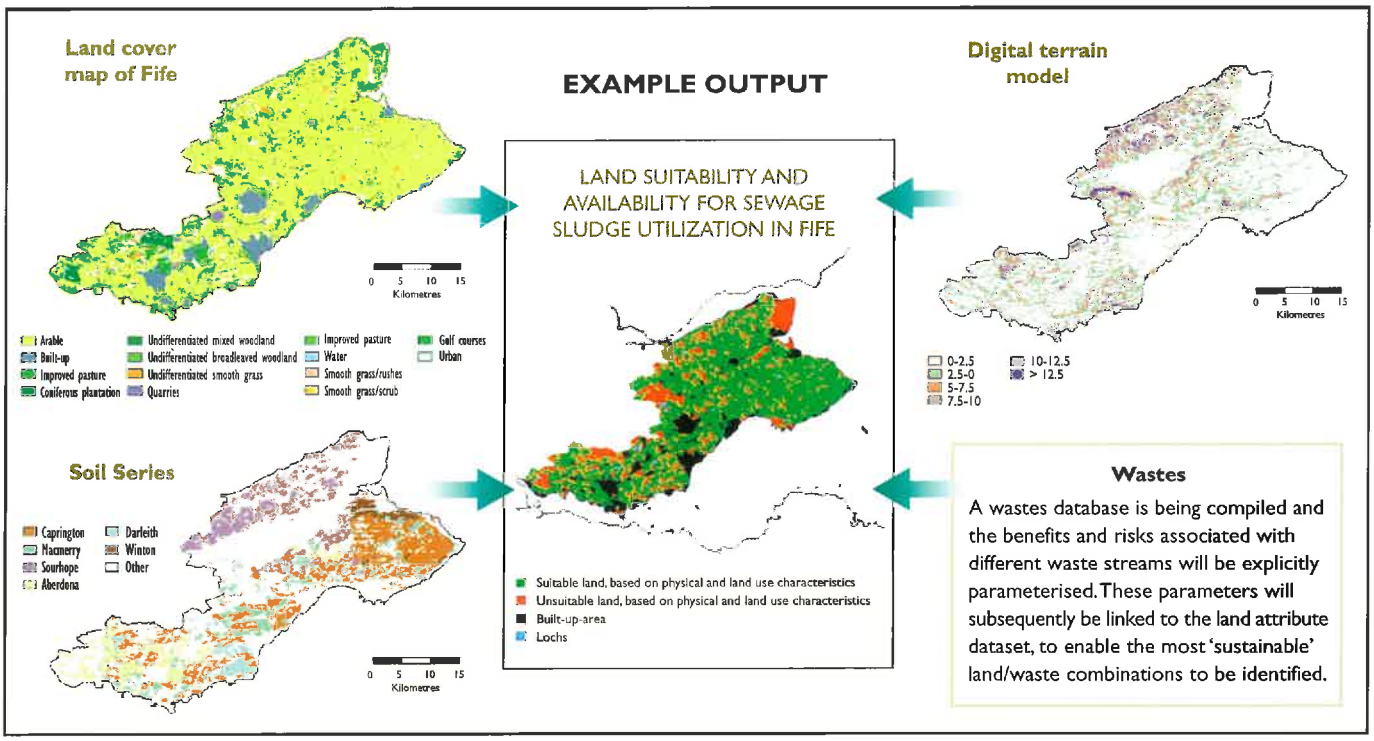
- Entry of pollutants into soils, waters and ultimately food chain.
- Emissions of odours and greenhouse gases.
- Soil physical damage due to ill-timed operations.

The Institute and SAC are collaborating in a joint research project to assess the feasibility of developing a spatially based decision support tool which takes account of the amount and nature of the wastes arising in a particular geographic area: it will define the impact of their management and use on soil, water and air of that area. Such an approach has direct relevance to using wastes efficiently in agriculture and forestry, protecting the environment and providing potable water.

In Scotland, there exists a considerable knowledge base of the chemical, physical and biological properties of wastes, which is being augmented in the current project by a risk assessment of the major groups of wastes applied to agricultural land. A range of models are being used to calculate losses of nutrients and toxins from agricultural systems. Finally, a wide range of environmental datasets have been collected at a range of spatial scales, including soil data, soil maps, landcover and climate maps (Figure 1). The intention of this proposal is to design a computer-based system which will bring together existing knowledge, models and spatial data in a form which will allow an assessment of the risks, benefits and impacts of the use of wastes on land.

The proposal is aimed at designing a two-stage framework for a decision support tool that will, ultimately, serve the needs of two groups of users - those whose principal concerns lie at the regional scale and those who are more concerned with operations at the farm scale. The approach is being developed using a well-defined geographical area, Fife, as a pilot area within Scotland because of the mixture of agricultural land use, and of industrial and urban development contained within it. A prototype system will be developed which will show how decisions taken at the farm scale may impact at the wider catchment and regional scale.

Contact: Ed Paterson



ORCHESTRA- a tool for modelling chemical and multidimensional transport processes in soil

The bio-availability of chemical substances in soil is strongly affected by their ability to migrate in the soil and to reach ground or surface water or plant roots. Therefore, prediction of the migration potential of chemicals in soil, as a function of soil parameters and environmental conditions, enhances the assessment of risks associated with soil pollution. However, this requires computer models that encapsulate the understanding of the processes that control mobility and transport of chemicals in soil. For most inorganic substances the predominant migration route is by convection or diffusion in the soil water phase. Most inorganic substances interact with soil particles, which strongly affects their concentrations in the water phase. Such interactions are usually competitive and non-linear, and can only be satisfactorily described with advanced adsorption models. Therefore, modelling transport rates of reactive substances requires the combination of sophisticated interaction models with models that describe the flow of soil water, or the diffusion of ions in water.

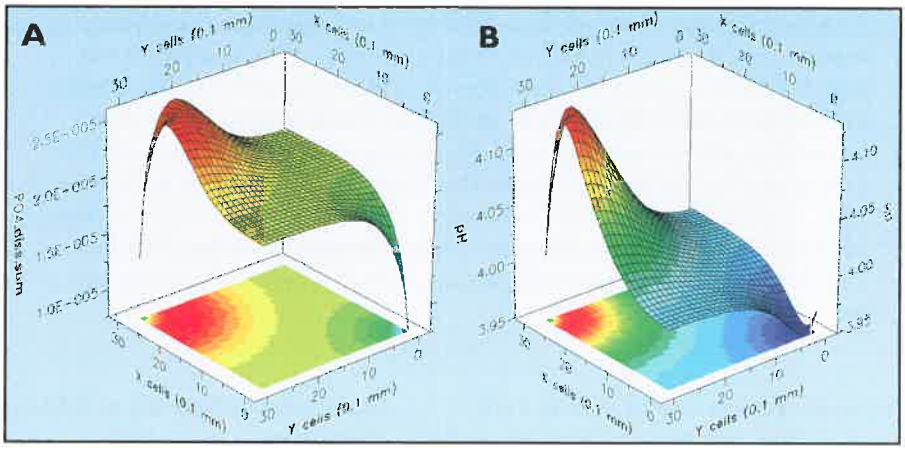


Figure 1. Simulated spatial distribution of phosphorus concentrations (a) and pH (b) in a root zone resulting from the uptake of phosphorus and exudation of citrate by roots. ORCHESTRA was used to create a two- dimensional diffusion model combined with multicomponent adsorption chemistry.

The recent development of the modelling framework ORCHESTRA (**O**bject **R**epresentation of **CHE**mical **S**peciation and **TRA**nsport models) allows us to combine the latest multicomponent adsorption models, with multidimensional physical transport models. In contrast to the approaches, ORCHESTRA does not represent a specific model, but is in fact a generic toolbox that allows users to create specific computer models. In ORCHESTRA models can be composed from predefined building blocks, so called objects, which are stored in an object database (not in source code) and are fully user definable. Such objects represent parts of a model at different abstraction levels, from basic numerical expressions, to chemical reactions, and even complete physico-chemical model systems. These objects can subsequently be used as building blocks themselves, which greatly facilitates the implementation of new chemical or physical models. They can also be used to make arbitrary combinations of existing chemical and transport models.

Currently we have implemented a framework of objects that represents standard equilibrium models and also several more advanced adsorption models. This set of objects is currently used to create specific models that describe complex chemical reactions in combination with transport processes.

Specific applications

The ORCHESTRA framework is currently being used to construct specific models within the following projects.

- Implementation of new adsorption models that take mineral-organic matter interaction into account (D.G. Lumsdon, Macaulay).
- Development of new adsorption models for humic/fulvic acids. (J. Filius, Wageningen Agricultural University).
- Modelling radial diffusion and convection in heterogeneous systems (W. van Beinum, H. Meeussen, Macaulay).
- Modelling convection and one-dimensional transport of sulphate and protons in a goethite silica system. (H. Meeussen, Macaulay).
- Modelling reaction kinetics of chromium reduction and oxidation in contaminated soils. (J. Geelhoed, Macaulay).
- Modelling transport of ions in the rhizosphere (J. Geelhoed, H. Meeussen, Macaulay).

Benefits to end users

The unique level of flexibility of ORCHESTRA allows it to be used as a purely scientific tool but also to package such detailed scientific knowledge, within objects, at an abstraction level that is meaningful to end users. Thus, we are currently using ORCHESTRA to build an end user model of the behaviour of chromium on contaminated sites.

Contact: Hans Meeussen

Establishment of vegetation for slope stability

Shallow slip failures on motorway embankments, typically up to one metre deep are more likely to occur in certain materials, e.g. consolidated clays. The reinstatement of these shallow failures can be both disruptive and costly. The potential for slope failures may be reduced by the use of vegetation. This not only provides reinforcement through the plant root system, but also reduces the moisture content and pore pressure within the embankment. The physical conditions in consolidated, cohesive clays will potentially limit root growth, but some species may be more suited to such conditions than others.

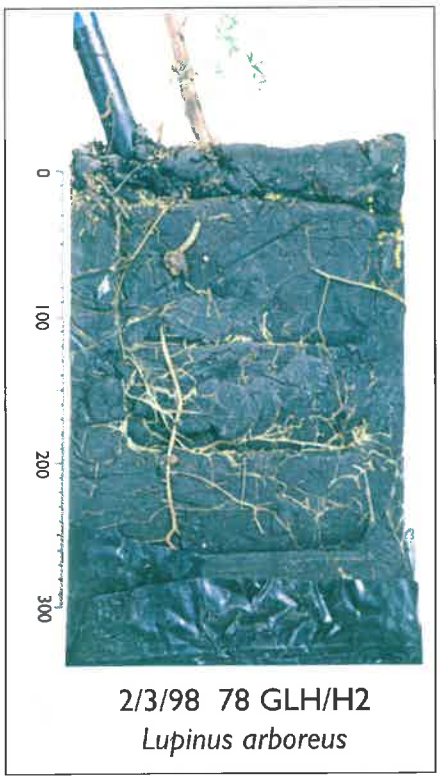
View of plants of the different species growing under greenhouse conditions to simulate warmer south-facing slopes.

Trials are being carried out to assess the suitability of different tree and shrub species. An initial literature survey determined a range of tree and shrub species that had the potential to grow in the environmental conditions alongside highways. Consideration of factors such as salt tolerance, resistance to wind and pollution, as well as the level of maintenance required was important.

A screening trial with 25 species was set up to determine whether the selected species could establish and grow in two different consolidated clays. Five species that had the most successful establishment and growth were then used in a 2 year experiment to measure shoot and root growth under different environmental conditions to simulate north and south facing slopes.

Generally more than 80% of plants survived until the end of the first growing season, but survival was poorer for *Betula* (<60%). All species grew better in Reading Beds clay than Gault clay, and shoot growth was generally greater for plants grown under conditions to simulate southern slopes without moisture limitations. Root measurements showed that roots had grown to the bottom of 40 cm deep clay blocks in all treatments. The experiment continues for a second growing season.

The seasonal patterns in soil water (using a Delta T Devices modified Theta Probe) and changes in soil physical parameters as a result of growing the different species are also being measured. This information along with the plant growth data will be used to assess the suitability of the species for improving slope stability and will provide opportunities to assess the long-term management requirements of the species when they are planted on earthwork slopes. The results will also be used in an economics study to determine the cost of applying technically acceptable options of planting of different species in standard motorway situations. This will enable a comparison of costs between engineering approaches, such as the revising of slope angles or incorporation of lime or aggregates, and a biological approach of planting deep-rooted species.



Root development of Lupinus arboreus in Gault clay under conditions to simulate south-facing slopes without moisture limitations. The dark cylinder at an angle is a borescope used to examine rooting within the block.

Better growth of Hippophae rhamnoides *in Reading Beds than in screening trial. Clay (right) Gault clay (left).*

Funding: Transport Research Laboratory Limited

Contact: Carol Marriott

Ythan Catchment - appraising impacts of agriculture

This project, which began in 1994 arose directly as a consequence of a report by SEPA to the Scottish Office identifying the Ythan estuary in NE Scotland as being eutrophic "due to nitrates arising from agricultural sources" under the EC Nitrates Directive (91/676/EEC). While a steady increase in the nitrate concentration of the River Ythan was clearly apparent from time trends of historical (from 1960) data, there was insufficient evidence of a causal relationship with the greater occurrence of algal mats. This project was one of three funded by the Scottish Office.

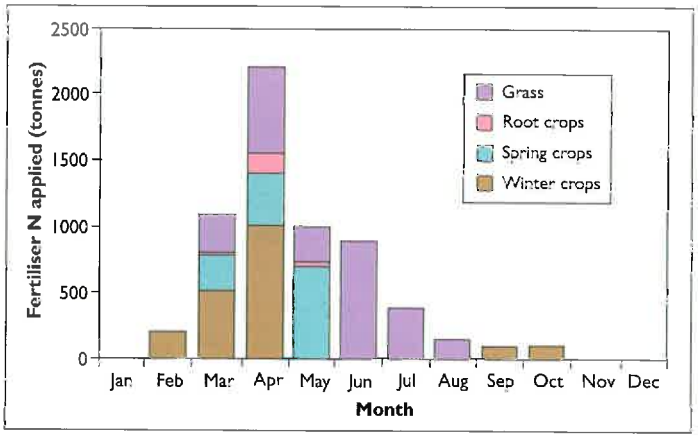


Figure 1. Annual distribution of fertiliser N applications to main crops and grass.

The following main issues have been addressed:

- Establishing the general context of the Ythan catchment regionally and within that of the UK.
- Quantifying the various changes to land use that have occurred since 1960 which could influence any aspect of the nitrogen cycle.
- Contrasting the dominant transfer pathways and amounts of nitrogen between the main farm types representative of the catchment.
- Extrapolating from individual farm level to whole catchment nitrogen fluxes by including a consideration of certain spatial aspects.
- Developing an understanding of, and modelling the catchment's hydrological properties.
- Assessing the usefulness of existing nitrogen models.

The Ythan Catchment covers an area 68 000 ha, 90% of which is used for agriculture. In 1994 the agricultural census data indicated that for the whole catchment 38% was grassland with 17% sown to autumn crops, 28% to spring and 3% to roots. Changes since 1960 have included a reduction in the area of grass and an increase in the area sown to autumn crops, and are typical of the region. Livestock, and cattle in particular, represent an important component of the farming system and only 9% of the 718 farms had no livestock. Stocking densities (1.2 LU/ha) are similar to comparable regions in the UK and EU. A Farm Nutrient Questionnaire was sent to 493 individual farm addresses associated with 718 farm codes. A very good response of 56% of the addresses was achieved and the co-operation of local National Farmers' Union of Scotland representatives, individual farmers and Scottish Agricultural College advisory staff was a significant contributory factor to the response rate achieved. During 1994 an average of 190 kg N ha^{-1} was introduced to the catchment of which 60% and 15% was derived from fertiliser and animal feed respectively. The estimated removal of N in crops and livestock approximates to 45% of the total input.

Fertiliser practices for most crops were similar to those currently recommended by SAC. The timing of N fertiliser application estimated for the whole catchment is shown in Figure 1.

By combining existing process-based N models (Sundial, Rothamsted) and an N cycle (IGER) model with a spatially distributed hydrological model it has been possible to test various scenarios of nitrate loss. While direct loss of N following fertiliser application is unlikely to contribute significantly to river nitrate the importance of soil processes in the long-term has been highlighted.

This study and the data it generated, represents an important reference against which the impact of changing agricultural practices can be assessed. It also provides a reliable source of information that enables informed decisions on the likely ease of compliance, and therefore effectiveness of specific management plans should a future designation of Nitrate Vulnerable Zone status ever be made.

The work has also highlighted that the general management and nutrient value of livestock wastes require greater emphasis. The lack of any real appreciation of the 'fertilising' value of livestock waste was readily apparent from this farm study data.

Future developments

The work strengthened the value of using nutrient budgeting approaches which has resulted in additional Scottish Office funding through SAC and the development of individual farm nutrient plans. Various areas of scientific uncertainty have been highlighted some of which are now being targeted for suitable funding. The general approach adopted within this work is being applied to regional and national assessments of nutrient cycles.

This project was undertaken in collaboration with the Scottish Agricultural College and the Institute of Hydrology.

Contact: Tony Edwards

Halladale Catchment - impacts of forestry establishment

The Highland Region in Scotland has an extensive, high quality freshwater system that supports important commercial and recreational fisheries. A large-scale proposal to afforest around 1000ha of the upper Halladale catchments in this region raised considerable environmental controversy concerning the threat to the local salmon fishery. During the forest establishment phase, the perceived risks from the proposed scheme included soil disturbances due to ploughing and drainage, fertilizer losses, altered inputs during canopy formation and stream acidification.

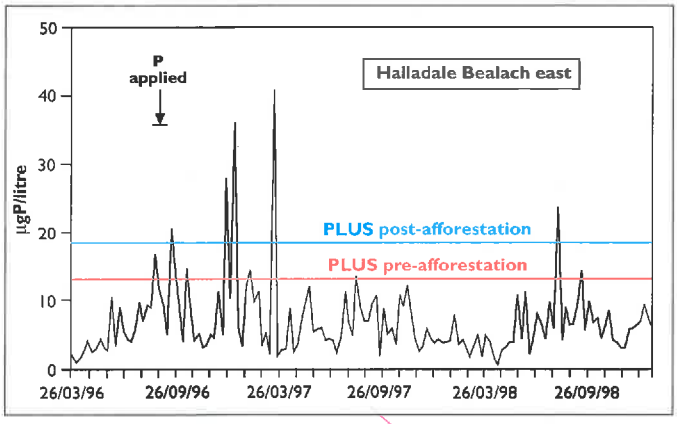


Figure 2. Total phosphorus concentrations (µg litre^{-1}) in the Bealach east stream (FR data) and predicted conentrations from PLUS model.

A consortium including the Institute, Scottish Environment Protection Agency, Freshwater Fisheries Laboratory and Institute of Terrestrial Ecology were funded by the Forestry Commission to carry out studies during 1993-94 to collect site-specific information. Consequently permission was granted for a modified scheme to proceed with the proviso that the research studies would be continued. Cultivation and planting took place in early 1996, fertilizer P was applied in late 1996 and some drainage was carried out in mid-1998.

Results to date show that there has been no change in either salmonid or invertebrate populations in the streams along with minimal responses in stream turbidity and colour. There have been no impacts on hydrology although wet periods in 1998 did result in some localised bank erosion, but this does not seem to be related to earlier site cultivation and drainage. The only impact has been enhanced concentrations of P in some streams from the applied fertilizer.

Base-line studies included the application of the PLUS model (Phosphorus Land Use and Slope) to selected sub-catchments to predict P losses. An example of the slope categories is shown in Figure 1 for the Bealach east sub-catchment that was identified during the base-line period as being the most sensitive. Pre-afforestation, output from the PLUS model for this sub-catchment (area 74ha) was forecast to be 6 kg yr^{-1} P, with losses of P from areas of heather in mid catchment. These losses increased to around 9 kg yr^{-1} P post-afforestation again dominated by losses from mid catchment, which was the main area of planting. Prior to afforestation the sub-catchment consisted of around 5ha of blanket bog and peatland with 69ha of heather in the steeper slopes in mid catchments whereas post-afforestation there was 31ha of trees with the area of heather reduced to 43ha.

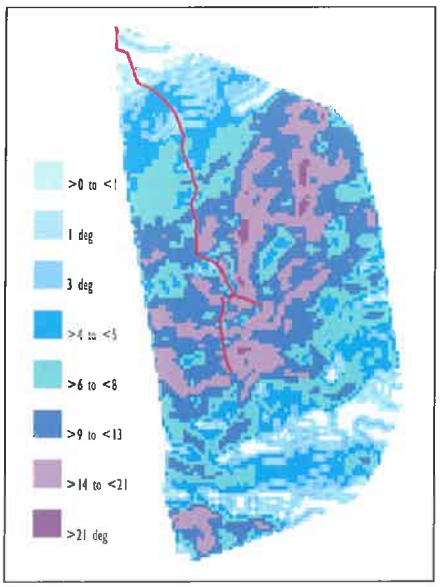


Figure 1. Slope categories (degrees) for the Bealach east sub-catchment.

These losses of P can be converted to concentrations of 12µg P litre^{-1} and 18µg P litre^{-1} pre- and post-afforestation respectively in the stream. Results in Figure 2 (Forest Research data from T.R.Nisbet) show that there have been marked increases in stream P concentrations at high flows in late 1996, early 1997 (linked to snowmelt) and continuing into 1998. Overall at this site the stream P concentrations are slightly less than those predicted with annual mean concentrations <10µg P litre^{-1}. However plot studies on both mineral and organic soils should lead to refinement in P loss-coefficients and improved model output.

These studies are important as the first practical opportunity to examine critically the application of the new 'Forest and Water Guidelines' in northern Scotland and will contribute to the debate on the sustainability of forestry in sensitive catchments. Results of the P studies have already provided valuable information for planning fertilizer operations in other parts of the Highland Region that contain sensitive waters.

Contact: John Miller

Review of the Harmonised Monitoring Scheme (Scotland)

Recently, the Scottish Office Agriculture Environment and Fisheries Department (SOAEFD) commissioned a review of the Harmonised Monitoring Network (Scotland) which was undertaken by a consortium of Macaulay Research and Consultancy Services (MRCS), the Institute of Hydrology (IH), and Biomathematics and Statistics Scotland (BioSS).

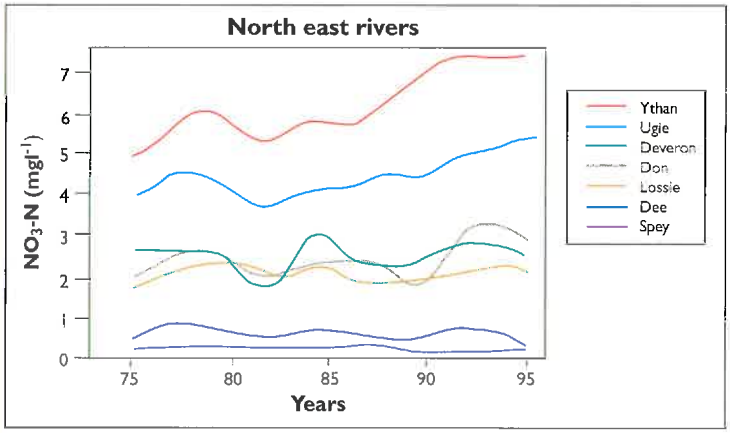


Figure 1. Nitrate concentrations in North east rivers.

The main aims of the project were to:

- review the characteristics of both the Harmonised Monitoring Scheme (HMS) and the National River Flow Archive (NRFA) for Scotland.
- develop and apply appropriate methodologies for the determination of trends in concentration data for the HMS.
- highlight relationships between water quality variables and catchment characteristics.
- undertake an analysis of aggregated mass loads for Scottish catchments.
- review the completeness, integrity and consistency of the HMS database, in particular the precision and accuracy of estimation of loads discharged into the marine environment.

In order to identify any long term trends within the water quality data of the HMS records, a statistical model was employed which identified the uncertainty associated with time, seasonality, and flow. Where data quality was high, model convergence was achieved. An example of output from the trend analysis model is shown in Figure 1 where the long term signal in nitrate-N for selected rivers in NE Scotland is presented.

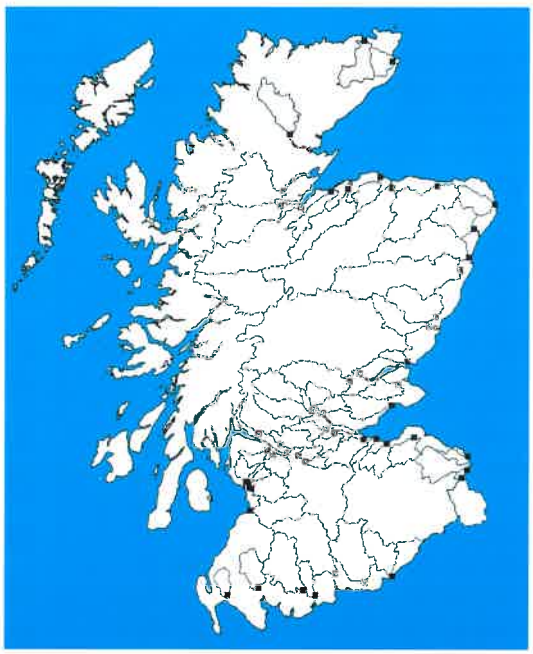
Further statistical analysis also identified strong relationships between a number of water quality variables (using data from the last five years of complete HMS records). In particular, suspended solids show a high positive correlation ($p<0.001$) with phosphate-P, biochemical oxygen demand (BOD), and a corresponding negative relationship with dissolved oxygen. The most significant correlation was between suspended solids and phosphorous. BOD also exhibited a highly significant ($P<0.001$) relationship with phosphate-P, nitrate-N, and ammoniacal-N.

In order to determine potential causal links between land use characteristics of the HMS catchments and water quality determinands a series of analyses were undertaken utilising the Land Cover of Scotland 1988 spatial database (LCS88) and the last five years of complete HMS records. Due to the high number of potential interactions between land use characteristics and determinand values, the model convergence matrix of the trend analysis was used to screen the data and prioritise analysis. This removed the problem of inconsistent or incomplete data. The analysis confirmed the strong correlations between catchment land use "types" and certain HMS determinands. In particular, the relationships between:

- urban catchments and suspended solids, ammonium-N, phosphate-P and BOD.
- arable catchments and nitrate-N.
- improved grassland catchments and phosphate, suspended solids and BOD.

The correlations identified between land cover types and HMS water quality determinands would be most prevalent in catchments with the appropriate land cover type banding.

The HMS remains the best source of water quality data for a 20-year time period, and therefore the best database from which to estimate loads to the marine environment. The availability and use of large spatially referenced datasets such as LCS88 and temporal data has done much to aid the interpretation of signals contained in the HMS record. This work has contributed to a linked terrestrial-aquatic database and management system for Scotland's running and standing waters which is being developed at the Institute.



Chemical sampling sites and associated HMS catchments.

Contact: Bob Ferrier

Predicting the potential distribution of native woodlands in Scotland

There is an increasing interest and commitment to safeguard and expand the native woodland resource of Scotland for landscape and natural heritage value. Within the UK Biodiversity Action Plan, expansion targets have been set for native pine woodlands and upland oakwoods (Figure 1). In addition, the development of Forest Habitat Networks, which seek to alleviate the consequences of previous native woodland fragmentation, is one of Scottish Natural Heritage's conservation initiatives into the next century.

Figure 1. An oakland on the Island of Islay.

The Native Woodland Model (NWM) has been developed to help identify the most suitable sites for the re-establishment of a number of native woodland types. It comprises a series of decision rules linking the requirements of different native woodland types to site conditions. Soils data, which also contain information on geology and associated landforms, have been integrated with land cover data within a Geographic Information System (GIS) to provide the site information .

The primary outputs are maps of potential native woodland cover, representing their potential natural extent under current environmental conditions; they do **not** represent aspirations for final woodland cover. The patterns of potential woodland cover from the NWM outputs conform with known remnant woodland communities, previously published views and expert opinion.

To date, the Native Woodland Model has been used as follows:

- as the 'template' to guide the initial Forest Habitat Network initiative in the Cairngorms (Scottish Natural Heritage).
- to indicate the potential for the expansion and establishment of native woods in areas as diverse as the Western Highlands (Figure 2), the Angus Glens and Rum (Scottish Natural Heritage, Highland Birchwoods and Tayside Native Woods).
- for estate audits.
- in the development of the Cairngorms Forest and Woodland Framework for the Forestry Commission, Scottish Natural Heritage and the Cairngorms Partnership. Specifically to:
    - indicate the suitability of sites for natural regeneration.
    - identify priority areas for the targeted and phased planting of native woodlands.
    - provide an indication of site capability for non-native species.

A cost-effectiveness analysis of woodland ecosystem restoration undertaken by the Institute suggested that in order to improve the delivery of biodiversity benefits, grant rates should be increased for natural regeneration.

The model continues to be modified and enhanced, notably in the prediction of montane scrub and its application in extensive wet heath/peatland areas. Its future use is likely to be extended to cover the whole of Scotland to provide the template on which a National Forest Habitat Network could be designed.

Contact: Willie Towers

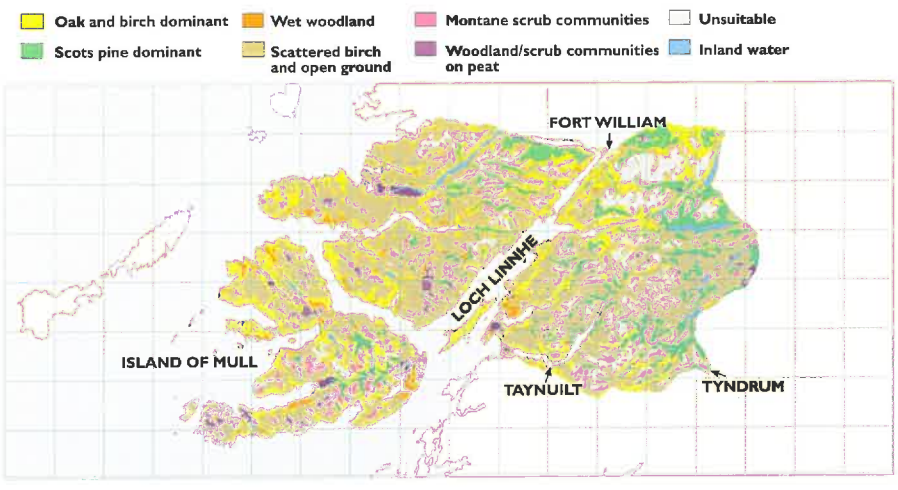


Figure 2. Potential Distribution of Woodland and Scrub Communities in part of Western Scotland.

HillDeer

HillDeer is a computer-based decision support tool designed to help deer managers determine the numbers of red deer that will allow the sustainable use of the open-hill deer forest areas of Scotland. HillDeer is being used by staff of the Deer Commission for Scotland and by Deer Management Groups to facilitate decision-making about the appropriate size of their red deer population in relation to the objectives that they, and other bodies, set. It allows the manager to determine what culling strategy they need to adopt to achieve their target populations. It is part of a package of tools which will enable Deer Management Plans to be produced for each Deer Management Group area. In conjunction with a Rapid Habitat Assessment methodology being developed for Scottish Natural Heritage and the Deer Commission for Scotland by the Macaulay Institute, HillDeer will assist in encouraging the grazing of Scotland's hill areas in a manner which will allow both rural development and conservation objectives to be met.

The background to the development of HillDeer was the setting up of Deer Management Groups throughout Scotland leading to the formation of the Association of Deer Management Groups in 1992. The Association, with the then Red Deer Commission, identified that there was a need to develop a tool, such as HillDeer, to assist in the process of developing Management Plans. Such plans require explicitly derived information on what the sustainable numbers of deer are for a Group area and a culling policy which allows that objective to be achieved. Sustainable use is considered to involve maintaining the most important vegetation types in an appropriate state and providing desired deer performance.

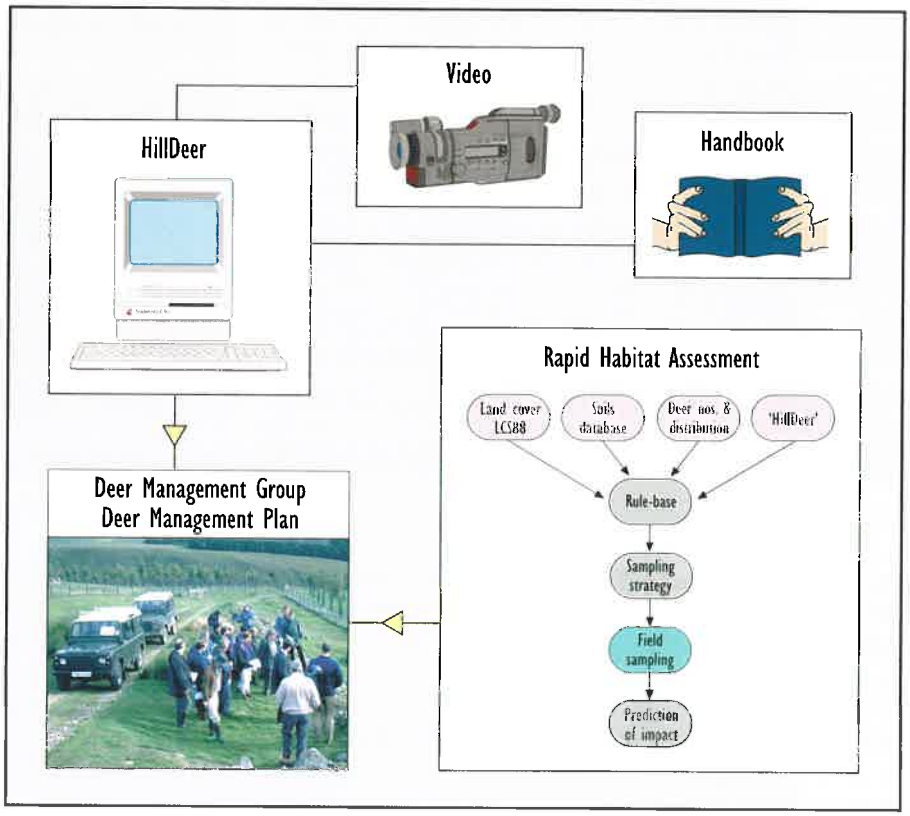


Figure 1. Deer management package.

HillDeer uses a small number of inputs as information, including the location of the Deer Management Group, the area of each of the six main vegetation types, which can be obtained from the Land Cover of Scotland dataset, and the status of the vegetation, obtained from a brief field survey, and the most recent counts of stags, hinds and calves and the cull records, which are recorded annually by Deer Management Groups themselves. Information is also required on the numbers of sheep and estimates of rabbit numbers as they influence the impact of grazing on the vegetation. The degree of disturbance of red deer populations by man is also taken into account as that may influence the vegetation types grazed. Finally, the amount of supplementary feeding of stags in winter is required since this can influence the vegetation grazed and the weight of stags.

This information is then used by the software programme to predict the amount of vegetation that is produced by each vegetation type, which vegetation types are grazed by red deer and what amount of vegetation is removed as this influences its productivity and its long-term nature.

The productivity of hinds and stags is then predicted. On the basis of this information and that on the counts of red deer and larder weights in previous years, the size of the red deer herd is predicted. The more information that is available on counts the more accurate will be simulations of future populations. By using different culling rates the effects on population size and performance can be predicted over periods of time up to 20-30 years ahead. As well as its use by the deer Commission for Scotland, HillDeer has been purchased by 20% of Deer Management Groups in the 3 months since it became available.

HillDeer was developed with Biomathematics and Statistics Scotland (BioSS) and the University of St Andrews.

A sister decision support tool, WoodDeer, is proposed which will facilitate the management of large sections of the Scottish red deer population which has access to both open hill areas and areas of native or commercial woodland.

Contact: Iain Gordon

Integrated bracken control and vegetation restoration

Bracken (*Pteridium aquilinum*) has been long recognised as an important weed of marginal agricultural areas, where it invades grassland and moorland. It reduces the land available for grazing, and brings with it associated problems of reduced biodiversity, toxicity and carcinogenicity to stock, increased tick densities, and potential, though unproven, human health risks.

Figure 1. Poor development of vegetation three years after bracken control by aerial spraying.

Bracken control by cutting or herbicide application is a relatively well understood process in experimental studies. Large areas are sprayed every year, but little is know about how successful treatment is in practice or why replacement of bracken by other vegetation is a slow and erratic process (Figure 1). In 1993, the Ministry of Agriculture, Fisheries and Food (MAFF) commissioned a project to investigate how bracken control and vegetation could be combined in order to benefit both agriculture and conservation.

To do this a number of related studies were instigated:

- Does aerial spraying control bracken in practice? Analysis of bracken suppression at a wide range of sites (>100) indicated that only about 25 % of sprayed sites had or could achieve long-term bracken control.

- What vegetation developed after control? Vegetation cover and diversity (Figure 2) increase at all sites after control, but analysis of regional differences showed that vegetation development was fastest in more oceanic areas (western and southern Scotland) where litter decayed quickly and slowest in drier areas (North York Moors, West Midlands). However, herbicide use is higher in northern England when the dry conditions necessary for spraying are more frequent.

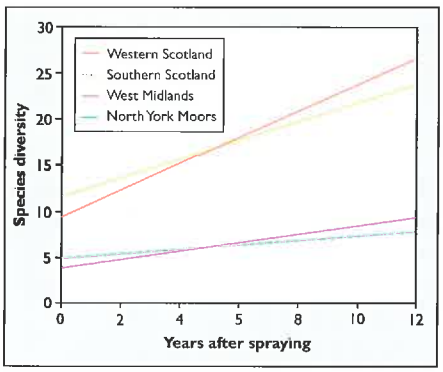


Figure 2. Increase in species diversity with time after bracken spraying in a range of bioclimatic regions.

- What type of vegetation develops after spraying? Heather (*Calluna vulgaris*)-dominated vegetation is most often the objective of land managers when they control bracken. However, the majority of sites surveyed had developed a grassland vegetation, often dominated by wavy hair-grass (*Deschampsia flexuosa*).

- Can bracken expansion be controlled? Both cutting and herbicide spraying reduced the spread of bracken into other vegetation.

- Can methods be developed to encourage vegetation development after control? To re-establish heather-dominated vegetation, experimental studies have shown that a number of stages must be carried out: (1) bracken control must be continued by follow-up spraying or cutting; (2) litter must be disturbed (raking or burning) to provide a seedbed; (3) seed of heather must be added and (4) the site must be lightly grazed or have grazing removed whilst heather plants establish.

In order to promote 'best practice' the project also entailed drawing up new guidelines on bracken control for MAFF. As well as synthesising the above information, they also provide information on how to select a suitable bracken control strategy. For instance, on land accessible by tractor, cutting is more certain of success than aerial spraying, and much of the work necessary to increase and direct vegetation development becomes easier.

The large quantity of data collected within the project can be exploited to provide a framework for a decision support system. Combined with previously developed models of bracken biology, it will be possible to create an interactive tool to allow land managers to explore possible control strategies, their associated costs and the likelihood of success.

This project was carried out in collaboration with the University of Liverpool.

Contact: Robin Pakeman

Conservation management in Skye

The species-rich grasslands (National Vegetation Classification CG10 and 11) of the Trotternish Ridge are important both to the crofting community for the rich grazings they provide, and also to the natural heritage interest since the area is a site of Special Scientific Interest and a candidate Special Area of Conservation as one of the EC Natura 2000 sites.

The Old Man of Storr, Skye.

The current prime concern is that there is an increasing threat to the landscape and vegetation from erosion, but the degree to which the activities of sheep and rabbits are accelerating the natural level due to the geomorphic processes is unknown. It is therefore vital not only to ascertain if herbivore removal or reduction could significantly alleviate the erosion problem, but also to learn what the effects of such action would be on the species-richness of the sward.

Figure 1. View of two of the sets of fenced exclosures on the slopes of Sgurr a' Mhadaidh Ruaidh.

A three-year investigation is now in progress using fenced exclosures which have been established near Lealt (Figure 1), with four grazing treatments (no-grazing/rabbits-only grazing/ sheep in summer in addition to rabbits/ sheep and rabbits grazing all year) on each of four sites located around Coir' an t-Seasgaich. In addition to vegetation data for heights, species utilisation and botanical composition, erosion rates are being monitored and the Scottish Agricultural College are examining soil physical properties. Additional studies include seedbank determinations and revegetation rates.

The results for the mean vegetation heights for each of the treatments in August 1998 are shown in Figure 2. As expected, the ungrazed exclosure has the tallest sward; what is more surprising is that all of the grazed treatments are of similar height, indicating that the offtake by rabbits alone is the same as that for sheep and rabbits grazing together. If these early findings are confirmed in the longer term, then it is unlikely that removing sheep would reduce the grazing impact on the sward. Indeed, as the field evidence suggests that burrowing rabbits are the principal biotic cause of erosion, reducing their numbers might prove most worthwhile.

This work will permit a more accurate specification of the roles of rabbits and sheep with respect to grazing and erosion. As the areas and properties of the other plant communities present are known, one of the Institute's decision support tools, 'HillPlan', can be used to convert from the plot to the landscape scale and estimate the sustainable sheep carrying capacity of the whole of the Ridge.

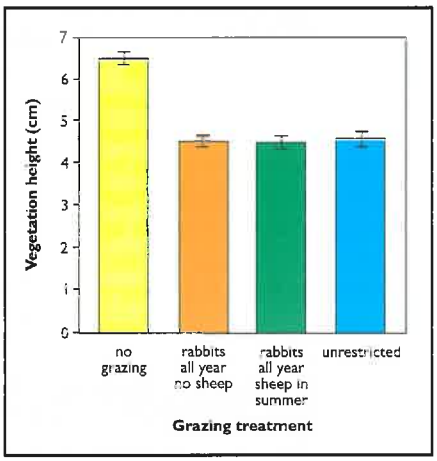


Figure 2. Trotternish: Mean vegetation heights for grazing treatments - August 1998.

The new information will also facilitate the development of long-term monitoring strategies which have to be implemented by SNH to meet the Habitats Directive and the Natura 2000 designation.

In more practical terms, the work will indicate if it is possible to formulate a management plan which will fulfil the desire to reduce erosion-risk to an acceptable level, whilst still maintaining crofters' incomes and the high conservation value of the SSSI.

Contact: David Henderson

HillPlan

HillPlan is a computer-based decision support tool designed to operate at the farm to estate scale and to predict the impact of sheep, cattle and deer grazing on the productivity and dynamics of upland vegetation in Scotland. This application is to aid the implementation of Agri-Environmental Schemes by the Scottish Office Agriculture, Environment and Fisheries Department (SOAEFD) which will provide environmental benefits at the farm level. To maintain the biodiversity of grass and heath plant communities, it is important for farmers to adopt a suitable grazing management plan. Hence a need was identified for a decision support tool which would predict the long-term impact of a grazing regime on semi-natural upland vegetation. HillPlan is also designed to predict the output of animal products from flocks of sheep and herds of cattle on the farm to allow an assessment of the economic consequences of a particular management at the farm scale

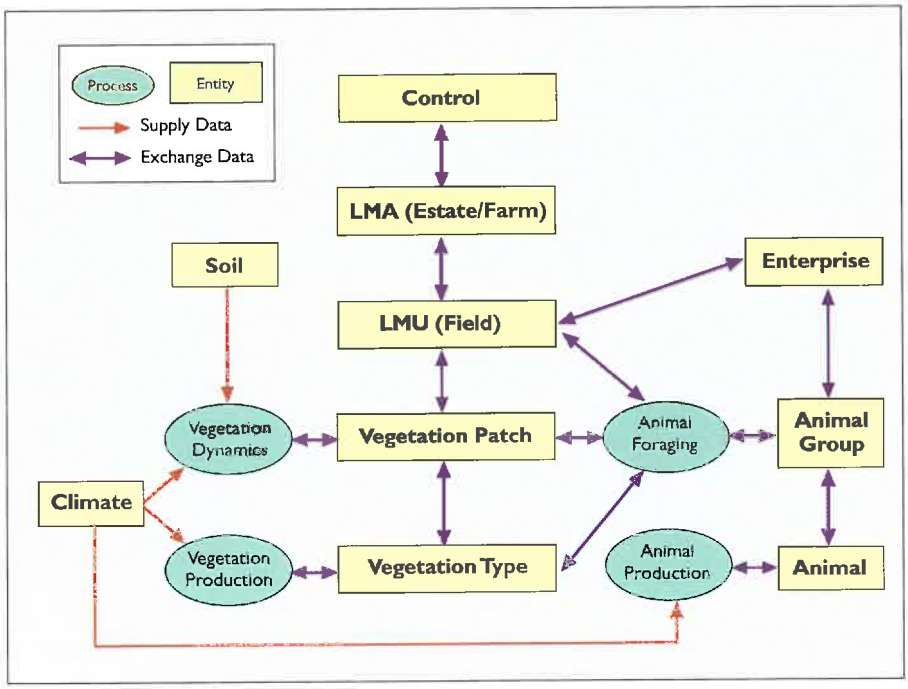


Figure 1. Diagrammatic representation of structure of the kernel of HillPlan.

HillPlan has an internal structure (Figure 1) which allows for a farm, or more generically a Land Management Area (LMA), to have any number of flocks or herds as enterprises (the economic sub-unit) which can graze on any field, or more generically, a land management unit (LMU). Within a LMU, there can be any number of patches of vegetation (vegetation patch) which themselves can contain any number of plant species (vegetation type). The seasonal growth of the grass vegetation types and the impact of defoliation on their growth is based on partly empirical and partly mechanistic models. The models require inputs of climate and soils information and operate on a daily time step. The growth of shrub vegetation types is modelled empirically, because there are no appropriate mechanistic models available. The flocks of sheep and herds of cattle can be divided into age and productivity classes and within each of these classes individual animals are modelled. The foraging behaviour model, which is based on a modified ideal free distribution model, which has been found to behave well in a previous grazing systems model, operates both at the vegetation patch and vegetation type levels and uses information on the mechanics of grazing to predict instantaneous intake rates. The resulting intakes of metabolisable energy and protein are then used to predict the amount of animal output produced on a daily basis using a modified livestock feeding standards model. The long-term effects of grazing on the proportion of plant species in a vegetation patch is predicted on an annual basis, using a new model specifically developed for this purpose. Farmers make planning and scheduling decisions on when to mate their animals, when to sell them, when to move them from one field to another, when to give supplementary feeding and when to house them. The model has been designed to allow this information to be incorporated and applied.

In the particular application for SOAEFD, inputs required must be kept to a minimum such that they can be collected from a half-day visit to a farm. They include the area and number of each LMU and the composition, area and number of patches in each LMU, the number of animals in each flock or herd, their location on LMUs at any time of the year and date of mating. There is a large number of outputs that can be generated and these can be adjusted to suit the application of HillPlan. In the particular SOAEFD application the most important outputs are those that relate to the vegetation communities.

Considerable interest has been expressed by several government agencies in other applications for England and Wales as well as Scotland. Because of its generic structure and design, it is relatively easy to change the user interface and substitute one component sub-model by another. Hence there is considerable scope for its use in designing and implementing Agri-Environment policies associated with grazing farm livestock. It also has the potential to be used in a farm-management context.

Contact: John Milne

The welfare of deer during transport and prior to slaughter

In order to satisfy regulatory requirements designed to protect human health, provide a product of consistent quality and safeguard animal welfare, there has been an increase in the abattoir slaughter of farmed red deer in both the UK and elsewhere, notably New Zealand. With the advent of a more centralised abattoir industry there has been an increase in the average length of journey time for the animals involved. In this project, supported by the SOAEFD flexible fund, the welfare of red deer during transport and prior to slaughter was investigated through both behavioural and physiological studies in order that advice could be provided to the deer farming industry and those responsible for legislation.

It is important that when animals are handled prior to slaughter, they are handled in such a way that their welfare is not unduly compromised (and that the quality of the meat ultimately produced is high). The benefits of careful handling on the farm and during transport may be lost if animals are subjected to acute stress immediately prior to slaughter. We confirmed that exposure of deer to unfamiliar species may have a detrimental effect on their welfare and reduce the ease with which they can be handled and so this should not happen in the abattoir lairage (or indeed in a multi-species transporter).

Using a range of behavioural and physiological measures we found that entering an unfamiliar lairage was a stressful experience for female yearling deer and suggested that, from a welfare point of view, it would be preferable to slaughter the animals as soon as possible after unloading from the transporter. We also found that some aspects of pre-slaughter handling can be stressful to deer and, in common with other species, there is clearly need for more work in this area.

The transport process exposes animals to an array of potential stressors - noise, confinement, vehicular motion, altered environmental conditions, exposure to novel housing, and close contact with humans. We found, for example, that during a three-hour journey, yearling deer (the class of animal most likely to be transported) spend more time standing in the transporter than before or after the journey, but that this depended on group size. More losses of balance occurred with a greater space allowance (Figure 1) and more losses of balance occurred on winding rather than straight roads. Analysis of physiological changes suggested that loading onto and confinement on the transporter may have been stressful and physically demanding for the deer and that vehicular motion increased some of the responses.

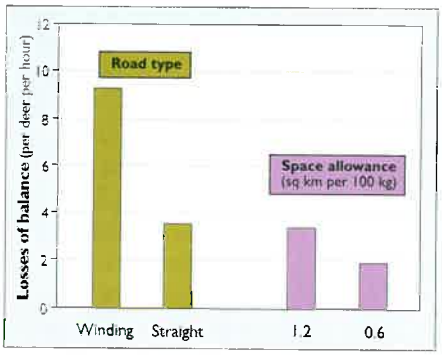


Figure 1. Effect of road transport on loss of balance.

However, although heart rates, for example, were increased during the initial stages in the transporter, they fell as the journey progressed. Plasma cortisol concentrations were elevated immediately after a journey but returned to baseline within 3 hours of unloading (Figure 2). We concluded that changes indicative of stress were short-lived and thus had little long-term effect on the welfare of the deer - at least within the maximum 6-hour journey which we studied. However,

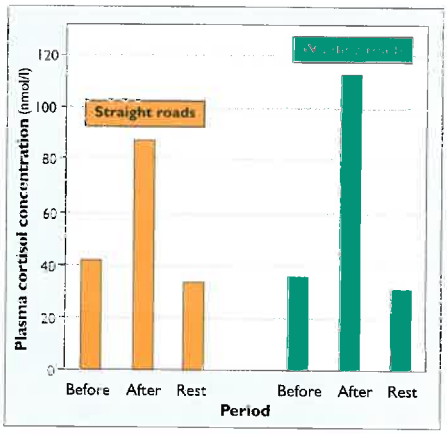


Figure 2. Effect of road transport for 6 hours on plasma cortisol concentrations. Samples taken before and immediately after the journey and after a 3-hour rest period.

journeys on winding roads appeared to be more physically demanding. From these and other studies, advice has been provided to the Scottish Office and MAFF who are revising the guidelines they issue regarding the transport of deer and our results have been made available to the deer farming industry.

Important aspects that remain to be addressed relate to the "quality" of both driving and stockmanship. During pre-slaughter handling there is a much greater opportunity for welfare to be poor and appropriately designed facilities and skilled stockmen, trained in the relevant aspects of deer behaviour, are necessary to ensure high standards of animal care.

Contact: Pete Goddard

Modelling of mixed grazing

Decision Support Tools like HillPlan and HillDeer (described on pages 49 and 46) can model aspects of grazing by mixtures of animal species but they cannot answer some questions about the relationship between the structure of vegetation mosaics and mixed grazing. Experimental work has supported the hypothesis that the scope for complementary grazing increases with pasture heterogeneity. Mixed grazing also has the potential to alter the amounts of vegetation found in mosaics. For example, cattle are less effective than sheep at avoiding unpalatable *Nardus stricta* where it occurs within *Agrostis-Festuca* communities and so mixtures of cattle and sheep have different impacts on the vegetation compared with either species alone. The changing priorities of landscape management, away from production and towards maintenance of a rural environment that has a high natural heritage value, mean that it is important to consider how grazing affects the vegetation composition.

A model developed in association with Dr Stephano Focardi of the University of Firenzia, Italy, has demonstrated that complementarity can result from the preferences of animals for taller and shorter grass vegetation, a preference which is related to the size of the animal. Sometimes a small number of large animals, which graze down tall vegetation to a more acceptable level for the small animals, can lead to an increased carrying capacity of a pasture (Figure 1).

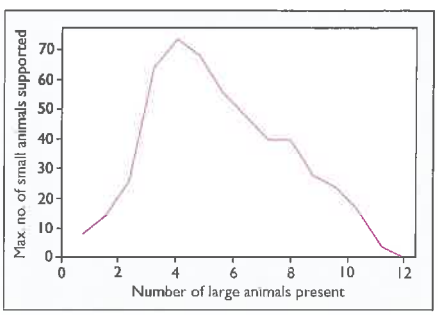


Figure 1. A theoretical model of complimentarity: large animals graze down tall vegetation which is unsuitable for small animals.

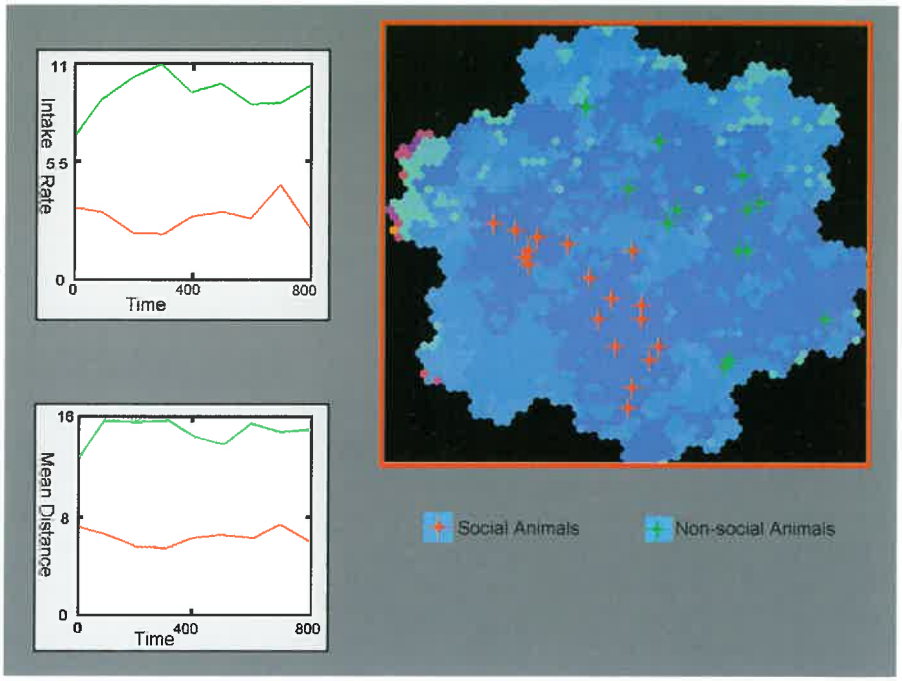


Figure 2. HOOFS simulation of foraging by two species (social animals and non-social animals) with different foraging strategies in a complex mosaic.

We have also developed a spatially explicit model known as HOOFS (Hierarchical Object-Orientated Foraging Simulator) which can model how animals' behaviour affects their interaction with the environment. Three factors affect how an animal decides where to forage. The first is how selective an animal is, with strategies varying from random choice of the next foraging location to a precise evaluation of the best patch to choose (optimisation). Optimisation can lead to less variation in vegetation height providing the quality of the forage always improves as the forage re-grows. However, mosaics of favoured and non-favoured patches can arise once the vegetation starts to deteriorate. The second decision is whether to choose forage of medium quality, which is close by, over better food, which may be further away and requires a greater travel time to reach. Existing theory gives an answer in terms of the cost-benefit analysis of time taken versus energy gained, but the HOOFS model also takes into account the reliability of long-range information and the animal's spatial memory. Finally, a foraging animal may be constrained by having to stay within a group. Data on preferred spacing of groups of grazing sheep recorded at the Macaulay is being used in the model.

Output of data from HOOFS is both in terms of the likely impact of grazing by a mixture of animal species on the environment and in terms of the energy obtained from foraging which can be fed into an animal production model. Figure 2 shows the effect of foraging by a social and non-social species on animal spacing and the biomass of a heterogeneous mosaic of a single vegetation species.

Once the HOOFS model has been parameterised for particular animal and plant species it will form part of the next generation of decision support tools. In the mean time, it is being used to generate hypotheses for experimental work on animal foraging ecology. For example, it is being used to help understand how grass-heather mosaics evolve.

Contact: Iain Wright
Jonathan Beecham

International Collaborative Research and Consultancy - Selected Projects

Much of the work in the Institute has relevance beyond Scotland and benefits from collaboration with colleagues throughout the world. The Institute has been very successful in joint funding applications to Europe particularly within the DG VI and DG XII research programmes. This has led to collaboration with universities and research institutes across the countries of the European Union. A number of these projects are reported upon briefly in the following pages. Opportunities have also been developed through the EC, Department for International Development and other sponsors to engage in research in developing countries such as Zimbabwe, Zambia, South Africa, Pakistan, Kazakhstan and Turkmenistan. Brief descriptions of this work follow, demonstrating how the systems approach, which addresses biological, ecological, economic and social issues together, and has been promulgated by the Institute, is an approach that is very relevant to the land use issues in developing countries. Finally, our international collaboration extends to other countries and laboratories whereby the use of complementary methodologies and techniques have allowed us to advance our understanding of some biological processes that are fundamental to our objectives. The benefits that arise from our international collaboration are incalculable but they undoubtedly provide new perspectives, new knowledge and new challenges that are the life-blood of an Institute such as the Macaulay.

The use of the HYPRES database to derive pedotransfer functions to predict soil hydrological properties for Europe

Collaborators

Winand Staring Centre, Wageningen

Macaulay Contact

Allan Lilly

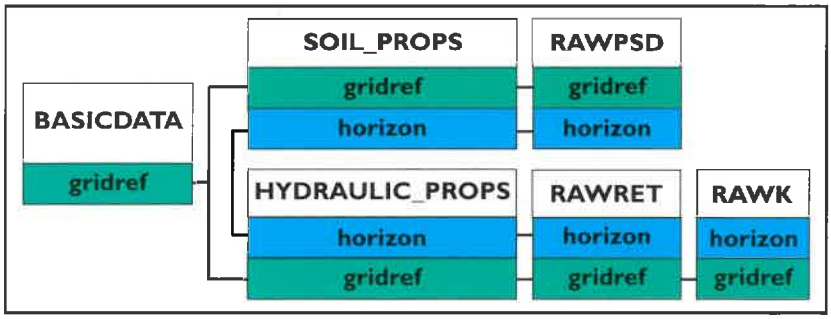


Figure 1. Structure of the HYPRES database.

Many of the soil water and solute transport models currently applied to the investigation of a wide range of complex environmental processes require data on the soil moisture retention and the hydraulic conductivity characteristics. However, these data are notoriously difficult and time consuming to measure, especially for undisturbed field soils. An alternative to direct measurement is the estimation of these hydraulic properties by pedotransfer functions. Pedotransfer functions relate complex soil properties to more easily measured soil data such as soil texture, organic matter content and/or other data routinely measured in soil surveys.

Increasingly, environmental problems are occurring across national boundaries and therefore the solutions require international co-operation. With this partly in mind, the European Union (EU) funded a project (~ CHRX-CT94-0639) in which 20 Institutions from 12 European countries collaborated to develop the HYPRES database (HYdraulic PRoperties of European Soils). This database draws together existing soil hydrological data and the more easily measured soil properties from throughout Europe thus allowing the derivation of European scale pedotransfer functions to address European-wide problems.

HYPRES has a flexible relational structure capable of holding a wide diversity of both the soil hydrological and pedological data needed to derive pedotransfer functions. The desire to have compatibility with existing EU-wide soils databases led directly to the selection of the key identifying attributes used throughout HYPRES as well as many of the other attributes stored. The HYPRES database is a unique inventory of the hydraulic conditions of European soils and will become a key dataset of the European Soil Bureau.

HYPRES Version 1.0 has around 25 Megabytes of data held in six separate tables. There are 1777 spatially referenced sample locations with a total of 5521 soil horizons. The soil horizons were allocated to one of 11 possible soil textural/pedological classes derived from the five mineral texture classes and two pedological classes (topsoil and subsoil) plus one organic texture class recognised within the 1 : 1,000,000 scale Soil Geographical Data Base of Europe. After the parameterisation of the soil hydrological data and standardisation of the soil textural data, class pedotransfer functions were derived for each of these 11 classes by calculating the average soil moisture retention and hydraulic conductivity characteristics within each texture class.

Multiple regression techniques were used to derive continuous pedotransfer functions and novel techniques such as Neural Networks have been tested on a subset of the data. Further work in this area will be done in collaboration with the United States Salinity Laboratory, Riverside, California.

Care was taken to ensure that the pedotransfer functions could be related to other EU-wide spatial datasets to derive map output. A map showing the available water for crop production has been produced and other potential products include infiltration rate maps for soil erosion studies and travel time maps for solute transport. The pedotransfer functions have also been used to provide soil hydrological data for an EU funded project investigating the long term management of radioactive contamination in agricultural systems.

A description of the database and the derived pedotransfer functions are given in J.H.M. Wösten, Lilly, A., Nemes, A. and Le Bas, C. 1998. *'Using existing soil data to derive hydraulic parameters for simulation models in environmental studies and in land use planning'* (CHRX-CT94-0639). Report 156. DLO Winand Staring Centre, Wageningen (The Netherlands).

Figure 2. Distribution of Network Partners.

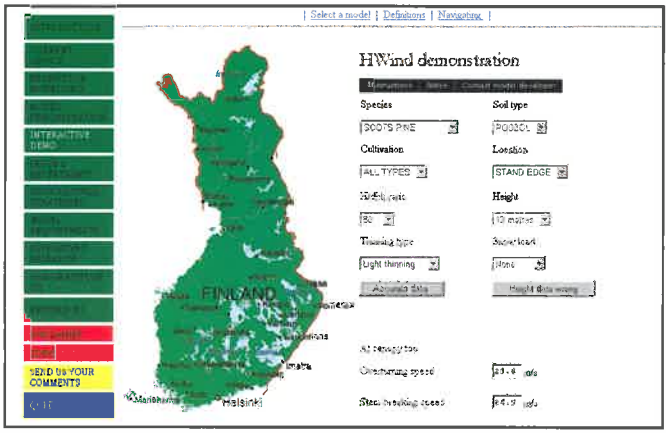
Silvicultural strategies for predicting damage to forests from wind, snow and fire

Collaborators

University of Joensuu, Finland
University of Aberdeen, Aberdeen
Forest Research, Scotland
Centro Nacional de Informação Geográfica, Portugal
Direcção Geral das Florestas, Portugal
Swedish University of Agricultural Sciences, Sweden
University College Galway, Republic of Ireland

Macaulay Contact

David Miller



Silvicultural strategies for predicting damage to forests from wind, snow and fire (STORMS) was a shared cost, EU research project, co-ordinated by the Faculty of Forestry at the University of Joensuu, Finland. The project produced generic modelling tools for quantifying the risk of wind, snow or fire damage to forests. These tools were based on an understanding of the forces and site factors which influence the risk of the damage types acting at scales ranging from single tree, to stand, to regional level. The international grouping of partners brought expertise and perspectives from Scandanavia (Swedish University of Agricultural Sciences, Sweden); southern Europe (Centro Nacional de Informação Geográphica, Lisbon, Portugal); and the oceanic areas of western Europe (University College Galway, Republic of Ireland, Forestry Commission, Edinburgh and the University of Aberdeen).

STORMS also brought together multi-disciplinary approaches to study the spatial patterns of processes operating on trees. The work has been integrated vertically, through an understanding of factors increasing the susceptibility of forestry damage at different scales and horizontally by incorporating geographical areas across the north/south range of the EU and including those areas with severe damage caused by wind, snow and fire.

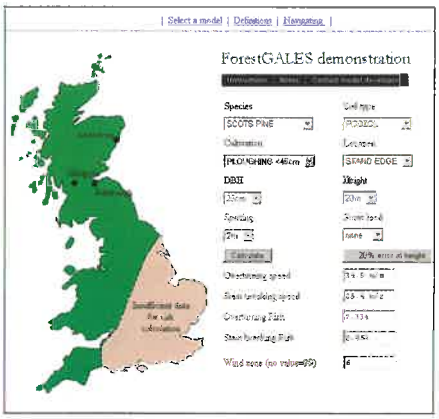
A particular focus of the research work at the Institute was the study of issues associated with the combination of data and models, that were derived and used at different scales. This included work on characterising the propagation of error from the source data through selected models to the output results. The Macaulay team developed the integration and presentation of the component models using a WWW interface to allow:

- A standardized approach for accessing and presenting models which operate at stand, regional and national levels in different countries.
- On-line, interactive operation of model demonstrations.
- The presentation of the models' outputs in response to an error in a highly significant input variable, such as tree height.
- Access to much of the state-of-the-art supporting research conducted within STORMS to enable the user to obtain a greater insight into the issues associated with the causes of abiotic damage.
- Prototype work on the use of metadata in a research environment.
- An example of model usage to assess the consequences of alternative management regimes on the risk of abiotic damage.
- On-line dissemination of the project results.

The demonstration package is currently being evaluated by higher education establishments in the European Union and Eastern Europe, Russia, Australia, Japan and North America for use as an Education Support Tool at postgraduate level. The demonstrator and the models to which it relates are also being reviewed by representatives of the insurance industry to assess what improvements may be made to the methods of assessing the risk of damage to trees and the setting of insurance premiums.

The STORMS project pages have also been used by the EU DGXII as an exemplar for WWW use in project management and the dissemination of information. The site continues to be maintained and updated with information relating to abiotic damage to trees. More than 500 external groups have visited the site, from 27 different countries.

The WWW techniques developed in this project are now being further developed in another EU shared cost research project: HYDALP (Hydrology of Alpine and High Latitude Basins) which couples remote sensing data and hydrological modelling. (http://bamboo.mluri.sari.ac.uk/hydalp/)



STORMS Web address
http://bamboo.mluri.sari.ac.uk/storms/

Integrating environmental concerns into European mountain agriculture

Collaborators

Euromontana, Paris (Co-ordinator)
Aristotle University of Thessaloniki, Greece
Bundesandstalt für Bergbauernfragen, Vienna
IKT, Vitoria-Gasteiz, Spain
INRA, Castanet Tolosan, France
GIS Alpes du Nord, SUACI Montagne du Nord, France

Macaulay Contact

Bob Crabtree

Cropping and grassland in the Eastern Alps.

The study used 25 agricultural case study areas in the main mountain regions of Europe to investigate the links between agricultural change and the environment. Two case study areas (in Sweden and Finland) were not in mountainous regions but had equivalent conditions and conformed to Directive 905/97. The project structure was unusual and ambitious. Five network leaders were established for each of five geographical zones. In each network around five research groups with local knowledge were asked to participate – a total of 25 research groups for the whole project. Bob Crabtree and Daisy MacDonald from the Macaulay organised the Nordic network of Scotland, Sweden and Finland and assisted in the central organisation of the project.

The analytical approach was pressure-state-response, attempting to understand the processes of change and their impact on environmental quality. All zones were affected by pervasive socio-economic pressures driving agricultural change but the responses differed depending on the area. In most cases abandonment of land or of traditional agricultural practices was occurring with a loss of agriculturally-related habitat and landscape. The types of adaption depended on the existing farm systems with, for example, in the case of traditional grassland farming five main types of responses. In essentially mixed arable/cropping systems the adaption was more typically towards monoculture, set-aside or a complete change of land use (afforestation or abandonment). The driving force for change was usually an attempt to maintain incomes, reduce labour costs or to reduce activities that had high personal or social costs (e.g. utilization of high mountain pastures). Pluriactivity was found to be widespread but its impact was ambiguous. In some cases pluriactivity allowed the contribution of traditional farming; whereas in others it was itself the driver of simplification, reduction in labour use and partial or total abandonment of practices.

The project found that the links between farming and environmental quality were complex. There was abundant evidence that farm practices supported biodiversity, valued landscapes and represented a valued cultural heritage. However, in many situations which included grassland and cropping systems, farming practices were causing environmental damage through high nutrient losses (and associated water pollution), erosion and fire-risk. Adaptation, and specifically intensification, that helped farm businesses to survive could be associated with some negative impacts.

The project examined possible policy initiatives as a response to the evolving situation. Agri-environmental measures under 2078/92 were found to be patchy in their effectiveness often through administrative problems in their application. Forestry measures were not found to be appropriate in areas already highly afforested because of the loss of landscape quality and open space. Elsewhere they represented a valuable component of biodiversity and could reduce total abandonment, erosion and fire-risk. Proposals for integrating structural and agri-environmental measures were explored and as a means of providing a more coherent basis for justifying support.

Grass conservation in the Austrian Tyrol.

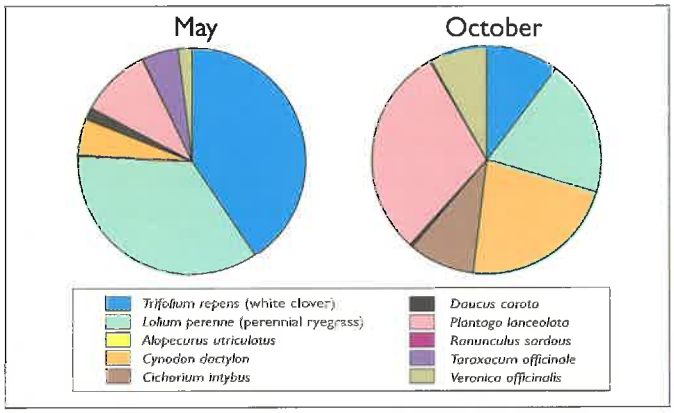
Long-term biological and economic sustainability of livestock production in Greece

Collaborator

Agricultural Development Office Granitsa, Evritania, Greece

Macaulay Contact

Carol Marriott



Percent species in unfertilized rotationally grazed swards in areas containing white clover

Grasslands of NW Greece contain a diverse range of species, including annual and perennial grasses, annual legumes and other broad-leafed species. However animal production in many areas is limited by low productivity of pasture resources and a lack of appropriate grazing management. High stock densities and a long history of uncontrolled communal grazing have led to serious damage to the vegetation and soil resources.

One solution to improve biological and economic sustainability of livestock production could be an integrated approach of introduction of improved plant material, such as *Trifolium repens* L. (white clover) and *Lolium perenne* L. (perennial ryegrass), to increase the production and quality of herbage, and controlled grazing management. However little information was available about the performance of white clover in species-rich swards under Mediterranean conditions in response to different defoliation and fertilizer managements. Furthermore little was known about spatial and temporal dynamics of the component species, although this is well recognised as important in determining species interactions and sward composition.

Our study was set within an experiment to determine the effect of different management regimes on the productivity of sown perennial ryegrass/white clover swards in NW Greece. Sward treatments imposed were a factorial combination of defoliation (rotational grazing by Boutsiko ewes and cutting) and nitrogen fertilization (0 and 40 kg N/ha). There were five defoliation periods (April, May, July, October and November). We tested the hypotheses that defoliation method, N-fertilization and initial content of white clover modified (1) the seasonal dynamics of white clover, perennial ryegrass and eight unsown species in species-rich pastures and (2) the spatial dynamics of white clover at the micro-scale. All measurements were made in 30 x 30 cm microplots divided into nine 10 x 10 cm cells.

There was a changing seasonal contribution of different sward components in the species-rich swards; sown species provided nutritious herbage early in the season until the summer drought, and unsown species were a valuable resource later in the year. Persistence of sown species into the autumn might be increased by using local cultivars that are more adapted to xerothermic Mediterranean conditions.

The small amount of N fertilizer applied had an effect on white clover and *Ranunculus sardous* cover only. However the method of defoliation influenced to some extent the seasonal dynamics of white clover, perennial ryegrass, *Alopecurus utriculatus*, *Cynodon dactylon* and *R. sardous*. These species and *Plantago lanceolata* were also affected by whether white clover was present initially, but the reasons underlying the species-specific responses require further investigation. In contrast four species (*Veronica officinalis*, *Taraxacum officinale*, *Cichorium intybus* and *Daucus carota*) were unaffected by either sward management or white clover presence. In areas where white clover was initially present, it persisted in virtually every microplot cell during first three defoliation periods. After the summer drought its distribution was more patchy and it occupied only one half of the number of cells. Colonisation of clover-free areas was slow.

Management of species-rich sown swards in low-input systems has to consider both overall productivity and sustainability of plant diversity. We found spatial and temporal differences in the contribution of different species to the swards; such differences allow a wide diversity of species to co-exist. Special attention should be paid to the different survival strategies of individual components of the sward and the impact of different management regimes. Management strategies may be required which target the requirements of individual species or groups of species, e.g. cutting rather than grazing to encourage the presence of species which are preferentially grazed and appropriate timings of grazing/cutting to allow seed production of annual species.

Boutsiko ewes grazing in May.

ELPEN – European Livestock Policy Evaluation Network

Collaborators

Staring Centre, Netherlands
Institute de l'Elevage, France
Federal Institute of Agricultural Economics, Germany
Agricultural University of Athens, Greece
Federal Institute of Agricultural Economics, Austria

Macaulay Contact

Iain Wright

European livestock systems provide economic, environmental and social benefits.

Within the European Union there is a large number of different livestock production systems, based upon a great diversity of natural and human resources. In many rural areas livestock production has historically been the mainstay of economic and social activity, supporting large numbers of rural communities. Livestock production has also been responsible, over centuries, for creating landscapes and habitats valued by so many. In many marginal areas of the EU this is still the case, although in recent years there has been severe rural depopulation in some areas and the intensification of livestock production in fertile lowland areas. In these latter areas livestock production is increasingly associated with deleterious effects on environmental quality. One of the challenges facing policy-makers is how to achieve a balance between the negative and positive economic, social and environmental impacts of livestock production.

Appraisal of policy is often constrained by current research methods, available data and lack of appropriate models. This is especially true when trying to appraise impacts on a regional basis.

The aim of the ELPEN project was to identify whether it was feasible to build the framework for a policy appraisal and evaluation decision support system within which the economic, environmental and social impacts of livestock policy could be evaluated. The project brought together a core group of researchers from a range of countries and disciplines, who between them have a very wide range of experience and expertise on livestock systems throughout Europe. By organising three workshops, each with 25-30 participants, on specific aspects it was possible to draw on an even wider range of expertise.

One of the first tasks of the project was to establish the needs of policy makers in the European Commission and National Ministries. From a series of structured interviews, it was clear that there was a need for a policy evaluation decision support tool which could integrate economic, environmental and social impacts. Because of the regional variations in livestock systems, climate, natural resources and social structures and the increasing trend towards de-centralisation of policy implementation, policy makers wished policy evaluation to be increasingly conducted not only at an EU or national level, but also at a regional level. This inevitably requires geographical specificity in any evaluation (Figure 1).

The types of data required by such a system have been identified and a way of organising and storing such data formulated (a data description). In order to assess the impacts of policy it is necessary to have models of how the livestock systems operate and while some formal models of aspects of livestock system exist (e.g. economic models) it is recognised that it will be necessary to use expert knowledge (captured and represented in a formal manner) where no other models exist. The ELPEN network represents a huge pool of knowledge which can be drawn upon to elicit this knowledge, and on which an expert-system based model could be built (Figure 2).

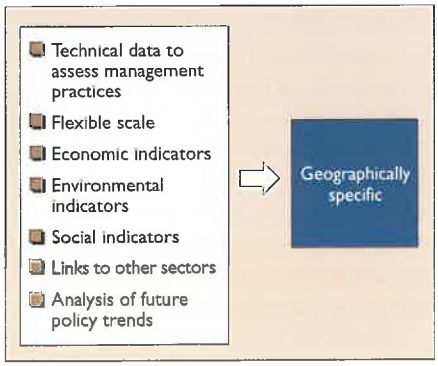


Figure 1. Policy makers' requirements of a policy evaluation decision support tool.

There is much enthusiasm for this approach amongst policy makers in the European Commission and National Ministries, and the ground work has been laid for the building of a unique and exciting policy decision support tool.

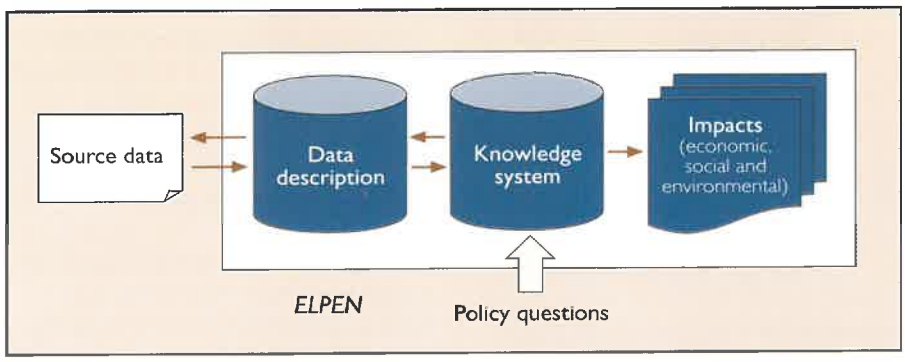


Figure 2. Structure of a livestock policy evaluation decision support tool.

Effects of afforestation of agricultural land on heavy metal mobility in soil (MEMO)

Collaborators

Swedish University of Agricultural Sciences
Geological Survey of Finland
Agricultural Research Centre, Finland
Royal Veterinary & Agricultural University, Denmark
Danish Forest & Landscape Research Institute
Staring Centre, The Netherlands
Institute of Terrestrial Ecology, UK

Macaulay Contact

Derek Bain

Group of collaborators discussing the agricultural plot at the Fetteresso site with the adjacent forest of 50 year old sitka spruce trees in the background.

The background to the MEMO project is concern about possible environmental consequences of the change in land use resulting from set-aside of agricultural land, particularly afforestation and the increased mobility of heavy metals resulting from acidification of the soils. This has implications for ecosystem processes and ground water quality.

The main aim of the project is to investigate how the behaviour of heavy metals in agricultural soils is affected by afforestation and to develop guidelines from the knowledge gained for the establishment and management of forests on set-aside agricultural land in northern Europe in order to minimise possible harmful effects of heavy metals. Four subsidiary aims are to

1) quantify the impact of soil properties on heavy metal behaviour;
2) quantify the integrated effect of stand and site properties on influencing factors such as dissolved organic carbon (DOC) and acidity;
3) integrate the knowledge from 1) and 2) in models predicting the impact of stand composition and forest management for different soil types and climatic regimes; and
4) elaborate guidelines for stand establishment and management for different soil conditions and climatic and deposition scenarios.

The research is based on paired plots (one in the forest and one in the adjacent agricultural land) in Finland, Sweden, Denmark, The Netherlands and Scotland. For each country, the sites have different tree species with a range of ages and the soils and climate. Variations are such that they represent a gradient in soil properties and climate across northern Europe. At the two Scottish sites, there are 50 year old sitka spruce stands on brown forest soils belonging to two soil associations covering very large areas of Scotland. The soils at the Fetteresso site near Stonehaven belong to the Strichen Association developed on acid schists, and at Elibank near Galashiels, the soils belong to the Ettrick Association, developed on shales and greywackes.

The soils are being analysed for heavy metals and are being characterised with respect to properties such as texture, pH, exchangeable base cations, mineralogy, organic C, total N, and ammonium oxalate soluble Fe and Al. Some analyses (e.g. mineralogy) are being carried out by one laboratory for all samples from all sites making this a truly collaborative effort. Speciation of heavy metals is being established through sequential extractions and a more direct approach using electron microscopy and associated chemical analysis. Soil waters are being extracted at different depths in the soils at different times in the growing season and analysed for heavy metals, cations and dissolved organic carbon.

In addition, laboratory experiments are being carried out on selected soils from all participating countries on the sorption and complexation reactions of heavy metals using DOC. Field acidification manipulation will be carried out at a Scottish site to quantify the potential for acidifying pollutant inputs to mobilise heavy metals.

A real benefit of this project is the international collaboration brought about by the different participating organisations contributing their particular expertise to the project. The environmental concerns being addressed and being studied in a more fruitful and effective manner than would be possible by any one of the organisations alone and the application.

Brown forest soil underlying the agricultural plot at Fetteresso.

Dynamic models to predict and scale up the impact of environmental change on biogeochemical cycling: The DYNAMO Project

Collaborators

Institute of Hydrology, UK
Finnish Environment Institute
Norwegian Institute
Winand Staring Center, The Netherlands

Macaulay Contact

Bob Ferrier

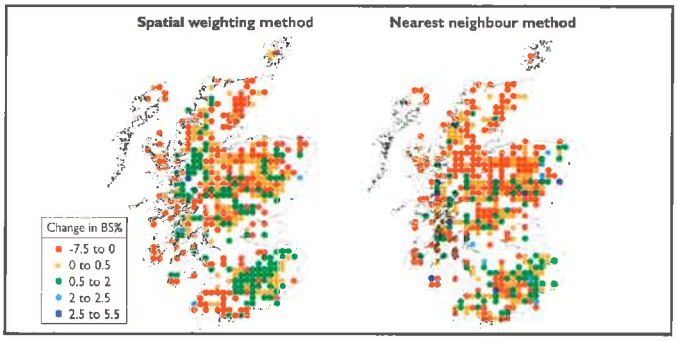


Figure 2. Predicted percentage change in soil base saturation from 1997 to 2050 in response to the UNECE Second S Protocol using two different methods of integrating spatial information into a modelling framework.

European concern about the consequences of anthropogenic impacts on environmental quality have led to the establishment of numerous ecosystem-scale manipulation experiments. This site-specific experimentation has also led to the development of various dynamic modelling approaches through which the consequence of impacts over time can be assessed. Similarly, throughout Europe there has been extensive collection of regional data on "environmental capital" resulting in the production of wide area mapping of environmental quality (soils, land use etc). The aim of the DYNAMO project was to integrate data and models, specifically to:

- enhance the existing process based models to evaluate the impacts of multiple drivers of environmental change;
- evaluate these models within intensively studied (and manipulated) catchments;
- scale up in time from observations collected over several years to predict the long term impacts over decades; and
- scale up in space from the individual site level to regional, National, and European scale.

Regionalisation techniques are necessary in order to provide meaningful information for evaluating environmental consequences of alternative control strategies of emissions of acidifying air pollutants and greenhouse gases. These methods are based on new kinds of mathematical constructs that are no longer calibrated just for individual sites, field plots, or catchments, but can make use of spatial information.

Model complexity is strongly determined by the degree of spatial and temporal resolution of the data available, and appropriate process representation. Simple empirical models need only relatively few input data and they generally do not allow quantification of impacts, since the empirical relationships are derived from present-day conditions. Site specific application of complex process-oriented models using detailed data records which predict observed responses (in particular, those responses determined from large scale ecosystem manipulation experimentation) represent our best formulations of systems functioning.

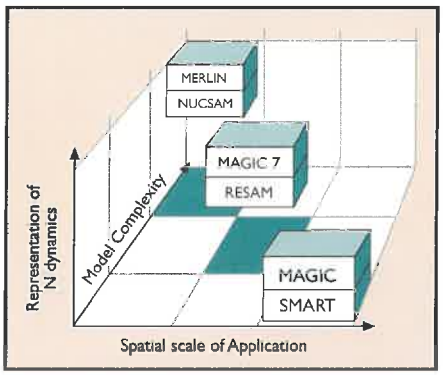


Figure 1. Examples of the different dynamic models used within the DYNAMO project in terms of their complexity, representation of N dynamics, and their spatial scales of application.

Indeed, in an ideal world where data availability and quality were not limiting, the application of highly mechanistic modelling approaches in a regional context would be the ultimate goal. However, there is a trade off to be made between model complexity and data resolution, such that scientifically robust determinations of regional responses can be determined (Figure 1). An example of the integration of spatial information is shown in Figure 2, where an assessment has been undertaken on the impact of using different methods to integrate soil characteristics into a modelling framework.

The project aims to develop and enhance regional modelling approaches so that European scale impacts of acidic deposition, land use (forestry practices) and global change can be determined without compromising process level understanding of ecosystem function. The DYNAMO project contributes to the EU TERI (Terrestrial Ecosystems Research Initiative) framework of the Environment and Climate Programme of the European Commission. The DYNAMO project homepage is located at : www.mluri.sari.ac.uk/dynamo.htm

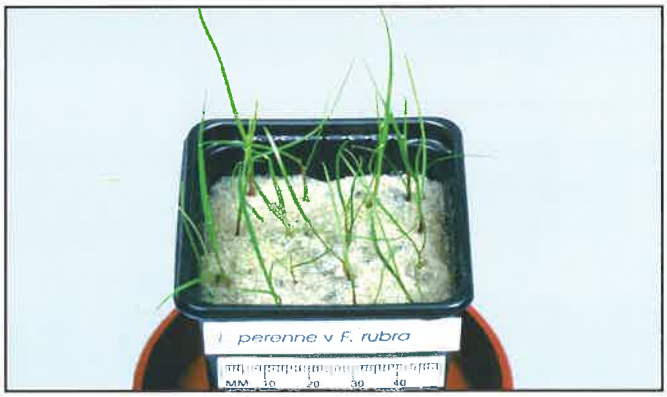
Developing conceptual models of resource acquisition and allocation by plants

Collaborators

INRA Lusignan, France

Macaulay Contact

Pete Millard



Festuca *and* Lolium *plants, growing in a resource competition experiment.*

A conceptual model of resource acquisition and allocation within a generalized, individual plant growing vegetatively in competition with others has been developed in collaboration with INRA (Figure 1). The model considers carbon and nitrogen acquisition, synthesis of assimilates and their transport and partitioning, growth of new tissues, reserve formation and recycling, and losses due to root exudation and respiration. Based on our understanding of the physiology of these processes, the model allows for regulation of these processes by the relative size of the carbon and nitrogen substrate pools in shoots and roots, in relation to meristematic sink strength. Translocation and allocation patterns are represented in the model by the Minchin phloem transport model

We have used the model to consider the impact of competition on resource acquisition and allocation first by considering a plant growing in isolation and in response to manipulation of light, CO_2 and N supplies. Secondly, competitive plants were introduced and the direct effects on plant responses in terms of resource depletion considered separately from indirect effects such as potential changes in the quality of resources available (e.g. light quality or soil N sources). In the past, many studies of plant competition have not established the importance of these indirect effects because they have not established all the processes involved in competition. We can use the model to interpret responses of whole plants to their neighbours in terms of the relative importance of both direct and indirect effects of competition.

The initiative to develop this conceptual model arose out of the Twinning Agreement between the Macaulay and INRA and collaboration in research on plant competition in grazed swards. Complementary research studies exist between the Institute and INRA and the model has been developed to provide a mechanistic framework for designing joint programmes of research to utilise our complementary skills. In this way research results generated from experiments in France can be integrated with those from Scotland, enabling plant competition to be analysed in a wider context than would be possible for either organisation working in isolation.

Further developments

The model will be used increasingly to coordinate research between Macaulay and INRA scientists and be developed further by integrating components of the design into simulation models. This will enable us to coordinate research considering soil-plant-animal interactions and plant ecophysiology at the Institute with complementary research on plant photomorphogenesis and biochemistry within INRA. The model will also provide a framework for designing complementary experiments in France and Scotland and facilitate the exchange of ideas, development of simulation modelling and further collaboration.

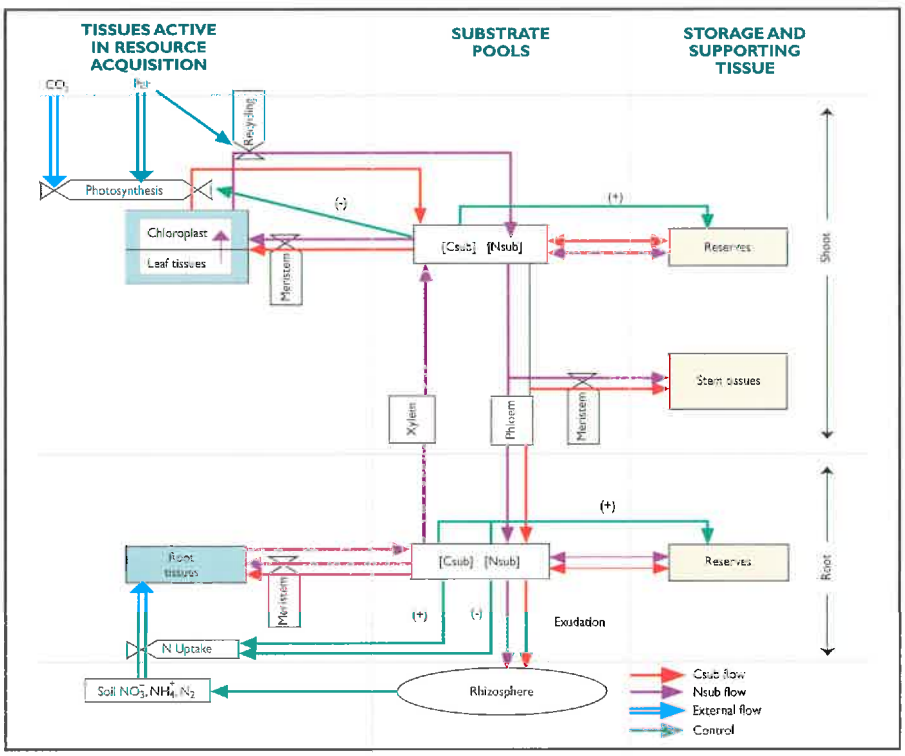


Figure 1. Schematic representation of C and N fluxes within a vegetative plant growing in isolation.

Effects of mineral-humic interactions in relation to modelling metal retention by soils

Collaborators

Department of Environmental Science, Sub-department of Soil Science and Plant Nutrition, Wageningen Agricultural University, The Netherlands

Macaulay Contact

David Lumsdon

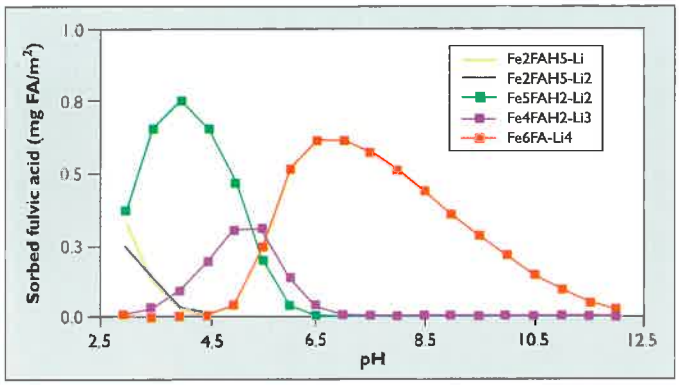


Figure 1. The contribution to the total adsorption of the four surface species used to describe the fulvic acid binding by geothite for the system containing a fulvic acid concentration of 62.5 mg/L and a background electrolyte concentration of 0.1 M.

The application of surface complexation models to predict the metal binding behaviour of geocolloids (heterogeneous geological materials) is less well advanced than the use of these models to describe metal binding by pure mineral and humic particles. A contributory factor to this is the presence of adsorbed humic substances associated with the mineral surfaces found in geocolloids. Therefore an important advance in the surface complexation modelling concept is the development of models to account for the binding of humic substances on mineral surfaces.

In collaboration with soil scientists at the University of Wageningen a surface complexation model has been developed that describes the binding of fulvic acid by the Fe (hydr)oxide mineral goethite. The development of such a model requires several essential components. These include:

- A source of purified and well characterized fulvic acid
- A model to describe the chemistry of the goethite surface
- Experimental data for the binding of fulvic acid by goethite
- A computational modelling framework to allow the implementation of models which cannot be done using existing geochemical models.

All these criteria were met in the in the project. A source of well-purified fulvic acid was available at the Institute, together with an experimental set up to obtain data on the adsorption of fulvic acid by goethite. The adsorption of fulvic acid by goethite was determined in a background electrolyte of $LiClO_4$ as a function of fulvic acid concentration, pH, and ionic strength. For the modelling work Wageningen had experience on the use of models for both humic and mineral surfaces, whilst at the Macaulay the ORCHESTRA modelling framework provided a means to implement new modelling ideas to describe mineral humic interactions.

For the modelling the protonation behaviour of the fulvic acid was described using a discrete functional group approach. The adsorption of the fulvic acid on the goethite was described using the CD-MUSIC model. This model allows the charge of the bound fulvate molecule to be distributed over the region of the goethite solid-solution interface. Simultaneously, the concentration, pH, and salt dependency as well as the basic charging behaviour of the goethite could be described well. The surface species used in the model (Figure 1) indicate that at low pH, inner sphere coordination of carboxylic groups of the fulvate molecule are important, whereas at high pH the outer sphere coordination with reactive groups of the fulvate molecule with high log K_H is important. Ion pair formation between non coordinated reactive groups of the bound fulvate molecule and Li^+ ions becomes more important with increasing pH.

The model has been applied to datasets of the binding of Strichen fulvic acid by goethite. It is shown that the model can describe the basic charging behaviour of both goethite and organic acid, and the concentration, pH and salt dependency of the adsorption satisfactorily (Figure 2).

Further developments will test the usefulness of such a modelling approach to model metal binding by the humic/fulvic/mineral mixtures.

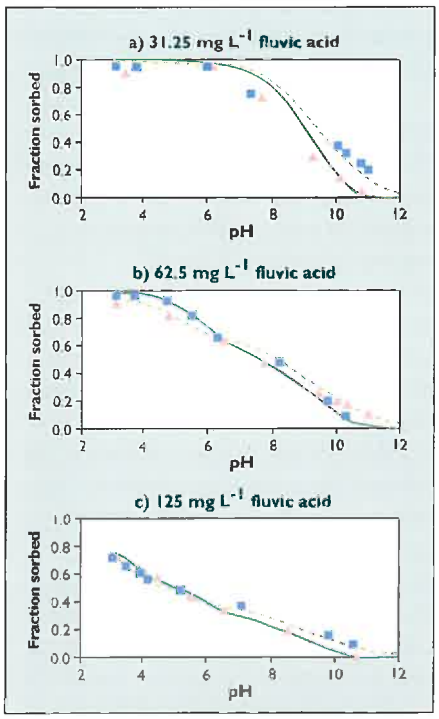


Figure 2. Model predicted adsorption edges for Strichen fulvic acid by geothite. Triangles show experimental data at 0.01 M ionic strength (model calculated, dashed line) and squares, data at 0.1 M ionic strength (model calculated, solid line).

Impacts of privatisation on range and livestock management in semi-arid Central Asia

Collaborators

Overseas Development Institute, London
Institute of Pasture and Fodder, Kazakstan
Institute of Sheep Breeding, Kazakstan
Institute of Animal and Veterinary Husbandry, Turkmenistan
National Institute of Statistics and Forecasting, Turkmenistan
Natural Resources Ecology Laboratory, Colorado State University, USA

Macaulay Contact

Iain Wright

A Kazak shepherd tends his flock on the steppe in winter.

The purpose of this project, funded by the Department for International Development, is to explore policy options for improving management of livestock and rangelands in Kazakstan and Turkmenistan, undergoing market and land reforms at different paces. Macaulay staff form part of a team of social and biological scientists studying the effect of policy changes on land use, land tenure and household economies.

Part of the Macaulay contribution to the project is to explore the impact of privatisation on livestock nutrition and productivity. This report concentrates on some of the findings in Kazakstan.

In Kazakstan most co-operatives (former collective and state farms) and private farmers cannot now afford to follow the traditional four-season migratory system of sheep management nor to obtain sufficient winter feed of good quality. Small-scale private farmers with less than about one hundred sheep, lack the resources (e.g. family labour, transport) to move animals the long distance between the different pastures. Co-operatives have reduced seasonal livestock movement to two or at most three ecological zones, again due to costs. The large decrease in sheep numbers has meant that there is now excess pasture in all zones, and many sheep now spend the whole year within 10 km of the home village or private farm. However, they need to be supplied with winter fodder since the vegetation ceases to grow in autumn and is often covered in snow from December to March.

Semi-structured interviews were conducted with a number of flock owners. Information was collected on the structure and productivity of the flocks and their nutritional management.

In summer all of the sheep were kept within a few kilometres of the village or barn. All flocks were kept indoors in winter although in some cases the sheep grazed pasture during the day. All sheep were fed hay in winter, cut in June, July and August from either natural or sown pasture, mainly *Agropyron* spp which had been sown in the past as an improved pasture species. Some flocks were fed concentrate, usually 200-500g barley, in winter.

Flocks which are fed concentrates in winter achieve higher levels of animal performance (Figure 1). The better performing flocks also tended to be the larger flocks. The mean flock size for flocks fed and not fed concentrates were 148 and 18. Owners of small flocks lack the resources to be able to acquire concentrate feed and good quality hay. The numbers of sheep in these small flocks were decreasing because the family needed to slaughter sheep for consumption, barter sheep for household inputs and therefore could not produce sufficient replacements to maintain the flock size. The larger flocks tended to be increasing in size since there were sufficient lambs produced as breeding replacements even after slaughter for consumption and selling or barter.

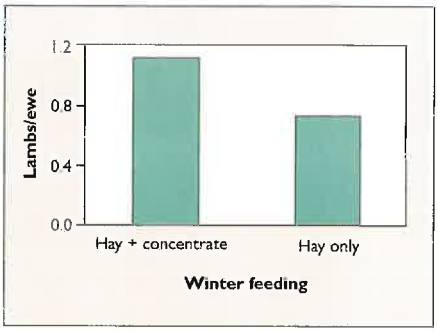


Figure 1. Winter feeding and lambs reared per ewe.

These preliminary data suggest that under a new, sedentary form of sheep husbandry, the level of winter feeding is a key determinant of sheep productivity. Flock owners suggested that level of nutrition in summer was probably adequate because of the massive destocking that has occurred in Kazakstan in the last 4 years, and the consequent increase in the supply of herbage available for grazing around the villages. Data on plant biomass collected by other team members supports the view that there has been an increase in herbage biomass. This may not, however, be the case in the future if sheep numbers increase.

In the future, more detailed studies of a greater number of flocks are planned to confirm these preliminary findings. These studies will also include flocks which have been moved to the traditional mountain pastures in summer.

Role of colloids in the environment and their characterisation by field-flow fractionation

Collaborators

Water Studies Centre, Department of Chemistry, Monash University, Caulfield East, Victoria, Australia

Macaulay Contact

Charlie Shand

Colloids are microscopic particles with sizes in the range 1 to 0.01 μm. Because of their small size they tend not to settle out of suspensions, being influenced by Brownian motion and minor currents in the bulk of the solution. Colloids play an important role in the transfer of nutrients and pollutants in the environment over short and long distances. For example, colloids can transport nutrients such as phosphate through channels in soil to deeper horizons, as well as over much longer distances in surface waters. For chemical species strongly bound to soil, colloids can be the main vehicle for their transport. A knowledge of the physical and chemical composition of environmental colloids involved in nutrient and pollutant transport is important if the relevant processes are to be understood and accurately modelled.

Field-flow fractionation represents a family of techniques for the separation of particles, colloids and large molecules depending on a specific property. Sedimentation field-flow fractionation (sed-FFF) methods offers a means to fractionate colloids, with high resolution. In the normal mode of operation, separations are based on the buoyant mass and diffusion coefficients of the colloids, and on the differential parabolic flow of liquid in the thin channel of the sed-FFF separator (Figure 1). Monash University is a lead centre for such work, being equipped with state-of-the-art FFF devices and detectors such as a high resolution, inductively coupled, mass spectrometer (HR-ICP-MS). With a suitable interface the eluent from FFF devices can be analysed on-line by HR-ICP-MS, providing continuous information about elemental composition of colloids and their corresponding size/mass. Other variants of the FFF method include those based on charge (electrical-FFF), particle size (flow-FFF) and thermal diffusion (thermal-FFF).

Figure 1. Field-flow fractionation channel wrapped inside centrifuge rotor.

To gain knowledge of the FFF methods and other procedures related to the characterisation of colloids, a 3-month visit, funded by the Institute and The Royal Society, was made to work with Dr R. Beckett and his group at the Water Studies Centre of Monash University in Melbourne, Australia. Experimental parameters were developed to allow sed-FFF separations of colloids derived from soils in Scotland. These soils had received sewage sludge contaminated with various heavy metals some years before and it was of interest to determine the distribution and availability of the heavy metals in different sized colloidal fractions. The size distribution of particles were determined by sed-FFF and a preliminary study was made of the elemental composition of the samples by graphite furnace atomic absorption spectroscopy on samples digested with aqua regia. This paved the way for experiments where the FFF device was connected on-line to the HR-ICP-MS.

Samples of the colloids, before and after extraction with solutions such as dilute acetic acid (which is often used to determine metal bioavailability in acid soils) were analysed on-line and the distribution of elements determined and related to particle sizes. This work was carried out in collaboration with a research student. Although the amount of sample which can be loaded onto the FFF channel is small, discrete fractions of colloids eluting from sedimention-FFF can be dried and analysed by electron microscopy to determine their shape and by X-ray diffraction to determine mineralogy.

SPLITT is a separation technique closely related to sed-FFF and allows "splitting" of particles in suspension into groups of sizes (typical range 25 to 2 μm) on a continuous basis using a flat, thin channel (Figure 2) and differential migration under gravitational force. The technique has application for preliminary separation of particles for sed-FFF.

Figure 2. SPLITT thin channel inside clear plastic block.

The Macaulay is equipped with sed-FFF and SPLITT devices.

Refining the management of fruit orchards

Collaborators

Pacific Agri-Food Research Centre, Summerland, British Columbia, Canada

Macaulay Contact

Pete Millard

An experimental orchard in the Okanagan Valley, British Columbia.

Orchard management in British Columbia is utilising irrigation coupled with fertilisation, and the planting of a high density of trees growing on dwarf rootstocks (see photo). Such intensive systems offer the scope for developing more sustainable management protocols through determining the impacts of both fertilisation and irrigation on fruit crops. Using our knowledge of the processes of internal cycling of nitrogen in deciduous trees, through storage and remobilisation, we have collaborated with Agriculture and Agri-Food Canada to help refine apple orchard management procedures. In doing so we have been able to apply an understanding of tree physiology gained from experiments with sapling trees grown in controlled environments to 'scale up' to more mature trees growing in soil.

This collaboration is allowing us access to well maintained and instrumented experimental orchards, where we can apply isotope techniques with a precision usually only found in pot experiments.

The timing of fertiliser application on tree development and growth has been studied. Because the majority of nitrogen used for tree growth each year can be remobilised from storage, the requirements for fertiliser application have to be considered in relation to tree development, and not just growth that year. An adequate balance between fruit production and vegetative growth and a high fruit quality is also necessary. Using novel ^{15}N labelling techniques we have shown that the growth of spur leaves and flowers in the spring relied almost entirely on N remobilisation, whereas the shoot leaves which form the new vegetative growth derived only half their nitrogen from remobilisation. This finding explained why fertilisation of fruit trees often leads to yield responses the following year, because spur leaves provide much of the carbon used for fruit growth. The results also demonstrated that applying fertiliser nitrogen to the trees during the first three weeks of their growth was wasteful because the roots did not take any nitrogen up, despite there being a plentiful supply.

The potential for further manipulating fruit tree development and growth through the timing of N supply is being investigated. Orchard-scale experiments are investigating the impact of supplying nitrogen fertiliser during discrete, short pulses at key stages of the annual growth cycle of the trees. These treatments include supplying N during the period of fruit development in the spring and later on in the year after harvest to try and increase the amount of N allocated to storage for growth the following year. Interactions between fertilisation and irrigation are also being studied.

Future developments

Further developments are planned to examine the impact of tree nitrogen status on growth and development leading to fruit yield and quality. In particular, we aim to study the interactions between tree N status and storage capacity on the one hand, and the formation of both vegetative and flowering buds as a developing sink strength on the other.

Developing a conceptual model of these interactions will allow us to design further experiments to consider the timing of N applications in relation to both other management inputs (such as bud thinning) and the stage of tree development. The ultimate aim will be to enhance the sustainability of orchard management while also enchancing the quality of the fruit. Building on the collaboration will involve both linking the agronomic and molecular aspects of the research programme in Canada with our tree physiology studies at the Institute. In this way it is hoped to provide a route for technology transfer from our programme on tree ecophysiology to orchard managers, while continuing to allow us to 'scale up' our understanding of storage and remobilisation by working opportunistically on trees growing in intensively managed field experiments.

Modelling the role of stores and reserves in grassland plants

Collaborators

Institute of Low Temperature Science, University of Hokkaido, Japan.

Macaulay Contacts

Colin Birch and Barry Thornton

A densely forested landscape including the volcano Ezo-Fuji, typical of Hokkaido, northern Japan.

Hokkaido's climate and flora have similarities with those of Scotland, but Hokkaido has a relatively short history of human impact and rich volcanic soil, so that its unenclosed land is predominantly forest. The Japanese flora is very diverse and influenced by habitats and factors unfamiliar in Britain, such as volcanoes and prolonged, deep snow cover. This project provided an exciting opportunity to exchange ideas about grassland ecology, see familiar species from British grasslands in natural habitats (no longer possible in Britain), and study the indigenous grassland vegetation of Japan, which appears to be a neglected resource.

Recent research and modelling at the Institute has emphasized the roles of storage and remobilization of photo-assimilates and nutrients in the recovery of grassland plants from grazing damage. In Japan, Dr Suzuki has been studying the role of storage in perenniality and species coexistence. The Anglo-Japanese collaboration developed ideas about links between allocation, morphology and ecology. Professor Hara and Dr Suzuki are establishing a new molecular biology laboratory to study local and regional genetic variation in plants. Dr Li was conducting experiments using genotypes of *Arabidopsis thaliana* from an international collection to study the interactions between known genetically determined life-history traits, defoliation and competition. This use of selected genotypes was unusual in a study of life history and fitness.

Macaulay staff used a model of grazing impacts to predict the likely results of Dr Li's proposed defoliation treatments.

The complex morphology of grasses makes it difficult to develop and test mathematical or simulation models of grazing impacts on them. Differences between experimental observations and model predictions may result from fundamental flaws in model assumptions, failures of the model to include processes peripheral to the main focus of interest, or merely inaccurate estimation of model parameters.

In contrast to Britain, Japan has a rich flora of spring ephemeral species that are potentially valuable model plants for testing growth models. For example, *Erythronium japonicum* (the Japanese dog-tooth violet) can consist entirely of a bulb in winter and a bulb, roots and a single leaf in spring. Numerous other species have individuals or units that are almost as simple and determinate. However, leaf expansion and growth in these species would need to be substantially self-supporting for these species to provide useful analogues of grass growth. Repeated measurements on plants of several species in the University of Hokkaido's botanic garden and in a local forest allowed identification of the timing of the end of leaf expansion. A small experimental study was also made on the effect of imposing deep shade on the leaf expansion over 48 hours of a population of *E. japonicum* in

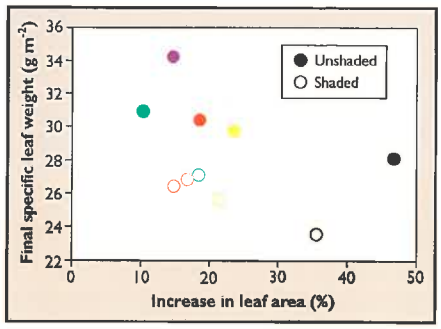


Figure 1. Specific leaf weight and increase in leaf area over 48 hours of Erythronium japonicum *growing at five sites with and without shade.*

an experimental forest at Moshiri in northern Hokkaido (Figure 1). Shading did not affect increases in leaf area, but reduced leaf mass. These results suggest that these species can be useful for future model development in Britain and Japan.

Erythronium japonicum *at the field site.*

Natural resource management within a multispecies system in the mid Zambezi Valley: implications for sustainable development in dry lands areas of Southern Africa

Collaborators

CIRAD – Elevage et Médecine Vétérinaire Tropicaux, France
IICT, Portugal
INDER Direcçao de Planeamento Regional, Mozambique
University of Zimbabwe, Institute of Environmental Studies, Zimbabwe
University of Zambia, Department of Animal Science, Zambia

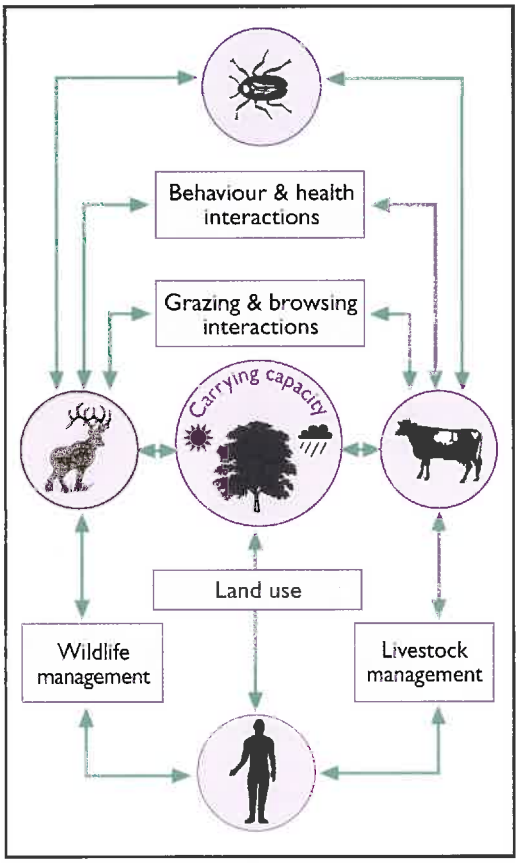
Macaulay Contact

Iain Gordon

Many of the world's poorest countries lie in the arid and semi-arid zone, where the connection between land degradation and resource use, particularly livestock production, is acknowledged to be a major limitation to the sustainable utilisation of these fragile ecosystems. In many regions of Southern Africa pristine dryland habitats, which are rich in biodiversity, are experiencing increased population pressure as a consequence of human immigration due to national population growth and the removal of disease, drought or human conflict. The development of sustainable resource use strategies in these areas requires the development of a predictive understanding of the constraints and opportunities for the development of pristine habitats for multispecies (livestock/wildlife) enterprises.

The primary limitation to the sustainable utilisation of natural resources in the drylands of Africa is an understanding of the biological relationships between climate, soils, plants and animals under socio-economic constraints. Using a multidisciplinary approach (ecologists, agronomists, geographers, economists and sociologists) this project is developing a holistic understanding of the resource use and animal production systems in the mid-Zambezi Valley (ZV; Zambia, Zimbabwe and Mozambique).

This project builds upon socio-economics based projects underway in the Guruve District of Zimbabwe to produce an integrated approach to assessment of the biological processes and functioning within this fragile ecosystem. Existing data is being collated on the biological functioning of semi-arid rangeland systems and on the major socio-economic determinants of natural resource use and management. Where specific information is lacking (Tete region of Mozambique and the Eastern Province of Zambia), field projects have been set up. These data will be incorporated into computer-based biological and socio-economics models. The final model will be coupled to a GIS in order to assess the spatial and temporal consequences of land use policy implementation at a range of scales (temporal 5 – 50 years; spatial 10 – 250 kms).



Implications for sustainable development in dry lands areas of Southern Africa.

The research will be summarised as a set of Decision Support Tools for local decision makers and will be disseminated using the CAMPFIRE programmes in Zimbabwe and Mozambique and the ADMADE programme in Zambia which will be involved in all aspects of the process.

The economic benefits will be the increased, less variable and more sustainable output from pastoral systems in the fragile ecosystems of the mid-Zambezi Valley.

Grazing ecology of the savannas of South Africa

Collaborators

Department of Livestock and Pasture Science, University of Fort Hare, South Africa

Institute of Cell, Animal and Population Biology, University of Edinburgh

Macaulay Contacts

Peter Dennis, Iain Gordon, Alison Hester and Carol Marriott

The aim of the five-year programme initiated in 1997 is to accelerate the development of non-white staff by building up centres of excellence at certain university departments, including the Department of Livestock and Pasture Science at the University of Fort Hare (UFH), South Africa. This is being achieved by providing funds for studentships and the running costs of field experiments combined with exchange visits between UFH and UK Universities and Research Institutes. UFH is located in the Eastern Cape, an area with wide diversity of soil, climate, vegetation and land use. Sustainable livestock production for the improvement of living standards is a local and national priority. The scientific objectives of the project are to improve the understanding of plant/animal interactions, and to establish and test basic principles for the optimum utilisation of vegetation resources. The collaborative projects focus on diet selection by goats, impacts of fire and grazing on vegetation dynamics and the effects of grazing management on system function in communally- and commercially-grazed rangelands. The involvement of Macaulay scientists gives them the opportunity to apply their scientific expertise to a novel ecosystem.

The False Thornveld is a widespread and economically important vegetation type in the Eastern Cape. The structure and composition of this vegetation is important both in terms of feed and conservation value. However much controversy exists about its past and present status and the impacts of different herbivores. Collaborative research projects have been initiated to measure long term changes in structural heterogeneity under different management regimes, using a combined approach of historical air photo interpretation and field measurement. A better understanding of herbivore impacts will guide the design of appropriate management regimes.

Themeda triandra is the most preferred and most productive commonly occurring grass species in veldt grassland, but it can be prone to local extinction in many communal grazing areas that are subject to drought and severe grazing. As well as differences in seed recruitment, differences in plant competition between established plants may be involved. Comparative studies of the dynamics of leaf growth and plant structure of *Themeda* with other grass species under a range of grazing intensities are in progress. A better understanding of these dynamics will improve the ability to assess veldt vigour.

Insect species contribute to all three components of biodiversity: ecosystem function, utility to humans and natural heritage value. Grazing and burning frequency may interact with insect populations through changes in habitat structure i.e. in the proportion of shrub to grassland in the vegetation mosaic and the height profile of the grassland element. The distribution and abundance of various taxa related to the three categories of biodiversity is currently being studied in structurally diverse grassland communities, created by different grazing, browsing and burning managements. This research will enhance our understanding of the relationship between insect assemblages and habitat spatial heterogeneity.

Animal production from semi-arid rangelands depends on the ability of the animal to ingest sufficient nutrients for maintenance and production. This is regulated by short-term decisions by the animal about which plants to select and how much to consume from the plant. Goats are common domestic browsers in African savannas and their nutrition depends on utilisation of woody plant species. Little is known about the intake rates of different goat breeds commonly found in the Eastern Cape. We are testing whether breeds of goats differ in their intake rate of browse species and whether this affects their diet choice in the field. This work will link with the studies on vegetation dynamics and the implications of management practices for biodiversity in order to develop an understanding of the ecology of semi-arid grazing systems.

Goats grazing thornveld savanna.

Rangeland management and livestock feeding strategies in Pakistan's Karakoram region

Collaborators

Consejo Superior de Investigaciones Cientificas
Department of Geography, University of Bonn
Aga Khan Rural Support Programme (AKRSP)
Pakistan Forest Institute
Pakistan Agricultural Research Council
International Centre for Integrated Mountain Development

Macaulay Contact

Alan Duncan

High altitude pasture in the Hunza valley.

Around 1 million people live in the remote Northern Areas of Pakistan and most of them are engaged in subsistence agriculture. The region is semi-arid, lying as it does, in the Himalayan rain-shadow. In order to grow arable crops and livestock fodder, farmers divert water from glacial rivers onto their fields through a complex system of irrigation channels. Cultivable land is a scarce resource and, to avoid crop damage, livestock are dispatched to high altitude, alpine-style pastures for the summer months.

This practice of "transhumance" is typical of many mountain agricultural systems. The Northern Areas of Pakistan have undergone dramatic change over the last 3 decades as a result of two factors. First, the construction of the Karakoram Highway along the ancient Silk Route has resulted in a marked increase in the movement of goods and labour between the Northern Areas and the rest of Pakistan. Secondly, community-based development activity initiated by the Aga Khan Rural Support Programme (AKRSP) has had a significant impact on local livelihoods.

Against this backdrop of change, we have embarked on a 3.5 year research project which started in December 1998, investigating ways of improving livestock production, while taking account of the impact of livestock grazing on the fragile ecological resource represented by the high altitude pastures. The project will examine current constraints to livestock production by measuring seasonal changes in feed availability and livestock productivity. It may then be possible to test ways of relieving these constraints in order to improve production in a sustainable fashion. We are particularly interested in whether changes in transhumance practices resulting from economic development are causing degradation of mountain pastures.

The farming system in Pakistan's Northern Areas is highly integrated in nature with a high degree of inter-dependence between arable cropping, forestry, fruit growing and livestock production. Furthermore, there is a close inter-relationship between livestock production within the village precincts and on the high pastures. The project therefore provides an exciting opportunity to bring established Macaulay expertise in systems research and apply it in wholly new circumstances.

In practical terms the research will involve a combination of questionnaires and actual field measurements of livestock productivity and pasture utilisation. This will be coupled with a study of farm household economics to allow appropriate interpretation of recent and predicted change in the livestock sector, within the wider socio-economic framework. The research will be conducted in 6 villages located across the full range of agro-ecological zones found in the Northern Areas. On the livestock side, seasonal measurements of animal production will be made in a sample of core households selected for intensive study. In addition seasonal utilisation of animal feed resources will be measured. These measurements will be combined to identify critical feed resource deficits during the annual livestock management cycle. For the pasture ecology component of the project, exclosure plots will be employed to estimate seasonal pasture productivity across the extreme altitudinal gradient found in the study region. In addition, the spatial utilisation of high pastures by different livestock species will be quantified. Finally, for the socio-economic component of the project, participatory rural appraisal techniques will be used to place the biological findings within the wider context of the social and economic infrastructure of the study region.

The project has a strong focus on international collaboration, providing ourselves and our European colleagues with the opportunity to work with a leading NGO in the area of participatory rural development and research (AKRSP). The project also aims to build capacity among developing world scientists with the training of two Pakistani PhD students and close collaboration with national Pakistani research institutions.

Dissemination of results to end-users ranging from development NGO's to small-holder farmers will be facilitated by close collaboration with AKRSP. Much of the research will be conducted within the framework of current AKRSP activities. With the strong emphasis on "on-farm research", innovations will be communicated directly to farmers.

Creating sustainable solutions for our land and people

Fertilising the Atmosphere with Fixed Nitrogen, the Roles of Fossil Fuel Combustion and Agriculture

David Fowler
Institute of Terrestrial Ecology, Edinburgh Research Station
The 22nd Macaulay Lecture, 14th May 1998

Introduction

This paper is focussed on the atmospheric nitrogen cycle and the effects of anthropogenic emissions on atmospheric processes and their consequences for terrestrial ecosystems. For simplicity fluxes of molecular nitrogen are ignored so that N_2 fluxes by de-nitrification or those fluxes into the soil are omitted. The paper is centred on the fate and effects of gaseous nitrogen compounds including ammonia (NH_3), nitric oxide (NO) and nitrogen dioxide (NO_2) and the extent to which anthropogenic emissions of these gases have modified the atmospheric nitrogen cycle. Following the discussion of a very simplified global atmospheric cycle of reactive nitrogen, the issues at regional and local scales are discussed and the characteristics of oxidised and reduced nitrogen species are contrasted.

The global atmospheric cycle of fixed nitrogen

The oxidised emissions of nitrogen from fossil fuel combustion at 20 Tg is quite well known. The figures in black (Figure 1) are the totals from each of the sources and in red are the anthropogenic fractions.

The biomass burning at 12 Tg (or megatonnes) is less well known but the largest fraction of the biomass burning is again believed to be anthropogenic. Ammonia emissions total 46 Tg. It is necessary to go back in the international literature only two or three years to find that ammonia emissions globally were believed to be between 120 and 150 Tg.

It is only with these new, rather detailed global inventories that the NH_3 emission is believed to be rather closer to 50 Tg. The 10 Tg from soils is emission of nitric oxide (NO) of which only a small fraction is believed to be anthropogenic and there is considerable uncertainty over the fraction of soil NO emissions which represent input the atmosphere. Surprisingly when it comes to N_2O, total emission (15 Tg N_2O-N) is quite well established. We know exactly how much N_2O there is in the atmosphere. We know how it is removed in the stratosphere, so the total we know rather well. Whether it is 13 Tg from land and 2 Tg from the oceans we are less sure. If the total of 15 Tg is compared with the anthropogenic component (2 plus 7 Tg) in red, it is clear that a substantial modification of this important greenhouse gas budget has been made. The chronology of N_2O concentrations in the atmosphere is well defined by the analysis of gas bubbles in ice cores from which the N_2O concentration in the atmosphere throughout the last 1000 years. The difficulty with N_2O is knowing where the sources are and the relative importance of each.

To put into perspective the global natural emissions of oxidised and reduced nitrogen, it is clear that more than two-thirds of the 55 Tg of NO_x (which is almost all from terrestrial emissions), are anthropogenic. Approximately 60% of emissions of reduced nitrogen are also anthropogenic, so the simple fact is that man's activities currently dominate the atmospheric nitrogen cycle.

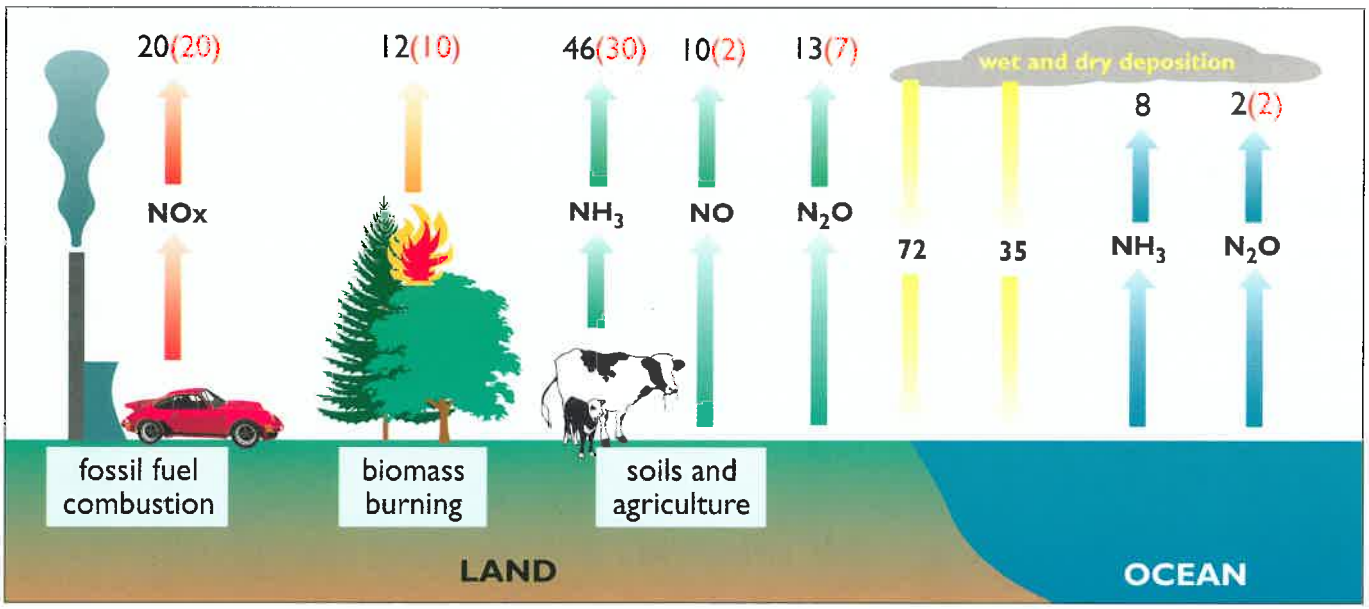


Figure 1. The Global Atmosphere-Surface Exchange of Fixed N, Tg N y^{-1}.

Oxidised Nitrogen

The first impression of the global emissions of NO_x is of an almost exponential increase (Figure 2) and although increases in the last decade or so have been very much smaller (and in Europe have begun to decline), the growing economies, (especially in southeast Asia), are likely to overwhelm any reductions in NO_x emissions that are made in Europe and North America.

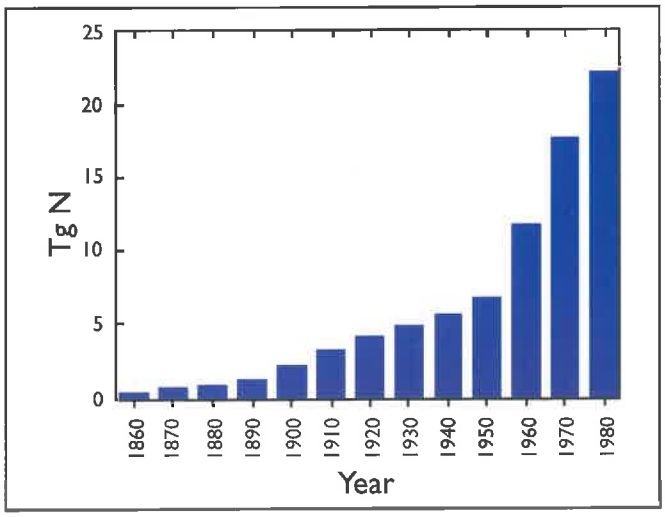


Figure 2. Global emissions of NOx (Tg-N) from combustion.

Over the last 15-20 years there have been very substantial increases in oxidised nitrogen emissions. The other emission of course is that from soils from the microbial oxidation of soil ammonium releasing nitric oxide. The size of the arrows on the diagram (Figure 3) are intended to indicate the primary route, so we believe most of the nitric oxide emitted from soils arises through nitrification. Likewise most of the N_2O is generally considered to come from de-nitrification. The NO fluxes are bi-directional with the two arrows above, whereas N_2O is essentially an emission flux. The major variables which regulate NO emission are soil temperature, soil water and the substrate supply (soil nitrogen). Once emitted from the soil the nitric oxide reacts very readily with ozone to form NO_2 and, the NO_2 is exchanged between the plants and the atmosphere

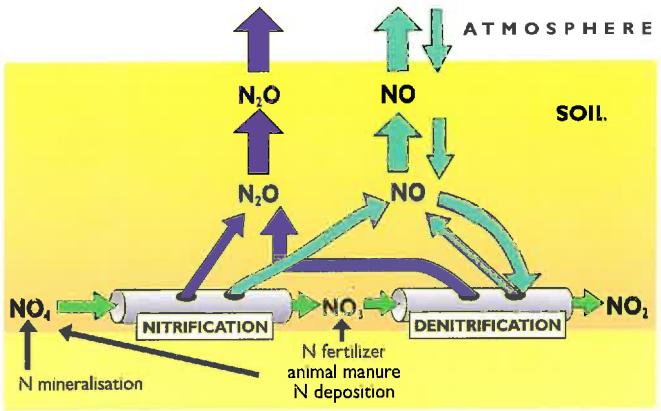


Figure 3. Illustration of nitrification and denitrification processes in soil.

depending on the atmospheric concentration. Once emitted the NO reacts very readily with ozone to form NO_2 and in warm, sunny conditions the NO_2 is photolysed by sunlight back to NO, releasing oxygen and an oxygen atom, and the oxygen atom reforms ozone so that the three compounds NO_2, ozone and NO form a photostationary equilibrium. Some of that NO_2 may react directly with the OH radical to form nitric acid which is very reactive and deposits to the ground or forms aerosols but the basic chemistry of ozone, NO and NO_2 (Figures 4 and 5) really is central to formation of photochemical smog. A small concentration of NO_2 in the atmosphere (>50ppt) leads to net O_3 production as shown in Figure 5.

At the turn of the century, south coast resorts in England measured ozone and advertised the ozone concentrations in 'The Times', as ozone was seen as an indicator of clean air. In fact it was simply a contrast against the very polluted air in the centre of London or other large urban areas. Ozone is not beneficial for human health but those ozone values reported (15-20 parts per billion in the summer) were about half the concentration we see today. At

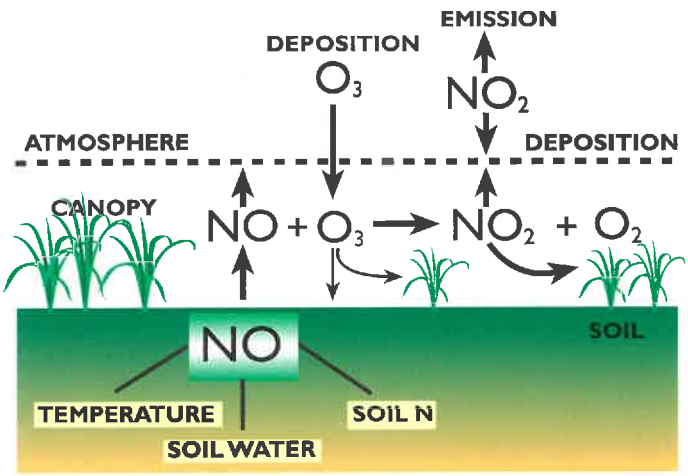


Figure 4. Emission/deposition pathways of NO.

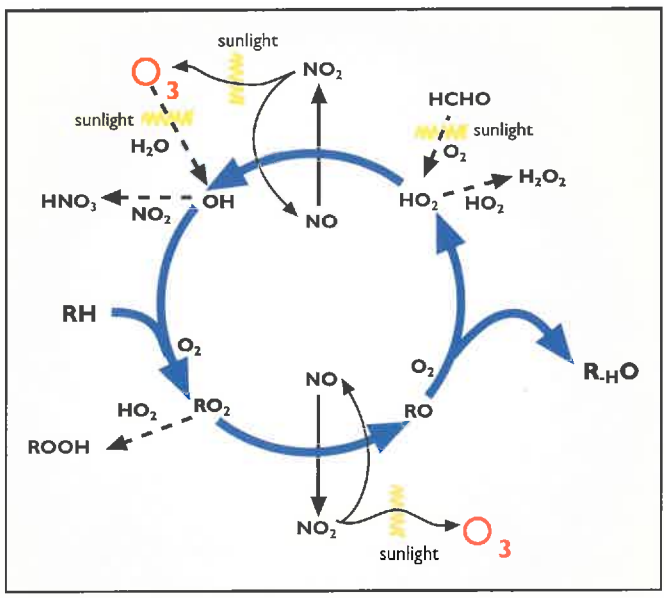


Figure 5. Schematic of the oxidation of a hydrocarbon leading to ozone production in a polluted atmosphere (NO_2 > 20 ppt).

concentrations in excess of 80ppb parts per billion, which is not much above the background, you can detect effects on lung function of children, which are exceeded throughout the UK during the average summer.

The UK atmospheric budget of fixed nitrogen

The atmospheric budget for the UK shows emissions of approximately 780 kT-NO_x (three quarters of a million tonnes), of which dry deposition is small – 40 kT N, and wet deposition from rain and clouds is rather more than double that at 110 kT N. However, the major feature is that what is left of the 780 emitted, – 690 is advected out of the country by the wind. Because of the position of the UK on the western edge of Europe we receive little nitrogen from Europe. So the UK is a rather large source of NO_x on a European scale. The UK footprint (Figure 6) represents the fraction of the landscape on which 60% of the emissions in the UK is deposited. So taking our emissions of 780 kT, 60% of that is deposited in this ellipse which has a long axis of about 2,000 km.

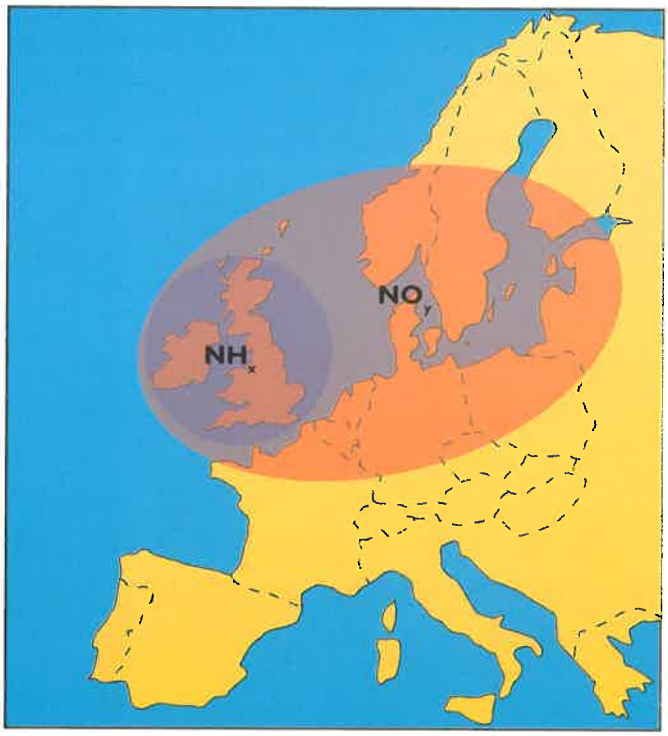


Figure 6 The UK footprint of NOx and NOy emissions.

Now turning to ammonia which is emitted from plants and from animals. The emission from plants depends on the apoplast concentrations of NH_4^+. The ammonium concentrations here produce an ammonia concentration in equilibrium. Taking the existing knowledge and using a model to simulate ammonia concentrations and deposition across the countryside the UK emits 290 kT – N . The measurement and modelling shows that about 110 kT of the emission is dry deposited and 120 from the measurement network are wet deposited. So that with a total deposition of 230, little is left as the exported fraction (Figure 7). A comparison of the oxidised and reduced nitrogen deposition budgets for the UK shows that the bulk of oxidised nitrogen emissions are exported. Furthermore, it shows that the bulk of the deposited nitrogen is in the reduced form. If we examine the total deposition of reduced and oxidised nitrogen and average it across the landscape, it is about 15-20 kg N ha^{-1} over the 24 million hectares of the UK, and ranges from about 3 N ha^{-1} up to about 60 N ha^{-1}, (considering the average deposition over a 20 km x 20 km grid squares (Figure 8).

These values may be contrasted with the early measurements from Rothamsted in southern England where in the latter part of the last century the N deposition ranged from 5 kg N ha^{-1} to 8 kg N ha^{-1}, and is currently (1990) in the range 35 to 50 kg N ha^{-1}. The total deposition of nitrogen in the UK, 380 kT, is partitioned rather differently for forests, moorland, grasses and arable and the average deposition on all the forest is about 30 N ha^{-1}

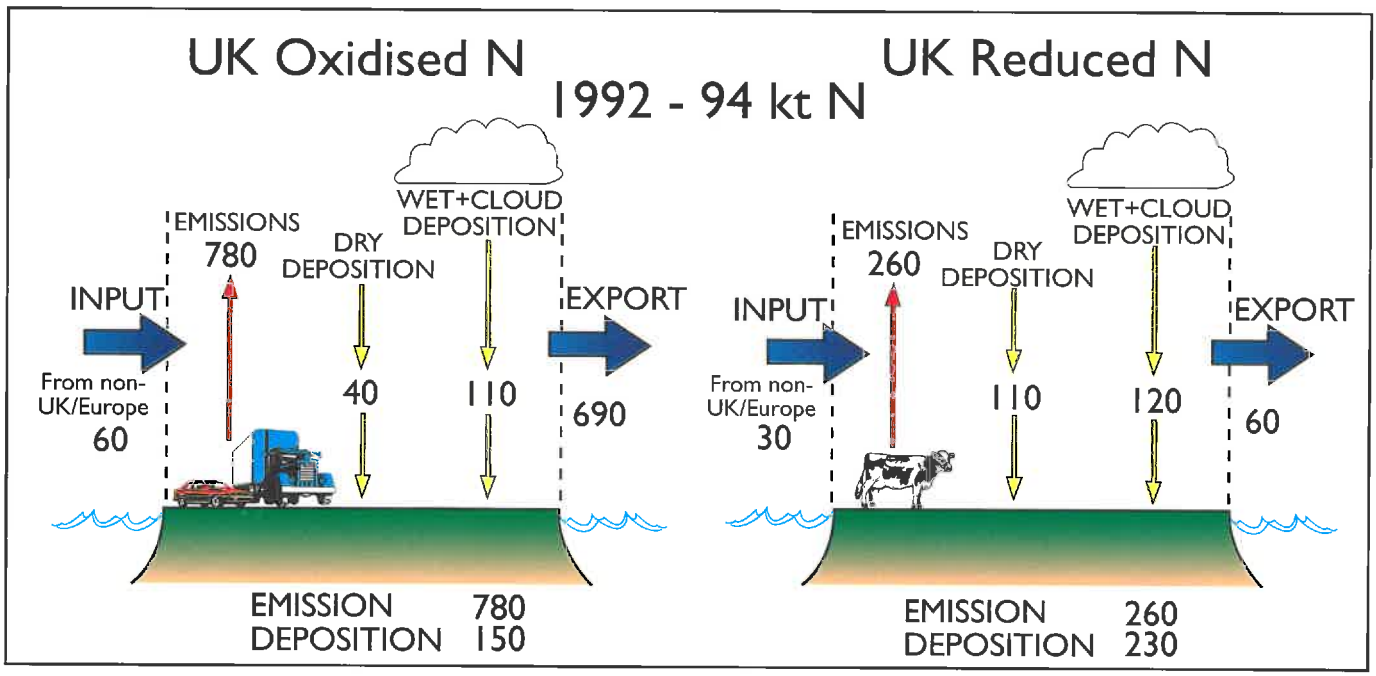


Figure 7 1992-94 Budgets for oxidised and reduced nitrogen in the UK.

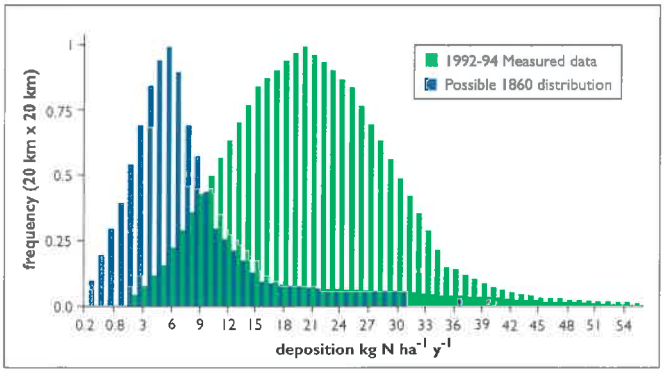


Figure 8. Measured and estimated distribution of atmospheric nitrogen in each 20 km x 10 km grid square covering the UK.

(Figure 9). Whereas the other land uses receive 15 or 16 N ha^{-1} and that is an average input for 400 km^2, there will of course be larger values at smaller scales. The concentrations of ammonia close to the farm reach 30 µg m^{-3} and in just the first few tens of metres down-wind of the source nitrogen deposition reaches about 50 N ha^{-1} $year^{-1}$ but at a distance of quarter of a kilometre from the farm concentrations are down to background values, so it is a very local problem and in terms of deposited nitrogen you would not detect the presence of individual poultry unit except within half a kilometre of the source; on a calm winter day the odour may be detected at rather longer range!

To illustrate the small scale variability in N deposition Figure 10 shows measurements of the emission, concentration and deposition of reduced nitrogen within 1 km of a poultry farm in the Scottish Borders. Some of the N emitted from the farm is captured by the shelter belt woodland although in the nearest quarter kilometre it amounts to only 4% of annual emissions. Woodland does have an important effect of increasing the dispersion of the ammonia close to the source. The same locally very large deposition of Nitrogen also occurs in cities, except that the high NO and NO_2 concentration which deposits large amounts of N to the parkland in the centre of the cities is a problem of oxidised rather than reduced N. However, the literature is very unclear as to how much N is deposited in cities and it is a rather important research question.

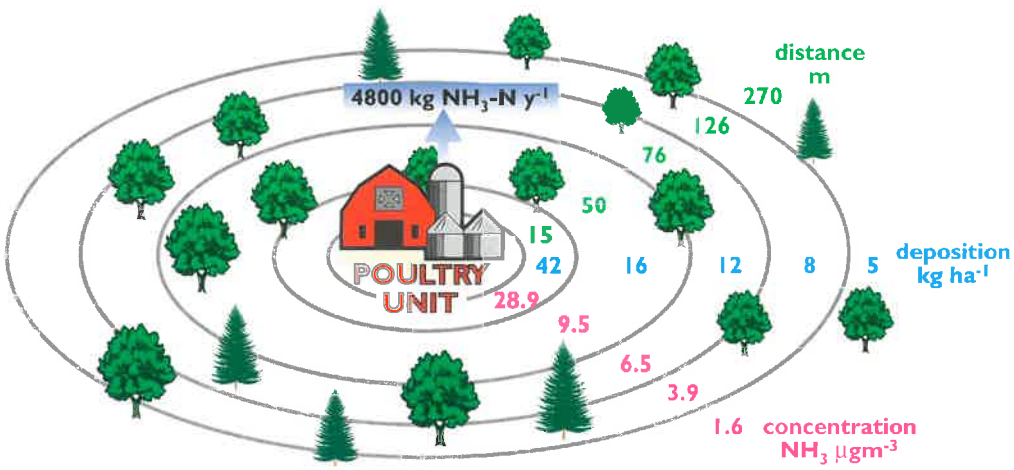
Conclusions

To conclude, it is clear that anthropogenic emissions now dominate on a global scale the emissions of fixed N to the atmosphere and it is a roughly even balance between the oxidised NO and NO_2 and the reduced ammonia emission. Environmental problems associated with the N emitted show that NO_x

	Total Deposition: 380 kt N			
	Oxidised 230		Reduced 150	
	Forest	Moorland	Grassland	Arable
Total N Deposition kt	68	124	98	124
Area, x 106ha	2	7.9	6.5	7.9
Mean Deposition kg N ha-1	33	16	15	16
% Reduced N	78%	65%	56%	65%

Figure 9. Partitioning of N deposition to the UK

and ammonia play major roles in most of the current regional or global scale atmospheric pollution problems including global warming and photochemical oxidant smogs that are no longer unique to Europe or Los Angeles but are common in all of the major cities of the world. In Europe the contribution of N to the acid deposition now exceeds sulphur in many areas. Atmospheric ammonia has a substantially shorter transport distance and lifetime in the atmosphere than the oxidised N and this means of course that for the UK most of our problems with Nitrogen deposition are those of reduced rather than oxidised N. The terrestrial effects of deposited N in the UK are dominated by ammonia and ammonium deposition. The intensive work of the last two decades on reduced and oxidised N has revealed some of the major problems that exist and shows the need for substantial improvements in understanding the fate of reduced nitrogen, to underpin the development of any control strategies.



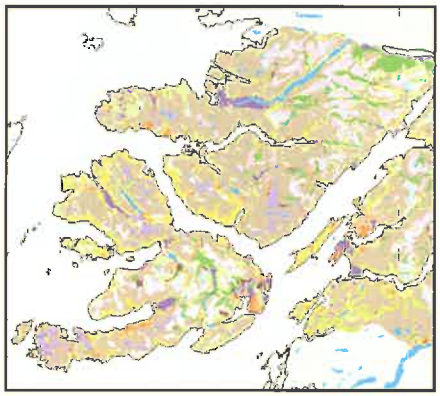
sum of deposition within 270 m of farm in woodland is: 155 kg N y^{-1} (4% of emissions)

Figure 10. Emission, deposition and concentrations of ammonia within 500 m of a chicken farm.

Macaulay Research & Consultancy Services

Macaulay Research and Consultancy Services was established in 1994 as the commercial arm of the Institute. MRCS has full access to the staff and facilities of the parent organisation and so is able to provide a wide range of specialist research and consultancy services for the land manager.

The symbiotic relationship between the Institute and MRCS continues to be a major competitive strength for the business and in 1999 we look forward to new consultancy opportunities arising from specialist decision-support tools being developed for the land manager.



Site Capability for Native Woodland in the area around Mull and Ardnamurchan.

Soils and water environmental management

- Water quality and catchment management
- Impacts of air pollution on terrestrial and aquatic ecosystems
- Management and utilisation of organic wastes on land
- Investigation and assessment of stability of contaminated sites

Sustainable rural land use

- Development and management of marginal lands
- Development of forestry, farm woodlands and agroforestry systems
- Land capability assessments
- Strategic land use planning
- Environmental and socio-economic impacts of land use

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Natural heritage management

- Soil, peat and vegetation surveys and habitat assessments
- Rangeland management

Data services and products

- Data leasing from Macaulays unique environmental datasets
- Data capture and GIS services
- Tailor-made environmental data products

Analytical services

- Wide range of analyses for environmental and rural industry markets
- Characterisation of inorganic and organic compounds for oil related sectors
- Method development and trouble shooting
- Competitive prices
- Fast turn around time

For further information on MRCS services please contact the External Affairs Officer, Dr Sue Bird.

Specialist Services for the Land Manager

MRCS

BioSS - 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. It has staff based at units in Aberdeen (at both the Macaulay Institute and Rowett Research Institute), Dundee (at Scottish Crops Research Institute), and Ayr (Hannah Research Institute) as well as at the BioSS Headquarters in Edinburgh.

Long-term collaborations between BioSS and staff in the Ecology and Animal Science group at the Macaulay have helped develop a better understanding of the relationship between animal grazing and species composition in mixed grasslands.

During 1998, there have been seven BioSS posts in Aberdeen, four of which were based in the Environmental Modelling Unit at the Macaulay. The primary activities of the Unit are:

- statistical consultancy for Macaulay scientists
- collaborative research with scientists from the Macaulay and elsewhere
- applied statistical research
- related contract work

The consultancy service is operated through an open door policy whereby a member of staff is available each afternoon of the week. Many projects are given statistical guidance from conception to completion, with separate meetings covering the statistical aspects of design, analysis, interpretation and presentation of results. During 1998, BioSS staff have had meetings with a total of 96 scientists, research students and visiting workers.

Collaborative projects leading to joint publications follow naturally from the initial consultancy contacts. During 1998 there were ten publications appearing in refereed journals that had both BioSS and Macaulay co-authors, whilst at the end of the year a further ten submissions were under consideration plus one paper in press. Currently active collaborations include:

- cost-benefit analyses of environmental improvement schemes using the principal-agent model;
- ordered categorical modelling of grazing impacts on semi-natural vegetation;
- estimation of mixing proportions of grass species from the alkane patterns in their roots;
- estimation of changes in land cover from air photographs.

The joint research project between BioSS and Macaulay to develop a decision support system for red deer management came to fruition this year with the launch of HillDeer. The package uses simulated Bayesian inference to integrate prior knowledge about closely studied deer populations with counts and cull data from any Deer Management Group area. Hence management decisions made by Deer Management Groups are based on the best available estimates of their likely consequences.

Each year, BioSS runs a cross-institute training programme which raises the level of statistical awareness and abilities amongst scientists. The programme has a modular structure, and consists of short, computer-based, courses in Statistics and Mathematical Modelling. As a result, the statistical consultants at each site are able to spend a greater proportion of their time on those projects which require the use of advanced statistical methods. During 1998, Macaulay staff attended 13 different BioSS courses and received a total of 48 person-days of training. Additionally, scientists received informal training through discussions with individuals and small groups.

The core funding received by the Unit is enhanced by income raised from external sources. The long-term contract involving BioSS, Macaulay and ITE scientists in monitoring the Scottish Environmentally Sensitive Areas has now completed its fifth year, and the repeat visits to monitoring locations are beginning to allow estimates of change to be made. Another long-standing contract is for BioSS to provide statistical input to projects at ITE Banchory. Successful collaboration within this contract has allowed the application of generalised linear mixed models to relate the over-winter survival rates of Soay sheep on St Kilda to meteorological effects experienced by all individuals in the population.

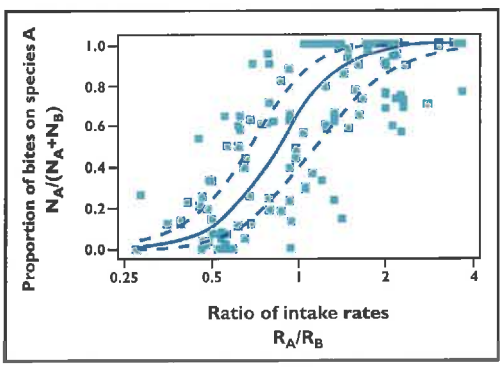

Figure 1. The relationship between selection amongst pairs of feeds and the relative intake rates when animals graze each feed in isolation. Details in Illius et al., 1999, Ecology 80, 1008-1018.

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Lynne Torvell BSc
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Gordon J Baillie HNC
Grant C Davidson BSc
David D Hamilton BSc
Carol E Kyle HNC
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David J Riach HNC
James L Small HNC (S)
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Sheila A Young HNC
Tracy A Brown BSc
Russell J Hooper BSc
Brenda Copland
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Lynn Bryce

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Hilary Redden BSc

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Loraine J F Shellard BSc
Stuart F Wright BSc

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Head of Group
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Inorganic Element Analysis
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Marjory A Wood

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Jennifer J Harthill HNC
Diane Smith BSc

Soil Analyses
I Jason Owen BSc MSc PhD
Kathleen H Davidson

Radiochemistry
Terry Atkinson LRSC (Consultant)

Colorimetric Analyses and Chromatography
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Pat E Moberly BSc
Arlene M Murray HNC
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Gillian Martin
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Allan I A Wilson HNC
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Ruth P Penny
Nessie M Rennie
Meg A Walker
Marjorie C Watt

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Brian N Kemp

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Wilfred F Wallace

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Doris M McCombie
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John W Black Jnr (Grieve)
James Scott (Shepherd)
John W Black Snr
June Scott (Cleaner)

Animal House
Officer-in-Charge
A Robson Fawcett AIMLS

Staff
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A Craig MacEachern

HARTWOOD (H)

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Typist
Catherine Walsh HND

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Jim C MacDonald BSc (Stockworker-Sheep Records)
Robert Armstrong (Stockworker)
Betty Farley (Cleaner)

SOURHOPE (S)

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John L Wallace (Head Shepherd)
Patricia Gentry (Recording Officer)
James C Pringle (Stockman/Tractorman)
T Gavin Rogerson DipFBom (Goats)
Pamela Tapson (Shepherd)
Matthew J Wilson (Shepherd)
Dorothy H Wallace (Cleaner)

ADMINISTRATION GROUP

Acting Institute Secretary
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Julie McKenzie
Fiona J Wilson

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Murray G C Mainland
Christina M R Burness
Catherine B Adams
Janice M Laing
Jacqueline S Wales

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Lucy M Burnett
Iona M Shand
Aileen Stewart
Carol A Smith

Telephonist
Coral A R Bannister

Stores
Lynne Thomson

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Catherine Milne

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Karen J Scott
Graham A Thomson
May L Watson

MACAULAY RESEARCH AND CONSULTANCY SERVICES

Head of Consultancy Division
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Secretary
Nicola G Paterson

Finance Officer
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John S Bell BSc
John Price BSc BAgr PhD
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Ann Malcolm BSc DMS
Margaret M McKeen BSc MSc
David A Tulett BSc MSc Dipl Surv
E Clare Waterhouse BSc

BioSS STAFF BASED AT MLURI

Head of Group
David A Elston BA MS Cstat

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Jacqueline M Potts PhD BSc MSc

Staff who have left BioSS at MLURI since the last Annual Report
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Trevor S Smart BA MSc

HONORARY FELLOWS

G Anderson BSc PhD
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Professor T S West CBE FRS BSc DSc CChem FRSC FRSE
E G Williams BSc PhD
M J Wilson BSc PhD DSc FRSE

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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 Robertson 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 1998

VISITING WORKERS

LAND USE SCIENCE GROUP

Isabel Augenstein, UFZ - Centre for Environmental Research Leipzig-Halle GmbH, Germany.
Lin Zhang Yang, Institute of Soil Science, Chinese Academy of Sciences, P R China.

SOIL SCIENCE GROUP

Yao Huaiying, Zheijang Agricultural University, P R China.
Per Jorgensen, Norwegian Agricultural University, Norway.
Erik Karltun, Swedish University of Agricultural Sciences, Sweden.
Soo Jin Kim, Seoul National University, Korea.
Ingrid Oborn, Swedish University of Agricultural Sciences, Sweden.
Klas Rosen, Swedish University of Agricultural Sciences, Sweden.
Akira Watanabe, Nagoya University, Japan.
Kevin Webb, Aberdeen University, Scotland.
Ye Ying, Zheijang University, P R China.

PLANT SCIENCE GROUP

Gilles Lemaire, INRA, France.
Tytti Sarjala, The Finnish Forest Research Institute, Finland.

ECOLOGY & ANIMAL SCIENCE GROUP

Adriana Di Trana, University of Basilicata, Potenza, Italy.
Stefano Focardi, Istituto Nazionale per la fauna Selvatica, Italy.
Yiannis Hadjigeorgiou, Ministry of Agriculture, Greece.
Sigrid Lammer, University of Bonn, Germany.
Ron Moen, University of Minnesota, United States of America.
Amrish Kumar Tyagi, National Dairy Research Council, India.
Yondon Zagdsuren, Research Institute of Animal Husbandry, Mongolia.

ANALYTICAL GROUP

Jae-Bum Jang, Jeonju University, Korea.

VISITING STUDENTS

LAND USE SCIENCE GROUP

Julia Pecci, Escuela Técnica Superior de Ingenieros Agronomos y de Montes de Cordoba, Spain.
Aurélie Sevet, Institut National Agronomique Paris-Grignon, France.
Sylvia Vignoli, University of Marburg, Germany.

SOIL SCIENCE GROUP

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Sandra Tough, Aberdeen University, Scotland.
Jacqueline van der Houwen, Wageningen Agricultural University, The Netherlands.
Kevin Webb, Aberdeen University, Scotland.

PLANT SCIENCE GROUP

Lora Crabtree, Aberdeen University, Scotland.
Freya Gledhill, Aberdeen University , Scotland.
Andrea Hawkins, Robert Gordon University, Scottish Agricultural College, Aberdeen, Scotland.
Dirk Malland, Europa Fachhoch schule Fresenius Idstein, Germany.
Marie-laure Martin, Universite Blaise Pascal, Clermont-Ferrand, France.
Alison Pottage, Aberdeen University, Scotland.
David-Georgie Tezier, Lycée Supérieur Pradeau la Sède, Tarbes, France.

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Gregory Tsianopoulos, Agricultural University of Athens, Greece.

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POSTGRADUATE RESEARCH STUDENTS

Current PhD students with University and funding sources as at 1 January 1999

(* indicate staff undertaking Doctorates)

LAND USE SCIENCE GROUP

Jon Ball, Robert Gordon University, RGU
Cameron Campbell, Robert Gordon University, RGU
Weiso Chen, Robert Gordon University, RGU
* Alexis Comber, University of Aberdeen, MLURI/University of Aberdeen
David Doxford, University of Sunderland, University of Sunderland
* Alistair Geddes, University of Lancaster, MLURI
* Matt Hare, University of Aberdeen, MLURI
* Gordon Hudson, University of Aberdeen, MLURI
Anne Humble, University of Aberdeen, ERSRC/MLURI
* Keith Matthews, Robert Gordon University, MLURI
Jia-en Sheu, University of Aberdeen, Self funding
JoAnna Wherrett, Robert Gordon University, RGU/MLURI

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Daisy Macdonald, University of Edinburgh, SOAEFD
* Gerard Wynn, University of Aberdeen, MLURI

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Jake Bundy, University of Aberdeen, Aberdeen Research Consortium
John Cooper, University of Strathclyde, Highland Malt Distilling Ltd
Jerone Dijkstra, Agricultural University of Wageningen, ECN Netherlands

POSTGRADUATE RESEARCH STUDENTS

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Alex Freeman, University of Edinburgh, EPSRC/MLURI
Jenny Gimpel, University of Lancaster, NERC
Martina Girvan, University of Aberdeen, NERC
* Rachel Helliwell, University of Aberdeen, EU
Clemencia Licona-Manzur. University of Edinburgh, Consejo Nacional de Ciencio y Technologia, Mexico
Bruce Thomson, Robert Gordon University, Self funding
Wendy van Beinum, Agricultural University of Wageningen, Macaulay Development Trust
Andrew Wade, University of Aberdeen, NERC

PLANT SCIENCE GROUP

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Donatella Malaguti, University of Bologna, MURST/CPRV
Safia Mediene, Aix-Marseille, INRA/Provence Alpes Cote d'Azur Region
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Mary Walsh, University of Dundee, NERC
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Miguel Bugalho, University of Aberdeen, Portuguese Government
Patricia da Silva, University of Aberdeen, BORC/MLURI
Julian Derry, University of Edinburgh, DfID
Sarah James, University of Edinburgh, BBSRC
Brenda Keir, University of Aberdeen, BORC/MLURI
Zivayi Magidzire, University of Edinburgh, DfID
Helena Martins, Technical University of Lisbon, Junta Nacional de Investigacoa Cientifico, Portugal
Charles Moyo, University of Pietermaritzburg, Zimbabwe, EU
Hamisi Mutundi, University of Sussex, Kenyan Government
Sander Oom, University of Edinburgh, Macaulay Development Trust
Alistair Pole, University of Aberdeen, University of Aberdeen/ MLURI
Shaila Rao, University of Aberdeen, NERC/MLURI
Catherine Reid, University of Plymouth, University of Plymouth/ MLURI
Gabrielle Rouzard, Robert Gordon University, EU 'FAIR'/BORC
Jo Anna Mairi Wynn, University of Manchester, NERC/MLURI

ANALYTICAL GROUP

Ahmed Ayoub, Robert Gordon University, Self funding

PROGRAMME OF RESEARCH

Current projects as of 1 April 1998

Unless otherwise stated research projects are funded by SOAEFD

PROGRAMME UNIT 21

GEOGRAPHICAL AND RESOURCE ANALYSIS

Programme Unit Manager: R V Birnie

121560 Development and testing of risk management methodologies with respect to organic waste re-cycling on farms (Willie Towers)

121606 Dynamic spatial modelling of one-dimensional soil water regimes for estimating risks to land use options (Gordon Hudson)

121607 The application of soil hydrological and land cover data to the regional modelling of gaseous nitrogen emissions (Allan Lilly)

121556 Development of efficient, biologically sustainable and economically viable upland sheep systems (Alan Sibbald)

121557 The role of spatially distributed interactions in integrated land-use systems (Alan Sibbald)

121559 Strategic development of RS Technology for characterisation at the field scale (Gary Wright)

121608 Framework for evaluation and assessment of regional land use scenarios (FEARLUS) (Alistair Law)

121666 Methodologies for evaluating the spatial characteristics of landscape and landscape change (David Miller)

121605 Validating the WEAVER complex systems modelling methodology (Matt Hare)

121561 The structuring of remote sensing and land cover knowledge for automated land cover change detection (Alistair Law) [Non-commissioned]

121634 Automated land cover change detection (Alistair Law) [Flexible funding]

121401 Integration of land cover and agricultural information from the Agricultural and Horticultural Census of SOAEFD with the Land Cover of Scotland 1988 (LCS88) to provide an enhanced, co-ordinated and multi-temporal Land Cover Database for Scotland (Dick Birnie) [Flexible funding]

121598 Integrated System for Analysing and Reporting on the Social, Economic and Environmental Dimensions of Rural Land Use Change (Dick Birnie) [Flexible funding]

121569 Hydrology of Alpine and High Latitude Basins (HYDALP) (Gary Wright) [European Commission]

121577 Developing agroforestry systems for the Southern Hill Region of the Yangtze River (Alan Sibbald) [Joint with The Royal Society]

121653 Sustainable waste water planning: issues of scale (David Miller) [The Robert Gordon University]

121633 Automatic analysis of the results of complex land use simulations (Alistair Law) [Joint with the University of Aberdeen]

121652 Streetscapes: their contribution to wealth creation and quality of life (David Miller) [Scottish Enterprise]

121643 A conceptual framework for modelling complex, adaptive agro-ecosystems: just enough detail to see the crops, not so much as to lose the field (Matt Hare) [Macaulay Development Trust]

PROGRAMME UNIT 22

SOCIO-ECONOMIC AND POLICY ANALYSIS

Programme Unit Manager: J R Crabtree

122609 The development of alternative methodolgies for the analysis of rural sustainability (Deb Roberts)

122563 Choice experiments, cost effectiveness and related valuation methods for assessing the benefits from investment in the rural environment (Craig Bullock)

122562 Environmental benefits of traditional agricultural systems in European agriculture. A socio-economic analysis (Bob Crabtree)

122668 The economic value of biodiversity in extensive Scottish farmland: its measurement and implications for Scottish Agricultural Policy (Gerard Wynn)

122667 Changing property institutions in land: impacts on rural development and local economic and social benefits (Bob Crabtree)

122669 Assessing sustainability: quantitative approaches to examining environmental policy impacts on rural sustainable development (Gary Hill)

122565 Change in land use, agricultural and rural structures: implications for rural sustainability (Bob Crabtree)

122462 Development and application of spatial analysis methods in rural sustainability (Dan van der Horst) [Non-commissioned]

122582 Socio-Economics and Agricultural Impacts of the Environmentally Sensitive Areas (ESA) Scheme in Scotland (Bob Crabtree) [Flexible funding]

122654 Communal ownership: implications for rural development in peripheral areas (Bob Crabtree) [European Commission]

122574 Improving Agri-environmental policies: A simulation approach to the role of the cognative properties of farmers and institutions (Bob Crabtree) [Joint with the Royal Agricultural College Cirencester]

122658 Western Isles input-output study (Deb Roberts) [Comhairle Nan Eilean Sir]

122657 Integrated water basin management: estimation of environmental and full recovery costs under the EU Water Policy Directive (Bob Crabtree) [Macaulay Development Trust]

PROGRAMME OF RESEARCH

PROGRAMME UNIT 23

ATMOSPHERIC DEPOSITION, LAND USE AND WATER QUALITY MANAGEMENT

Programme Unit Manager: R C Ferrier

223672 The biogeochemical significance of critical loads and their exceedance (Simon Langan)

223670 Geochemical controls on the spatial and temporal solute chemistry of surface waters (Derek Bain)

223530 Water resource modelling: impacts of global change, atmospheric deposition, and land use change on soil and water quality (Bob Ferrier)

223532 Nutrient changes in soil hydrochemistry between extensively managed hill slopes and output streams (Hamish Anderson)

223492 Consequences of initial afforestation practices on catchment behaviour in northern Scotland (John Miller)

223673 Assessing and improving the spatial integrity of catchment scale hydrological and hydrochemical modelling (Sarah Dunn)

223671 Contrasting the processes of formation, transport and their significance for influencing the environmental impact of N and P (Tony Edwards)

223611 Characterisation and origins of dissolved organic nitrogen (DON) and dissolved organic carbon (DOC) in upland soils (Berwyn Williams)

223533 Contribution and pathways of soil derived particles to the suspended loads of rivers (Steve Hillier)

223500 The assessment of ground water quality in Grampian Region (Tony Edwards) [Non-commissioned, joint with The Robert Gordon University]

223579 Significance of physical heterogeneity for scaling of solute chemistry in soils from fine scale to subcatchment (Tony Edwards) [Flexible funding]

223632 Sorption-microflotation method for the purification of water from soluble components of fuels and oils (Jeff Wilson) [European Commission]

223629 Improving the productivity and sustainability of crop systems on fragile slopes in the highlands of South China and Thailand (Jeff Wilson) [European Commission and Dalhousie Estates]

223507 Total nitrogen and phosphorus losses from upland ecosystems: significance of instream processes (Pippa Chapman) [Joint with the Natural Environment Research Council]

PROGRAMME UNIT 24

SOIL QUALITY, CONTAMINATED LAND AND WASTE UTILISATION

Programme Unit Manager: E Paterson

224431 Effects of mineral-humic interactions in relation to modelling metal retention by soils (David Lumsdon)

224328 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)

224541 National assessment of factors and processes responsible for recent trends in the fertility of Scottish soils (Tony Edwards)

224539 Modelling diffusive-convective transport of reactive solutes in soils (Hans Meeussen)

224538 Soil ecosystem recovery in relation to organic micropollutants and heavy metals (Colin Campbell)

224612 Microbial processes and diversity as quality indicators of soils subject to land use change (Steve Chapman)

224432 Changes in time in the chemical association of the heavy metals cadmium, copper, lead, nickel and zinc in grassland and forest soils likely to receive sewage sludge (Jeff Bacon)

224544 Contribution of clay mineralogy to soil structural stability and release of mobile colloids from soils (Ed Paterson)

224642 Effects of long-term nitrogen deposition on VA mycorrhizal functioning in grasslands (Colin Campbell) [Non-commissioned, joint with the Natural Environment Research Council]

224665 Chemical speciation of trace metals in freshwater and seawater (Tony Edwards) [Non-commissioned]

224593 Modelling metal interactions with humic substances (David Lumsdon) [Non-commissioned]

224517 Assessment of the biological impact and remediation of oil contamination in soils (Colin Campbell) [Non-commissioned]

224602 Wastes to land-planning and design of a spatially based decision support tool (Ed Paterson) [Flexible funding]

224571 Effects of afforestation of agricultural land on heavy metal mobility in soil (Derek Bain) [European Commission]

224664 Candidate CRM 679 Cabbage Powder: subcontract for certifying laboratories (Jeff Bacon) [European Commission]

224649 Health risks of heavy metals in the food chain of industrial area of Central and Eastern Europe (Jeff Bacon) [European Commission]

224359 Characterisation, management and utilisation of red soil resources of southern China (Jeff Wilson) [European Commission]

224520 Trace metal and phosphate extraction from sediments and soils (Jeff Bacon) [European Commission]

224647 Urban regeneration of coalfields: generic studies of contaminated land and groundwater issues exemplified in Wolverhampton (Alistair Smith) [unclassified, joint with the Natural Environment Research Council]

224626 Integrated assessment and modelling of soil contaminant behaviour, transport and impact at remediable urban sites (Ed Paterson) [unclassified, joint with the Natural Environment Research Council]

224627 Multicomponent transport of reactive chemicals in physically and chemically heterogeneous systems (Hans Meeussen) [Macaulay Development Trust]

PROGRAMME UNIT 26

LAND USE OPTIONS FOR PLANTS

Programme Unit Manager: P Millard

326674 Nitrogen remobilisation by trees in relation to bud break dynamics and allocation within the tree (Pete Millard)

326547 Canopy size, nutrient supply and assimilate partitioning in native Scots pine seedlings (Mike Proe)

326546 Models of carbon and nitrogen allocation, growth and remobilization in plants of extensively managed pastures (Colin Birch)

326436 Suitability of whole tree harvesting of Sitka spruce as a sustainable land use on different site types within the UK (Mike Proe)

326613 Acquisition and utilisation of nitrogen by plants of upland ecosystems (Barry Thornton)

326545 Consequences of defoliation for nutrient acquisition and root dynamics in a heterogenous soil environment (Lorna Dawson)

326438 Phenotypic and genotypic basis of population dynamics in heterogeneous species - rich grassland (Pete Millard) [Flexible funding]

326591 Physiological and molecular responses of grasses to defoliation and their consequences for the vegetation dynamics of grazed swards. (Barry Thornton) [Director's commissioned, joint with BBSRC]

PROGRAMME UNIT 27

NATURAL HERITAGE MANAGEMENT – VEGETATION DYNAMICS

Programme Unit Manager: R J Pakeman

427614 Maintenance and function of biodiversity in grazed systems: understanding the role of the regeneration niche (Robin Pakeman)

427450 Effects of pre- and post-burning management on the recovery of rehabilitated dry and wet heather moorland (Peter Hulme)

427675 Spatio-temporal dynamics of montane dwarf shrub-dominated vegetation: control by climatic, nutrient and management factors. (Andrea Britton)

427487 Responses by tree saplings to browsing damage by cattle and red deer (Alison Hester)

427549 Spatially explicit models of vegetation dynamics (Colin Birch)

427548 Extent and development of spatial aggregation of species in extensive grassland communities (Carol Marriott)

427488 Influences on plant species balance in extensively managed grassland grazed by sheep and cattle (Titus Barthram)

427585 Transitional Machair Systems of the Outer Hebrides (Robin Pakeman) [Non-commissioned]

427637 Control of reproduction of bracken (Robin Pakeman) [unclassified, joint with the Natural Environment Research Council]

427641 Spatial pattern and process in the fragmentation of heather moorland (Alison Hester) [Macaulay Development Trust]

PROGRAMME UNIT 28

NATURAL HERITAGE MANAGEMENT – HERBIVORE FORAGING

Programme Unit Manager: I J Gordon

428485 Measurement of the ranging behaviour of red deer using a Global Positioning Satellite system to aid development of computer-based models (Angela Sibbald)

428489 Methods of estimating diet composition and intake by herbivores foraging in heterogeneous ecosystems (Bob Mayes)

428448 Effect of social behaviour on foraging by ruminants in heterogeneous ecosystems (Angela Sibbald)

428550 Conditioned food aversions and their influence on the foraging behaviour of free-ranging ruminants (Alan Duncan)

428615 Develop a theory for how large herbivore foraging decisions interact with the ecosystem processes at different spatio-temporal scales (Keith Farnsworth)

428552 Effects of spatial aggregation of grass species on frequency dependent selection in grazing herbivores (Iain Gordon)

428449 Effect of shelter and food supply on behaviour and energy status of ruminants in heterogeneous upland ecosystems (Alan Duncan)

428553 Spatial and temporal variation in population performance

of red deer in relation to density, climate and land cover (Iain Gordon)

428486 Functional basis for predicting interactions between red deer and natural vegetation communities (Glenn Iason)

428551 Determinants of habitat selection by wild rabbits and their influence on fragmentation of Calluna moorland (Glenn Iason)

428506 Quantify the role of species interactions during foraging on the functioning of mammalian communities (Iain Gordon) [Non-commissioned]

428573 Mechanisms of food selection by mountain hares and their importance on native woodland dynamics (Glenn Iason) [Non-commissioned, joint with the Natural Environment Research Council]

428522 The potential of urinary metabolites of dietary plant compounds as markers for assessing the intake, composition and nutritive value of the diet of free ranging ruminants (Bob Mayes) [Non-commissioned]

428588 Successional processes in upland vegetation: predicting critical herbivore loads over large spatial scales (Alison Hester) [Flexible funding]

428646 Theory and optimisation modelling in whole-animal goal-oriented food intake studies (Iain Gordon) [Flexible fund joint with the University of Edinburgh]

428644 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]

428592 Natural resources management within multispecies system in the mid-Zambezi Valley: Implications for sustainable development in dry lands area of Southern Africa (Iain Gordon) [European Commission]

428521 An integrated approach to radionuclide flow in semi-natural ecosystems underlying exposure pathways to man (Bob Mayes) [European Commission]

428578 Effects of food-borne glucosinolates on human health (Alan Duncan) [European Commission]

428504 The herbivore's dilemma: Trade-offs between nutrition and parasitism in foraging decisions (Iain Gordon) [Joint with the Natural Environment Research Council]

428594 Environmental variability and productivity of semi-arid grazing systems (Iain Gordon) [Joint with the Natural Resources Institute]

428639 Tracking of environmental uncertainty in foraging herbivores (Iain Gordon) [Macaulay Development Trust]

428663 Competition and co-existence in the African carnivore guild (Iain Gordon) [Director's commissioned]

PROGRAMME UNIT 29

LAND USE OPTIONS FOR ANIMALS

Programme Unit Manager: I A Wright

429554 Concentrations of environmental oestrogens (xenoestrogens) in tissues of domestic animals grazing pasture treated with sewage sludge (Stewart Rhind)

429619 Matching animal genotype to nutritional resources in upland beef and sheep systems (Iain Wright)

429617 Environmental effects on hair and wool follicle activity in sheep and goats associated endocrine and paracrine control mechanisms (Stewart Rhind)

429621 Methods of assessment of motivation in ruminants (Hans Erhard)

429618 Developing and testing of models of animal foraging in mixed grazing of heterogeneous vegetation resources (Jonathan Beecham)

429620 Response of extensively reared animals to intensive handling (Pete Goddard)

429616 Estimating genetic parameters for fibre quality traits in cashmere goats (Margaret Merchant)

429581 Neuroendocrine control of appetite and reproduction in sheep (Stewart Rhind) [Non-commissioned]

429508 Pre- and post-natal development of the reproductive axis in intrauterine growth- restricted lambs (Stewart Rhind) [Non-commissioned]

429630 Effect of undernutrition in utero on the development of the reproductive system in sheep (Stewart Rhind) [Flexible funding]

429511 Increasing competitiveness of high quality European animal textile fibres by improving fibre quality (John Milne) [European Commission]

429604 Selecting for reduced aggression in pigs (Hans Erhard) [Joint with MAFF]

INTEGRATED PROGRAMME UNIT 36

SOIL-PLANT-ANIMAL INTERACTIONS

Programme Unit Manager: P Millard

536524 Influence of excretal urine-N on availability of soil phosphorus (Charlie Shand)

536622 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)

536525 Soil nitrogen dynamics in urine patches in extensively

managed sheep pastures (Berwyn Williams)

536526 Impact of grazing on microbial community structure and activity and the consequences for nutrient cycling (Sue Grayston)

536398 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]

536651 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) [Joint with the Natural Environment Research Council]

536650 Effects of leaf nitrate on mineralisation and uptake of N from organic patches (Eric Paterson) [Joint with BBSRC]

536661 Management of field experiments at Sourhope (Pete Millard) [Joint with the Natural Environment Research Council]

536640 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]

536589 Colloid chemistry in soil solution and its impact on P transfers from grasslands (Charlie Shand) [Director's commissioned, joint with BBSRC]

536590 Plant stress effects on C:N efflux into the rhizosphere (Sue Grayston) [Director's commissioned, joint with BBSRC]

INTEGRATED PROGRAMME UNIT 37

LONG-TERM MEASUREMENT AND MONITORING OF CHANGE

Programme Unit Manager: J A Milne

537493 Use of long-term monitoring sites and historical re-sampling strategies in the detection of environmental changes (John Miller)

537527 Development of the methodologies for use in LCS 2000 (Dick Birnie)

537528 Development of methodology for large-scale habitat assessment (Andrew Nolan)

537623 Environmental Change Network: measure long-term changes in climate, soils, vegetation and wildlife populations at two upland agricultural sites in Scotland (David Henderson)

537624 Integrating remotely sensed vegetation indices with biophysical data to provide measures of the structure and biomass of upland vegetation types (Gary Wright)

537529 Design of strategies for environmental and compliance monitoring (Bob Crabtree)

537662 Theoretical Land Use Science (Keith Farnsworth) [Non-commissioned]

538655 Software engineering of decision support tools (Glyn Stanworth) [Non-commissioned]

537601 Modelling plant and animal biodiversity in a Scottish catchment devoted to agriculture (Peter Dennis) [Flexible funding]

537635 Land Cover monitoring system for Scotland (Dick Birnie) [Flexible funding]

537587 Effect of change in grazing pressure of sheep on erosion and vegetation cover on Trotternish, Skye (David Henderson) [Flexible funding]

537580 Rapid habitat condition assessment of six deer management group areas and determination of the repeatability and accuracy of a range of methods for carrying out such assessments (John Milne) [Joint with the Deer Commission for Scotland, SNH]

INTEGRATED PROGRAMME UNIT 38

DEVELOPMENT OF DECISION SUPPORT SYSTEMS

Programme Unit Manager: J A Milne

538676 An integrated data management, analysis and retrieval system for land use information about Scotland (Alistair Law)

538625 Development of a decision support tool for the management of upland vegetation, with a wide range of applications (John Milne)

538534 Construction of a land use modelling environment to aid decision support tool development (Jim McLeod)

MRCS CONSULTANCY SERVICES DIVISION

539415 Monitoring of Environmentally Sensitive Areas in Scotland (Jim Gauld)

STAFF PUBLICATIONS

REFEREED PUBLICATIONS

ABEYESINGHE, S.M. AND GODDARD, P.J. The preferences and behaviour of farmed red deer (*Cervus elaphus*) in the presence of other farmed species, *Applied Animal Behaviour Science*, 56, 59-69.

ADAMO, P, MCHARDY, W.J. AND EDWARDS, A.C. SEM observations in the back-scattered mode of the soil-root zone of *Brassica napus* (cv Rafal) plants grown at a range of soil pH values, *Geoderma*, 85, 357-370

BAATH, E, DIAZ-RAVINA, M, FROSTEGARD, A. AND CAMPBELL, C.D. Effect of metal-rich sludge amendments on the soil microbial community, *Applied and Environmental Microbiology*, 64, 238-245.

BACON, J.R, CRAIN, J.C, VAN VAECK, L, WILLIAMS, J.G. Atomic spectrometry update : atomic mass spectrometry, *Journal of Analytical Atomic Spectrometry*, 13, 171R-208R

BAIN, D.C, LANGAN, S.J, HODSON, M.E. AND MILLER, J.D. Rates of loss of calcium from Scottish catchments measured by different methods, *Geologica Carpathica - Series Clays*, 6(2), pp73-75. N.B. Journal dated 1997, Real publication date December 1998.

BAIN, D.C, MIDWOOD, A.J. AND MILLER, J.D. Strontium isotope ratios in streams and the effect of flow rate in relation to weathering in catchments, *Catena*, 32, 143-151.

BAKKER, M.L, GORDON, I.J. AND MILNE, J.A. Effects of sward structure on the diet selected by guanacos (*Lama guanicoe*) and sheep (*Ovis aries*) grazing a perennial ryegrass-dominated sward, *Grass and Forage Science*, 53, 19-30.

BARCLAY, M, HART, H, KNOWLES, C.J, MEEUSSEN, J.C.L. AND TETT, V.A. Biodegradation of metal cyanides by mixed and pure cultures of fungi: biodegradation of metal cyanides, *Enzyme Microbial Technology*, 22, 223-231

BAYFIELD, N.G. AND NOLAN, A.J. Vegetation and soils of the Allt A'Mharcaidh catchment, Cairngorm mountains, *Scottish Geographical Magazine*, 114, 18-21

BEDROCK, C.N, CHESHIRE, M.V, WILLIAMS, B.L, SOLNTSEVA, I, CHAPMAN, S.J, CHUDEK, K.A. AND GOODMAN, B.A. Identification of nitrogenous components of fungal and bacterial origin immobilised in decomposing wheat straw by NMR spectroscopy using ^{15}N CPMAS, *Soil Biology and Biochemistry*, 30(1), pp113-115.

BEECHAM, J.A. AND FARNSWORTH, K.D. Animal foraging from an individual perspective: an object orientated model, *Ecological Modelling*, 113, 141-156.

BERESFORD, N.A, CROUT, N.M.J, MAYES, R.W, HOWARD, B.J, AND LAMB, C.S. Dynamic distribution of radioisotopes of cerium, ruthenium and silver in sheep tissues, *Journal of Environmental Radioactivity*. 38(3), 317-338

BULLOCK, C.H, ELSTON, D.A. AND CHALMERS, N.A. An application of choice experiments to a traditional land use - deer hunting and landscape in the Scottish Highlands, *Journal of Environmental Management*, 52(4), 1998

BUNDY, J.G, WARDELL, J, CAMPBELL, C.D, KILLHAM, K. AND PATON, G.I. Application of bioluminescence-based microbial biosensors to the ecotoxicity assessment of organotins, *Letters in Applied Microbiology*, 25, 353-358

CHAPMAN, S.J. AND THURLOW, M. Peat respiration at low temperatures, *Soil Biology and Biochemistry*, 30(8-9) 1013-1021.

CHESHIRE, M.V, SHAND, C.A, WOOD, K.A, SMITH, S. AND COUTTS, G. Factors controlling the movement of radiocaesium in organic soils, *In: Energy and the Environment. Geochemistry of Fossil*, Nuclear and Renewable Resources. Ed. K. Nicholson, MacGregor Science, pp141-152.

COMMON, T.G, WRIGHT, I.A. AND GRANT, S.A. The effect of grazing by cattle on animal performance and floristic composition in *Nardus* dominated swards, *Grass and Forage Science*, 53, 260-269

CRABTREE, J.R. AND BAYFIELD, N. Developing sustainability indicators for mountain ecosystems : a study of the Cairngorms, Scotland, *Journal of Environmental Management*, 52(1), 1-14.

CROUT, N.M.J, BERESFORD, N.A, HOWARD, B.J, MAYES, R.W. AND HANSEN, H.S. A model of radiostrontium transfer in dairy goats based on calcium metabolism, *Journal of Dairy Science*, 81, 92-99

CROUT, N.M.J, MAYES, R.W, BERESFORD, N.A, LAMB, C.S. AND HOWARD, B.J. A metabolic approach to simulating the dynamics of C-14, H-3 and S-35 in sheep tissues, *Radiation and Environmental Biophysics*, 36, 243-250

DANIELS, M.J, BALHARRY, D, HIRST, D, KITCHENER, A.C. AND ASPINALL, R.J. Morphological and pelage characteristics of wild living cats in Scotland : implications for defining the "wildcat", *Journal of Ecology*, 244, Part 2, 231-247

DENNIS, P, ASPINALL, R.J. AND GORDON, I.J. Spatial association of arthropod distribution related to the spatial patterns of topography, vegetation and grazing regime in upland Scotland, *Journal Environmental Management*

DENNIS, P, YOUNG, M.R. AND GORDON, I.J. Distribution and abundance of small insects and arachnids in relation to structural heterogeneity of grazed indigenous grasslands, *Ecological Entomology*, 23, 253-264

DOMBURG, P, EDWARDS, A.C, SINCLAIR, A.H, WRIGHT, G.G. AND FERRIER, R.C. Changes in fertilizer and manurial practices during 1960-1990: Implications for N and P inputs to the Ythan catchment, NE Scotland, *Nutrient Cycling in Agroecosystems*, 52, 19-29

DONALD, D. AND CHAPMAN, S.J. Use of powdered elemental sulphur as a sulphur source for grass and clover, *Communications in Soil Science and Plant Analysis*, 29, 1315-1328.

DUNCAN, A.J, HARTLEY, S.E. AND IASON, G.R. The effect of previous browsing damage on the morphology and chemical composition of Sitka Spruce (*Picea sitchensis*) saplings and on their subsequent susceptibility to browsing by red deer (*Cervus elaphus*), *Forest Ecology and Management*, 103, 57-67

DUNN, S.M, MCALISTER, E. AND FERRIER, R.C. Development and application of a distributed catchment-scale hydrological model for the River Ythan, North East Scotland, *Hydrological Processes*, 12, 401-416

EDWARDS, A.C. AND WITHER, P. Soil phosphorus management and a water quality : a UK perspective, *Soil Use Management*, 14, 124-130

ERHARD, H.W, PRICE, E.O. AND DALLY, M.R. Competitive ability of rams selected for high and low levels of sexual performance, *Animal Science*, 66, 403-408

EVANS, C.D, JENKINS, A, HELLIWELL, R.C. AND FERRIER, R. Predicting regional recovery from acidification : the MAGIC model applied to Scotland, England and Wales, *Hydrology and Earth System Sciences*, 2, 543-554

STAFF PUBLICATIONS

FARMER, V.C. Differing effects of particle size and shape in the infrared and Raman spectra of kaolinite, *Clay Minerals*, 33, 601-604.

FARNSWORTH, K.D. AND ILLIUS, A.W. Optimal diet choice for large herbivores : an extended contingency model, *Functional Ecology*, 12, 74-81

FERRE, I, GODDARD, P.J, MACDONALD, A.J, LITTLEWOOD, C.A. AND DUFF, E.I. Effect of method of blood sample collection on adrenal activity in farmed red deer and sheep following administration of ACTH, *Animal Science*, 67, 157-164

FERRIER, R.C. The dynamo project : an introduction. Dynamic models to predict and scale up the impact of environmental change on biogeochemical cycling, *Hydrology and Earth Systems Science*, 2, 375-383

FISHER, E.A, THORNTON, B, HUDSON, G. AND EDWARDS, A.C. The variability in total and extractable soil P under a grazed pasture, *Plant and Soil*, 203, 249-255

FRUTOS, P, BURATOVICH, O, GIRALDEZ, F.J, MANTECON, A.R. AND WRIGHT, I.A. Effects on maternal and foetal traits of feeding supplement to grazing pregnant ewes, *Animal Science*, 66, 667-673

FRUTOS, P, DUNCAN, A.J, KYRIAZAKIS, I. AND GORDON, I.J. Learned aversion towards oxalic acid-containing foods by goats: does rumen adaptation to oxalic acid influence diet choice?, *Journal of Chemical Ecology*, 24, 383-397.

GARDNER, P.T, MCPHAIL, D.B, AND DUTHIE, G.G. Electron spin resonance spectroscopic assessment of the antioxidant potential of teas in aqueous and organic media, *Journal of the Science of Food and Agriculture*, 76, 257-262

GODDARD, P.J. The welfare of deer, *Acta Veterinaria Hungarica*, 46(3), 395-404

GODDARD, P.J, FAWCETT, A.R. AND MACDONALD, A.J. The adaptation of hill lambs to housing conditions, *Applied Animal Behaviour Science*, 58, 331-339

GODDARD, P.J, GASKIN, G.J. AND MACDONALD, A.J. Automatic blood sampling equipment for use in studies of animal physiology, *Animal Science*, 66, 769-775.

GONZALEZ, S.G. AND GODDARD, P.J. The provision of supplementary colostrum to newborn lambs: effects on post-natal lamb and ewe behaviour, *Applied Animal Behaviour Science*, 61, 41-50

GRAYSTON, S.J, CAMPBELL, C.D, LUTZE, J.L. AND GIFFORD, R.M. Impact of elevated CO_2 on the metabolic diversity of microbial communities in N-limited grass swards, *Plant and Soil*, 203, 289-300

GRAYSTON, S.J, WANG, S, CAMPBELL, C.D. AND EDWARDS, A.C. Selective influence of plant species on microbial diversity in the rhizosphere, *Soil Biology and Biochemistry*, 30(3), 369-378.

GRIFFITHS, B.S, RITZ, K, EBBLEWHITE, N, PATERSON, E. AND KILLHAM, K. Rye grass rhizosphere microbial community structure under ambient and elevated carbon dioxide concentrations, with observations on wheat rhizosphere, *Soil Biology and Biochemistry*, 30, 315-321

GRIGOR, P.N., GODDARD, P.J. AND LITTLEWOOD, C.A. The relative aversiveness to farmed red deer of transport, physical restraint, human proximity and social isolation, *Applied Animal Behaviour Science*, 56, 255-262

GRIGOR, P.N, GODDARD, P.J. AND LITTLEWOOD, C.A. The behavioural and physiological reactions of farmed red deer to transport : effects of group size, space allowance and vehicular motion, *Applied Animal Behaviour Science*, 56, 281-295

GRIGOR, P.N, GODDARD, P.J, LITTLEWOOD, C.A. AND DEAKIN, D.W. Pre-transport loading of farmed red deer : effects of previous overnight housing environment, vehicle illumination and shape of loading race, *Veterinary Record*, 142, 265-268

GRIGOR, P.N, GODDARD, P.J, LITTLEWOOD, C.A. AND MACDONALD, A.J. The behavioural and physiological reactions of farmed red deer to transport : effects of road type and journey time, *Applied Animal Behaviour Science*, 56, 263-279.

GUSTAFSSON, J.P, LUMSDON, D.G. AND SIMONSSON, M. Aluminium solubility characteristics of spodic B horizon containing imogolite-type materials, *Clay Minerals*, 33, 77-86

HAGGARTY, P, ROBINSON, J, ASHTON, J, MILNE, E, ADAM, C.L, KYLE, C, CHRISTIE, S.L. AND MIDWOOD, A.J. Estimation of energy expenditure in free living red deer with the doubly labelled water method, *British Journal of Nutrition*, 80, 263-272

HALL, J.M, PATERSON, E. AND KILLHAM, K. The effect of elevated CO_2 and soil pH on the relationship between plant growth and rhizosphere denitrification potential, *Global Change Biology*, 4, 209-216

HANLEY, N, MACMILLAN, D.C, WRIGHT, R.E, BULLOCK, C, SIMPSON, I, PARSISSON, D. AND CRABTREE, J.R. Contingent valuation versus choice experiments : estimating the benefits of Environmentally Sensitive Areas in Scotland, *Journal of Agricultural Economics*, 49(1), 1-15

HARRIMAN, R, CURTIS, C. AND EDWARDS, A.C. An empirical method of predicting NO_3 leaching for upland catchments in the UK using deposition and runoff chemistry, *Water, Air and Soil Pollution*, 105, 193-203

HATT, J.-M, LECHNER-DOLL, M. AND MAYES, R.W. The use of dosed and herbage n-alkanes as markers for the determination of digestive strategies of captive giraffes (*Giraffa camelopardalis*), *Zoo Biology*, 17(4), pp295-309.

HAYGARTH, P.M, CHAPMAN, P.J, JARVIS, S.C. AND SMITH, R.V. Phosphorus budgets for two contrasting grassland farming systems in the UK, *Soil Use and Management - Special issue on Phosphorus*, 14, 160-167

HELLIWELL, R.C, FERRIER, R.C. AND JENKINS, A. A two layer application of the MAGIC model to predict the effects of land use scenarios and reductions in deposition on acid sensitive soils in the UK, *Hydrology and Earth System Sciences*, 2, 497-507.

HELLIWELL, R.C, SOULSBY, C, FERRIER, R.C, JENKINS, A. AND HARRIMAN, R. Influence of snow on the hydrology and hydrochemistry of the Allt A'Mharcaidh, Cairngorm mountains, Scotland, *Science of the Total Environment*, 217, pp59-70

HESTER, A.J. AND BAILLIE, G.J. Spatial and temporal patterns of heather use by sheep and red deer within natural heather/grass mosaics, *Journal of Applied Ecology*, 35, 772-784

HESTER, A.J, KIRBY, K.J, MITCHELL, E.J.G, GILL, R.M.A, LATHAM, J. AND ARMSTRONG, H. Ungulates and forest management in the British Isles, *In: Grazing as a management tool in European forest ecosystems: a review of research priorities. Eds. J.W Humphrey*, R.M.A. Gill and J. Claridge. Forestry Commission Technical Paper 25, Forestry Commission, Edinburgh. pp25-36.

HEYWORTH, C.J, IASON, G.R, TEMPERTON, V, JARVIS, P.G. AND DUNCAN, A.J. The effect of elevated CO_2 concentration and

STAFF PUBLICATIONS

nutrient supply on carbon-based plant secondary metabolites in Pinus sylvestris (L.), *Oecologia*, 115(3), 344-350

HODGE, A. AND MILLARD, P. Effect of elevated CO_2 on carbon partitioning and exudate release from *Plantago lanceolata* seedlings, *Physiologia Plantarum*, 103, 280-286

HODGE, A, PATERSON, E, GRAYSTON, S.J, CAMPBELL, C.D, ORD, B.G. AND KILLHAM, K. Characterisation and microbial utilisation of exudate material from the rhizosphere of *Lolium perenne* grown under CO_2 enrichment, *Soil Biology and Biochemistry*, 30(8-9), 1033-1043

HODSON, M.E, LANGAN, S.J. AND LUMSDON, D.G. A comparison of soil sensitivity to acidification based on laboratory-determined short term acid buffering capacity and the Skokloster classification, *Water Air and Soil Pollution*, 105, 53-62

HODSON, M.E, LANGAN, S.J. AND MERIAU, S. Determination of mineral surface area in relation to the calculation of weathering rates, *Geoderma*, 83, 35-54

HODSON, M.E, LANGAN, S.J, KENNEDY, F.M. AND BAIN, D.C. Variation in soil surface area in a chronosequence of soils from Glen Feshie, Scotland and its implications for mineral weathering calculations, *Geoderma*, 85(1), 1-18

HOUSE, W.A, JICKELL, T.D, EDWARDS, A.C, PRASKA, K.E. AND DENISON, F.H. Reactions of phosphorus with sediments, *Soil Use and Management*, 14, 147-153

HUTCHINGS, M.R, KYRIAZAKIS, I, ANDERSON, D.H, GORDON, I.J. AND COOP, R.L. Behavioural strategies used by parasitised and non-parasitised sheep to avoid ingestion of gastro-intestinal nematode associated with faeces, *Animal Science*, 67, 97-106

IBRAHIM, L, PROE, M.F. AND CAMERON, A.D. Interactive effects of nitrogen and water availabilities on gas exchange and whole-plant carbon allocation in poplar, *Tree Physiology*, 18, 481-487

JENKINS, A, HELLIWELL, R.C, SWINGEWOOD, P.J, SEFTON, C, RENSHAW, M. AND FERRIER, R.C. Will reduced sulphur emissions under the Second Sulphur Protocol lead to recovery of acid sensitive sites in UK ?, *Environmental Pollution*, 99, pp309-318

JOHNSON, D, LEAKE, J.R, LEE, J.A. AND CAMPBELL, C.D. Changes in soil microbial biomass and microbial activities in response to 7 years simulated pollutant nitrogen deposition on a heathland and two grasslands, *Environmental Pollution*, 103, 239-250.

JONES, D.L. AND EDWARDS, A.C. Influence of sorption on the biological utilization of two simple carbon substrates, *Soil Biology and Biochemistry*, 30, 1895-1902

JONES, K.H. A comparison of algorithms used to compute hill slope as a property of the DEM, *Computers and Geosciences*, 24, 315-323

KYRIAZAKIS, I, ANDERSON, D.H. AND DUNCAN, A.J. Conditioned flavour aversions in sheep: the relationship between the dose rate of a secondary plant compound and the acquisition and persistence of aversions, *British Journal of Nutrition*, 79, 55-62

LILLY, A, BOORMAN, D.B. AND HOLLIS, J.M. The development of a hydrological classification of UK soils and the inherent scale changes, *Nutrient Cycling in Agroecosystems*, 50, pp299-302

MACLEOD, F, MCGAW, B.A. AND SHAND, C.A. Sequential extraction of selenium from four Scottish soils and a sewage sludge, *Communications in Soil Science and Plant Analysis*, 29(5&6), 523-534

MAGUIRE, R.O, EDWARDS, A.C. AND WILSON, M.J. Influence of cultivation on the distribution of phosphorus in three soils from NE Scotland and their aggregate size functions, *Soil Use and Management*, 14, 139-146

MAIDEN, N.A.M. AND HARE, M.P. Problem domain categories in requirements engineering, *International Journal of Human Computer Studies*

MANSO, T, MANTECON, A.R, CASTRO, T. AND IASON, G.R. Effect of intake level during milk-feeding period and protein content in the post-weaning diet on performance and body composition in growing lambs, *Animal Science*, 67, 513-521.

MARRIOTT, C.A. AND CARRERE, P. Structure and dynamics of grazed vegetation, *Annales de Zootechnie*, 47, 359-369

MAXWELL, T.J, SIBBALD, A.R, DALZIEL, A.J.I. AND AGNEW, R.D.M. The implications of controlling sward height for the operation and productivity of upland sheep systems in the UK. 4. The effect of seasonal pattern of nitrogen fertilizer application and annual stocking rate, *Grass and Forage Science*, 53, 279-286.

MCDONALD, S. AND ROBERTS, D. The economy-wide effects of the BSE crisis : a CGE analysis, *Journal of Agricultural Economics*, 49, 456-469.

MEEUSSEN, J.C.L, BOER, G, EXALTUS, R.P. AND KARS, H. Effects of soil acidification and declining groundwater tables on the decay of buried archaeological features, *Proceedings of the State Service for Archaeological Investigations in the Netherlands*, 42, 1996-1997 pp475-490

MIDWOOD, A.J. AND BOUTTON, T.W. Soil carbonate decomposition by acid has little effect on $^{13}C_{PDB}$ of organic matter, *Soil Biology and Biochemistry*, 30, 1301-1307.

MIDWOOD, A.J, BOUTTON, T.W, ARCHER, S.R. AND WATTS, S.E. Water use by woody plants on contrasting soils in a savanna parkland : assessment with ^{2}H and ^{18}O, *Plant and Soil*, 205, 13-24

MILLARD, P, WENDLER, R, HEPBURN, A. AND SMITH, A. Variations in the amino acid composition of xylem sap of *Betula pendula* Roth. trees due to remobilisation of stored N in the spring, *Plant*, Cell and Environment, 21, 715-722

MILLER, G.R, CUMMINS, R.P. AND HESTER, A.J. Red deer and woodland regeneration in the Cairngorms, *Scottish Forestry*, 52(2)

MILLER, J.D. AND HIRST, D. Trends in concentrations of solutes in an upland catchment in Scotland, *The Science of the Total Environment*, 216(1-2), 77-88

NEILSON, R, HAMILTON, D, WISHART, J, MARRIOTT, C.A, BOAG, B, HANDLEY, L.L, SCRIMGEOUR, C.M, MCNICOL, J.W. AND ROBINSON, D. Stable isotope natural abundances of soil, plants and soil invertebrates in an upland pasture, *Soil Biology and Biochemistry*, 30, 1773-1782.

NEMES, A, WOSTEN, J.H.M. AND LILLY, A. Proposal for a national database of soil hydraulic functions in Hungary, *Agrokemia es Talajtan*, 47, 39-48

NOLAN A.J, HENDERSON, D.J, STILL, M.J, MADDEN, S. AND BELL, J.S. Effects of excluding wild herbivores on the growth of small saplings in some woodlands within the Breadalbane and Loch Lomond Environmentally Sensitive Areas, *Scottish Forestry*, 52, 22-29

PAKEMAN, R.J, HANKARD, P.K. AND OSBORN, D. Plants as biomonitors of atmospheric pollution : their potential for use in

STAFF PUBLICATIONS

pollution regulation, *Review of Environmental Contamination and Toxcicology*, 157, pp1-23

PEREZ-BARBERIA, F.J. AND GORDON, I.J. Factors affecting food comminution during chewing in ruminants : a review, *Biological Journal of the Linnean Society*, 63, 233-256.

PRICE, E.O, DALLY, M.R, ERHARD, H.W, KELLY, M, MOORE, N, GERZEVSKE, M, SCHULTZE, A. AND TOPPER, C. Fostering lambs: manipulating odor cues facilitates add-on fostering in sheep, *Journal of Animal Science*, 76, 961-964

RHIND, S.M. AND MCNEILLY, A.S. Effects of level of food intake on ovarian follicle number, size and steroidogenic capacity in the ewe, *Animal Reproduction Science*, 52, 131-138

RHIND, S.M, ELSTON, D.A, JONES, J.R, REES, M.E, MCMILLEN, S.R, AND GUNN, R.G. Effects of restriction of growth and development of Brecon Cheviot ewe lambs on subsequent lifetime reproductive performance, *Small Ruminant Research*, 30, 121-126

RHIND, S.M, MCMILLEN, S.R, DUFF, E, HIRST, D. AND WRIGHT, S. Seasonality of meal patterns and hormonal correlates in red deer, *Physiology and Behaviour*, 65, 295-302.

RHIND, S.M, REID, H.W, MCMILLEN, S.R. AND PALMARINI, G. The role of cortisol and B-endorphin in the response of the immune system to weaning in lambs, *Animal Science*, 66, 397-402

RIGOL, A, VIDAL, M, RAURET, G, SHAND, C.A. AND CHESHIRE, M.V. Competition of organic and mineral phases in radiocaesium partitioning in organic soils, *Environmental Science and Technology*, 32, 663-669.

ROBERTS, D.J. Rural-urban interdependencies: Analysis using an inter-regional SAM model, *European Review of Agricultural Economics*, 25(4), 506-527

SIBBALD, A.M. AND DAVIDSON, G.C. The effect of nutrition during early life on voluntary food intake by lambs between weaning and 2 years of age, *Animal Science*, 66, 697-703.

SMART, R.P, SOULSBY, C, NEAL, C, WADE, A, CRESSER, M.S, BILLETT, M.F, LANGAN, S.J, EDWARDS, A.C, JARVIE, H.P. AND OWEN, R. Factors regulating the spatial and temporal distribution of solute concentrations in a major river system in NE Scotland, *Science of the Total Environment*, 221, 93-110

SOULSBY, C, CHEN, M, FERRIER, R.C, HELLIWELL, R.C, JENKINS, A. AND HARRIMAN, R. Hydrogeochemistry of shallow groundwater in an upland Scottish catchment, *Hydrological Processes*, 12(7), 1111-1127

TAGLIAVINI, M, MILLARD, P. AND QUARTIERI, M. Storage of foliar-absorbed nitrogen and remobilisation for spring growth in young nectarine(*Prunus persica* var. *nectarina*) trees, *Tree Physiology*, 18, pp203-207

THORNTON, B. Influence of pH and aluminium on nitrogen partitioning in defoliated grasses, *Grass and Forage Science*, 53, 170-178

TOWERS, W. AND HORNE, P. The conflicts between sewage sludge recycling and livestock farming in the Strathclyde Region, Scotland, *Livestock Farming Systems. More than Food Production. EAAP Publication No.89. Wageningen*, 1997, Chapter 51, pp307-312.

TRENKEL, V.M, PARTRIDGE, L.W, GORDON, I.J, BUCKLAND, S.T, ELSTON, D.A. AND MCLEAN, C. The management of red deer on Scottish open hills : results of a survey conducted in 1995, *Scottish Geographical Magazine*, 114, 57-62

TWIST, H, EDWARDS, A.C. AND CODD, G.A. Algal growth responses of two contrasting tributaries to the River Dee, North East Scotland, *Water Research*, 32, 2471-2479

VILLAR, D, RHIND, S.M, DICKS, P, MCMILLEN, S.R, NICOL, F. AND ARTHUR, J.R. Effect of propylthiuracil-induced hypothyroidism on thyroid hormone profiles and tissue deiodinase activity in cashmere goats, *Small Ruminant Research*, 29, 317-324.

WHITTINGTON, G, CONNELL, R.E, COOPER, G, EDWARDS, K.J, HALL, A.M, HULME, P.D. AND JARVIS, J. Devensian organic interstadial deposits and ice sheet extent in Buchan, Scotland, *Journal of Quaternary Studies*, 13, 309-324

YODER, C.K, BOUTTON, T.W, THURROW, T.L. AND MIDWOOD, A.J. Differences in soil water use by annual broomweed and grasses, *Journal of Rangeland Management*, 51, 200-206

ZHU, X, HEALEY, R.G. AND ASPINALL, R.J. A knowledge-based systems approach to design of spatial decision support systems for environmental management, *Environmental Management*, 22(1), 35-48

REVIEWED PUBLICATIONS

BAIN, D.C. The use of strontium isotopes in weathering studies, *Proceedings of the Ninth International Symposium on Water-Rock Interaction*, Taupo, New Zealand, 30March - 3 April 1998. pp379-382.

BAYFIELD, N, CRABTREE, J.R. AND WOOD, M. Farmland conversion to woodland: impacts on biodiversity and landscape, *International Association of Landscape Ecologists Annual Conference*, Stirling, September 1996.

BOUTTON, T.W, ARCHER, S.R, MIDWOOD, A.J. AND ZITZER, S.F. ^{13}C values of soil organic carbon and their use in documenting vegetation change in a subtropical savanna ecosystem, *Geoderma*, 82, 5-41

CHAPMAN, P.J, EDWARDS, A.C, REYNOLDS, B, CRESSER, M.S. AND NEAL, C. The nitrogen content of rivers in upland Britain: The significance of organic nitrogen, *In: Hydrology*, Water Resources and Ecology in Headwaters. IAHS Publication No.248, 443-450.

CRABTREE, J.R. Local sustainability indicators: development and application in a contested environment, *European Association of Agricultural Economists*, 48th Seminar on "Rural Restructuring within Developed Countries", Dijon, March 1997.

CRABTREE, J.R. AND MACDONALD, D. The supply of access to the countryside: financial efficiency in government provision of a local public good, *In: Proceedings of the 8th EARE Conference*, Tilburg, Netherlands, 26 June 1997.

CRABTREE, J.R. AND MILNE, J.A. Applications of actions for environmentally sensitive areas : Examples in Scotland, *Annales de Zootechnie*, 47, 491-496.

GASPAR, J. AND MILLER, D.R. Global positioning systems and TM data for providing forest inventory information, *Application of Remote Sensing in European Forest Monitoring*, ed. P. Kennedy and S. Folving, J.R.C.

GOTTS, N.M. AND CALLAHAN, P.B. Emergent structures in sparse fields of Conway's "Game of Life", *In: Adami, C, Belew, R.K, Kitano, H. and Taylor, C.E. (eds) Artificial Life VI: Proceedings of the*

STAFF PUBLICATIONS

Sixth International Conference on Artificial Life, pp.104-113.

HOPPE, G.M, MCADAM, J.H, DECONINCK, J, CLEMENTS, V, SIBBALD, A.R. AND EASON, W. Tree growth form in the silvopastoral national network experiment, *Agroforestry Forum*, 9(1), 20-23

KOSTIC, N, WILSON, M.J, ZIVKOVIC, M. AND BAIN, D.C. Mineralogy and geochemical speciation of heavy metals in some serpentine soils of Serbia, *Proceedings of the World Congress of Soil Science*, Montpellier.

MARRIOTT, C.A. AND BOLTON, G.R. Changes in species composition of ungrazed, unfertilised swards after imposing seasonal cutting treatments, *Ecological aspects of grassland management.Proceedings of the 17th European Grassland Federation Meeting*, Debrecan, Hungary, May, 1998. Nagy,G.(Ed) and Peto, K.(Ed), pp465-468.

MILLER, D.R, QUINE, C.P. AND BROADGATE, M.L. The application of digital photogrammetry for monitoring forest stands, *Application of Remote Sensing in European Forest Monitoring*, ed. P. Kennedy and S. Folving, J.R.C.

PAKEMAN, R.J, MARRS, R.H, HOWARD, D.C. AND BARR, C.J. Predicting the effects of climate and land-use change on the spread of bracken, *In: Bracken: An Environmental Issue*, eds R.T.Smith & J.A.Taylor, Leeds University Press, pp69-72.

SIBBALD, A.R, HISLOP, A.M, AGNEWS, R.D.M, DALZIEL, A.J.I. AND MACLEOD, A. Glensaugh silvopastoral national network site - annual report 1997, *Agroforestry Forum*, 9(1), 18-19

SIBBALD, A.R, HISLOP, A.M, DICK, I. ELSTON, D.A, IASON, G.R, NWAIGBO, L.C. AND HUDSON, G. Soil-plant-animal interactions in the establishment phase of a silvopastoral system in N.E. Scotland, *Agroforestry Forum*, 8(3), 23-26

STEWART, F. AND HESTER, A.J. The impact of red deer on woodland and heathland dynamics in Scotland, *In: "Population Ecology*, Management and Welfare of Deer" Eds. C.R. Goldspink, S. King, and R.J. Putman. The Manchester Metropolitan University, Manchester, pp54-60.

CONFERENCE PAPERS

BARTHRAM, G.T, MARRIOTT, C.A. AND BOLTON, G.R. Leaf growth and senescence in intensively and extensively managed swards grazed by sheep, *Occasional Publication No.3. of Concerted Action AIR3-CT93-0947*, Pasture Ecology and Animal Intake, Proceedings of a workshop, Dublin, September 24-25, 1996.pp76-81

BUCKLAND, S.T, TRENKEL, V.M, ELSTON, D.A, PARTRIDGE, L.W. AND GORDON, I.J. A decision support system for red deer managers in Scotland, *In: Goldspink C.R.*, King, S.and Putman, R.J. (eds.) Population Ecology, Management and Welfare of Deer: Proceedings of the Third Deer Symposium Manchester 1997. Published by Dept Biological Sciences, Manchester Metropolitan University. pp82-87.

CHRISTIE, M, STEE, W. AND CRABTREE, J.R. An economic evaluation of the provision of recreational opportunities in the countryside: a case study of Grampian Region, *International Seminar on Marginal Regions*, Inverness/Stornoway, 12th July 1997.

CRABTREE, J.R. AND BARRON, N-J. ESAs: Cost benefit for the taxpayer, *British Grassland Society Conference*, "Grassland Management in the ESAs", September 1997.

CRABTREE, J.R. AND MACDONALD, D. Land abandonment in mountain areas of Europe: environmental impact and policy development, *2nd International Conference of the European Society for Ecological Economics*.

D'HOUR, P, REVILLA, R. AND WRIGHT, I.A. Possible adjustments of suckler herd management to extensive situations, *Elevase*, Espace et Environment. (Livestock farming, land use and environment). Annales de Zootechnie, 47, 453-463.

D'HOUR, P, REVILLA, R. AND WRIGHT, I.A. Adaptations possibles de la conduite du troupeau allaitant aux situations extensives, *INRA Produccion Animales 11*, 379-386

DENNIS, P. AND PAKEMAN, R. Agricultural management options for protecting and enhancing biodiversity, *Electronic Conference on Research and Biodiversity*. European Union/Ministry of Environment, Catalonia. http://www.gencat.es/medizimb/biod/

DENNIS, P, DOWNIE, I.S, MILLIGAN, A.L, ABERNETHY, V.J, MCCRACKEN, D.I, FOSTER, G.N, MURPHY, K.J, WATERHOUSE, A. AND FURNESS, R.W. Modelling plant and animal diversity in a Scottish catchment devoted to agriculture, *In: Key Concepts in Landscape Ecology (eds. J.W. Dover*, and R.G.H. Bunce), IALE (UK), Myerscough College, Preston, 1998. (Proceedings of the 1998 European Congress of IALE, Preston, UK), pp161-166.

DUNCAN, A.J. Extensification in a cold climate: implications for thermal balance in sheep, *Proceedings of an EU Workshop "The implications of extensification for the health and welfare of beef cattle and sheep. 5-6 March*, 1998, Aberdeen. Goddard, P.J. (Ed), pp25-28.

DUNCAN, A.J, FRUTOS, P. AND KYRIAZAKIS, I. Conditioned food aversions to oxalic acid in the food plants of sheep and goats, *International Symposium on Poisonous Plants*, SanAngelo, Texas. May 18-23, 1997.

DUNN, S.M. Large scale hydrological modelling using small scale processes, *Hydrology in a Changing Environment*, Volume 1. Ed. H. Wheater and C. Kirby, pp11-20, John Wiley.

DUNN, S.M. AND LANGAN, S.J. Climate, snow and the water resources of a major Scottish river, *Proceedings*, Second International Conference on Climate and Water, Espoo, Finland, August 1998. Volume 1, pp178-187.

DUTHIE, G.G. AND MCPHAIL, D.B. Comparison of plant phenolics in model systems and in-vivo, *2nd International Conference on Natural Antioxidants and Anticarcinogens in Nutrition Health and Disease*.

ERHARD, H.W, MENDL, M. AND VAN SCHOTHORST, L. Qualitative and quantitative effects of handling on tonic immobility in pigs, *Proceedings of the 32nd International Congress of the International Society for Applied Ethology*, 21-25 July 1998, Clermont-Ferrant, France.

FRUTOS, P, WRIGHT, I.A, MANTECON, A.R, GIRALDEZ, F.J. AND IASON, G.R. Seasonal variation in nutrition and supplementation in extensive sheep systems in North Central Spain, *The implications of extensification for the health and welfare of beef cattle and sheep. (ed. P.J. Goddard). Macaulay Land Use Research Institute*, Aberdeen, pp17-23.

STAFF PUBLICATIONS

GEDDES, A. Integrating Scottish land cover and agricultural statistics data, *1998 Royal Geographical Society / Institute of British Geographers Conference.*

GODDARD, P.J. AND MATTHEWS, L.R. Stress and animal welfare, *Proceedings of the Third World Congress on the Biology of Deer*, Edinburgh, pp336-346.

GORDON, I.J. AND HOPE, I.M. The future management of red deer in Scotland: Aiding decision making in a complex world, *In: Goldspink CR.*, King S. and Putman RJ (eds.) Population Ecology, Management and Welfare of Deer: Proceedings of the Third Deer Symposium, Manchester 1997. Published by Dept. Biological Sciences, Manchester Metropolitan University, pp79-81.

GORDON, I.J, WELCH, D, HESTER, A.J. AND CLARKE, J.A. The foraging behaviour of red deer (*Cervus elaphus*) and sheep (*Ovis aries*) on vegetation mosaics, *In : Recent Developments in Deer Biology*, Proceedings of Third International Congress on the Biology of Deer, 1994, pp284.

GRAYSTON, S.J, CAMPBELL, C.D, BARDGETT, R.D, MAWDSLEY, J.L, GRIFFITHS, G.S, RODWELL, J.S, DAVIES, W.M. AND EDWARDS, S.J. Biodiversity of soil microbial communities across a range of grasslands differing in management intensity, *Abstracts of the Society for Experimental Biology Annual Meeting*, York, March 1998

HANLEY, N, SIMPSON, I, PARSISSON, D, WRIGHT, R, MACMILLAN, D.C, CRABTREE, J.R. AND BULLOCK, C. Choice experiments versus contingent valuation : valuing the conservation benefit of ESAs in Scotland, *Agricultural Economics Society Conference*, Edinburgh, March 1997.

HANLEY, N, SIMPSON, I, WRIGHT, R, MACMILLAN, D.C, BULLOCK, C. AND CRABTREE, J.R. Valuing the landscape and wildlife benefits of woodlands in an agricultural context, *International Symposium of the Non-Market benefits of Forestry. Forestry Commission*, Edinburgh.

HARLEY, D, MACMILLAN, D.C. AND MORRISON, R. Cost-effectiveness of new native pinewoods for nature conservation, *International Symposium on Non-Market Benefits of Forestry*, Edinburgh, 1996.

HELLIWELL, R.C, FERRIER, R.C, JENKINS, A. AND SOULSBY, C. Influence of altitude on bulk and enhancement deposition in the Cairngorm mountains, Scotalnd, *Headwater '98*, MERAN, 20-23 April 1998. Headwater Control IV : Hydrology, Water Resources and Ecology in Headwaters, pp209-212

LAMB, A.J, GAULD, J.H, REID, D.C, LILLY, A, MCGAW, B.A. AND CURNOW, J. Microbiological risk assessment of private water supplies, *Workshop of Royal Environmental Health Institute of Scotland*, Annual Congress, Inverness, June 1998.

LANGAN, S.J. Acidification : assessing environmental damage and recovery prospects, *National society for Clean Air*, Environmental Protection Conference, Glasgow, 20-23 October 1997.

LILLY, A. The influence of soils and land use on groundwater quality, *The Royal Environmental Health Institute of Scotland Magazine*, 10(5), pp4-6.

MACKIE-DAWSON, L.A, LAVENDER, E.A. AND ATKINSON, D. The effect of nitrogen, phosphorus and mycorrhizal infection on root and shoot growth of two contrasting genotypes of *Betula pendula* Roth, *In: Root demographics and their efficiencies in sustainable agriculture*, grasslands and forest ecosystems. Proc. of the 5th Symp. of the Int. Soc. of Root Research, 1996, Clemson University, South Carolina, USA. (ed. J.E.Box). Dordrecht, Kluwer, pp165-175

MACMILLAN, D.C. Non-market benefits of restoring native woodlands, *International symposium on the non-market benefits of forestry*, Edinburgh, 1996

MACMILLAN, D.C, SMART, T.S. AND THORBURN, A.P. A comparison of real and hypothetical donations when incentives to free ride and over-bid are equivalent across surveys, *Paper presented at AES Conference*, University of Reading

MACMILLAN, D.C, SMART, T.S. AND THORBURN, A.P. A comparison of real and hypothetical donations when incentives to free ride and over-bid are equivalent across surveys, *Paper presented at World Congress of Environmental and Resource Economists*, Venice.

MENDL, M, ERHARD, H.W. AND CHRISTIANSEN, S.B. No evidence for strong links between personality traits in pigs, *Proceedings of the 32nd International Congress of the International Society for Applied Ethology*, 21-25 July 1998, Clermont-Ferrant, France.

MILNE, J.A, SIBBALD, A.R, FARNSWORTH, K.D. AND BIRCH, C.P.D. HILLPLAN - a decision support tool for predicting the impact of grazing ruminants on animal production and vegetation changes in temperate grasslands and rangelands, *The Earth's Changing Lland*, GCTE Science Conference, Barcelona, 14-18 March 1998, pp141-142.

PEREZ-BARBERIA, F.J. AND GORDON, I.J. The influence of sexual dimorphism in body size and mouth morphology on diet selection and sexual segregation in Cervids, *Acta Veterinaria Hungarica*, 46(3), 357-367

SHAND, C.A, CHESHIRE, M.V, HILLIER, S.J, NEWBAUER, C. AND ROSEN, K. Plant availability of radiocaesium in contaminated organic soils, *Society of Environmental Toxicology and Chemistry (SETAC) Conference*, Bordeaux, 8th Annual Meeting, 14-18 April 1998, p61.

SIBBALD, A.M, WRIGHT, I.A. AND SIBBALD, A.R. Some factors affecting grazing behaviour and diet selection of livestock grazing hill areas of Northern Europe, *In: Pasture Ecology and Animal Intake*, Proceedings of EU Concerted Action AIR3-CT93-0947 Workshop, (ed. M.G.Keane and E.G.O'Riordan), pp38-45, Dublin, Ireland.

WADE, A.J, LANGAN, S.J, SOULSBY, C, SMART, R, EDWARDS, A.C, JARVIE, H.P. AND CRESSER, M.S. Impacts of land use and flow on nitrate concentration and fluxes of an upland river system in North East Scotland, *Headwater '98. Water Resources and Soil Conservation. International Interdisciplinary Conference*, Merano, Italy. Chapter 46, pp127-137

WHERRETT, J.R. Managing scenic resources : modelling natural landscape preferences, *Resource Technology 98*, Nordic Rovanierni, Finland.

WRIGHT, G.G. Remote sensing and environmental land use planning, *Remote Sensing Applications in GIS*, AGI/RS Conference at University of Greenwich, 18th June, 1998.

WRIGHT, I.A. Identifying biological constraints acting on livestock systems in marginal areas, *Livestock Systems in European Rural Development. Proceedings of the 1st Conference of the LSIRD network*, Nafplio, Greece. (eds. J.D. Laker and J.A. Milne). Macaulay Land Use Research Institute, Scotland, pp11-18.

STAFF PUBLICATIONS

CONFERENCE POSTERS/ABSTRACTS

ASPINALL, R.J. AND BIRNIE, R.V. Modelling future patterns of land use change : a case study of afforestation in Scotland, *Proceedings of "Earth's Changing Land". GCTE-LUCC Open Science Conference on Global Change*, 14-18 March 1998, Barcelona.

ATKINSON, D, BLACK, K, FORBES, P, GRAYSTON, S, HODGE, A, HOOKER, J, MILLARD, P. AND MUNRO, M. The effects of climate change on plants and mycorrhizal development, *SCI Conference on Climate Change*, London.

ATKINSON, D, MACKIE-DAWSON, L.A, LAVENDER, E.A. AND BLACK, K.E. Root growth and development in woody perennials, *Woody Root Meeting*, Bordeaux, July 1998.

BAIN, D.C. The influence of mineralogy on the effects of acid deposition in Scottish catchments, *International Soil Science Society. World Congress 1998. (Abstract)*

BAUSENWEIN, U, MILLARD, P, THORNTON, B. AND RAOEN, J. The origin of nitrogen for spring growth in three common grassland species, *Abstract for 1998 SEB Annual Meeting*, York, March 1998. Journal of Experimental Botany, 49, pp43(Supplement).

BIRNIE, R.V. Assessing the potential for short rotation coppice in Scotland : a GIS-based approach, *The Rank Prize Funds Symposium on "Energy in Agriculture"*, 30th March-2nd April 1998.

BULLOCK, C.H. AND MCHENRY, H.L. A way forward for environmentally sensitive farming that meets the needs of public and farmer, *British Grassland Society Conference Proceedings*

BUTCHER, C.S, MATTHEWS, K.B. AND SIBBALD, A.R. The implementation of a spatial land allocation decision support system for upland forms in Scotland, *European Society for Agronomy - 4th Congress*, Wageningen, Veldghaven, The Netherlands, 7-11th July 1996

CHAPMAN, P.J, EDWARDS, A.C. AND REYNOLDS, B. Speciation of soluble nitrogen in surface waters: The significance for sensitive upland streams, *Second Euroconference on Environmental Analytical Chemistry for the Protection of Sensitive Ecosystems*, Cordoban, Spain, October 31 - November 6th 1998.

CHAPMAN, P.J, EDWARDS, A.C, REYNOLDS, B, CRESSER, M.S. AND NEAL, E. Nitrogen concentrations in upland rivers of Britain: Contibution made by organic forms, *BHS Conference on Hydrology in a Changing Environment. 6-10 July 1998*

CHAPMAN, S.J, CAMPBELL, C.D, NORRIE, A. AND DAVIDSON, M.S. Community substrate induced respiration, *ISME 8 Conference*, Halifax, Canada, 9-14 August 1998. (Poster abstract)

CHEN, B, BECKETT, R. AND SHAND, C.A. FFF-ICP-MS Assessment of the distribution of extractable metals in the clay-sized material from a soil amended with contaminated sewage sludge, *Seventh International Symposium on Field Flow Fractionation (FFF '98)*, Utah, 8-11 February, 1998.p8.

CRABTREE, J.R. AND MILNE, J.A. Applications of actions for environmentally sensitive areas : Examples in Scotland, *Proceedings of the First International Symposium on Research into the Management of Sensitive Rural Areas (European Uplands)*, France, 27-30 April 1998.

DAWSON, L.A, THORNTON, B. AND GASTAL, F. Resource capture and biomass partitioning within semi natural grassland species, *Abstract for the 1998 SEB Annual Meeting*, York, March 1998. Journal of Experimental Botany, 49, pp37 (Supplement)

DOMBURG, P, EDWARDS, A.C. AND SINCLAIR, A.H. A comparison of N budgets for three farm types in NE Scotland, *SCI Meeting on Managing Nitrogen in Crop Rotations.*

DUNHAM, R, BENHAM, T, WRIGHT, G.G, MILLER, D. AND WRIGHT, R. HYDALP : integrating EO data with snow melt models, *ERDAS UK Users Group Meeting*, Cambridge, September 1998.

DUNHAM, R, WRIGHT, G.G. AND MILLER, D.R. Integration earth observation data with the snow melt runoff model, *4th SRM Workshop*, University of Berne, Switzerland, 29 June - 3rd July 1998, Berne.

DUNHAM, R.A, MILLER, D.R. AND BROADGATE, M.L. A decision Support Demonstrator for abiotic damage to trees using a WWW interface, *Extended abstracts GIS Research UK*, 6th National Conference, Edinburgh

EDWARDS, A.C, COOK, Y, SMART, R. AND WADE, A. Nutrient transfers from terrestrial to aquatic components of the Dee catchment NE Scotland: a question of timing, transport and ratios?, *Abstract for BES meeting January 1999*, as part of final report on NERC Large Scale Processes Project.

ELFOUL, L, RABOT, S, DUNCAN, A.J, GODDYN, L, KHELIFA, N. AND RIMBAULT, A. Metabolisme des glucosinolates par une souche intestinale humaine. Bacteroides tuetaiotaomicron chez des rats guotoxeniques, *Annual Meeting of "l'Association Francaise de Nutrition"*, Paris, November 1997.

ELFOUL, L, RABOT, S, DUNCAN, A.J, GODDYN, L, KHELTA, N. AND RIMBAULT, A. Glucosinolate metabolism by the human intestinal bacterial strain, Bacteroides thetaiotaoinicron in gnotobiotic rats, *Second International conference at "Agri Food Quality II"*, Turku, Finland, April 1998.

FARNSWORTH, K.D. Acquisition and analysis of GPS data for animal ranging studies, *Ungulate Research Group Abstracts*, 1997

GIMONA, A. AND BIRNIE, R.V. Construction and visualisation of a resource landscape for bird populations, *European meeting of the International Association for Landscape Ecology (IALE)*, 3-5 September 1998.

GIRVAN, M.S, GLOVER, L.A, KILLHAM, K, PROSSER, J.I. AND CAMPBELL, C.D. The study of Eubacterial Community change over time with respect to pollutant pressure, *8th International Symposium of Microbial Ecology*, Nova-Scotia, 14th-18th August 1998. Proceedings.

GOTTS, N.M. Describing the topology of spherical regions using The "RCC" formalism, *Proceedings of Mind III: Annual Conference of the Cognitive Society of Ireland*, Dublin City University, 17-19 August 1998.

GRAYSTON, S.J, CAMPBELL, C.D, GRIFFITHS, G.S, MAWDSLEY, J.L AND BARDGETT, R.D. Regulation of soil microbial communities of temperate upland grasslands, *Abstracts of the 8th International Symposium on Microbial Ecology (ISME8)*, Halifax, Nova Scotia, August 1998.

GRELET, G.A, MILLARD, P, ALEXANDER, I.J. AND FROSSARD, J.S. Storage and remobilisation of nitrogen in relation to carbohydrate partitioning in Vaccinium species, *Abstract for the 1998 SEB Annual Meeting*, York, March 1998. Journal of Experimental Botany 49, pp42 (Supplement).

GUSTAFSSON, J.P, SIMONSSON, M, BERGGREN, D. AND LUMSDON, D.G. Aluminium solubility in the spodic B horizon and

STAFF PUBLICATIONS

its relationship with pedogenesis and acidification, *Biogeomon Conference*, Abstracts, 2, 190.

HANLON, A.J, RHIND, S.M, REID, H.W, BURRELLS, C, LAWRENCE, A.B, MILNE, J.A. AND MCMILLEN, S.R. Comparative immunity of weaned red deer calves derived from wild and farmed stock, *In: Recent Developments in Deer Biology (Ed. J. Milne) Proceedings of the 3rd International Congress on the Biology of Deer*, Sept 1994, Edinburgh, MLURI, Aberdeen.

HILLIER, S. Accurate quantitative clay mineral analysis of sandstones by XRD, comparison of a Rietveld and an RIR approach and the importance of sample preparation, *6th Cambridge Diagenesis Conference*, 1998

KOSTIC, N, WILSON, M.J, ZIVKOVIC, M. AND BAIN, D.C. Mineralogy and geochemical speciation of heavy metals to some serpentine soils of Serbia, *Proceedings of the World Congress of Soil Science*, Montpellier.

LAWRENCE, A.B. AND WRIGHT, I.A. Synopsis of workshop discussion - "Land usage", *The Potential Role of Rare Livestock Breeds in UK Farming Systems (ed. R. M. Lewis)*, British Society of Animal Science Meeting and Workshop Publication.

LEMAIRE, G. AND MILLARD, P. Ecophysiological approach to C and N resource fluxes in plant competition, *Abstract for the 1998 SEB Annual Meeting*, York, March 1998. Journal of Experimental Botany, 49, pp37 (Supplement).

LILLY, A. AND WOSTEN, J.H.M. Development and use of a database of measured soil hydraulic properties for European soils, *In: Land Information Systems: Developments to planning the sustainable use of land resources. H.J. Heineke*, W. Eckelmann, A.J. Thomasson, R.J.A. Jones, L. Montanarella and B. Buckley, Eds. European Soil Bureau Research Report No.4. ESB/JRC.

LILLY, A, BALL, B.C, MCTAGGERT, I.P. AND HORNE, P.L. Regional modelling of nitrous oxide emissions, *British Soil Science Society Annual Conference*, Belfast.

MARRIOTT, C.A. AND CARRERE, P. Structure and dynamics of grazed vegetation, *1st International Symposium on Research into the Management of Sensitive Rural areas (European Uplands)*, Clermont Ferrand, France, April 1998.

MATTHEWS, K.B. AND SIBBALD, A.R. Implementation of a spatial decision support system for rural land use planning : integrating GIS and environmental models with search and optimisation algorithms, *First International Conference on Geospatial Information in Agriculture and Forestry*, Lake Buena Vista, Florida, 1st-3rd June 1998.

MCINROY, S.G, CAMPBELL, C.D, HAUKKA, K.E, ODEE, D.W, SPRENT, J.I, WANG, W-J, YOUNG, J.P.W. AND SUTHERLAND, J.M. Rhizobia from African acacis and other tropical woody legumes : characterisation using Biolog and partial 16S or RNA sequencing, *8th Congress of the African Association for Biological Nitrogen Fixation*, University of Capetown, South Africa, 23-27 November 1998.

MIDWOOD, A.J, BOUTTON, T.W. AND ARCHER, S.R. ^{2}H and ^{18}O of plant and soil water in a subtropical savanna parkland: Vertical stratification of soil water acquisition and plant response to rainfall, *Application of stable isotope techniques to ecological studies*, Meeting Proceedings, Environment Canada, Saskatoon, Canada, 1998.

MILLARD, P. Uncoupling tree growth form resource acquisition: The role of storage and remobilisation of nutrients, *Abstract for the 1998 SEB Annual Meeting*, York, March 1998. Journal of Experimental Botany, 49, pp40 (Supplement).

MILLARD.P, NEILSEN, D. AND TAGLIAVINI, M. Internal cycling of nitrogen in deciduous fruit trees, *Workshop on Physiological and mechanical directions ecocompatible for fruit tree nutrition. 27th International Exhibition of Mechanical Industry for Agriculture*, 12 November 1996.

MILNE, J.A. AND SIBBALD, A.R. Modelling of grazing systems at the farm level, *Proceedings of the First International Symposium on Research into the Management of Sensitive Rural Areas (European Uplands)*, Clement Ferrantd, France, 27-30 April 1998. Ann. Zootech. 47, 407-417.

NWAIGBO, L.C, HUDSON, G, SIBBALD, A.R. AND MILLER, H.G. Spatial patterns of N, P and K at the tree scale in a grazed silvopastoral system, *First International Symposium on Research into the Management of Sensitive Rural Areas (European Uplands); Adopting livestock production to the new demands made on grasslands in disadvantaged areas. Published as Annales de Zootechnie*, 47(5-6), pp512.

OESS, A, VEDY, J.C, SPACK, L, ALAILI, M. EL, CHESHIRE, M.V, MCPHAIL, D. AND STOLL, S. Dynamics of phenols in an alpine ecosystem and its relation to heavy metal mobilisation and immobolisation, *16th World Congress of Soil Science*, Montpellier.

PATERSON, E, TOWERS, W. AND VISSER-LYONS, H. Development of a site selection strategy to monitor changes in soil quality, *Scottish Soils Discussion Group Meeting.*

PATERSON, E, TOWERS, W. AND VISSER-LYONS, H. Development of a sampling strategy to monitor changes in soil quality, *Soil Monitoring for the UK*, Cranfield University, March 1998

PRIHA, O, GRAYSTON, S.J, PENNANEN, T. AND SMOLANDER, A. Microbial communities in the rhizospheres of *Pinus sylvestris*, *Picea abies* and *Betula pendula, Abstracts of the 8th International Symposium on Microbial Ecology (ISME8)*, Halifax, Nova Scotia, August 1998.

PROE, M.F, CRAIG, J, MCKAY, H, GRIFFITHS, J. AND DENHAM, S. Changes in soil parameters associated with whole-tree harvesting on a site with major treatment effects on the growth of Sitka spruce, *IUFRO Conference : Indicators for Sustainable Forest Management*, Abstract. Centre for Forest Tree Technology, Melbourne, Australia, pp153-155.

QUARTIERI, M, TAGLIAVINI, M, MARANGONI, B, CONCARI, G, MALAGUTI, M. AND MILLARD, P. Internal cycling of nitrogen in peach trees, *Atti IV Gironate Scieutifiche S.O.L. 1998*, pp389-390

RIGOL, A, VIDAL, M, RAURET, G, SHAND, C.A. AND CHESHIRE, M.V. Competition of organic and mineral phases in radiocaesium partitioning in organic soils of Scotland and the area near Chernobyl, Environmental Science and Technology, 32, 663-669

SIBBALD, A.R, HISLOP, A.M, DICK, J, ELSTON, D.A, IASON, G.R, NWAIGBO, L.C. AND HUDSON, G. Soil-plant-animal interactions in the establishment phase of a silvopastoral system in NE Scotland, *First International Symposium on Research into the Management of Sensitive Rural Areas (European Uplands): Adapting livestock production to the new demands made on grasslands in disadvantaged areas. Published as Annales de Zootechnie*, 47(5-6), pp512.

SIBBALD, A.R, CLEMENTS, V, CAMPERO, V. AND DALZIEL, A.J.I. Tree growth form in the establishment phase of a silvopastoral system in North East Scotland, *First International Symposium on Research into the Management of Sensitive Rural Areas (European Uplands): Adapting livestock production to the new demands made on*

STAFF PUBLICATIONS

grasslands in disadvantaged areas.Published as Annales de Zootechnie, 47(5-6), pp513.

SKELSEY, C.D.AND MATTHEWS, K.B. AI techniques for land use science, *Gensym Users Society Meeting*, Newport Rhode Island, 13th-15th May 1998.

TALKKARI,A, DUNHAM R.A, MILLER, D.R.AND BROADGATE, M.L. A World Wide Web based demonstrator of a forest damage risk decision support system, *Resource Technology '98 Nordic*, Rovaniemi, Finland

THORNTON, B.AND BAUSENWEIN, U. Seasonal protease activity of storage tissue in a deciduous grass, *Abstract for Annual Meeting of the Society of Experimental Biology*,York, March 1998. Journal of Experimental Botany, 49, pp42 (Supplememt).

TOWERS,W.AND CAMPBELL, C.D. Recycling distillery wastes to land opportunities and constraints, *Abstracts of "Profiting from Technology"*, Institute of Brewing Conference, Aviemore, May 1998.

WALSH, M.F, PARSONS, R, SPRENT, J.I.AND MILLARD, P. A potential bark storage protein in *Alnus glutinosa*, *Abstract for the SEB Annual Meeting*,York, March 1998. Journal of Experimental Botany, 49, pp60 (Supplement).

WHERRETT, J.R. Scenic landscape evaluation : combining visualisation and predictive preference modelling, *GISRUK 1998*, Edinburgh.

WIKLUND, E, GODDARD, P.J, REHBINDE, C.AND MALMFORS, G. Blood metabolites and ultimate pH values of transported reindeer bulls, *IV International Deer Biology Congress*, Kaposvar, Hungary.

WILLIAMS, B.L. Environmental factors influencing fate of inorganic N in soils beneath natural vegetation, *Abstracts of International Conference on Nitrogen Deposition*, Netherlands.

WOSTEN, J.H.M, LILLY,A, NEMES,A.AND LE BAS, C. Use of soil hydraulic pedotransfer functions for the assessment of soil quality on a European scale, *Symposium 1 of the 16th World Congress of Soil Sciences*.

TECHNICAL AND CONTRACT REPORTS

BAIN, D.C. Water-rock interaction. *Report to MDT on Ninth International Symposium held at Taupo*, New Zealand. 30 March 3 April 1998.

BAIN, D.C. Effects of afforestation of agricultural land on heavy metal mobility in soil, *EU Progress Report*

BELL, J.S. The soils and land capability for agriculture of a site at Waggon Road, Crossford, near Dunfermline, *Report prepared for Wimpey Homes*.

BELL, J.S. The soils and land capability for agriculture of a proposed development site, *Report prepared for UK Waste*.

BELL, J.S. Soils and land capability for agriculture of the proposed opencast coal extraction site at Bogleys Farm, Kirkcaldy. *Report prepared for J.W.H. Ross & Co.*

BELL, J.S. The soils and land capability for agriculture of a proposed opencast coal extraction site at Bogleys and Bogwells farms, Kirkaldy, *Report prepared for J.W.H. Ross & Co.*

BELL, J.S. The soils and land capability for agriculture of Kinknockie and Auchnacant Farms, *Report prepared for Mr.A. Sinclair (Farmer)*.

BELL, J.S. The soils and land capability for agriculture of a site at Pinkie Mains, Musselburgh, *Report prepared for Wimpey Homes*.

BELL, J.S. The soils and land capability for agriculture of three sites on Gortonlee Farm, Rosewell, *Report prepared for H.J. Banks and Co. Ltd.*

BERESFORD, N.A. MAYES, R.W, COLGROVE, P.M. BARNETT, C.L, DODD, B.A, MACEACHERN, P.J, LAMB, C.S.AND BRYCE, L. The effectiveness of alginates to reduce the transfer of radiostrontium to the milk of dairy animals, *Final Report to Ministry of Agriculture*, Fisheries and Food. Institute of Terrestrial Ecology (NERC). MAFF Project RP0243, 40pp.

BERESFORD, N.A, MAYES, R.W, CROUT, N.M.J, DAWSON, J.M, MACEACHERN, P.J, DODD, B.A, SOAR, J.B, BARNETT, C.L.AND LAMB, C.S. Transfer of heavy metals from feeding stuffs and environmental sources into meat, milk and other foods of animal origin. Part II - Lead, *Final report to Ministry of Agriculture*, Fisheries and Food, Institute of Terrestrial Ecology (NERC). Project No. T07051X1, MAFF Contract No.: FS2179.

BROADGATE, M.L.AND WRIGHT, G.G. Report on water balance and evapotranspiration. Technical Report WP332; ENV4-CT96-03634, *EU Technical Report for CEO*

BROOM, G, CRABTREE, J.R, HILL, G.AND ROBERTS, D. Socio-economic impact or natura 2000 - site designation, *Contract report to Scottish Office*.

BROOM, G.F, CRABTREE, J.R, ROBERTS, D.AND HILL, G. Socio-economic benefits from Natura 2000, *Report to Scottish Office*

CAMPBELL, C.D. Report on follow up site visit to La Ladera and comments on workshop, *Confidential Report*

CAMPBELL, C.D. Chemical and physical analysis of plant material from Venezuela, *Confidential Report*.

CAMPBELL, C.D, LUMSDON, D.G.AND GAULD, J.H. Mine reclamation project, Brazil - a technical review of contract tenders, *Confidential Report*.

CAMPBELL, C.D, LUMSDON, D.G.AND SMITH,A. Bioremediation of oil well drill cuttings and their potential for recycling to land, *Confidential Report*.

CAVES, R, MILLER, D.R, NADLER, T,VOIGHT, S, BROADGATE, M. AND WRIGHT, G.G. RM3 - Report on remote sensing methods, *EU Technical Report for CEO (RM3*, ENV4-CT96-03634).

CHAPMAN, S.J.AND CAMPBELL, C.D. Effects of native woodland expansion on soil carbon balance,Abernethy Forest, *Draft Report to SNH*.

CUMMINS, R, GAULD, J, HEWISON, R, MILLS, C, REES, T, ELSTON, D.AND PICOZZI, N. Monitoring environmentally sensitive areas in Scotland. Report for 1997-1998, *SOAEFD*.

DAVIS,A, FERRIER, R.C, EDWARDS,A.C, MCMILLAN, D.C.AND MALCOLM,A. Eutrophication of Loch Davan and remedial management options, *Final Report to SNH (Phase I)*.

DOMBURG, N, EDWARDS,A.C, DUNN, S.M, CHALMERS, N, FERRIER, R.C, MCALISTER, E,WRIGHT, G.G, SINCLAIR,A.H, BOORMAN, D.AND JENKINS,A. Predictive modelling of eutrophication within the River Ythan catchment and development of an integrated management plan, *Final Report to SOAEFD*.

STAFF PUBLICATIONS

DUNHAM, R, MILLER, D, BROADGATE, M. AND LAW, A. STORMS: Participant report - January 1995-January 1998, *Technical Report to EU.*

DUNHAM, R, MILLER, D, LAW, A. AND BROADGATE, M. STORMS Participant 05 (MLURI). Exploitation Report, *EU. DGXII - Contract Report*

EDWARDS-JONES, G, OGLETHORPE, D, DOYLE, C, MARSHALL, K, MOXEY, A. AND SIBBALD, A.R. Modelling environmental impacts of land use change, *Contract Progress Report*, March 1998, to D.E.T.R.

EDWARDS-JONES, G, OGLETHORPE, D, MARSHALL, K, DOYLE, C, MOXEY, A. AND SIBBALD, A.R. Modelling the environmental impacts of land use change, *Final Contract Report prepared for the Department of Environment*, Transport and the Regions

FARRINGTON, J, GRAY, D, MARTIN, S. AND ROBERTS, D. Car dependence in rural Scotland : challenges and policies, *Final report to the Scottish office.*

FERRIER, R.C, LITTLEWOOD, I.G, HIRST, D. AND WATTS, C.D. Review of Harmonized Monitoring Scheme Scotland 1974-1994. Final report, *Scottish Office Environment Protection Unit.*

GAULD, J.H. Soils and land capability for agriculture proposed opencast coal extraction site at Gourlaw Farm, Midlothian District, Lothian Region, *Scottish Coal*

GIBON, A. AND SIBBALD, A.R. Report of the EAAP Working Group on livestock farming systems, *Livestock Production Science*, 55, 171-172

HALL, J, BULL, K, BRADLEY, I, CURTIS, C, SMITH, P.F, HORNUNG, M, HOWARDS, D, LANGAN, S.J, LOVELAND, P, REYNOLDS, B, ULLJETT, J. AND WARR, T. Status of UK critical loads and critical land maps (Part 1), *DETR and UNECE Status Report*

HESTER, A.J, IASON, G.R, STOLTE, A. AND SIM, D. 1997 Vegetation survey; Abernethy Forest RSPB Nature Reserve, *Contract report to RSPB*

HILLIER, S. Report of the validation of the "Methods for quantitative phase analysis by XRD of random powder samples" (Method J024), *Internal technical report for the purposes of NAMAS accreditation.*

HILLIER, S. Report on the validation of the "Methods for quantitative analysis by XRD of clay minerals in orientated specimens" (Method J022), *Internal technical report for the purposes of NAMAS accreditation.*

HODSON, M.E. AND LANGAN, S.J. The calculation of weathering rates in relation to the determination of critical loads of acidity, *Final report to National Power*

LAMB, A.J, REID, D.C, LILLY, A, GAULD, J.H, MCGAW, B.A. AND CURNOW, J. Improved source protection for private water supplies : Report on the development of a microbiological risk assessment approach, *Report to Scottish Office*

LANGAN, S. Aspects of base cation releases and weathering in relation to the calculation of critical loads for acidity in normal soils, *Final Contracted Report for Department of Environment*, Transport and Regions.

LANGAN, S.J. AND WADE, A. Report for Ballogie Estates environmental and water quality data for the Birse, Beltie and Callie sub-catchments of the River Dee, North East Scotland, *Contract Report*

MILLER, D.R. AND MORRICE, J.G. Assessing the visibility of Cemaes B, *Submission to Public Enquiry*, Welsh Office, July 1998.

MILLER, D.R, WRIGHT, G.G. AND DUNHAM, R. WP311 - Extraction of catchment characteristics : Review of methods and improvements, *EU Technical report for CEO (RI311*, ENV4-CT96-03634)

MILLER, J.D. AND ANDERSON, H.A. The sustainability of afforestation development within Highland catchments supporting important salmonid fisheries, *Report to FC*, SNH and CASE. Part sections by SEPA, FFL and FC.

MILLER, J.D, DUFF, E, HIRST, D, ANDERSON, H.A, BELL, J.S. AND GAULD, J.H. Sampling strategies for ECN soil profiles, *SOAEFD - report on Flexible Fund 537596. ECN.*

MILNE, J.A. AND SOUCHET, C. Consolidated Progress Report for EC Contract " Increased competitiveness of high quality European animal fibres by improving fibre quality, *European Commission.*

MILNE, J.A, BIRCH, C.P.D, HESTER, A.J, ARMSTRONG, H.M. AND ROBERTSON, A. The impact of vertebrate herbivores on the natural heritage of the Scottish uplands - a review, *Scottish Natural Heritage*, No.95, pp1-127.

MORGAN-DAVIS, J, WRIGHT, G.G. AND MILLER, D.R. WP 224 Hydromet database for BASUK, *Internal Report DI224-HYDALP.*

NOLAN, A.J, GILLICK, T.H. AND SELLERS, J.E. The status of heather (*Calluna vulgaris*) on the Ronas hill - North Roe SSSI, Shetland, *A report for Scottish Natural Heritage.*

PATERSON, E, TAYLOR, A.G, CAMPBELL, C.D, HUDSON, G. AND GAULD, J.H. Development of a framework for soil monitoring for state of the natural heritage reporting, *Scottish Natural Heritage Review. MRCS Contract Report.*

PROE, M.F. Growth response to whole tree harvesting, *EU Concerted Action No. AIR3 CT94-2122. Final report. Tree Nutrition : Sustainability of Wood Production in Relation to Harvesting and Remedial Fertilisation. pp80-86*

ROBERTS, D. An evaluation of the economic impact of "Signpost: Cornwall and the Isles of Scilly.", *Final Report*, West Cornwall Leader Group.

ROTT, H, QUEGAN, S, BAUMGARTNER, M, FERGUSON, P. AND MILLER, D.R. Internal Report RPRG. Three monthly progress report 6 : August 1998, *EU*, CEO.

ROTT, H, QUEGAN, S, BAUMGARTNER, M, FERGUSON, R. AND MILLER, D. HYDALP : Progress Report RPR, *EC Report*

ROTT, H, QUEGAN, S, BAUMGARTNER, M, FERGUSON, R. AND MILLER, D.R. HYDALP: Internal Report - 3 Monthly Progress Report 3 : November 1997, *European Community CEO*

RUSSEL, A.J.F. Research on the production of high quantity cashmere from goats and its potential for agricultural diversification, *Final report to European Commission on Contract No. AIR3-CT94-0822*

STOLTE, A.M, HENDERSON, D.J. AND NOLAN, A.J. Assessment of impacts on upland habitats for North-East and South-West sections of Cairngorm/Speyside Deer Management Group Area, *Deer Commission for Scotland (MLURI Technical report - restricted circulation).*

STOLTE, A.M, NOLAN, A.J, HENDERSON, D.J. AND HORSFIELD, D. Overall impact of grazing and trampling, Cairngorm/Speyside

STAFF PUBLICATIONS

Deer Management Group Area, *A report for the Deer Commission for Scotland and Scottish Natural Heritage. MLURI Technical Report.*

TOWERS, W, MALCOLM, A. AND HESTER, A.J. Mapping the potential distribution of NVC woodland types in the Angus glens, *Irvine Ross Forestry Management/Tayside Native Woods.*

TOWERS, W, MALCOLM, A. AND HESTER, A.J. Mapping the potential distribution of NVC woodland types in part of the Western Highlands, *Scottish Natutal Heritage / Highland Birchwoods.*

TOWERS, W, SINCLAIR, A, HORNE, P. AND STILL, E. Assessment of land availability for the recycling of digested sludge cake and digested dried granules within the North of Scotland Water Authority area, *Halcrow Crouch Consulting Engineers*

WATERHOUSE, E.C. AND NOLAN, A.J. Review of current practices - Muirburn management by Upper Deeside, *Report for Scottish Natural Heritage.*

WATERHOUSE, E.C, NOLAN, A.J, CONNOLLY, H, ELSTON. D.A, WILSON, D.B, MACCOLL, A.D.C. AND HENDERSON, D.J. Cairngorm baseline habitat survey : recording of footpath data, diffuse impacts and trampling experiments on the vegetation of the Cairngorm - Ben MacDui area, *A Final Report for the Cairngorm Chairlift Company*, December 1998. Macaulay Research and Consultancy Services, Aberdeen.

WOSTEN, J.H.M, LILLY, A, NEMES, A. AND LE BAS, C. Using existing soil data to derive hydraulic parameters for simulation models in environmental studies and in land use planning, *Final report of the EU funded project 'Using existing soil data' (CHRX-CT94-0639). Technical Report No. 156*, DLO Winand Staring Centre, Wageningen.

WRIGHT, G.G, MILLER, D.R, DUNHAM, R, HODSON, A, TURPIN, O. AND FERGUSON, R. WP242/WP243 Preparation and conductance of BASUK field work, *EU Technical Report for CEO (RI242 and DI243*, ENV4-CT96-03634)

WRIGHT, G.G, MORGAN-DAVIS, J. AND GAULD, J.H. HYDALP - Hydrology of alpine and high latitude basins. Report on customer requirements, RM-1 (Interim Report), *JRC-CEO (for DGXII of the European Union)*, ISPRA (Contract ENV4-CT96-03634).

MAPS

MILLER, D. AND ROBERTSON, R.A. Peat survey maps of Batton Fell; A0 and A4 plots and sections (paper and plastic copies), *William Sinclair Horticulture Ltd.*

MILLER, D.R. ROBERTSON, R.A. AND BELL, J. Peat survey - Greca Moss, *Richardson's Moss and Litter Co. Ltd.*

MILLER, D.R, ROBERTSON, R.A, BELL, J. AND MALCOLM, A. Peat survey map for Drumbow moss. Surface Contours, Basal contours, Isopachytes : height, depth and sample points, *Richardson's Peat Moss Litter Company*

MILLER, D.R, ROBERTSON, R.A, BELL, J.S. AND MCKEEN, M. Peat survey maps for Letham moss. Surface contours. Basal contours. Isopachytes, height: depth and sample points, *Maps provided at A0 and A3 sizes: paper and film. Richardson's Peat Moss Litter Company.*

BOOKS/CHAPTERS/THESES

BADGER, R.J. The effectiveness of policy instruments for wildlife conservation on farmland, *Ph.D. Thesis*, University of Aberdeen.

BIRNIE, R.V. SNH Advances 4 (Chapter 7 "Land Cover Mapping"; Chapter 8 "The Land Cover of Scotland 1988 (LCS88) Survey"; Chapter 9 "So what? Future Landscapes of Scotland", *Scottish Natural Heritage*, Advances Series, No.4. " Land Cover of Scotland".

CHESHIRE, M.V. AND SENESI, N. Electron spin resonance spectroscopy of organic and mineral soil particles, *In: Structure and Surface Reactions of Soil Particles. (Ed. P.M. Huang*, N.Senesi and J. Buffle). John Wiley 1998, pp326-273

CHRISTIE, M.E. An analysis of the provision of recreation improvements in the Grampian countryside, *Ph.D. Thesis*, University of Aberdeen.

COHN, A.G, GOTTS, N.M, CUI, Z, RANDELL, D.A, BENNETT, B. AND GOODAY, J.M. Exploiting temporal continuity in qualitative spatial calculi, *In: Golledge*, R.G. and Egenhofer, M.J. (eds) Spatial and Temporal Reasoning in Geographical Information Systems, Elsevier.

CRABTREE, J.R. Policy instruments for environmental forestry: Carbon retention in farm woodlands, *In: Adger*, W.A, Pettnella, D. and Whitby, M (Eds), Climate change mitigation and European Land Use Policies, CAB International, Wallingford.

HARE, M.P. On modelling complex knowledge and data-poor domains, *Computing Science Department*, Aberdeen University. MPhil Conversion Thesis.

MOLDAN, F, WRIGHT, R.F, FERRIER, R.C, ANDERSSON, I. AND HULTBERG, H. Simulating the Gardsjon covered catchment experiment with the magic model, *Experimental Reversal of Acid Rain Effects. John Wiley and Sons.*

REYNOLDS, B, JENKINS, A, CHAPMAN, P.J. AND WILKINSON, J. Stream hydrochemistry of the Khumbu, Annapurna and Langtang regions of Nepal, *In: Top of the World Environmental Research: Mount Everest - Himalayan Ecosystem. Edited by R. Baudo*, G. Tartari and M. Munawar, pp123-141. Ecovision World Monograph Series. Backhuys Publishers, Leiden, The Netherlands 1998.

RUSSEL, A.J.F. The nutrition of goats, *AFRC technical Committee on Responses to Nutrients. Report No. 10. CAB International*, 1998. Reprinted from Nutrition Abstracts and Reviews, Series B, 67(11)

RUSSEL, A.J.F. AND MOWLEY, A. Goats, *Management and Welfare of Farm Animals*, Universities Federation for Animal Welfare. (4th edition) Ewbank, R.(Ed) and Kim-Madslien, F.(Ed)

WHITE. C, DIKKO, A, CRUICKSHANK, K, CRESSER, M. AND LANGAN, S. Critical loads and soil damage : is mineralogical analysis a useful diagnostic tool?, *In: Nicholson*, K. (Ed.) 1998. Energy and the Environment : Geochemistry of fossil, nuclear and renewable resources, MacGregor Science, pp107-118.

POPULAR ARTICLES AND REVIEWS

BARTHRAM, G.T. Controlling the species composition of pastures, *Lothian Lamb Newsletter*, February 1998.

BARTHRAM, G.T, DUFF, E.I. AND BOLTON, G.R. Selection for height or selection for species within grass swards. *Working Group on Pasture Ecology Newsletter*, 42, p8.

BEECHAM, J.A. Book Review : Mathematical models in the applied science. A.C. Fowler. Cambridge University Press, Cambridge. ISBN 0521 46140 5, *Journal of Applied Ecology*, 35, p837

BIRNIE, R.V. The land cover of Scotland 1988: a baseline for monitoring change in the Scottish countryside, *Newsletter of the*

STAFF PUBLICATIONS

British Urban and Regional Information Systems Association (BURISA)

BIRNIE, R.V. SNH Advances 4. Scotland land cover : notes and slide set, *SNH Advances 4. Scotlands Land Cover.*

COMMON, G.C. AND MILNE, J.A. ECN Site Lines - Sourhope, *ECN Newsletter*, Summer 1998.

DENNIS, P. Book Review: Biodiversity : exploring values and priorities in conservation. D.L. Perlman and G.Adelson (1997). Blackwell Science Ltd, *Journal of Applied Ecology*, 35, p618.

FARRINGTON, J, GRAY, D, ROBERTS, D. AND MARTIN, S. Rural sustainability and the fuel price escalator, *Town and Country Planning*, 67(11), 370-371.

GORDON, I.J. Book review : Conservation and the use of wildlife resources edited by M.Bolton. Chapman and Hall, London, *The Biologist*, 45, p91.

GORDON, I.J. Book review : Horn of darkness: rhinos on the edge by C.Cunningham and J.Berger. Oxford University Press, *The Biologist*, 45(1), pp46

HILL, G. A geographer's view of sustainability, *Land Use Policy*, 15(2), 177-178

HUDSON, G. Discussion of : J.J. Ibanez, S.De-Alba, A. Lobo and V. Zucarello, Pedodiversity and global soil patterns at coarse scales, *Geoderma*, 83, pp199-201.

MERCHANT, M. Cashmere quality assessment to meet the requirements of the fibre manufacturing industry, *European Fine Fibre Network*, Workshop Report No.3, pp21-22.

MERCHANT, M. Rearing surplus dairy kids for meat, *Goatmeat Producers (Scotland) Ltd. Newsletter.*

MILLER, D.R. AND HADLEY, W. Mapping and visualizing forest change using GIS, *Forestry and Timber Products. Sterling Publications.*

RUSSEL, A.J.F. Breeding programme achieving significant gains in cashmere production, *Scottish Cashmere News*, No.36.

SIBBALD, A.R, AGNEW, R.D.M. AND DALZIEL, A.J.I. Agroforestry experience at Glensaugh - Can you have your cake and eat it?, *Newsletter of North of Scotland Grassland Society*, NORGRASS, No 38, pp19-23.

SIBBALD, A.R, DALZIEL, A.J.I. AND AGNEW, R.D.M. Agroforestry - can you have your cake and eat it?, *Trees :The Journal of the International Tree Foundation*, 58, 2-3

CONFERENCES and VISITS ABROAD

UK Conferences attended by staff during 1998

LAND USE SCIENCE GROUP

BENNETT, A J. Biodiversity Conference - putting policy into practice at the local level. Edinburgh, 4 March.

BENNETT, A J. Landscape Character (Perspectives on Management and Change). University of Aberdeen, 1-2 September.

BIRNIE, R V. Integrated Land Management Plans in the Lake District. Lake District, 12-14 May.

BIRNIE, R V. Bracken 1999 - The IV International Bracken Conference. University of Manchester, 20-26 July.

BIRNIE, R V. Landscape Character (Perspectives on Management and Change). University of Aberdeen, 1-2 September.

BIRNIE, R V. The 5th McEwen Lecture "Land Reform for the 21st Century". Coylumbridge, 4 September.

BIRNIE, R V. The contribution of native woodland to land management. Inverness, 23 September.

COMBER, A J. Remote Security Society 1998. University of Greenwich, 9-11 September.

COMBER, A J. Answering the Land Question. Perth, 30 October.

DALZIEL, A J I. Trees in Fields and Farming Landscapes. University of Wales, Bangor, 30 June-2 July.

DALZIEL, A J I. Special Meeting of UK Agroforestry Forum. Cranfield University, 17-18 November.

DUNHAM, R. GIS Research UK 6th National Conference. Edinburgh University, 31 March-2 April.

DUNHAM, R. 5th ERDAS Users' Group Meeting. Cambridge University, 31 August-2 September.

GEDDES, A. Institute of British Geographers. Kinston University, 5-8 January.

GEDDES, A. GIS Research UK 6th National Conference. Edinburgh University, 31 March-2 April.

GEDDES, A. Workshop on Investigating Locational Data. Lancaster University, 9-10 July.

GEDDES, A. Third International Conference of Geocomputation. Bristol University, 17-19 September.

GIMONA, A. UK Workshop on Ecological Networks. Heriot Watt University, Edinburgh, 2-3 July.

GIMONA, A. European Meeting of the International Association for Landscape Ecology. Preston, 3-5 September.

GOTTS, N M. The 5th McEwen Lecture "Land Reform for the 21st Century". Coylumbridge, 4 September.

HARE, M P. European Conference on Artificial Intelligence '98. Brighton, 22-28 August.

HUDSON, G. International Biometric Society. Edinburgh, 7-8 April.

LEADBEATER, S. Landscape Character (Perspectives on Management and Change). University of Aberdeen, 1-2 September.

LILLY, A. Assessment of Human Impacts on the Soil. Stirling University, 12 May.

LILLY, A. Royal Environmental Health Institute of Scotland Annual Congress. Inverness, 20 May.

LILLY, A. Improved source protection for private water supplies. Stirling University. 27 May.

LILLY, A. British Society of Soil Science Autumn Meeting. Queens University, Belfast, 6-9 September.

LILLY, A. Catchment Management - The Scientific Challenges. MLURI Aberdeen, 29 Sept-1 October.

MILLER, D R. GIS Research UK 6th National Conference. Edinburgh University, 31 March-2 April.

MILLER, D R. Public Enquiry into extension of Cemmaes A windfarm. Wales, 26-31 July.

MILLER, D R. Landscape Character (Perspectives on Management and Change). University of Aberdeen, 1-2 September.

MILLER, D R. Third International Conference on Geocomputation '98. Bristol University, 17-19 September.

SIBBALD, A R. Trees in Fields and Farming Landscapes. University of Wales, Bangor, 30 June-2 July.

SIBBALD, A R. Special Meeting of UK Agroforestry Forum. Cranfield University, 17-18 November.

TOWERS, W. Organic Amendments to Soils. SCI London, 20 January.

TOWERS, W. Grazing Management Options for Native Woodlands. MLURI, Aberdeen, 23 April.

TOWERS, W. Assessment of Human Impacts on the Soil. Stirling University, 12 May.

TOWERS, W. Profiting from Technology - Institute of Brewing Scottish Section. Aviemore, 25-29 May.

TOWERS, W. British Society of Soil Science Autumn Meeting. Queens University, Belfast 6-9 September.

TOWERS, W. The Contribution of Native Woodland to Land Management, the Opportunities and Benefits. Inverness, 23 September.

WHERRETT, J R. GIS Research UK 6th National Conference. Edinburgh University. 31 March-2 April.

WHERRETT, J R. Landscape Character (Perspectives on Management and Change). University of Aberdeen, 1-2 September.

WHERRETT, J R. Understanding the Historical Landscape in its Environmental Setting. Perth, 22 September.

CONFERENCES and VISITS ABROAD

WRIGHT, G G. Remote Sensing Applications in GIS. University of Greenwich, 18 June.

WRIGHT, G G. 5th ERDAS Users' Group Meeting. Cambridge University, 31 August-2 September.

ENVIRONMENTAL AND SOCIO-ECONOMICS GROUP

CRABTREE, J R. Regional Studies Association Annual Conference. London, 19 November.

CRABTREE, J R. Water Resources and Environmental Economics. London, 3 December.

HILL, G W. New Needs and Perspectives for Environmental Information. London, 3-5 June.

MACDONALD, D. Agricultural Economics. University of Reading, 23-28 March.

THORBURN, A P. The Contribution of Native Woodland to Land Management: The Opportunities and Benefits. New Lanark, 24 September.

WYNN, G. Land Reform, Local Government and Land Value Taxation. Perth, 30 October.

SOIL SCIENCE GROUP

BACON, J R. Biological and environmental applications of ICP-MS and ICP-OES. MLURI, Aberdeen, 24 June.

CHESHIRE, M V. Radiochemical Methods. Edinburgh, 7 January.

DUNN, S M. Hydrology in a Changing Environment. Exeter, 6-10 July.

FERRIER, R C. Atlantic Frontier Environmental Conference. University of Aberdeen, 6-7 October.

HILLIER, S J. Mineral Diagenesis and Reservoir Quality - The Way Forward. Cambridge University, 26-27 March.

HILLIER, S J. Minerals in the Oil Industry. University of Aberdeen, 27-28 October.

LANGAN, S J. Acidification: Seminar on Environmental Damage and Recovery Prospects. University of London, 1 May.

LANGAN, S J. British Society of Soil Science Autumn Meeting. Queens University, Belfast, 6-9 September.

MCMURRAY, E M. 26th Scottish Microscopy Group Symposium. Dundee, 11 November.

ROE, M J. 26th Scottish Microscopy Group Symposium. Dundee, 11 November.

PLANT SCIENCE GROUP

BAUSENWEIN, U. The Society of Experimental Biology Annual meeting. University of York, 23-27 April.

CHAPMAN, P J. British Hydrological Society International Conference on Hydrology in a Changing Environment. Exeter, 6-10 July.

DOMBURG, P. Managing Nitrogen in Crop Rotations. London, 17 March.

DOMBURG, P. Optimising the Nutrient Balance in Agriculture: a bonus for farming and for the environment. London, 20 October.

EDWARDS, A C. Managing Nitrogen in Crop Rotations. London, 17 March.

EDWARDS, A C. Constructed Wetlands Biofiltration Workshop. Cardiff University, 31 March.

EDWARDS, A C. British Society of Soil Science Autumn Meeting. Queens University, Belfast, 6-9 September.

EDWARDS, A C. Precision Agriculture - Practical Applications of New Technologies. Cambridge University, 9-11 December.

GRAYSTON, S J. The Society for Experimental Biology Annual Meeting. York University, 23-27 March.

HOODA, P. Practical and Innovative Measures for the Control of Agricultural Phosphorus to Water. Belfast, 16-19 June.

MILLARD, P. The Society for Experimental Biology Annual Meeting. York University, 23-27 March.

MILLARD, P. Forest Growth Responses to the Pollution Climate of the 21st Century. 21-23 September.

PATERSON, E. The Society for Experimental Biology Annual Meeting. York University, 23-27 March.

PROE, M F. Annual Conference of the World Wildlife Fund and the 1995+ Group. London, 28-29 January.

SHAND, C A. The Royal Society of Chemistry - "Biological and environmental applications of ICP-MS and ICP-OES". MLURI, Aberdeen, 24 June.

SHAND, C A. Co-ordination Group for Research on Environmental Radioactivity. Stirling, 2-4 September.

THORNTON, B. The Society for Experimental Biology Annual Meeting. York University, 23-27 March.

ECOLOGY AND ANIMAL SCIENCE GROUP

ARCHER, Z. British Endocrinology Society Meeting. Edinburgh 23-25 March.

DA SILVA, P. Reproductive Endocrinology and Gonadal Development. Glasgow, 6-8 July.

DENNIS, P. ECOFACT - Landscape Pattern Workshop. Bristol, 12 March.

DENNIS, P. European IALE Congress - Key Concepts in Landscape Ecology. Preston, 3-5 September.

DENNIS, P. FRCC - Workshop on Research Related to Biodiversity Conservation. Peterborough, 29 September.

CONFERENCES and VISITS ABROAD

DUNCAN, A. British Society of Animal Science Annual Meeting. Scarborough, 23-25 March.

ERHARD, H. International Society for Animal Ecology Winter Meeting. London, 2-4 December.

GODDARD, P J. Annual Namod Veterinary Surgeon's Weekend. Midlands, 4-6 September.

GODDARD, P J. International Society for Animal Ecology Winter Meeting. London, 2-4 December.

GORDON, I J. UK Forum on Agricultural Research for Development. N R International , Kent, 20 November.

HENDERSON, D J. Grazing Management Options for Native Woodlands. MLURI, Aberdeen, 23 April.

HESTER, A J. Conservation and Rural Development. Nethy Bridge, 27-28 April.

HESTER, A J. Native Woodlands Discussion Group Annual Field Meeting 'New Woodlands'. Melrose, 28-31 May.

KEIR, B L. British Society of Animal Science Annual Meeting. Scarborough, 23-25 March.

MAYES, R W. IXth European Intake Workshop. IGER North Wyke, 18-20 November.

RHIND, S M. British Endocrinology Society Meeting. Edinburgh, 23-25 March.

SIBBALD, A M. British Society of Animal Science Annual Meeting. Scarborough, 23-25 March.

WRIGHT, I A. British Society of Animal Science Annual Meeting. Scarborough, 23-25 March.

WRIGHT, I A. Delivering Livestock Services to the Rural Poor. Reading, 12 June.

WRIGHT, S. Grazing Management Options for Native Woodlands. MLURI Aberdeen, 23 April.

ANALYTICAL GROUP

MIDWOOD, A J. Biological and Environmental Applications of ICP-MS and ICP-OES. MLURI, Aberdeen, 24 June.

MIDWOOD, A J. British Mass Spectrometry Society 23rd Annual Meeting. Warwick, 13-16 September.

OWEN, I J. Biological and Environmental Applications of ICP-MS and ICP-OES. MLURI, Aberdeen, 24 June.

OWEN, I J. Assessment of Human Impacts on the Soil. Stirling, 12 May.

SMITH, A. British Mass Spectrometry Society 23rd Annual Meeting. Warwick, 13-16 September.

COMPUTING AND INFORMATION SERVICES GROUP

MCGUINNESS. J A. British Library Collections, Services, Databases. Glasgow, 21 April.

ROBERTSON, L E. Current Awareness Sources. University of Aston, Birmingham, 2 March.

ROBERTSON, L E. Copyright. Glasgow Caledonian University, 8 June.

ROBERTSON, L E. Scottish Agricultural Librarians Group. SAC Auchincruive, 29 May.

ADMINISTRATION GROUP

SLATER, D J. The Grammar Game. Aberdeen, 14 July.

MACAULAY RESEARCH & CONSULTANCY SERVICES

GAULD, J H. Understanding the Historical Landscape in its Environmental Setting. Perth, 22 September.

HEWISON, R L. Grazing Management Options for Native Woodlands. MLURI, Aberdeen, 23 April.

MALCOLM, A. Understanding the Historical Landscape in it's Environmental Setting. Perth, 22 September.

Conferences abroad attended by staff during 1998

LAND USE SCIENCE GROUP

BIRNIE, R V. GCTE-LUCC Open Science Conference on Global Change. Barcelona, Spain, 14-18 March.

BROOKER, N. ESRI User Conference - Geographic Information Systems, Use and Development. San Diego, 27-31 July.

DUNHAM, R. Modelling of Abiotic Forest Damage. Finland, 10-14 August.

GIMONA, A. International Ecological Congress. Florence, Italy, 18-25 July.

GOTTS, N M. Constructive Cellular Automatoa Theory Workshop. Santa Fe Institute, New Mexico, 13-20 November.

HARE, M P. AIRIES '98 - Workshop on Artificial Intelligence Research in Environmental Science. British Colombia, Canada, 21-23 October.

HUDSON, G. Comparative Evaluation of European Methods for Soil. Athens, Greece, 18-22 November.

MATTHEWS, K D. Geospatial Information in Agriculture and Forestry. Florida, 1-3 June.

CONFERENCES and VISITS ABROAD

MILLER, D R. Modelling of Abiotic Forest Damage. Finland, 10-14 August.

WHERRETT, J R. Resource Technology '98. Finland, 8-12 June.

WHERRETT, J R. Permanent European Conference on Studies for Rural Landscapes. Norway, 7-11 September.

ENVIRONMENTAL AND SOCIO-ECONOMICS GROUP

CRABTREE, J R. 2nd International Conference of European Society of Ecological Economics, Geneva, 4-6 March.

CRABTREE, J R. World Congress of Environmental and Resource Economics. Venice, 25-28 June.

MACDONALD, D. 2nd International Conference of European Society of Ecological Economics, Geneva, 4-6 March.

SOIL SCIENCE GROUP

BACON, J R. INCO-COPERNICUS EC Project Workshop. Giessen, Germany, 29-31 July.

BACON, J. Comparative Evaluation of European Methods for Soil. Athens, Greece, 18-22 September.

BACON, J R. Evaluation Workshop for CEEM Project. Athens, Greece, 18-22 November.

BAIN, D C. 16th World Congress of Soil Science, Montpellier, 20-26 August.

CAMPBELL, C D. Microbial Biosystems - New Frontiers, 8th International Symposium on Microbial Ecology. Nova Scotia, Canada, 8-16 August.

CHAPMAN, S J. Microbial Biosystems - New Frontiers, 8th International Symposium on Microbial Ecology. Nova Scotia, Canada, 8-16 August.

DUNN, S M. The Second International Conference on Climate and Water. Finland, 17-20 August.

FERRIER, R C. European Climate Science Conference. Vienna, 19-23 October.

GIRVAN, M S. Microbial Biosystems - New Frontiers, 8th International Symposium on Microbial Ecology. Nova Scotia, Canada, 8-16 August.

HELLIWELL, R C. Headwater Control IV: Hydrology, Water Resources and Ecology in Headwaters. Merano, Italy, 20-23 April.

PLANT SCIENCE GROUP

CHAPMAN, P J. Headwater Control - Hydrology, Water Resources and Ecology in Headwaters. Merano, Italy, 20-23 April.

CHAPMAN, P J. Environmental Analytical Chemistry for the Protection of Sensitive Ecosystems. Cordoba, Spain, 31 October-6 November.

GRAYSTON, S J. Microbial Biosystems - New Frontiers, 8th International Symposium on Microbial Ecology. Nova Scotia, Canada, 8-16 August.

PROE, M F. Soil Biology in Relation to Sustainable Land Use. Uppsala, Sweden, 15-16 January.

PROE, M F. IUFRO International Conference on Indicators for Sustainable Forest Management. 24-28 August.

SHAND, C A. Society of Environmental Toxicology and Chemistry. Bordeaux, 14-18 April.

WILLIAMS, B L. Nitrogen, the Conference. Netherlands, 23-27 March.

ECOLOGY AND ANIMAL SCIENCE GROUP

BARTHRAM, G T. FAO Lowland Grassland Sub-Network Conference. Spain, 13-16 October.

BEECHAM, J. Workshop on Integration of Multi-Agent Simulations and GIS. Santa Fe, New Mexico, 18-22 March.

DA SILVA, P. Joint Winter Meeting of the Society for the Study of Fertility with the German Society for Fertility and Sterility. Aachen, Germany, 17-19 December.

DUNCAN A J. V International Symposium on the Nutrition of Herbivores. San Antonio, Texas, 10-16 April.

ERHARD, H. Evaluation of Behaviour Tests in Ethology. Greve, Denmark, 29-30 January.

ERHARD, H. 32nd International Conference of the International Society for Applied Ethology. Clermont-Ferrand, France, 21-25 July.

GODDARD, P J. World Biology of Deer Conference. Hungary, 30 June-4 July.

GODDARD, P J. 32nd International Conference of the International Society for Applied Ethology. Clermont-Ferrand, France, 21-25 July.

GORDON, I J. World Biology of Deer Conference. Hungary, 30 June-4 July.

IASON, G R. V International Symposium on the Nutrition of Herbivores. San Antonio, Texas, 10-16 April.

MARRIOTT, C A. Ecological Aspects of Grassland Management, 17th EGF Meeting. Hungary, 17-24 May.

MARRIOTT, C A. 1st International Symposium on Research into the Management of Sensitive Rural Areas. Clermont Ferrand, France, 25 April-1 May.

MARRIOT, C A. FAO Lowland Grassland Sub-Network Conference. Spain, 13-16 October.

MAYES, R W. V International Symposium on the Nutrition of Herbivores. San Antonio, Texas, 10-16 April.

MAYES, R W. INCOCOPERNICUS EC Project Workshop. Giessen, Germany, 29-31 July.

CONFERENCES and VISITS ABROAD

RHIND, S M. Endocrine Disrupting Agents, Food Contamination and Reproductive Health in Farm Animals. The Netherlands, 20-22 November.

SIBBALD, A M. Measuring Behaviour '98. The Netherlands, 18-21 August.

ANALYTICAL GROUP

MIDWOOD, A J. Applications of Stable Isotope Techniques to Ecological Studies. Saskatoon, Canada, 20-22 April.

Staff visits abroad during 1998

LAND USE SCIENCE GROUP

BIRNIE, R V. Workshop on the use of indicator in monitoring landscape change. NIJOS, Norway, 10-11 June.

DUNHAM, R. 4th SRM Workshop. University of Berne, 29 June-3 July.

GIMONA, A. EUROLUS Project Workshop. Vienna, Austria, 9-11 July.

HARE, M P. EAWAG Institute, Zurich, 1-2 April.

HUDSON, G. Short course on Plurigaussian Simulations in Mining and Petroleum. Fontainebleau, France 21-23 September.

JONES, K. G2 Diagnostic Assistant Course. Cambridge, USA, 18-25 January.

MILLER, D R. Forest Planning and Management: Future Developments. Portugal, 7-15 October.

SOIL SCIENCE GROUP

BACON, J R. INCO-COPERNICUS Project - contract negotiation. Germany & Belgium, 8-9 May.

BACON, J R. EU SEPHOS Project - meeting of participants. Nantes, France, 14 September.

BACON, J R. EU Initial Meeting of New Certification Exercise. Brussels, 7-8 December.

WILSON, M J. Visit to Institute of Water and Colloid Chemistry. Kiev, Ukraine, 6-13 December.

PLANT SCIENCE GROUP

DAWSON, L. Collaborative Research. INRA Lusignan, 1 July-10 August.

GRAYSTON, S J. Natural Resource Ecology Laboratory. Colorado, USA, 17-20 August.

PATERSON, E. Visits to INRA sites, France, 13-17 October.

WILLIAMS, B L Visit to INRA Clermont-Ferrand, France, 18-22 May.

ECOLOGY AND ANIMAL SCIENCE GROUP

FARNSWORTH, K D. British Council Funded Alliance Collaboration. INRA Toulouse, 26 September-1 October.

GORDON, I J. British Council Funded Alliance Collaboration. INRA Toulouse, 30 September-4 October.

HESTER, A J. University of Fort Hare. South Africa, 8-16 August.

RHIND, S M. Danish Institute of Agricultural Sciences. Denmark, 20-23 August.

SIBBALD, A M. British Council Funded Alliance Collaboration. INRA Toulouse, 29 September-4 October.

ANNUAL FINANCE STATEMENT FOR YEAR ENDING 31 MARCH 1998

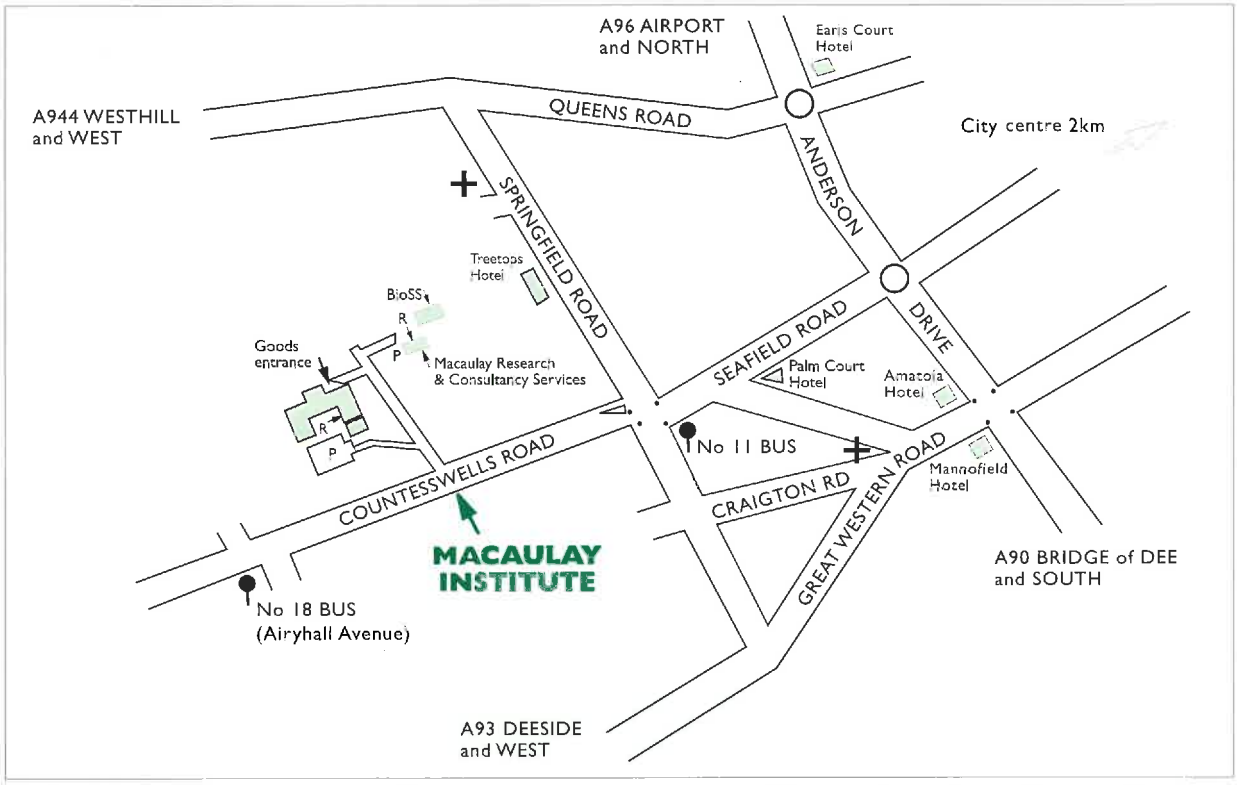
Income	£k
Scottish Office Agriculture, Environment and Fisheries Department	5,880
SOAEFD Flexible Research Funding and other SOAEFD contracts	816
European Union research contracts	478
Funding from other Government Departments, Public Bodies and Agencies	140
Private research and consultancy contracts	236
Other income	229
	7,779
less Income deferred or applied to capital purchases	-73
Total Income	**7,706**

Expenditure	
Staff costs	5,254
Research expenditure including Research Station costs	1,222
Other operating costs	1,401
	7,877
Surplus (defecit)	-171

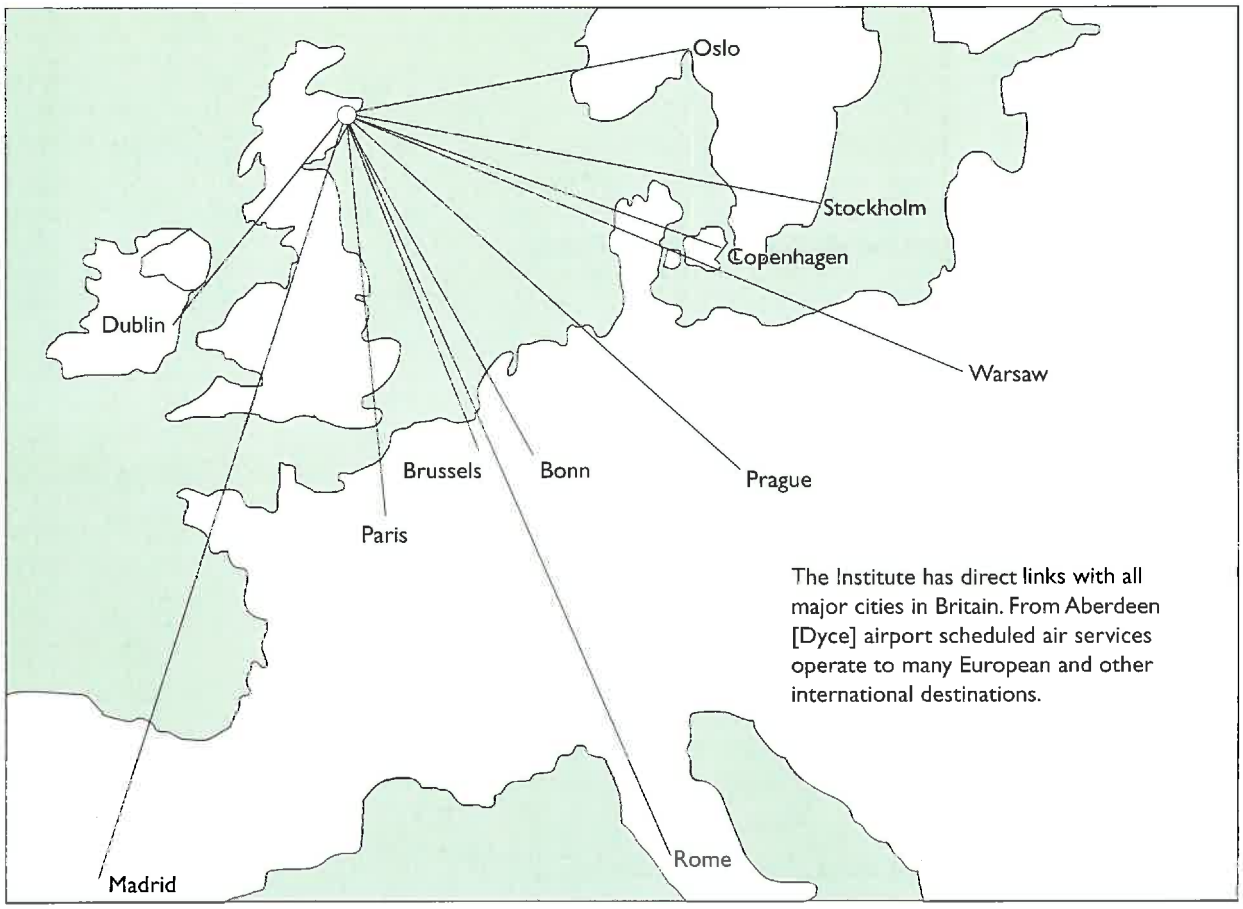
The capital funds received from SOAEFD totalled £318,330

During the year the turnover of Macaulay Research and Consultancy Services was £623,663

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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Macaulay Land Use Research Institute

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